IMPACTS WORLD 2013

International Conference on Climate Change Effects

CONFERENCE PROCEEDINGS

Potsdam, Germany
27-30 May 2013

SPONSORED BY THE

Federal Ministry
of Education
and Research

www.climate-impacts-2013.org

2013
Potsdam Institute for Climate Impact Research
Telegrafenberg
P.O. Box 60 12 03, 14412 Potsdam
GERMANY

DOI: 10.2312/pik.2013.001

Potsdam, September 2013

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Introduction

The IMPACTS WORLD 2013 conference was aimed at developing a new vision for climate impacts research by laying the foundations for regular, community-driven syntheses of climate change impact analyses. The conference took place from 27-30 May 2013 in Potsdam and brought together leading scientists and decision makers from local to international levels.

A broad array of scientific knowledge about the impacts of climate change has been gathered over the last decades. Yet, in many respects it remains fragmentary, and a quantitative synthesis of climate impacts, including consistent estimates of uncertainties, is still missing.

In light of the great wealth of existing knowledge and continuous need for policy-relevant research results, the climate impacts community is perfectly placed to combine individual contributions to initiate a coordinated climate impact research agenda.

IMPACTS WORLD 2013 was a discussion-based conference designed to tackle five fundamental challenges:

1. **Can we integrate our existing knowledge across sectors?**

2. **How certain are we?**

3. **What is still missing?**

4. **How do we bridge the divide between regional and global impact studies?**

5. **Is anybody listening?**

This Conference Proceedings includes all submitted papers of the conference participants, each of them addressing one of the key challenges mentioned above. The Organizing Committee thanks all the authors and participants for their valuable contribution to the success of IMPACTS WORLD 2013.

Topic 1:

How certain are we?

Linking Climate Change to Water Sector: A Case Study of Urban Drainage System

M. Abdellatif, W. Atherton, R.M. Alkhaddar and Y.Osman

Abstract— The issue of climate change has been increasing and its effects have already been observed around the world with further changes in climate are projected to take place in the future. For future management of urban drainage system (considering the on-going trend of climate change) long-lasting decisions about the urban drainage system have to be taken, even if the future is uncertain and it is expected that the basis for these decisions will change. It is not possible to defer the decisions until the future uncertainties are reduced. This paper seeks to assess how the climate change on interannual to multidecadal timescale will affect design standards of waste water networks in the North West England of the UK (selected site). The study compares the future conditions of the drainage network using two downscaling approaches.

Index Terms— Artificial Neural Network, climate change, flooding, urban drainage systems Introduction

1 Introduction

The possible impact of climate change on urban drainage systems has been a topic of intensive scientific discussion over the last decade. The expected modifications in intensity and frequency of extreme rainfalls (see e.g. IPCC (2007)) will affect urban drainage systems in view of both flooding and pollutant loads emitted to the environment as they were not designed to take climate change into account. Regardless of the eventual impacts Ashley et al. (2005) stress that designers and operators will have to prepare for greater uncertainties in the effectiveness of drainage systems.

It is widely recognised that obtaining a reliable future rainfall time series to use for simulating future behaviour of a combined system is not an easy task, as rainfall is one of the most difficult elements of the hydrological cycle to forecast, and great uncertainties still affect the performances of both stochastic and deterministic rainfall prediction models. Interesting perspectives for the future are offered by global circulation models (GCMs), but up to now, they unfortunately do not seem able to provide rainfall forecasts at the temporal and spatial resolution required by many hydrologic applications, therefore downscaling is required.

The current paper compares between stochastic and regression downscaling techniques in simulating future design storm of an urban drainage system of Hoscar catchment in Northwest (NW) of England (Figure 1) and then assess the impact of climate change in the 2050s (2039-2070) relative to the base period (1961-1990) using climate variables of scenarios A1FI and B1 obtained from HadCM3 GCM. The exposure of the NW region to westerly maritime air masses and the presence of extensive areas of high ground mean that the region is considered as one of the wettest places in the UK. The average annual rainfall in the highest parts is over 3200mm over period 1971 - 2000, in contrast to low area where the average annual rainfall is only 860mm (Met office web site, 2010).

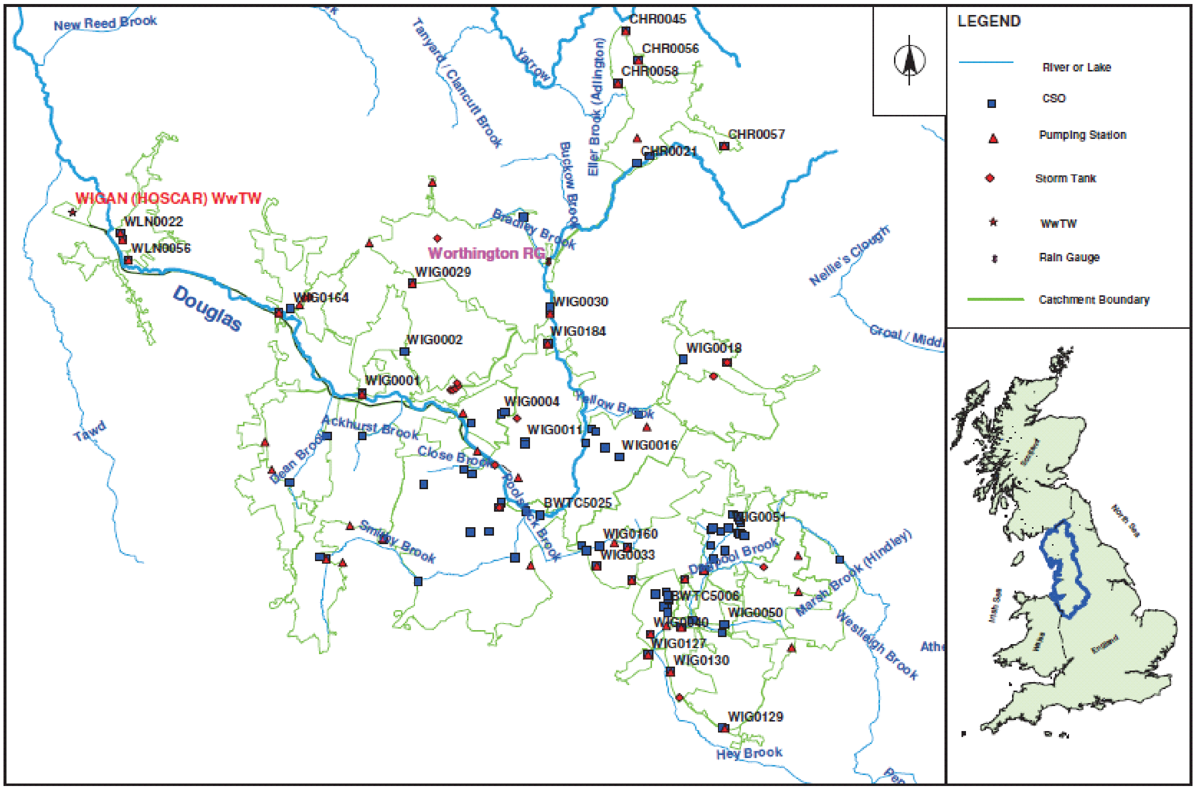

Fig 1 Hoscar Urban Drainage Chatchment

2 Methodogy

Urban drainage systems handle two types of flows, wastewater (foul flow or dry weather flow) and stormwater through two conventional sewerage systems; a combined system in which wastewater and stormwater flow together in the same pipe, and a separate system in which wastewater and stormwater are kept in separate pipes. The focus in this paper is on combined systems as they are more affected by rainfall. In order to investigate the performance of Hoscar drainage network model, which built in InfoWorks CS software, inputs from base period (1961-1990) and the future (2050s) rainfall together with the Dry Weather Flow are used to assess flood risk in the catchment.

2.1 Dry Weather Flow

The main constituents of Dry Weather Flow (DWF) needed as input to the flow model are:

1. **Domestic Flow** which is population generated flow based on the average per capita water consumption of 128 l/head/d. 95% of the human consumption is considered to be wastewater and entered the system.

2. **Infiltration flow** which enters the sewerage network through cracks and joints within various parts of the sewerage network will be calculated from the formula:

   $$I = DWF - PG - E \quad (1)$$

   where

   E = Measured Trade Effluent and Measured Commercial effluent

   P = Population (heads) and G = Current UU per capita consumption

   If no evidence is recorded by flow monitors due to poor monitoring conditions or loss of data then a typical default value of 120 litres/head/day to represent the infiltration will be included in the model (Squibbs, 2010; Butler and Davies, 2004).

3. **Traders and Commercial flows** (E) which are modelled separately from domestic flow using the Trade Wastewater Generator file. A total trade and commercial flow of 53.6l/s and 108.24 l/s, respectively, are is used for Hoscar catchment model.

2.2 Future Rainfall

This study applied the output of a Multi-layer Feed forward Artificial Neural Network (MLF-ANN, or shortly ANN) model (Figure 2), which was used to build a non-linear relation between the observed daily rainfall (Y) series and the selected set of climatic variables (predictors, X) for winter (months December, January and February) and summer (months June, July and August) rainfall. The study used two sets of simulated future rainfall generated by this model for the period 2050s; the first set is generated using HadCM3 GCM outputs corresponding to SRES emission scenario A1FI (high), and the second set is generated using SRES emission scenario B1 (low). Rainfall magnitudes (or Design Storms), which are standard synthetic rainfalls for specific durations (hours or minutes) and return periods used to test level of services in combined sewer systems, are then obtained from the future rainfall time series by frequency analysis methodology (cf. Abdellatif 2012). The change prercentage of the future design storms relative to the base period for a specified return period and duration is then applied to InfoWorks drainage model to simulate future behaviour of the system.

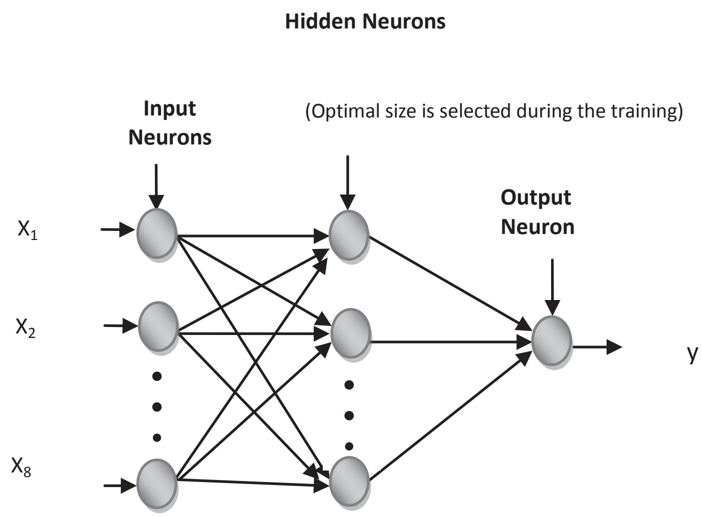

Fig 2 Artificial neural Network structure used for simulating future rainfall

Future rainfall has been also generated by the stochastic weather generator (WG), developed by the UK Climate Projection 2009 (UKCP09) project (the latest version of UKCIP), for the same two emission scenarios, to compare with the ANN outputs. The rainfall model used in the UKCP09 weather generator is the Neyman-Scott Rectangular Pulses (NSRP) model (Cowpertwait et al. 1996 a & b), which is one of a family of point process models. Future design storms for return periods (as in the ANN case) are also obtained by frequency analysis.

3 Results and Discussions

Figures 3a, b, c and d display comparative plots of seasonal design storms obtained from rainfall generated by the ANN and WG models under scenarios A1FI and B1 for the 2050s, together with the base period. The comparative plots in Figures 3a & b for winter season clearly show that an increase in design storm is projected to occur under both emission scenarios as obtained by both downscaling models. Though, there is a difference in the magnitude of the design storm generated by either model for the same return period, which is attributed to the nature of the two models (i.e. deterministic vs. stochastic). For the summer seasons, the two downscaling models consistently generated significant decrease in the design storms under both scenarios with varying levels of change.

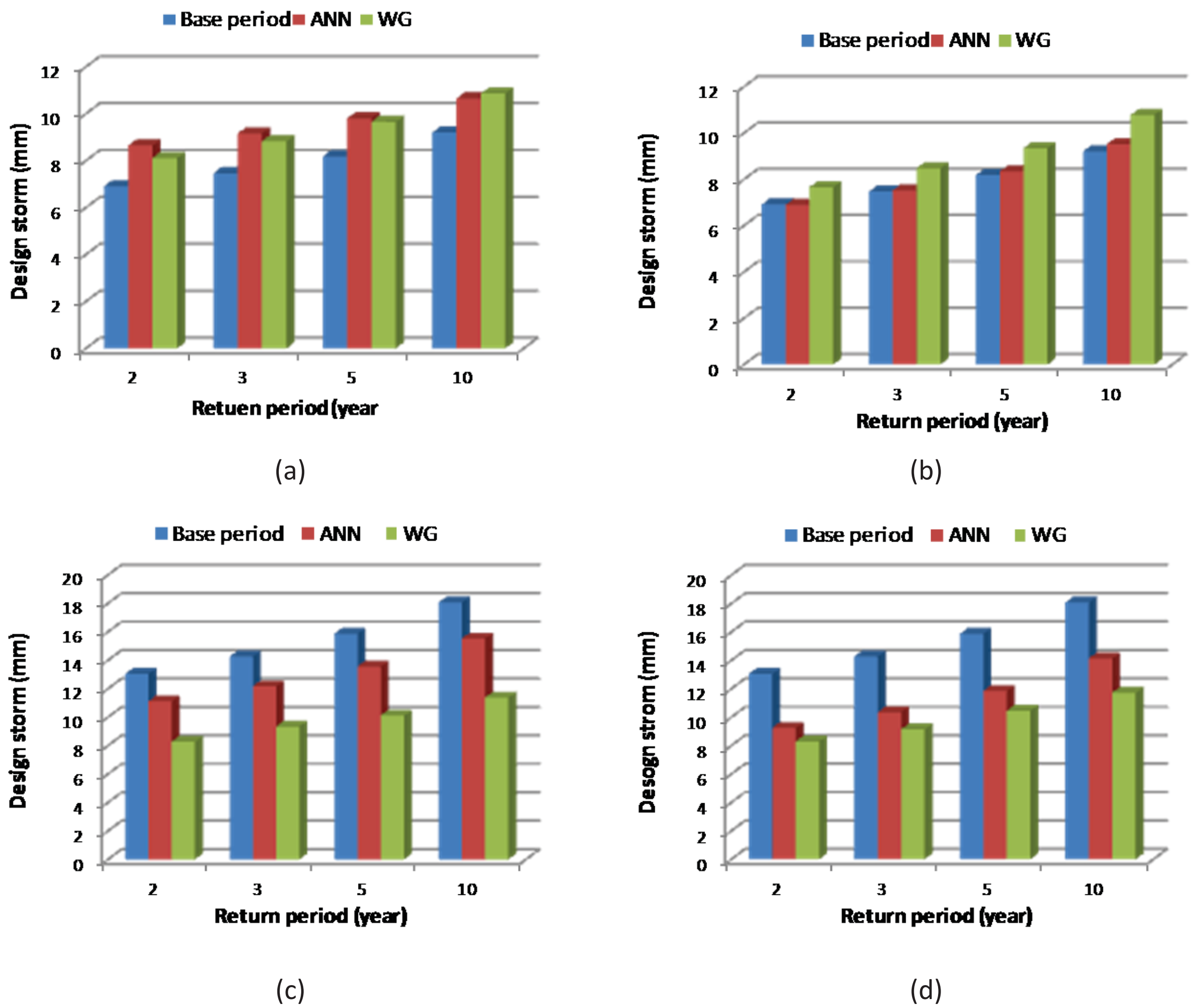

Fig 3 Hourly design storms for different return periods simulated by ANN and WG for winter (a) A1FI and (b) B1 and summer (c) A1FI and (d) B1 for the 2050s relative to base period (1961-1990)

The future design storms obtained above are used as inputs to the InfoWorks model of Hoscar drainage catchment to assess possible future impacts of climate change on the catchment surface flooding, sewer surcharge and the number of properties at risk of flooding in Hoscar. For the purpose of the comparison, a 5 year return period design storm for storm durations 60, 120, 180, 360, 480 and 1440 minutes, obtained from future rainfall simulated by both downscaling models, are used as inputs to the Hoscar model. Simulation results obtained, for winter and summer, in terms of total flood volume (m^3) are presented in Tables 1 and 2. As can be observed from Table 1, the future winter surface flooding volume is projected to increase, under both scenarios, with the increase in storm duration. Under scenario A1FI, the projected surface flooding volumes are generally higher when simulated with the ANN model than when simulated with the WG model; under scenario B1, the reverse is true. Simulation results for summer design storms, presented in Table 2, indicate a decrease in surface flooding volume is predicted by both model, confirming a decrease of flood risk to properties during this season.

Table 1 Flood/Lost Volume (m^3) from manholes for the two statistical downscaling approaches for winter for design strom of 5 year retrun period.

Duration	ANN Model			WG Model	
	Base period	A1FI	B1	A1FI	B1
60	43755	66933	46215	51491	47526
120	53924	90809	73245	65951	62303
180	62528	122760	64420	81291	74703
360	83603	137622	63682	93497	90884
480	90691	162533	67150	103884	93346
1440	106064	149003	43370.1	134714	124636

Table2 Flood/Lost Volume (m^3) from manholes for the two statistical downscaling approaches for summer for design strom of 5 year retrun period.

Duration	ANN Model			WG Model	
	Base period	A1FI	B1	A1FI	B1
60	40579	26977	19174	26029	28889
120	50132	33904	8680	32789	36221
180	57994	32686	14980	39795	41116
360	73456	57585	23264	59531	61496
480	78319	57628	22749	69860	69860
1440	93290	57859	23968	91305	88630

The number of properties at risk of flooding, due to combined effects of manholes surface flooding and sewer surcharge above cellar or property floor levels, is also assessed here under the base period and future conditions. Figures 4 a, b, c and d present the number of properties at risk of flooding for future winter and summer seasons, under scenarios A1FI and B1, as projected by both downscaling models. The number of properties at risk of flooding is expected to increase as projected by both models in winter under A1FI emission scenario and mix between increase/decrease for B1 with the highest increase associated with 60 minutes storm durations (A1FI). The pattern of increase here is similar to that in the surface flooding volume. During the future summer, as expected, the number of properties at risk of flooding is projected to decrease sharply.

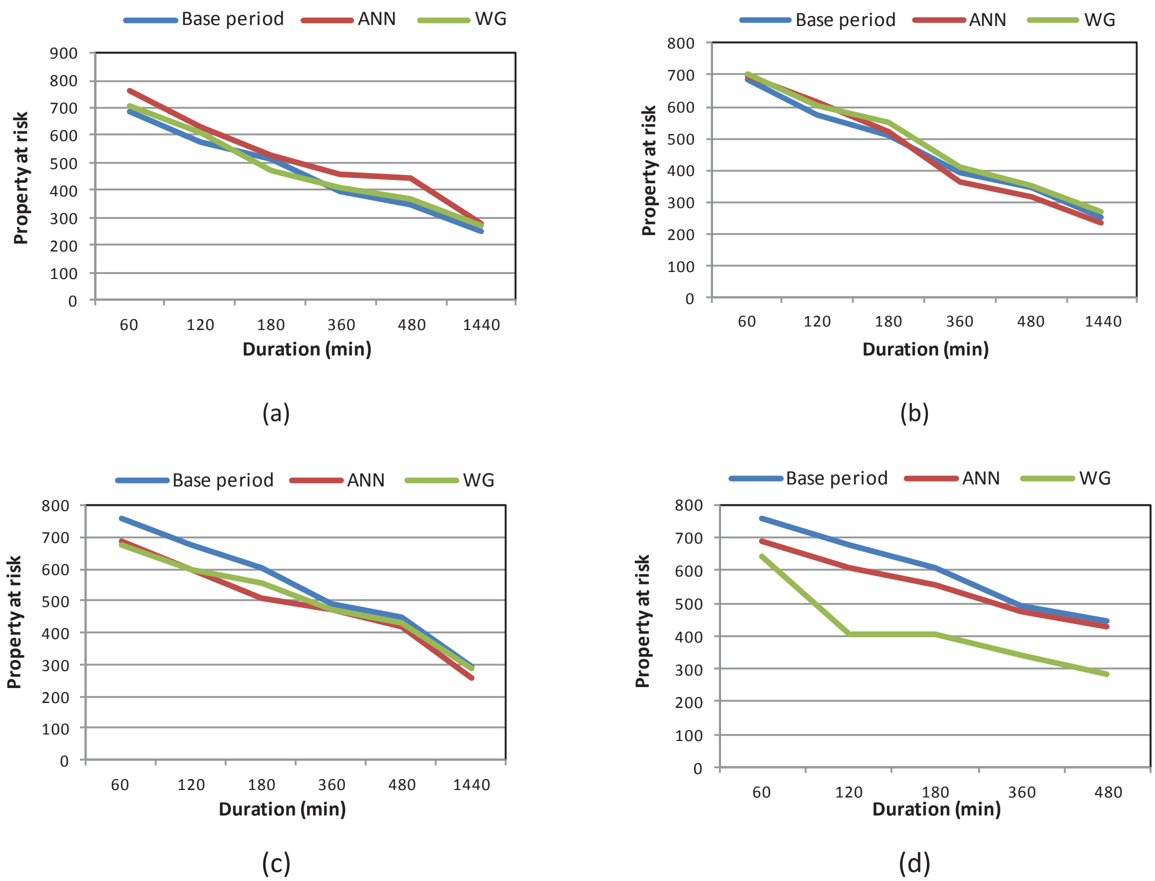

Fig 4 Comparison between ANN and WG in simulating properties at risk of flooding for different durations for winter (a) AFI and (b) B1 and summer(c) A1FI and (d) B1 in 2050s for design storm of 5 year return period

The simulation results presented here show differences in results yielded in the design storms generated by the two downscaling models and in turn the impact on the drainage system. This could be attributed mainly to the structure of the WG which is based on reproducing the observed mean daily rainfall stochastically using NSRP approach rather than the daily variability. This is beside the fact that WG is calibrated with data record of 30 years, which lead to significant underestimation of the observed extremes (Jones et al., 2009). Unlike the WG, ANN model has found to have reasonable fit in reproducing the extremes and daily variability which is calibrated with good rainfall data set (41 years). Moreover, the fact that the non- linear relation between rainfall and climate variables as predictors with deterministic features of ANN help in obtaining rainfall with the same statistical properties of the observed series. Another issue which could contribute to this difference is the method of fitting used in each model; the ANN model has been calibrated with backpropagation technique, whereas the WG was calibrated using the approach of objective function based on historical moments (namely mean, variance, covariance lag 1, etc). Estimation of parameters of the WG model is sensitive to the ideal number of the historical moments used in calibration which is still an un-ended problem. So although the results of both statistical approaches show some differences, both models gave indication of climate change impact on urban drainage system.

4 Conclusions

In the present study, two different approaches of statistical downscaling models were used to downscale future rainfall from outputs of HadCM3 GCM under scenarios A1FI and B1. Design storms obtained by frequency analysis of the future rainfall were used as inputs in the urban drainage system model of Hoscar catchment to study the behavior of the catchment in the future period of 2050s. Simulation results obtained show that:

1. Some agreements have been captured between the WG and ANN models but differences are still there when the comparison is held with the design storm and flood risk for the same emission scenario, which introduced uncertainties in the downscaled rainfall. This is due to model structure, method of calibration and data set used in each model.
2. Although there are differences in the results obtained by the two downscaling models, they are both indicating possible impacts of climate change on the drainage systems as follow:
    - Magnitude of the design storm for a specified return period is expected to increase during winter and decrease during summer for both considered scenarios.
    - Surface flooding volume from manholes is projected to increase during winter time under considered scenarios.
    - Risk during summer season is getting lower as confirmed by both downscaling approaches
3. As for future work, it is recommended to compare the results with more different methods of downscaling rainfall and asses the quality of the various methods to address the inherent uncertainty in the downscaling approaches and hence it would provide robust assessment tool for water management.

In conclusion, the outcomes of this study could contribute to this important and timely area of research which tries to answer some questions relating to climate change impact of hydrological extremes on urban drainage systems for long term future.

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Extreme Weather Event Verification: Case study on heavy rainfall over western Niger

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1. African Centre of Meteorological Applications for Development(ACMAD)
2. National Oceanic Atmospheric and Administration(NOAA)

Abstract— The African economy is partially dependent on meteorological information which is related to the rainy season, periods favorable to the sowing and to the harvests, the long dry spell (several days with a few weeks). This information is crucial to optimize the planning. They favor long-lasting (sustainable) and economic decision-making regarding vulnerable communities. So, their needs in products of forecasts cover the short term up to medium scale. The occurrence of extreme weather events related to flooding and climate variability is a challenge for our Met services through forecasting department, therefore forecasting these events in advance will be essential for our communities, decisions takers and decisions makers. In this study 24-hor rainfall forecasts by three Global models (NCEP/GFS, ECMWF, and UKMET) are verified against gauge rainfall observation, based on the heavy rainfall event that occurred on August, 06th 2012 over Niger Republic. The weather systems that led to this heavy rainfall event include an organized MCS over Western Niger, deep low level monsoon inflow, vortices and wind convergence in lower troposphere, very well define AEJ and AEW between 700 and 300mb, as well as TEJ at 200hpa. We also noticed the less frequently occurring 700mb vortex, which in this case, has led to deep and pronounced MCS and squall lines. The gauge rainfall data over 62 stations provided by the Niger Meteorological services was used to verify the deterministic rainfall forecasts. This case was selected based on the high amount of rainfall accumulated over the study area on the day of August, 06th 2012) and its associated flooding event reported in the region. The model inter-comparison and verification statistics results are also presented. In general, the GFS model showed better skill in predicting spatial distribution of rainfall (higher spatial correlation), while ECMWF seem to have performed better in predicting

the rainfall amount (lowest error). However, all the models looked to have their own weaknesses and strengths; while one model shows weaknesses in depicting certain features, the other model may have better representation of the feature.

NCEP: National Center of Environmental Prediction; GFS : Global Forecast System; ECMWF: European Center for Medium Range Weather Forecast; UKMET: United Kingdom Meteorological Office; MCS: Mescale Convective System; AEJ: African Easterly Jet; AEW; African Easterly Waves; TEJ: tropical Easterly Jet

Keywords: Extreme Weather, Forecast, Numerical Weather Prediction Out Put, Verification

1 .Introduction

Frequent extreme rainfall events have significant impact on various socio economic activities in West Africa. This study is one of the attempts to predict ahead such phenomenon by studying the behavior of weather elements and the occurrence of weather events so as to help minimize the losses incurred from their destructive effects and also maximize their potential for sustainable development and early warning system. Short time forecasting of weather elements to help track, monitor and be able to forecast Mesoscale convective System in their movement and occurrence.

It is therefore expedient to verify the performance of the models in use so as to know how accurate they can be and to what extent they can be relied on. This study considers three models

1.1: BACKGROUND INFORMATION

Niger is one of Sahel region roughly located between latitude 11°1’-23°17’ North and longitude 0° 16’- 16° East. It is set within 3 main zones namely; the Sahara, Central and North Sahel Savanna and South Sahel with River Niger and highland (such as Damagaram, Air ect …). Half of the country is under the influence of the Sahara. The temperature gradient between the SSTs over the Atlantic Ocean (in connection with Pacific’s) and the Sahara Heat lows associated with the behavior of Azores, Siberian and St Helena High modulate the weather patterns over the country. Weather forecast majorly depends on observation data and forecast models. A better understanding of the strength and weakness of these models will help to improve weather forecast for better used by decision makers and takers, and end users. Models such as the ECMWF, UKMET and METEOFRANCE are mostly used. A fourth model, the GFS is incorporated for the sake of this study.

The raining season start around May in the extreme south of the country and roughly end through early October. Maximum rainfall expected during July and Augusts.

We distinguish deterministic or probabilistic forecast. It could be spatiotemporal or could be object/event oriented, etc. According to Murphy (1993), a good forecast is consistent (degree to which forecast corresponds with forecasters best judgment based on his knowledge base), has quality (degree to which forecast agrees with actual) and has value (degree to which forecast helps decision makers to gain incremental economic and other benefits). The quality and consistency of the forecast models will be looked at in this study as well as the deterministic, probabilistic and event oriented forecast will be verified.

2 .0 DATA AND METHODOLOGY

2.1. General

The study area is Niger in West Africa roughly located between latitude 11 – 24 °N and longitude 02 – 17°E. However, more emphasis is given to Western Niger in this particular study.

Figure 1 Map of Niger with a zoom over Western Niger in box .

The data used in this study include:

- Gauge rainfall data from 62 stations; provided by the Niger Meteorological Service

3

- GDAS analysis data downloaded from the NOAA data achieving system (NOMADS).
- Global model prediction data for the NCEP/GFS, ECMWF and UKMET, downloaded from the TIGGE/ECMWF data portal.
- Satellite data obtained from the NOAA/CPC local computers.

The methods used in this study include:

- Eye-ball method of verification for model Inter-comparison
- Basic verification statistics such as, mean error (bias), rmse, critical success index (CSI) and spatial correlation.

2.2. Description of Statistical Scores:

Quantitative statistical analysis of the model in predicting occurrence of the event was done using a non-parametric skill score following (wilks, 1995, Hanssen Kuiper, 1965) methodology. The analysis was decomposed categorically for a number of precipitation threshold forecasts and observations. This methodology was chosen because of its suitability for this kind of verification and often Forecasters conceptually interpret model output in a similar way. Moreover the methodology avoids penalization of the model for the forecasts that are not exact but can be considered approximately correct and useful.

The skill scores are summarized using statistical analysis.

$$BIAS = \frac{hits + false\ alarms}{hits + misses}$$

Bias score (frequency bias) = (BIAS= Hits +False alarms) /Hits + Misses

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$$

Root mean square error = RMSE

$$TS = CSI = \frac{hits}{hits + misses + false\ alarms}$$

Threat score (critical success index) = TS= CSI= Hits/(Hits + Misses + False alarms)

3. Results and Discussions

3.1 Satellite Imageries

Figure 2 show Mesoscale convection that developed across Northern Nigeria and portion of Niger, and then propagate westwards to affect West Niger and most part of Burkina Faso through 5th to 06th August2012. Significant rainfall amount were reported in relation to this specific squall line.

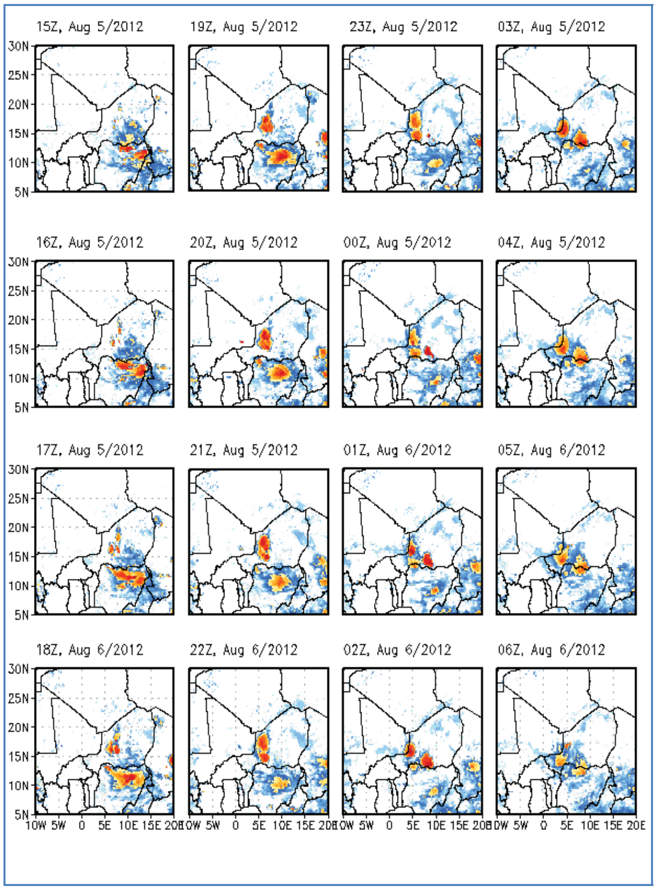


Figure 2.Satellite Imageries

Figure2 and figure 3 show the further propagation of the squall line over some West African countries.

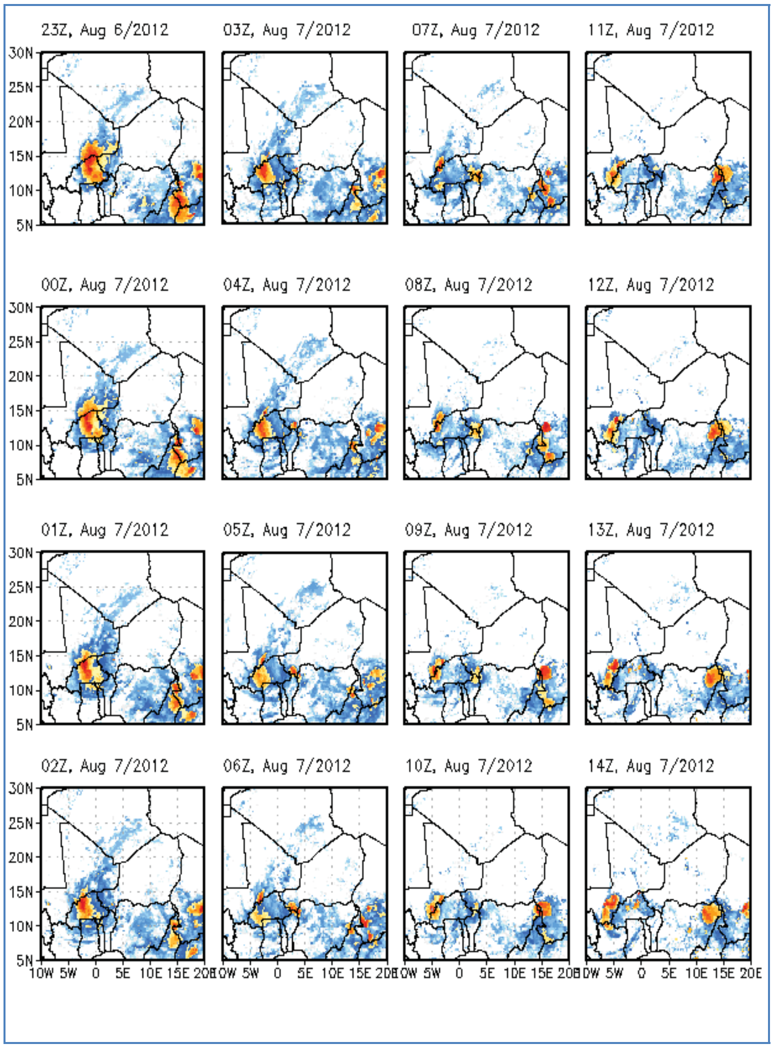


Figure 3.Satellite Imageries

3.2 Rainfall Forecast, Models Inter-comparison

24-hour rainfall forecast from three global NWP models are compared with rainfall observation from 62 stations gauge rainfall (Figure4). The result shows that ECMWF and UKMET were able to predict significant rainfall over West Niger, but the spatial distribution was not well captured by both models. However the GFS model seems to overestimate rainfall over western Niger, while the rainfall predicted by the GFS model seems to cover lager area of heavy rainfall as compared to the gauge observation.

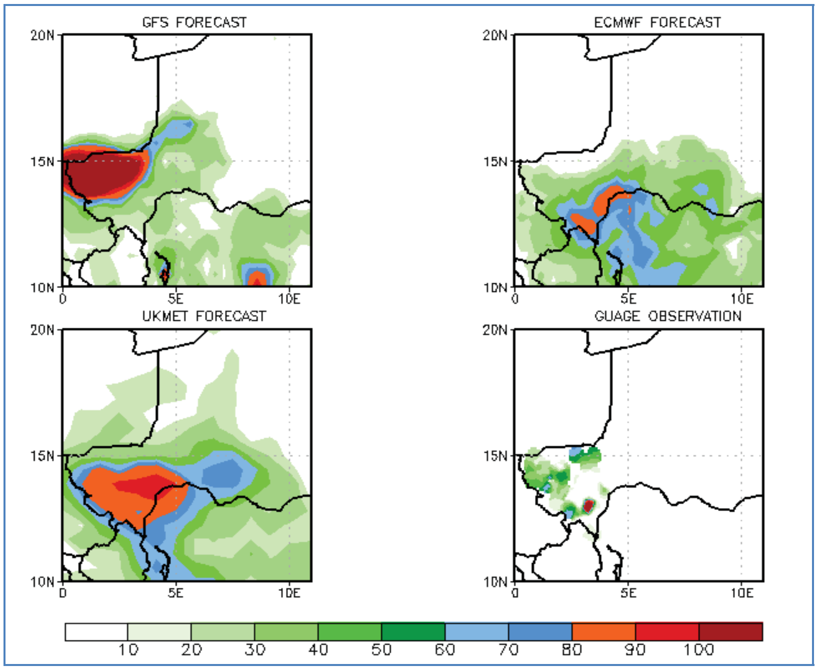


Figure 4. Model Inter-Comparison; Global Models VS gauge rainfall.

3.3 Diagnosis of Vertical Profile

Figure 5; 6 and 7 shows diurnal variation of the vertical wind profile along 12; 13 and 14N latitudes respectively. The diagnosis shows the depth of the monsoon flow, AEJ, AEW, vortex, TEJ and their westward propagation.

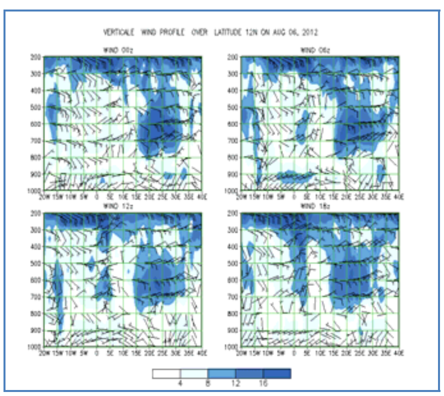


Figure 5: Vertical wind profile, showing deep AEW up to 300mb, significant AEJ at 600mb with a vortex at 700mb and the TEJ at 200mb (along 12^{o}N latitude).

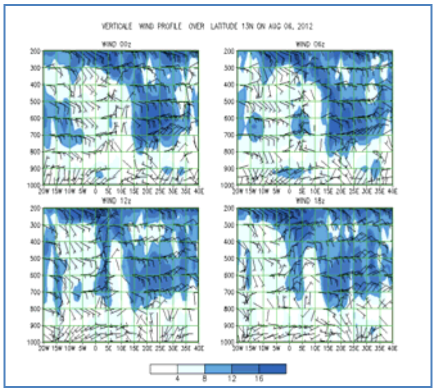


Figure 6: Showing deep AEW up to 400mb, significant AEJ at 600mb with a vortex at 850mb and the TEJ at 200mb (along 13^{o}N latitude).

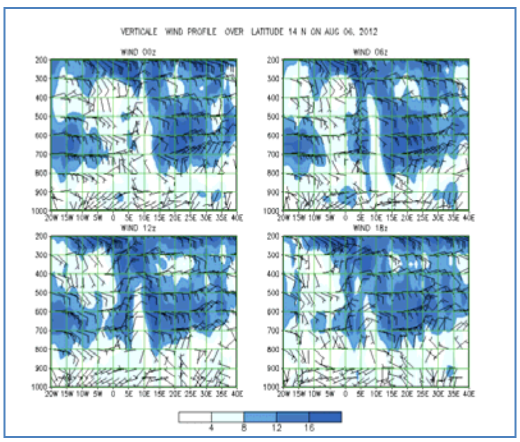


Figure 7 Showing deep AEW up to 300mb, significant AEJ at 600mb with a vortex at 800mb and the TEJ at 200mb (along 14^{o} N Latitude).

3.4 Pressure and temperature Tendency

Figure 8 and 9 shows diagnosis of the Temperature and Pressure tendencies, respectively. Figure 8 shows intense heating and as a result, significant pressure falls (figure 9) occur over south and west Niger on 5^{th} and 6^{th} August, consequently latent heat and sensible heat which serve as energy reservoir for the system in association with the Conditional Instability of Second Kind (CISK).

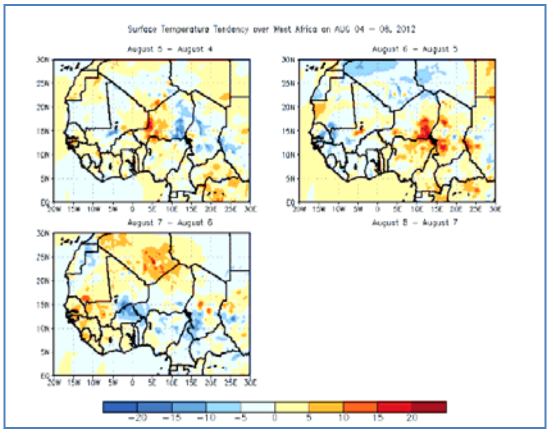


Figure 8, Temperature Tendencies; Aug 5 – Aug 4 (top-left), Aug 6-Aug 5(top-right) and Aug 7- Aug 6(bottom-left)

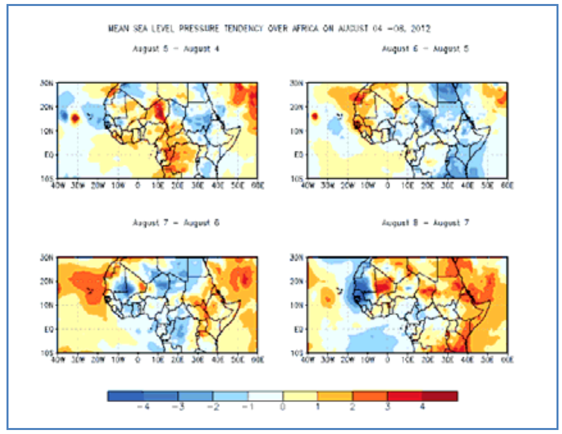


Figure 9, Pressure Tendencies; Aug 5 – Aug 4 (top-left), Aug 6-Aug 5(top-right) and Aug 7- Aug 6(bottom-left)

3.5 Inter Tropical Discontinuity(ITD)

The 10m wind and Td at 2meter have been used to determine ITD relative position around latitude 20°N, however all the models (figure 10) seem to be shifting the ITD position 1.0° to 1.5° North compare to its position form diurnal cycle analysis (figure 11).

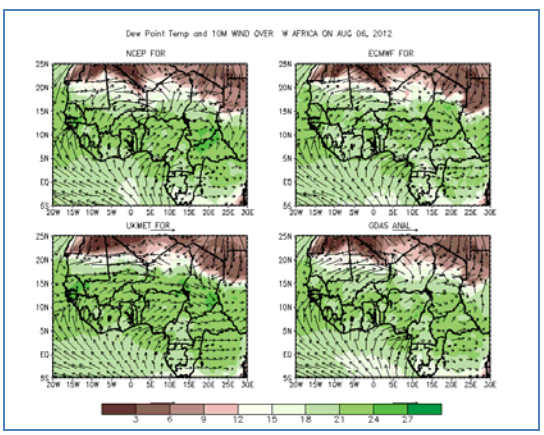


Figure 10, Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis)

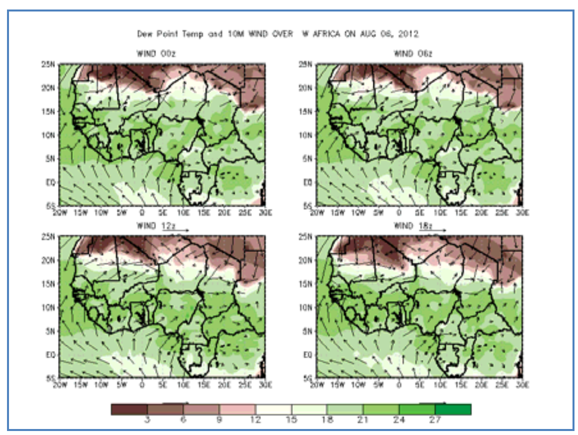
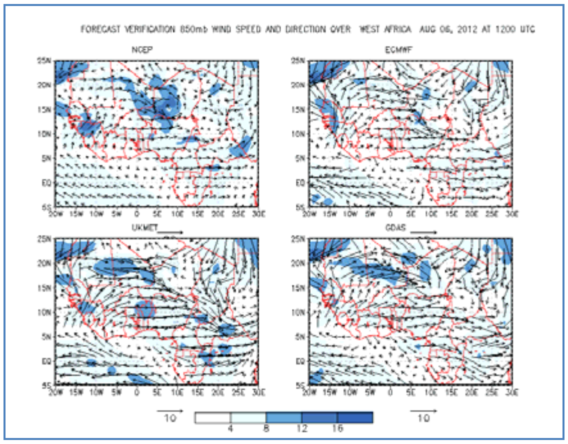


Figure 11, Diurnal Variation based on GDAS analysis (00Z to 18Z)

3.6 Wind flow at 850mb

Figure 12 and figure 13 show model inter-comparison of the 24-hour 850mb wind forecast against GDAS analysis, valid at 12Z and 18Z, respectively. In general, The GFS model shows deeper and significant monsoon influx and monsoon vortex , while UKMET and ECMWF depicted only trough, velocity and wind convergence over Niger both at 1200 UTC and 1800 UTC.



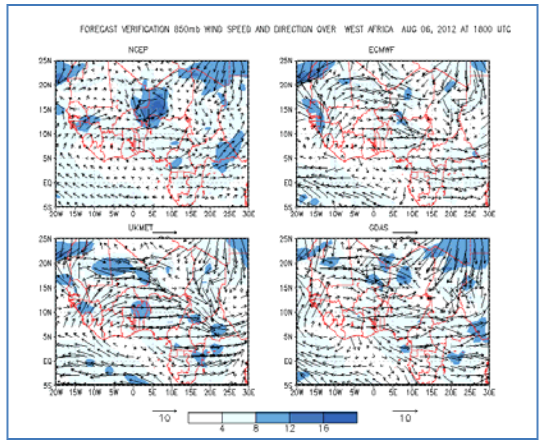


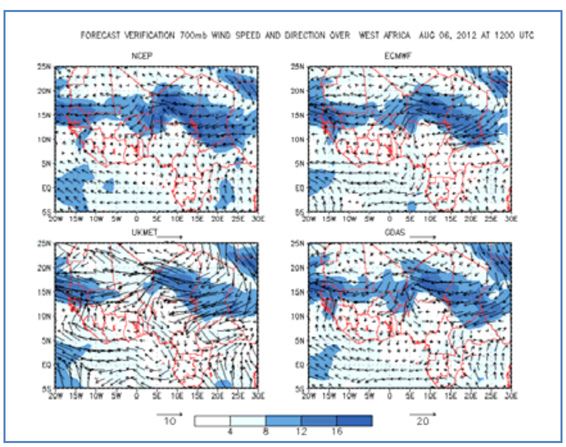
Figure 12, 24-hr 850mb wind forecast. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 12Z)

Figure 13, 24-hr 850mb wind forecast. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

3.7. 700mb

3.7.1. Wind Flow

Figure 14 and 15 at 700mb, more or less all the models were able to show a very well defined vortex, a pronounced westward propagating AEW and moderate to strong AEJ affecting portion of Niger. In general, the NCEP model was able to depict patterns seen in the GDAS analysis better, as compared to the other two models. The deep convection observed on August 6 over Niger was embedded within the extent of African easterly waves. The strength of AEJ, hence the vertical wind shear determines the type and severity of the storm.



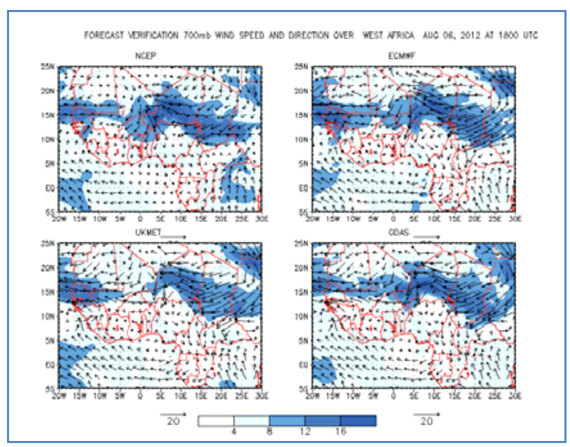


Figure 14. 24-hr 700mb wind forecast. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 12Z)

Figure 15. 24-hr 700mb wind forecast. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

3.7.2 Relative Vorticity

As shown in figures 16 and 17, at 700 mb, all the three models were able to depict higher relative vorticity values and pattern across the Sahel region, which is somewhat similar to that of indicated by the GDAS analysis. These patterns of vorticity must have contributed to the observed high rainfall over Niger and neighboring areas.

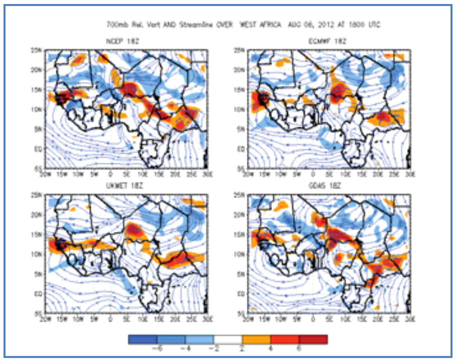


Figure 16, 24-hr 700mb relative vorticity. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 12Z)

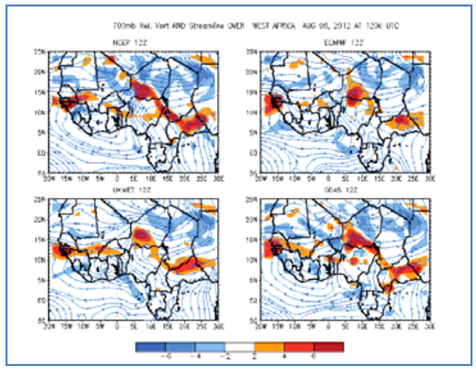


Figure 17, 24-hr 700mb relative vorticity. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

3.7.3 Horizontal Convergence

As shown in Figures 18 and 19, the NCEP and the ECMWF models were able to capture the convergence pattern observed on the GDAS analysis. However, the patter n seen on the NCEP model resembles better the patterns of the GDAS analysis. This convergence pattern must have contributed in triggering and maintaining the observed MCS.

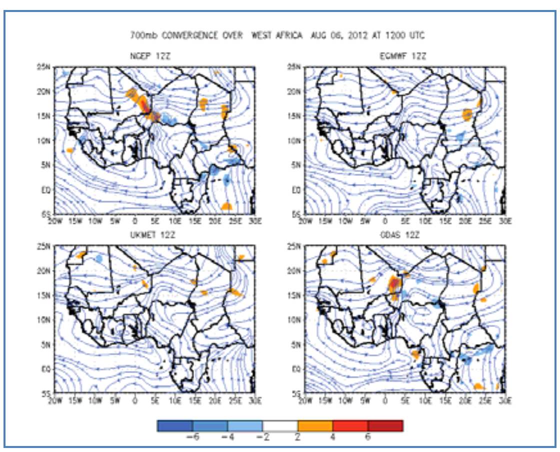


Figure 18, 24-hr 700mb horizontal convergence. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 12Z)

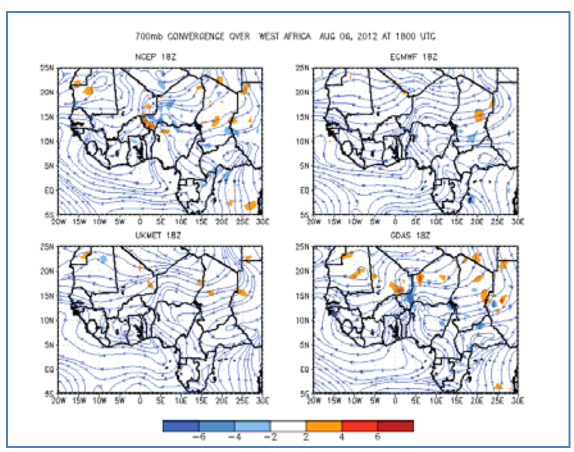


Figure 19, 24-hr 700mb horizontal convergence. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

3.8. Diurnal Cycle of Vertically Integrated Moisture Flux

Figure 20 show the vertically integrated moisture fluxes from surface up to 500mb as per the GDAS analysis. The analysis clearly indicates the contributions of the monsoon flux as well as fluxes due to westward propagating systems. Higher fluxes and their associated convergences were observed over Niger, close to the area heavy rainfall event, while slightly propagating westward between 00Z and 18Z.

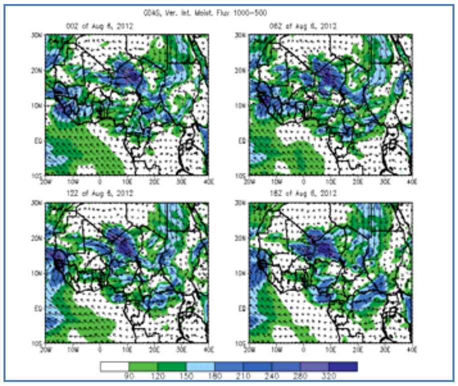


Figure 24, Analysis of diurnal variation of vertically integrated moisture flux for August 6, 2012.

3.9 Upper Level Divergence and Wind Flow

3.9.1 Upper level divergence

Figure 20 and 21 show strong upper level divergence near the convection area both at 12z and 18z. All the three models are able to depict these patterns which really contribute to maintain the system.

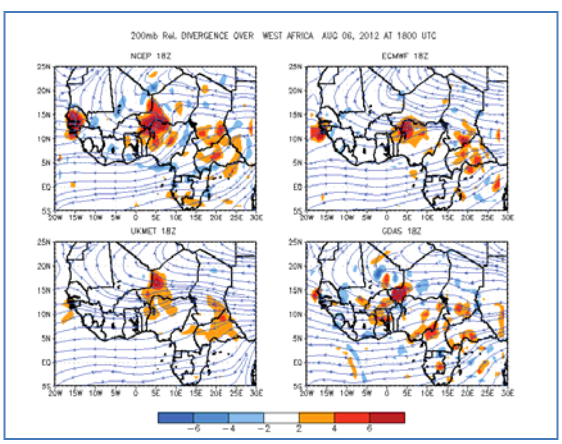


Figure 20, 24-hr 200mb upper level divergence. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 12Z)

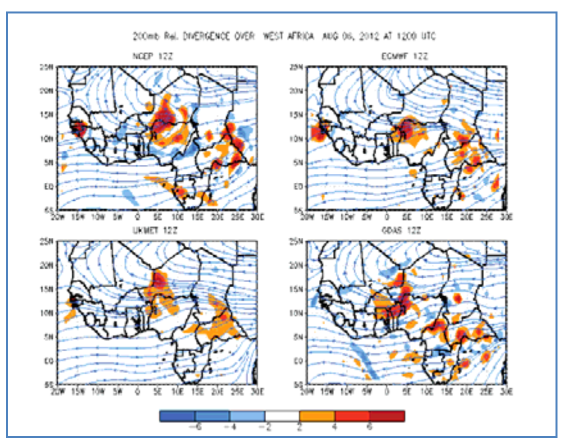


Figure 21, 24-hr 200mb upper level divergence. Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

3.9.2 Wind flow at 200mb and TEJ models inter-comparison

Figure 22 and 23 show models inter-comparison for 200mb wind forecast. The flow pattern shows the seasonal upper level Easterlies and the associated Tropical Easterly Jet that may have contributed to the westward propagation of the convective systems.

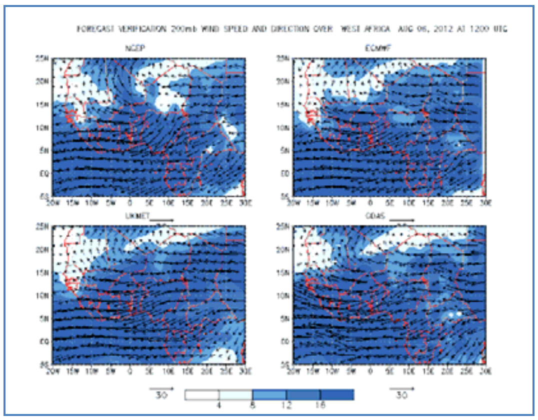


Figure 22, 24-hr wind flow at 200mb upper level Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis at 18Z)

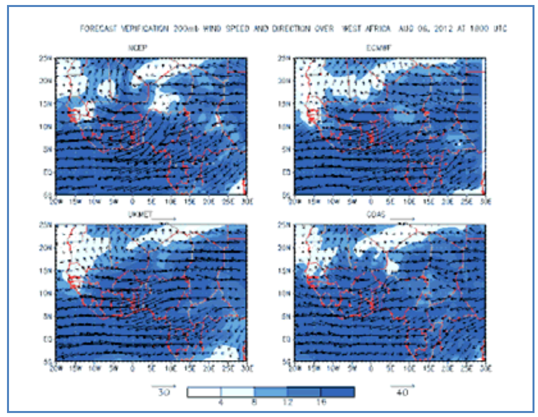


Figure 23, 24-hr wind flow at 200mb upper level Model Inter-comparison (GFS, ECMWF, UKMET VS GDAS analysis

4. Statistical Analysis

4.1 Bias

Figure 24 shows the average bias over West Niger (mean error) for GFS, UKMET and ECMWF 24 hours rainfall forecast versus observed rainfall amount; it clearly appears that GFS show the highest positive bias, an indication of significant over forecasting, in contrast ECMWF show the lowest bias as compare to the other models. From this statistic the ECMWF appears to perform better.

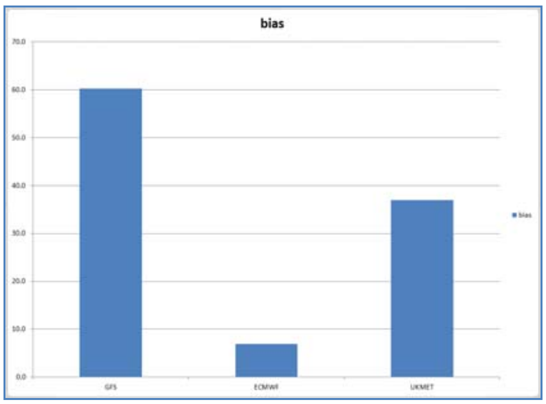


Figure 24 Bias (mean error)

4.2 Root Mean Square Error

Figure 25, show that the GFS model has the highest error, while the error for ECMWF was the lowest one.

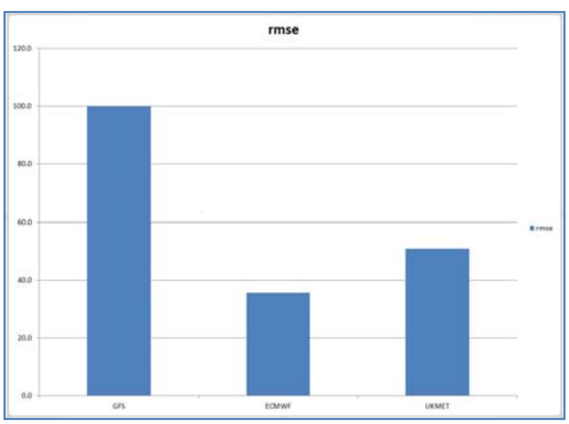


Figure 25, Root Mean Square Error GFS, ECMWF, UKMET

4.3 Spatial Correlation

Figure 26 show spatial distribution and GFS has the highest positive spatial correlation compare to UKMET and ECMWF (negative spatial correlation). In terms of spatial distribution, GFS model perform much better than the others.

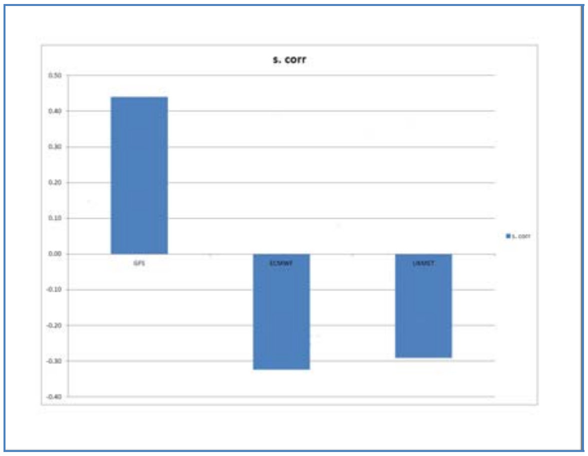


Figure 26 Rainfall spatial correlation GFS, ECMWF, UKMET VS Observed Rainfall

4.4 Threat Score (Critical Success Index)

Figure 27, show the threat Score Analysis of the three models with respect to the observed rainfall. The GFS models present high and better Critical Success Index compare to UKMET and ECMWF models for almost all threshold values.

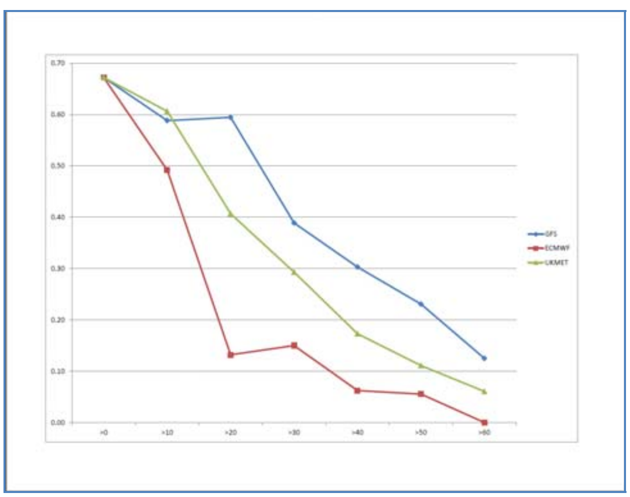


Figure 27 Threat Square of GFS, ECMWF, UKMET

5. Conclusion and Recommendation

5.1. Conclusion

- On August 6, 2012 , combination of excess surface heating and the associated fall in pressure, active AEW and AEJ, vortices at 700mb, lower-level wind convergence and upper-level divergence led to heavy rainfall over Niger and neighboring areas. The easterly flow associated with the AEW was deep in the atmosphere, extending from about 700mb up to 300mb

- The GFS model showed better spatial correlation with the observed gauge rainfall as compared to the ECMWF and UKMET models, while the ECMWF model showed relatively lower rmse values as compared to the other two models.

- The GFS model also showed better skill in forecasting rainfall, with higher Critical Success Index values at all rainfall thresholds.

- Even though, the GFS model showed better performance in forecasting the rainfall event on august 06th, 2012, each of three models has their own weaknesses and strengths. While one model shows weaknesses in depicting certain features, the other model may have better representation of the feature.

- Since each model has shown its own weakness and strengths, the use of multi-model approach may give better results in predicting rainfall in Niger.

5.2. Recommendation

- Performance of NWP models can't be concluded based on 1 case study; hence, there is a need to make some more case studies.
- Since the West African convective systems have meso-scale nature, there is a need to customize and use regional models such as WRF.
- There is also a need to investigate the performances of ensemble systems.
- Downscaling rainfall from the GCMs should also be used to avoid spatial variation of rainfall pattern.

6.0 References.

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Linkages among Key Actors in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

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Abstract

The study used the innovation system approach to ascertain the intensity and trends of linkages among key actors in the climate change innovation system in Nigeria, Sierra Leone and Liberia. Data were collected through the use of structured interview schedule, key informant interviews and focus group discussions (FGDs) and analyzed using percentages, mean scores and trend analysis. The presence of local collaboration among actors was higher in Nigeria than in Sierra Leone and Liberia. There was non-existence of overseas linkages with majority of the enterprise actors across the three countries. The intensity of linkages / collaborations existing among actors in the enterprise domain, in the three countries, outweighs that with other domains, with higher collaborations existing among the small-scale farmers and famers' associations. However, there was a perceived increase in the trend of linkage between enterprise actors and R & D institutions in Nigeria between 2007 and 2009, with a linkage index of more than 2. There was also higher linkage index (of more than 2) between enterprise actors and technology delivery institutions in Nigeria than in Sierra Leone and Liberia, but a low linkage index of less than 2 between enterprise actors and policy making bodies for all the countries. The study points to the need to intensify the collaborative efforts, between local and foreign partners, as this will bring about the generation of better and improved innovations on food security and adaptive measures.

Keywords: agricultural innovation framework; enterprise actors; intensity of collaboration; linkage index,

1.0 Introduction

Africa remains one of the most vulnerable continents to climate change because of multiple stresses (resulting from both politics and economic conditions), the continent's dependence on natural resources and its weak adaptive capacity. The area suitable for agriculture, the length of growing seasons and yield potentials, are expected to decrease due to climate change. Yields from rain-fed agriculture in some countries could be reduced by up to 50%. Thus, climate change may have particularly serious consequences in Africa, where some 800 million people are undernourished.

In the West African sub region, agriculture is critical to the economy. While the world average contribution of the agriculture sector to the Gross Domestic Product (GDP) is only 4.5 %, the sector's contribution is about 30 % in West Africa. In addition, over 65 % of the population in the region is rural, and about 90 % of the rural population directly depends on rain-fed agriculture for income and food security. Therefore reduction in rainfall as predicted by various climate models translates to threat to livelihood of the population and the economy of the sub-region.

Unfortunately, many researches in Nigeria, Sierra Leone and Liberia show that the performance of the agricultural sector continues to be relatively disappointing in the sub-region as growth has been increasingly on the decline. Traditionally, the agricultural research systems in the region are characterized by a top-down, centralized, monolithic and isolated structures. Linkages, interactions and learning mechanisms among the component actors are notably weak and/or often non-existent. Empirical evidence revealed several linkage gaps and missing links among and between the actors in the systems (Agbamu, 2000; Egyir, 2009). Institutions, for example, universities and research institutes innovate in isolation and although research were taking place at various national and international organizations, the coordination is dysfunctional, and poorly linked to the productive sector. Besides, farmer innovations were not being included in the knowledge system because traditional approaches such as the NARS (National Agricultural Research System) perspective and AKIS (agricultural knowledge and information system) depict research as the sole source of innovation. Without research, it implies, there is no innovation. Consequently, this study sought to determine the presence of linkages among key actors in the climate change innovation system in Nigeria, Sierra Leone and Liberia.

2.0 Methodology

Tools of participatory research namely, structured questionnaire, structured interview schedule, key informant interviews and focus group discussions (FGDs) were used to collect data from 1,424 respondents selected through a multistage sampling from the three countries. The intensity of collaboration was measured on a five point Likert-type scale of “None”, “Weak”, “Average”, “Strong” and “Very strong”, with nominal values of 1, 2, 3, 4 and 5, respectively, while “Decreasing”, “Remained the same” and “Increasing” (scaled -1 to +1) were used to measure linkage trend among the key actors over the past five years. Mean scores and trend analyses were used to summarize all the information gathered.

3.0 Results and Discussion

3.1 Intensity and trends of Linkages / Collaboration among Key Actors in the Climate Change Innovation System

3.1.1 Existence of local and overseas collaborations in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Fig. 1 indicated the non – existence of overseas linkages / collaboration in the area of climate change among majority of the rural households across the three countries. The presence of local collaboration was higher in Nigeria (11.0 percent) than in Sierra Leone (2.0 percent) and Liberia (3.2 percent). Collaboration among actors in the climate change innovation system is essential for relevance, capacity building and increase innovative performance of the actors and the system in general. The extent of collaboration also suggests the level of involvement in climate change activities.

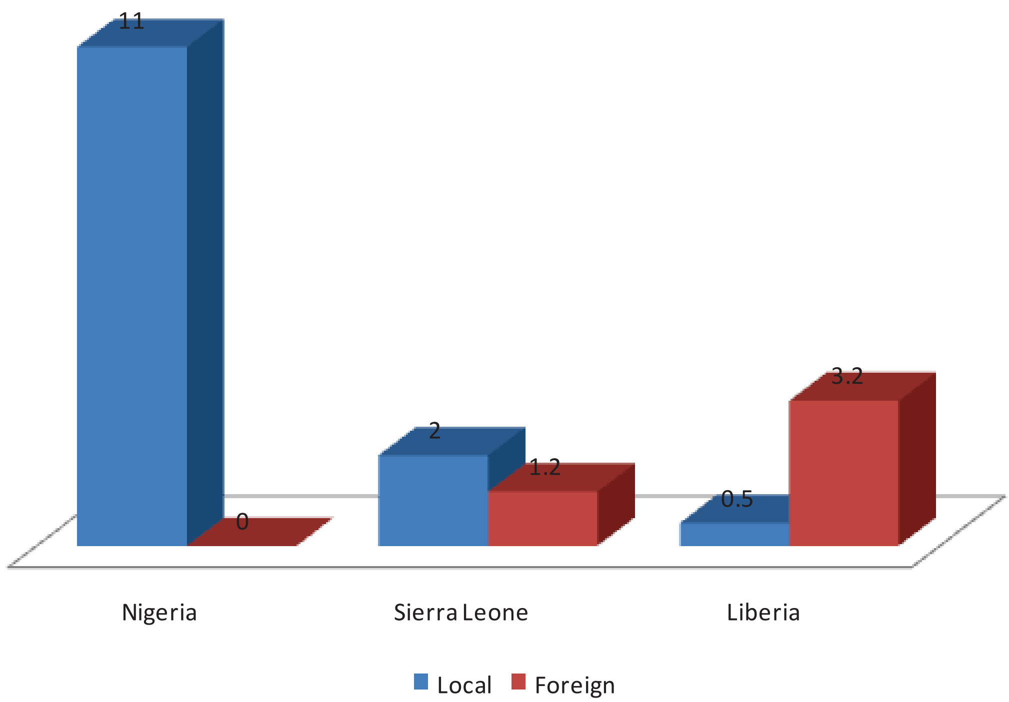

Figure 1: Existence of local and overseas collaborations on climate change in Nigeria, Sierra Leone and Liberia

3.1.2 Intensity of linkages/collaborations between enterprise actors and other actors in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Table 1 reveal that the intensity of linkages / collaborations existing among actors in the enterprise domain, in the three countries, outweighs that with other domains, with higher collaborations existing among the small-scale farmers and famers' associations. Nigeria tends to have higher linkages / collaborations between the actors in all the domains followed by Liberia in three out of the four major domains, while Sierra Leone only showed a higher intensity than Liberia in the area of linkage with policy makers. This finding shows that the level of cohesion and/or involvement of the different actors in climate change activities are minimal.

Table 1: Mean scores of intensity of linkages / collaborations between enterprise actors and other actors in the climate change innovation system

Collaborating Actors	Nigeria		Sierra Leone		Liberia	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
R &D Agencies Domain						
National agricultural research organization (e. g. NIHORT, FIIRO, NRCRI, IAR, etc.)	2.14	1.17	1.07	0.25	1.09	0.34
Regional agricultural research organization / network	1.36	0.66	1.07	0.25	1.13	0.44
International agricultural research organization / network (e.g. IITA)	2.21	1.46	1.05	0.22	1.05	0.22
Universities	1.89	1.29	1.09	0.34	1.21	0.42
Overall mean	***1.90***	***1.15***	***1.07***	***0.27***	***1.12***	***0.36***
Policy Makers Domain						
National agricultural research council	1.42	0.62	1.14	0.35	1.06	0.30
Policy makers	1.66	1.13	1.19	0.39	1.21	0.41
Standard setting body (e. g. NAFDAC, SON, etc.)	2.06	1.06	1.03	0.18	1.01	0.09
Overall mean	***1.71***	***0.94***	***1.12***	***0.31***	***1.09***	***0.27***
Enterprise Domain						
Small – scale Farmers	2.93	1.08	1.19	0.38	1.42	0.70
Medium – large scale farmers	2.69	1.40	1.17	0.39	1.14	0.44
Farmers Association	2.88	1.35	1.22	0.44	1.25	0.70
Agricultural cooperatives	2.37	1.09	1.22	0.44	1.19	0.49
Financing/ credit/ venture capital	2.44	1.38	1.03	0.17	1.02	0.15
Input suppliers e.g. Seed companies	2.00	1.09	1.03	0.18	1.03	0.17
Agricultural machinery suppliers	1.41	0.69	1.05	0.23	1.04	0.30
Agricultural produce marketers	2.39	1.21	1.09	0.25	1.18	0.48
Consumers of agricultural products	2.81	1.32	1.08	0.21	1.18	0.54
Overall mean	***2.44***	***1.18***	***1.13***	***0.30***	***1.16***	***0.44***
Extension Agencies Domain						
Extension agencies (e. g. ADPs including private extension services)	1.98	1.17	1.12	0.37	1.25	0.46
Federal / State Ministries of Agriculture	1.84	0.91	1.11	0.39	1.33	0.47
Federal / State Ministries of Environment	2.10	1.12	1.05	0.22	1.28	0.45
Overall mean	***1.97***	***1.07***	***1.09***	***0.33***	***1.29***	***0.46***

3.2 Linkage trends among key Actors between 2005 and 2009

3.2.1 Linkage trends between enterprise actors and R & D Institutions in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Figure 2 shows the perceived linkages existing between enterprise actors and research and development institutions between 2005 and 2009 in the three countries. The result reveal a perceived increase in the trend of linkage between the enterprise actors and the R & D institutions in Nigeria between 2007 and 2009, with a linkage index of more than 2. On the other hand, data from Sierra Leone and Liberia show a stabilized trend in their linkage with R &D institutions over the past five years (with linkage index of less than 2 each), with Sierra Leone showing a higher intensity of linkage than Liberia.

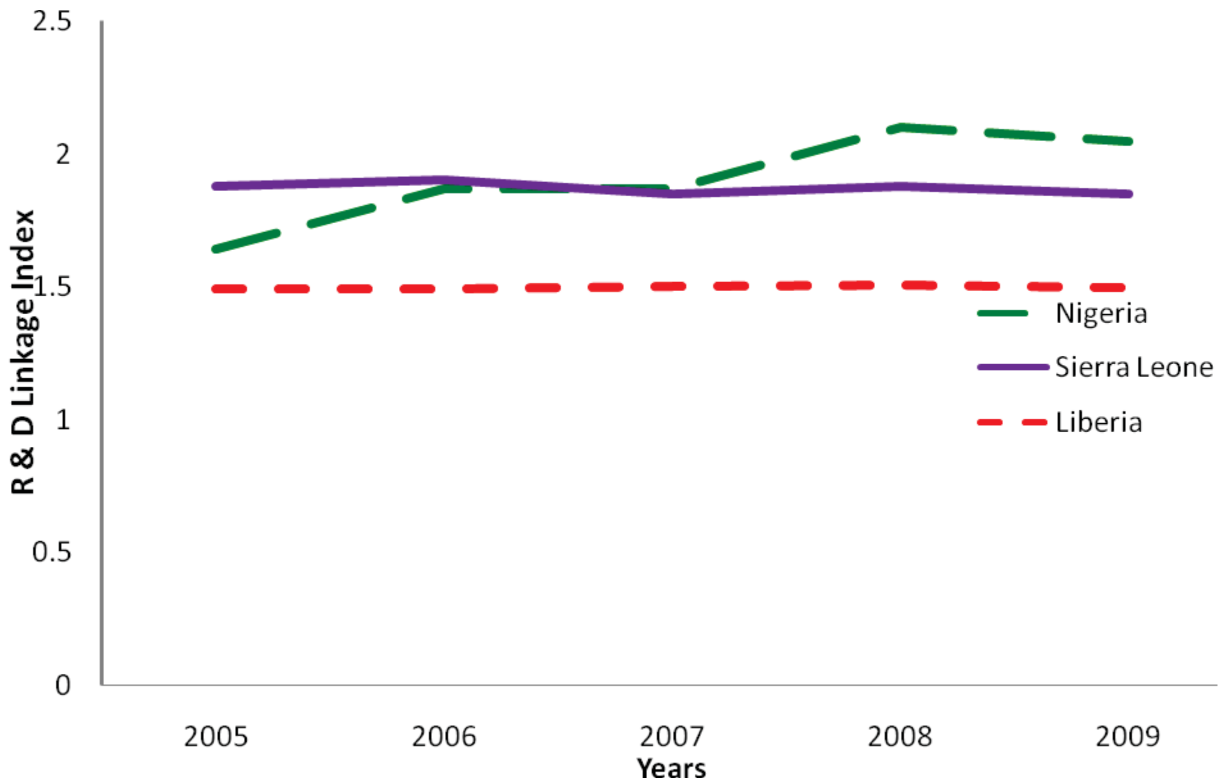

Figure 2: Percieved trend of linkage between farmers and R &D institutions in Nigeria, Sierra Leone and Liberia

3.2.2 Linkage trends between enterprise actors and policy making bodies in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Figure 3 show the linkage trend between enterprise actors and policy making bodies in the different countries. The Figure shows a low linkage index of less than 2 for all the countries. However, result from Nigeria show an unstable trend between 2005 and 2008, with an upward trend since 2008. On the other hand, data from Sierra Leone and Liberia reveal a more stable linkage between the enterprise actors and policy making bodies, with Sierra leone having a higher colllaboration intersity than Liberia.

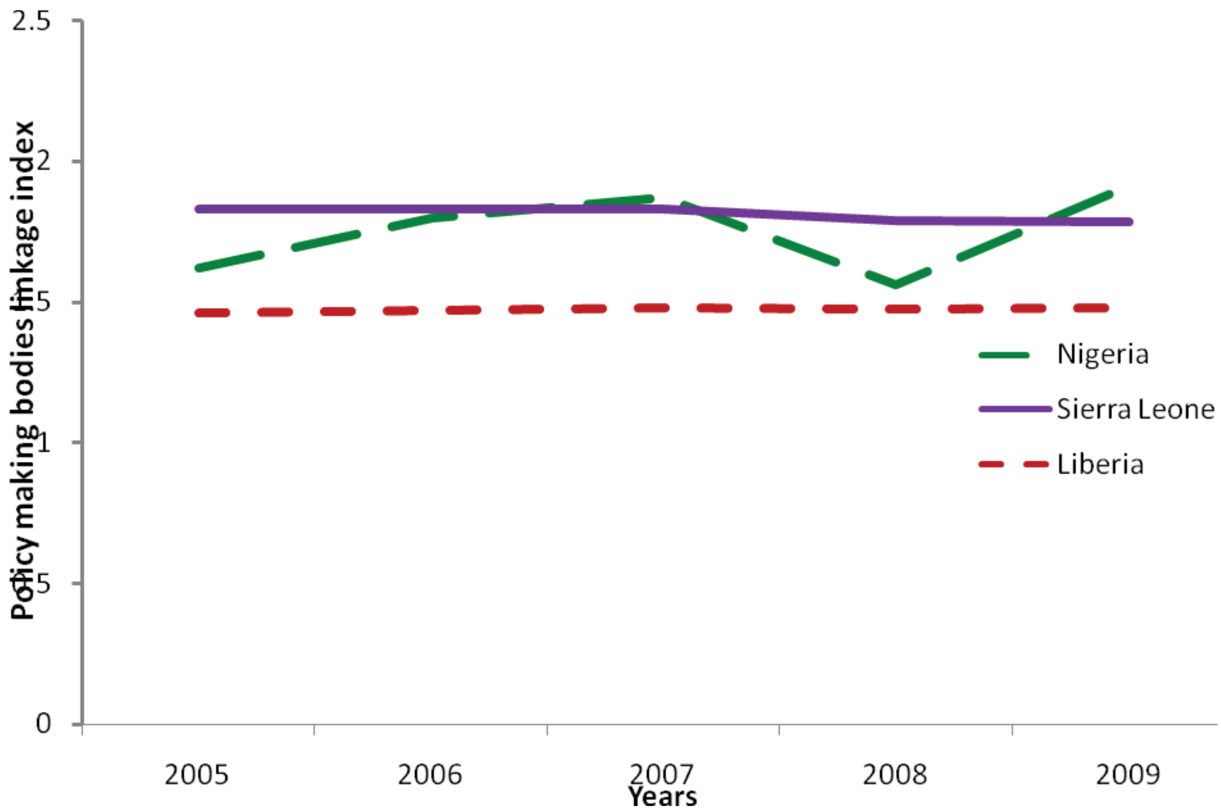

Figure 3: Percieved trend of linkage between enterprise actors and policy making bodies in Nigeria, Sierra Leone and Liberia

3.2.3 Linkage trends among actors within the enterprise domain in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Figure 4 show the linkage trend among key actors (which include Small – scale farmers, medium – large scale farmers, farmers association, agricultural cooperatives, financing/ credit/ venture capital, Input suppliers, agricultural machinery suppliers, agricultural produce marketers and consumers of agricultural products) within the enterprise domain. The result reveal a higher linkage index among these actors than with other actors in the climate change innovation system across the three countries. The result also show an increasing linkage trend among these actors in Nigeria than in Sierra Leone and Liberia, with Sierra Leone showing a higher linkage intersity trend than Liberia.

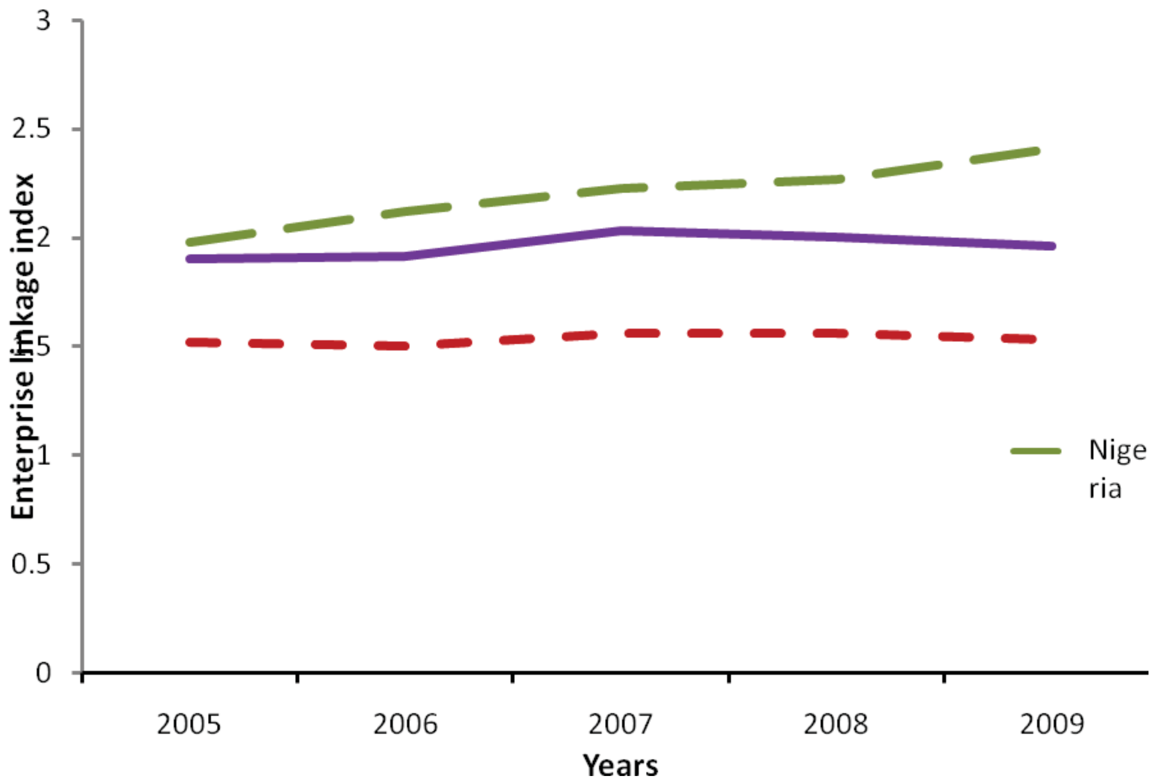

Figure 4: Percieved trend of linkage among actors in the enterprise domain in Nigeria, Sierra Leone and Liberia

3.2.4 Linkage trends between enterprise actors and technology delivery institutions in the Climate Change Innovation System in Nigeria, Sierra Leone and Liberia

Figure 5 shows the linkage trends between enterprise actors and technology delivery institutions across the three countries. The result reveal an incresing higher linkage index (of more than 2) between farmers and technology delivery institutions in Nigeria than in Sierra Leone and Liberia. On the other hand, result from Sierra Leone also shows an uneven increasing linkage trend over the past five years, with Liberia showing a more stable linkage trend between the enterprise actors and technology delivery insitutions. The linkage index between enterprise actors and the technology delivery insitutions in Sierra Leone and Liberia was less than 2.

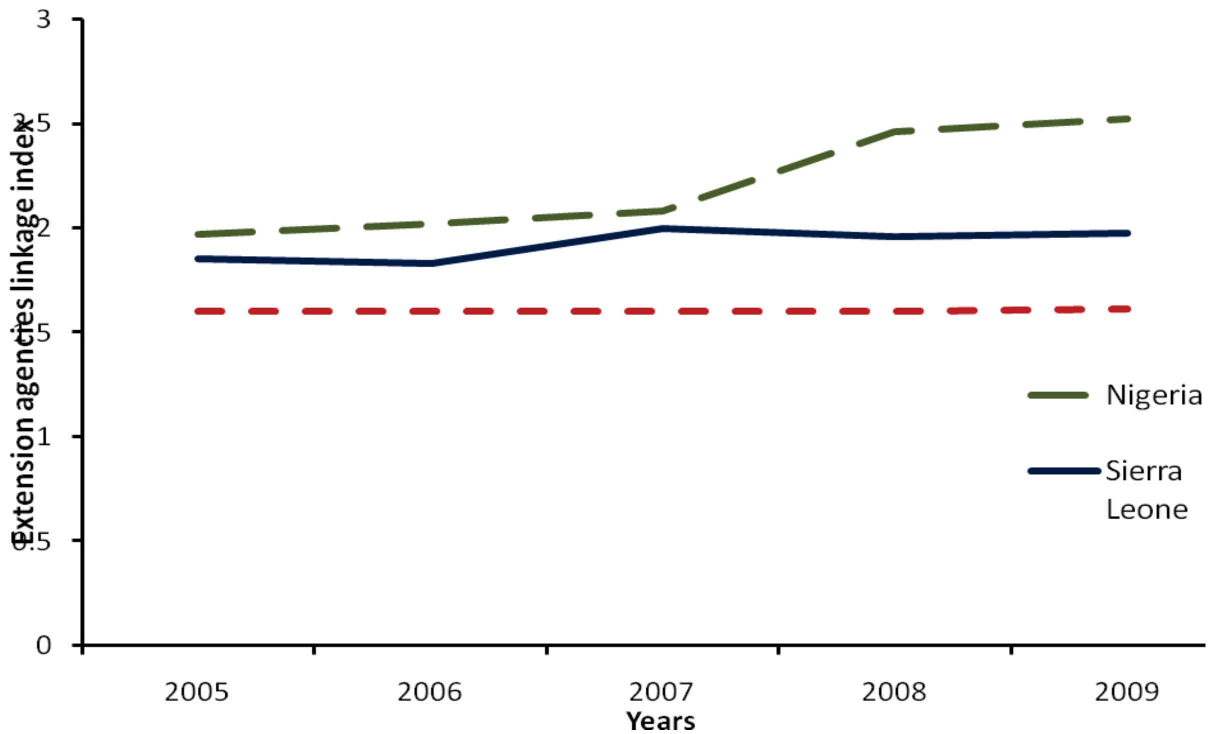

Figure 5: Linkage trends between enterprise actors and technology delivery institutions in Nigeria, Sierra Leone and Liberia

Conclusion and Recommendation

Studies on innovation indicate that the ability to innovate is often related to collective action and knowledge exchange among diverse actors, incentives and resources available for collaboration, and having in place conditions that enable adoption and innovation e.g., by farmers or entrepreneurs. However, the results showed that there was a poor intensity of collaborations with foreign partners across the three countries, even though there appeared to have been more collaboration with local institutions, especially in Nigeria. Foreign collaboration is needful to bridge the gap in knowledge and experience on innovative adaptive measures to climate change. Collaboration with foreign partners will also help in the transfer and build up of strong teams of experts which could pull resources together towards the generation of more innovative ways of adapting to climate change and also ensuring that the sub-region has better chances of addressing the challenge of climate change.

The following were recommended:

1) Formulation of a comprehensive climate change policy at the a global level and within Africa and especially in the West African sub-region will be a necessary first step towards dealing with the challenge of climate change within the sub-region. A number of climate change conferences have been held in recent years all over the world. Such conferences are platforms which provide necessary input into a global climate change policy, which would in turn be translated or domesticated in the respective countries taking cognizance of their varying agro-ecological and climatic characteristics.
2) Collaboration efforts, between local and foreign partners should be intensified. This will bring about the generation of better and improved innovations on climate change adaptive measures.

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Acknowledgement

This paper was produced as part of the implementation of the ATPS Phase VI Strategic Plan, 2008 – 2012 funded ATPS Donors including the Ministerie van Buitenlandse Zaken (DGIS) the Netherlands, and the Rockefeller Foundation, amongst others. The authors hereby thank the ATPS for the financial and technical support during the implementation of the program.

Improving data and information exchange in the chain of climate research, impact research, to policy making

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Abstract— It is all too often difficult for a stakeholder to obtain an overview of available climate and impact data, judge their quality and the assumptions behind or how uncertainties are taken into account. This implies a serious limitation in the sense that stakeholders risk to miss crucial information, misinterpret what they obtain and base complex decisions on non-consistent data.

As part of the Knowledge for Climate programme a project was initiated in which we attempt to integrate information and data on climate change and its impacts in a similar way for a number of sectors (climate, hydrology, ecosystems, agriculture, land use) among others through a web portal and integrated data sets on climate change and its impacts for the Netherlands. An important research question is “How can this data and information be made consistent across location, disciplines and applications?”

The approach followed includes among others the following aspects: 1) stakeholder consultations, 2) generation of data on climate change and impacts for a predefined and limited number of combinations of climate scenarios and spatial scenarios and time horizons, 3) overview of interactions, exchange of data, inconsistencies, ways of handling uncertainties, etc. for the various disciplines.

Index Terms— integrate climate and impact information, stakeholder consultations, uncertainties

1 Problem definition and aim

Many long term decisions on infrastructure, spatial planning, economy etc. are based on information on the climate for the lifetime of the object in question. Governments, businesses and private companies, as well as organisations increasingly need data and tailored information on climate change and its impacts in order to allow them to make informed decisions on climate adaptation strategies. However, it is all too often difficult for a stakeholder to obtain an overview of available data, judge their quality and the assumptions behind or how uncertainties are taken into account. This implies a serious limitation in the sense that stakeholders risk to miss crucial information, misinterpret what they obtain and base complex decisions on non-consistent data. Getting an overview and integrated data sets is even more difficult when stakeholders are involved in border crossing projects.

In the Netherlands recent research on climate change, its impacts and adaptation options has been substantial. There are, however, some shortcomings which hamper the dissemination, the proper use of data and information and the integration of information from the various sectors and which are related to the above mentioned aspects:

1. No cross sectoral overview on available information on climate change and its impacts;
2. Results sometimes inconsistent between sectors;
3. Results often not available in format that can be used directly.

As part of the research programme Knowlegde for Climate (KfC) a project was started up with the aim to improve data and information exchange in the chain of climate research, to impact/adaptation research, to policy making. In the first phase a pilot web portal was developed with the goal to integrate information and data on climate change and its impacts from projects within the KfC and Climate changes Spatial Planning (CcSP) programme[1] in a similar way for a number of sectors (climate, hydrology, ecosystems, agriculture, and land use) (Bessembinder et al., 2012). The second phase of the project builds on by creating integrated data sets and an overview of the available data and information from various disciplines.

2 Approach followed and some results

2.1 Web portal

In this project a web portal was developed to overcome the above mentioned problems partly. It attempts to:

1. Provide overview of available data and information, but also of interactions and exchange of data between disciplines, inconsistencies, ways of handling uncertainties, etc.;
2. Synchronize the presentation of the available data and information form the various sectors;
3. Tailor data and information.

[1] The KfC programme is the follow-up of the CcSP programme. Both KfC and CcSP are scientific research programmes and project plans and results undergo a scientific and societal review

The web portal focuses on data and information for the physical climate system, water, nature, agriculture and changes in land use due to socio-economic developments[2]. These subjects comprise the most important factors in land use in the Netherlands. Researchers for all these disciplines are included in the project as partners[3]. In this project especially researchers were the target group.

At the web portal (Climate Impact Guide (CIG)/KlimaatEffectWijzer (KEW): www.klimaatportaal.nl) available data and information from KfC and CcSP-projects are presented in a common structure on all sub portals per sector. The synchronization should make it easier for users to find information from other sectors. The sub portals are connected to each other with the help of several common web pages with among others information on the (lack of) exchange of data between sectors (e.g. models on ecosystems and agriculture often generate their own information on water supply from the soil), discrepancies and the possible consequences. For example, using land use data with a time horizon of 2040 for around 2050 may lead to a relatively small overestimation of the area with agriculture in the Netherlands.

Table 1. Examples of the type of information provided about discrepancies and the consequences.

Discrepancies	Use of climate data within other sectors	Consequences
Land Use	Projections for future land use for 2040, impact studies often for 2050	Changes in land use during 10 years are often not large, but some over/underestimation possible
Water	Makkink refence evapotranspiration, other sectors use sometimes other methods for evapotranspiration	May lead to other values for actual evapotranspiration, and therefore to over/underestimation of water demand, drought and water excess.

For tailoring regular or constant contact with users is required, since users can not always specify their requirements directly and their requirements may change over time (Bessembinder et al., 2011b). In this project the nature of the tailoring activities per discipline differs considerably:

1. Improving access to available data: information is given on which data are available;
2. Processing of available data;
3. Tools for making/selecting specific data;
4. Guidance on the use of data.

[2] In the second phase also air quality is included
[3] The partners in the project are: Wageningen UR (University & Research centre), Deltares, VU University Amsterdam, KWR Water cycle Research Institute, TNO, KNMI

The first two activities were executed by all partners, but the others are not.

2.2 Integrated data set

When impact researchers use different climate scenarios, land use scenarios and time horizons, it becomes more difficult to integrate the results of the various impact studies. Consequently, it also becomes more difficult to draw conclusions relevant for policy makers from it. For hydrology, agriculture and nature the required climate data do not differ very much. Therefore, climate data sets will be generated that can be used by all three disciplines. When these disciplines also use the same land use scenarios and time horizon (2050), an integrated dataset can be developed for climate and impacts that can be used as a reference. The synchronization of the use of scenarios is part of the second phase of the project. A first version of climate datasets is now developed and will be used in the coming half year by the impact researchers. In this project we focus mainly on the time horizon of 2050 for the following reasons:

1. Most users are interested in time horizons up to 2050. Time horizons beyond 2050 are only used by a limited group, e.g. for coastal protection and for urban sewerage systems in the Netherlands (Bessembinder et al., 2011a);
2. For time horizons closer than 2050 it is much more difficult to distinguish between natural variability of the climate system and climate change due to the increase of GHG-emissions.

2.3 User consultations

The added value of the CIG/KEW portal depends on the usefulness of the provided data and information for the intended users. The main aim of this project is to improve the access and usability of data and information on climate change and its impacts for users. For this, user feedback and knowledge of users' requirements is essential (Bessembinder et al., 2011a). Therefore, different forms of user consultations are organised:

1. Workshops/meetings with larger groups of users: e.g. to find out which information users need;
2. Evaluation: the pilot version of the web portal was reviewed by 30 users in the beginning of 2011. The results confirmed the need for more overview on available data and information. For

38% of the reviewers it was already easier to find data and information, 48% mentioned that the portal did not yet contain enough data and information. The most important points of improvement are the further synchronization of the web pages of the different sectors and adding more information and overview;

3. The project partners themselves are users of some of the information from other partners. Discussion on the needs, assumptions, discrepancies, etc. among eachother resulted in a better understanding of eachothers requirements.

3 Preliminary conclusions and discussion

3.1 Synchronization of sub portals

At the moment the structure of the sub portals still differs to a certain extent. For some of the intended users (researchers) the current structure makes it already easier to find similar information for various disciplines. It seems not easy to use a similar structure for each discipline. This is partly due to the different nature of the data and information that is presented: some present data and information that stem from individual projects (e.g. for nature and agriculture), some present data-bases with long term observations (e.g. for climate). In some cases the results of models can be made available through internet (e.g. for water and land use), in other cases this is not possible. Sometimes it seems better to present information on uncertainties together with the description of the model components (e.g. for nature), sometimes a summary of the uncertainties can be given on the separate web pages (e.g. for climate). After comparison of the subportals by the project team, several suggestions were made to improve the synchronization (move part of the texts/data, include more links, etc.), without disregarding the specific aspects of the various disciplines. In the second phase these are implemented.

3.2 Overview of available data and information

The sub portals in the CIG/KEW give an overview of the results of projects executed within the Dutch CcSP and KfC projects. It is difficult to give a complete overview of all research and data on climate change and climate change impacts in the Netherlands and outside. The CIG/KEW focuses especially on the Netherlands and the river basins of the Rhine and Meuse, since this area is considered most relevant for the water management of the Netherlands. We realize that for e.g. nature and agriculture larger areas also may be interesting. As the result of the review of the pilot version of the web portal, we are now working on including a short overview of the research organisations per discipline in the Netherlands and to include an overview of the most important international organisations, projects and databases per sector.

During the review also some policy makers were asked to review the pilot web portal, although the intended user groups are researchers. From the reactions it became clear that a portal that is developed for researchers is not automatically the most useful for policy makers. In general, policy makers need different types of information than impact/adaptation researchers. Summaries of the information on this CIG/KEW portal may be useful (as the basis) for information for policy makers.

3.3 Dealing with uncertainties

When people talk about climate change, always the issue of uncertainties pops up. There are considerable differences in the way uncertainties are described and dealt with between disciplines. Therefore, "uncertainties" is included as a separate entry in the menu on the web portal. In the description of the various types of uncertainties per discipline it is tried to use the typology as presented by Walker et al. (2003). In most of the descriptions now explicitly a distinction is made between input uncertainties and parameter uncertainties. Comparison of the web pages by the project team also resulted in some suggestions for more streamlining of the description of uncertainties. In the second phase of the project an autumn school was organized in October 2012 on "Dealing with uncertainties in research for climate adaptation". The aim of this autumn school was, among others, to create more understanding of the various ways of dealing with uncertainties between the various disciplines and to start creating a "Common Frame of Reference"[4]. Information from this autumn school will also be included on the web portal.

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Acknowledgements

The authors would like to thank the Knowledge for Climate programme for funding, as well as their colleagues within the Theme 6 on Climate Projections in this programme for their fruitful collaboration.

The utility of an agro-ecological niche model of coffee production for future change scenarios

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Abstract— While the debate on crop impact modeling often focusses on advancing sophisticated process models for the key staple crops, less researched crops like coffee arguably lack the scientific base to follow this approach. Nevertheless, coffee is of undeniable importance in many tropical regions and likely to be deeply impacted by climatic changes.

We explore a spatially explicit machine learning based modeling approach that is based on the ecological niche concept to generate climate change impact scenarios for Arabica and Robusta coffee production systems. A global current suitability index for coffee production is modeled using no more than geo-referenced locations of production and climate information. The index estimates the probability that a location is climatically suitable for coffee production. We show that this global climate based index not only correctly predicts presence of global production but also correlates with local Brazilian area statistics, indicating that the index reflects well the actual distribution of coffee growing areas and can thus be used to spatially disaggregate national level harvested area statistics.

The climate-suitability function is applied to downscaled global circulation model (GCM) outputs to yield spatially explicit future suitability scenarios for coffee that are coherent with the current suitability model. Both *Coffea arabica* and *Coffea robusta* production are likely to lose large shares of suitable areas in their predominant production regions.

We stop short of integrating our scenario data with a partial equilibrium model but argue that our approach could be a viable alternative both to generate spatially explicit current disaggregation of current production data and future change scenarios for crops with a limited physiological knowledge background and a scarce data basis.

Index Terms—Coffee, Data Disaggregation, Species Distribution Model, Suitability

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1 Introduction

The livelihood of about 100 million people in some of the most vulnerable societies depends on coffee (Pendergrast 2010). While grown mostly for export to rich societies its producers often suffer malnourishment when the crop fails. Despite a decade of low prices worldwide production is increasing and novel coffee plantations are driving deforestation in frontier regions (e.g. Bosselmann 2012, Tan 2000). Raw coffee is produced using two distinct species, the very frost sensitive *Coffea robusta*, and the more heat sensitive *Coffea arabica*. Especially the predominant *Coffea arabica* production has been shown to be very sensitive to climatic changes (e.g. Gay Garcia et al. 2006, Zullo et al. 2011, Schroth et al. 2009). Forward looking climate adaptation research is further justified by the lifespan of plantations which can be over 50 years in precarious conditions.

Biophysical impact assessments for coffee identified climatic change as a key risk to the sector. A contextualization of these impacts within the framework of a spatially explicit partial equilibrium model allows the quantitative comparison of the effects of adaptation pathways. However, this model class, e.g. GLOBIOM (Havlik et al. 2010), requires disaggregated production statistics on a simulation pixel level as input data, while crop production statistics are usually aggregated over an administrative entity. Such disaggregated data is provided for example by the MapSpam database (You and Wood 2006) that allocates acreage and yield values to global grid cells. Even though MapSpam already features coffee data, this is currently limited to a generic production systems concept (You et al. 2012). We argue that for a climate change impact assessment of the coffee sector a differentiation between Arabica and Robusta production systems is more meaningful than a “green coffee” aggregation because the two coffee species differ in the range of environmental conditions in which they prosper.

The aim of this work is to demonstrate the utility of a species distribution modeling (SDM) solution to generate meaningful agro-ecological suitability surfaces than can be used for climate change impact assessments and the disaggregation of national production statistics with minimal input data. We use the machine learning software Maxent (Phillips et al. 2006) that is widely applied in macro ecology to model the distribution of Arabica and Robusta production systems. We first demonstrate the application of Maxent to model the current distribution of climatic suitability; show that this distribution correlates with an available dataset of subnational production distribution to validate the modeled distribution; and finally present a possible method to spatially disaggregate national production statistics based on the suitability index, and how the suitability index distribution changes under climate change scenarios.

2 Methodology

The Maxent approach is popular in macro ecology because no more than a carefully defined set of geo-referenced known presences is needed to model the distribution of a species. The machine learning algorithm trains on the presence locations against a random abiotic background space to extrapolate based on the maximum entropy principle (Phillips et al. 2006). Its output is an estimate of the probability that a species is present at a location, ranging from 0 to 1. There are several applications of this method to agriculture and also coffee (e.g. Schroth et al. 2009), and more recently has been shown to estimate a distribution of yield potential when trained appropriately (Estes et al. 2013). We define two separate Maxent models for Arabica coffee (*Coffea arabica*) and Robusta coffee (*Coffea canephora*).

As climatic input information for Maxent we include the 19 bioclimatic variables of the Worldclim database (Table 1, Appendix)(Hijmans et al. 2005). The training dataset consist of 2920 known locations of Arabica production and 364 Robusta locations respectively, chosen to represent the most important coffee production regions globally. We generate 100,000 background points at random in coffee producing countries between latitudes 30°N and 30°S. Each Maxent model is trained and projected in 25 independent cycles and the results averaged. The suitability function is extrapolated for future scenarios using 19 downscaled GCM outputs (Ramirez & Jarvis, 2010) from the 4th Assessment Report (IPCC 2007) for the A2 scenario family for 2050. We run Maxent with the specified input data using default settings with the exception of a more restrictive regularization of 0.5. Doing so forces Maxent to increase model complexity at the cost of model smoothness (Elith et al. 2011).

To assess the performance of our distribution model we employ two statistics, the area under the receiver operating characteristic curve (AUC) and a standard linear regression model. The AUC value is widely used in species distribution modeling. The statistic compares the ability of the model to discriminate areas with species presence from areas without known species presence to a model with random discrimination. The random model should have an AUC value of 0.5, while a perfect model has an AUC value of 1. The AUC method has been criticized to be insensitive to commission errors, i.e. it does not reflect well overprediction of presence (Lobo et al. 2008).

We use the harvested area statistics of the “green coffee” category provided by the IBGE (Instituto Brasileiro de Geografia e Estatística 2012) as a reference observed distribution. The dataset contains consistent data for 5490 municipalities and thus reflects the distribution of coffee production in Brazil with good detail. We test whether the distribution of our Maxent suitability indeces based on climate data correlates with this subnational distribution. To do so, we accumulate the present index for Robusta and Arabica production by municipality and define a standard multiple regression model with total harvested area as the dependend variable and Robusta index sum and Arabica index sum as independents.

The harvested area statistics provided by FAO (2012) for the years '98-'02 is aggregated over "green coffee". For the downscaling step we require data for both production systems. We therefore divide the FAO dataset according to our systems definition into Robusta and Arabica systems area based on production shares by system of USDA statistics (USDA 2012) to prepare this data for the disaggregation step.

In the final step we use the Maxent suitability surfaces serve as a prior probability to disaggregate the FAO national harvested area data. Exemplary we integrate the coffee production system data into the database of the GLOBIOM land use change model (Havlik et al. 2010). I.e. coffee production area is only assigned to areas that are not occupied by the other crops in Globiom using a cross entropy approach similar to You and Wood (2006). For each country the sum over each model unit of the squared difference between the area share of total area and the suitability share of total suitability is minimized (Eq 1).

$$\min \sum_i \left(\frac{Area_i}{\sum_{Country} Area} - \frac{Suit_i}{\sum_{Country} Suit} \right)^2 \forall country \tag{1}$$

Where $Suit_i$ is the suitability index in cell i and $Area_i$ the area assigned to cell i.

3 Results

The results are maps of a climatic suitability index for both Arabica production and Robusta production under current conditions and under the conditions as given by the 19 downscaled AR4 GCM outputs for 2050. Here we present exemplary the distribution of suitability for Arabica and Robusta production in Brazil (Fig.1) which are an excerpts from the global map. The full global maps of suitability distributions are moved to the appendix.

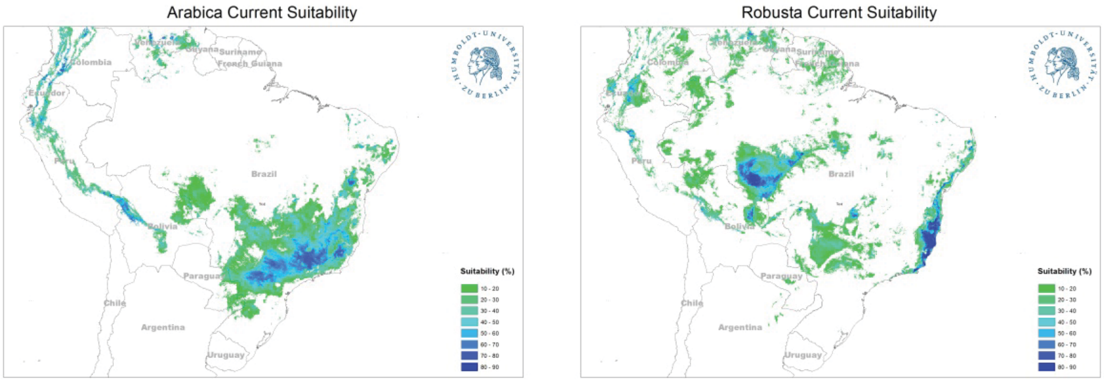

Figure 1 - Current suitability distribution modeled by Maxent for (a) Arabica and (b) Robusta

To evaluate how well the suitability indeces reflect actual distribution of coffee production we use two metrics, the AUC and a multiple regression with the observed distribution of area statistics as dependent variable and the suitability indices for Arabica and Robusta as independent variables. The AUC is consistently high over all model repeats for both the Arabica (mean AUC= 0.95) and the Robusta model (mean AUC=0.93). The model thus correctly predicts the global distribution of point locations with coffee production.

The correlation coefficient for the multiple regression model of modeled distribution and actual observed distribution is R= .584 ($p<0.001$, df=5489). Fig. 2 shows the plot of the Maxent suitability distribution based modeled area distribution versus the observed area data for the Brazilian municipalities. The plot shows three groups of municipalities: Along the x-axis municipalities that according to our suitability model have suitable area available that is not planted with coffee, this result is to be expected as the model only uses climatic variables. Along the y-axis group cases of municipalities that do produce coffee but are not suitable according to our model, representing an omission error. The largest group of cases groups along the line of perfect model fit indicating that our global suitability model based on climate information correlates well with the actual distribution of coffee production. We conclude that the global suitability index reasonably well describes the actual subnational distribution of coffee production in Brazil.

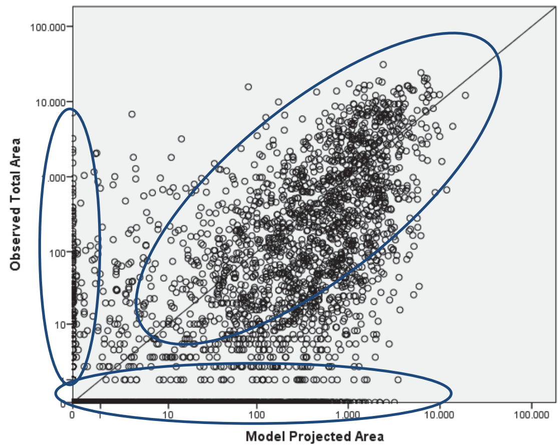

Figure 2 - Plot of areas by municipality as modeled based on Maxent suitability distributions vs. observed area data (in ha)

We perform the downscaling in GAMS as described before and visualize the resulting area distribution for Brazil in Fig. 3.

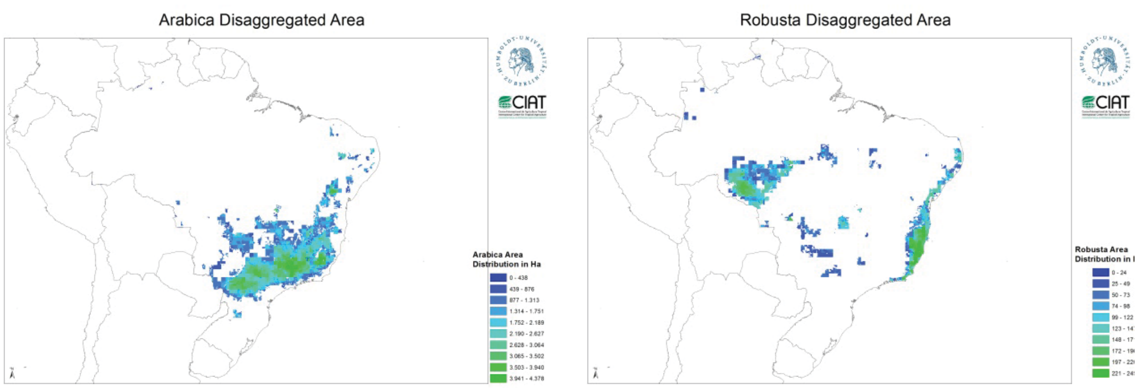

Figure 3 - Disaggregated Area distribution in Brazil for a) Arabica and b) Robusta

We correlate the sum of the Arabica and Robusta area with the observed area in the 5500 minicipalities. The correlation coefficient after the disaggreagation is $R = .268$ ($p < 0.001$; df=5489) between the sum of Arabica and Robusta area. It is thus lower than the agreement between prior suitability distribution and observed area. The plot is similar to Fig.2, however the modeled distribution cases center on a value of ~1000ha per municipality (Fig 4)

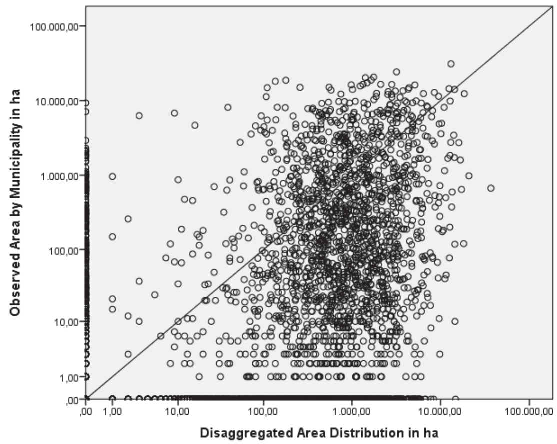

Figure 4 - Scatter plot of areas as disaggregated vs. observed area in Brazil (in ha)

Nevertheless, a map comparing the observed area statistics with the total area disaggreagated summed over Arabica and Robusta area shows good agreement between the two distributions (Fig 5).

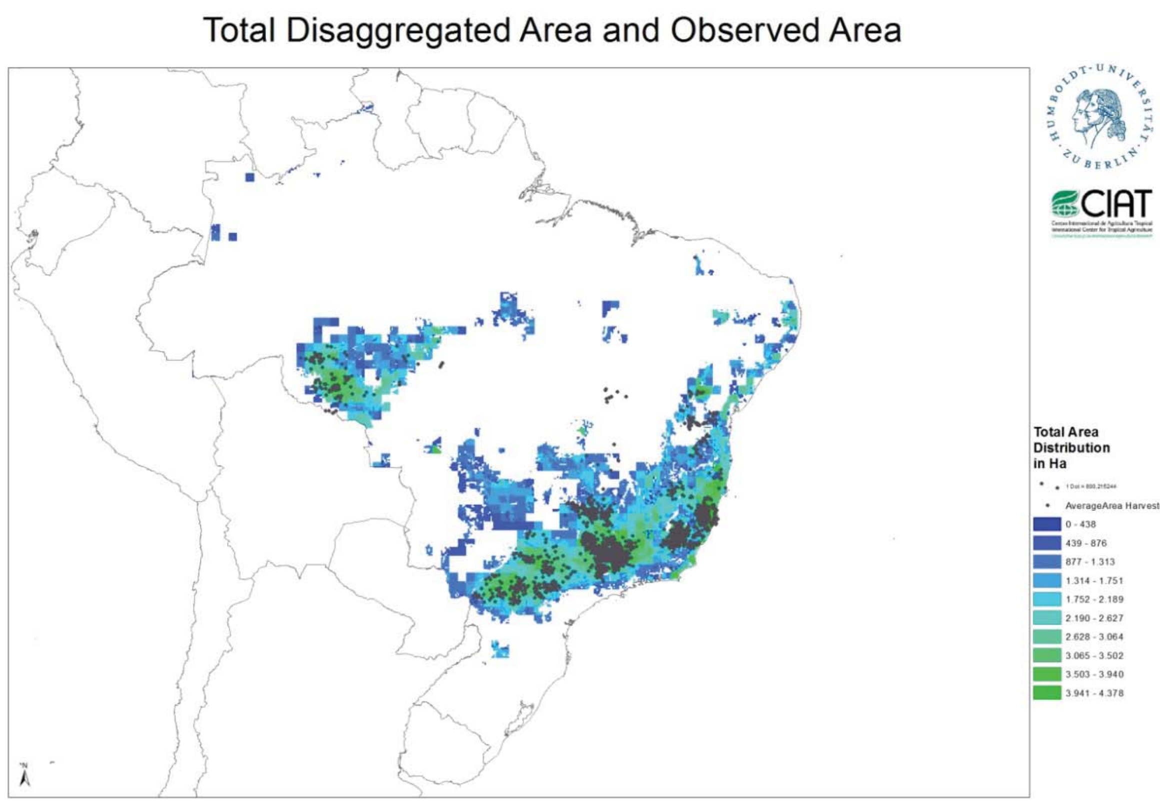

Figure 5 - Total disaggregated area (blue to green) and observed total coffee area (dot density, 1 dot=800ha) in ha

We therefore conclude that our suitability index model can provide an estimate of actual distribution of coffee area. We extrapolate this model based on 19 downscaled GCM outputs of the AR4 A2 SRE scenar-

7

ios for 2050 to generate climate change impact scenarios. Exemplary we present the median change over the 19 GCM projections for Arabica and Robusta distributions in Brazil (Fig. 6). Additional maps are moved to the appendix.

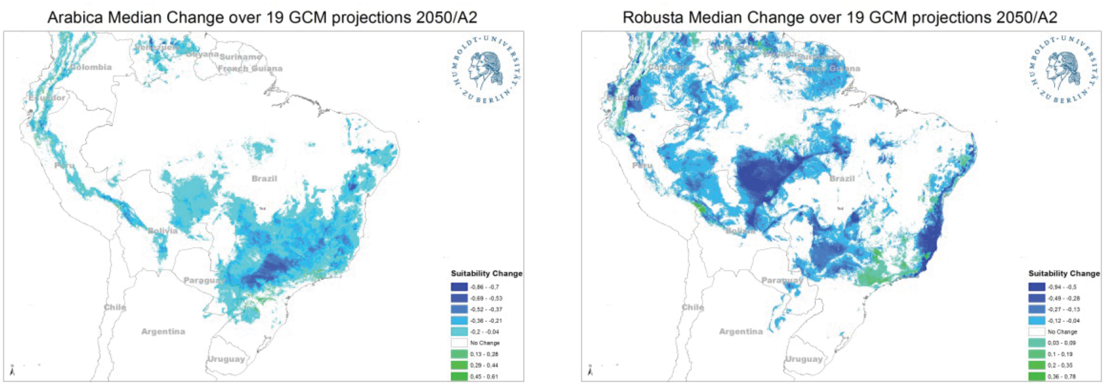

Figure 6 - Median change of the suitability index until 2050 by GCM projections, a) Arabica suitability and b) Robusta suitability distribution

Maxent provides the 10th percentile of suitability for the given input presence points. This value is generally between a suitability index of 0.20 and 0.35 for the 25 independent model runs. To determine area losses and gains we therefore compare future areas and current areas above a threshold of 0.20 for the suitability index. As areas with higher suitability are more likely to have production area, we calculate the sum of grid cells above the threshold weighted by their suitability value under current and future conditions. Globally 77% of Robusta suitability is lost by 2050 under the median impact of the 19 GCM A2 outputs, and 59% of Arabica suitability (Fig 4).

We furthermore calculate the share of areas that are novel, or are also currently suitable of the total future suitability. Of the future Robusta suitability 29% can be found in novel areas that were unsuitable under current conditions. New Arabica areas constitute 13% of the future available areas. The change in the suitability distribution by region can be found in Fig. 7 and the share of novel areas of total suitability by 2050 is presented in Fig. 8.

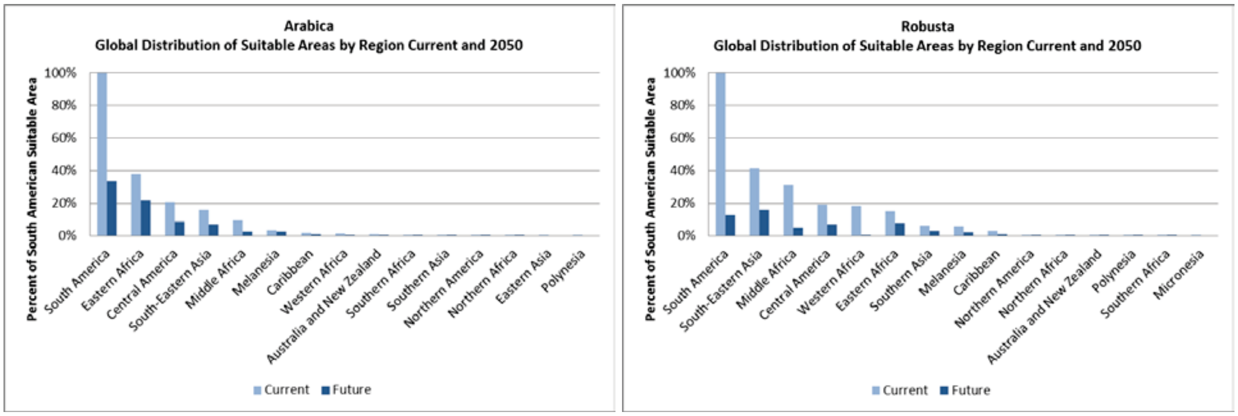

Figure 7 - Change of global distribution of the suitability index for a) Arabica and b) Robusta; Data shows the sum of grid cells above the threshold weighted by their suitability value in percent of the South American value. Current availability of suitable areas in light blue and future in dark blue

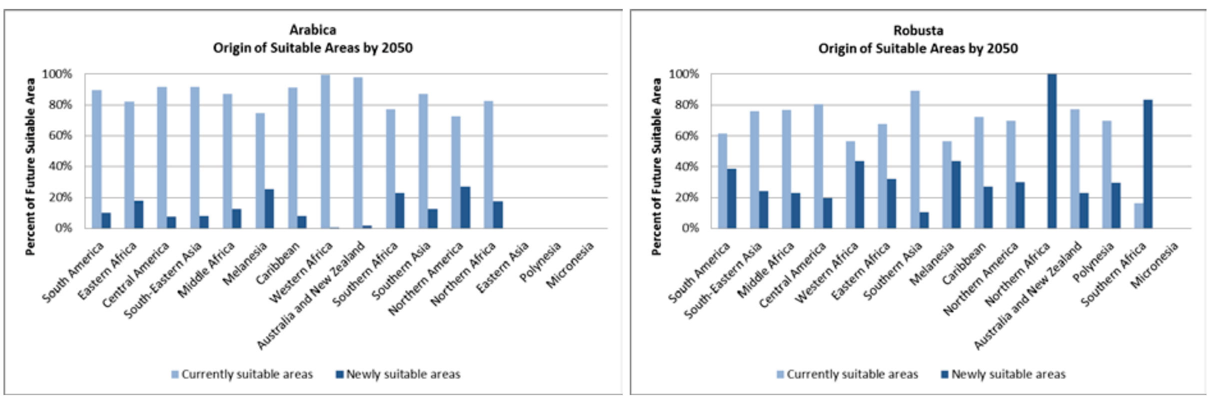

Figure 8 - Share of novel suitable areas and current areas of future suitabilty for a) Arabica and b) Robusta

As can be seen especially the South American and West African Robusta production is projected to migrate to novel areas, but also a large share of the significant South East Asian production may migrate.

4 Discussion

We demonstrated the generation and practicability of climate information based distribution maps for two production systems for coffee, applied these to downscale production area data and generated future suitability scenarios. AUC and regression metrics are used to assess the practicability of the suitability distribution. As the modeled distribution within Brazil correlated with the observed distribution in Brazil we concluded that it is possible to apply the suitability maps as a prior probability for a disaggregation of national statistics to pixel level. The positive correlation means that the harvested area statistics would be disaggregated to the correct regions of actual production. We correlate our downscaled distribution with the observed distribution and find sufficient agreement. The correlation coefficient is comparable to the correlation coefficients presented in You and Wood (2006) for crops modeled in the MapSpam database.

While most municipalities grouped along the line of correlation, we could also observe a group of over-predicted municipalities, and a group of omitted municipalities. These results are not desired but have to be accepted as the distribution exercise was done using only climatic variables. We did not exclude urban or protected areas so that some overprediction would be expected. As for the omitted municipalities it would be interesting to see if an irrigation variable would improve the distribution to include the underpredicted areas.

The projection of the suitability function trained by Maxent onto 19 downscaled GCM outputs for the year 2050 in the A2 scenario shows drastic changes in future suitability distribution. While for Arabica our impact projections are similar to other models, the finding that Robusta coffee could be even more harmed is new and should be further investigated.

The future scenarios imply regional shifts in the production structure. Especially South American production locations could loose suitability. This would render currently unproductive areas in Asia and Africa potentially economically viable for coffee production. Furthermore, as temperatures increase coffee might migrate to higher altitudes with current forest cover as new areas become suitable.

The Maxent biophysical model is unable to quantify these shifts in spatial production structure. The aim is therefore to employ our distribution and scenario data to model the impact of climate change on global coffee production in a partial equilibrium context, using a model like GLOBIOM. This would allow to address the latter questions by modeling the differential impacts of climate change on a range of crops and forestry by incorporating market feedbacks into the analysis.

We demonstrated that for coffee it is possible to model the distribution well based on climate layer information only, despite a scarce knowledge basis. A great advantage of our methodology is the applicability to a wide range of GCM data, making the method easily adaptable for model comparisons. Another advantage lies in the coherent modelation of current and future distributions using a single suitability model.

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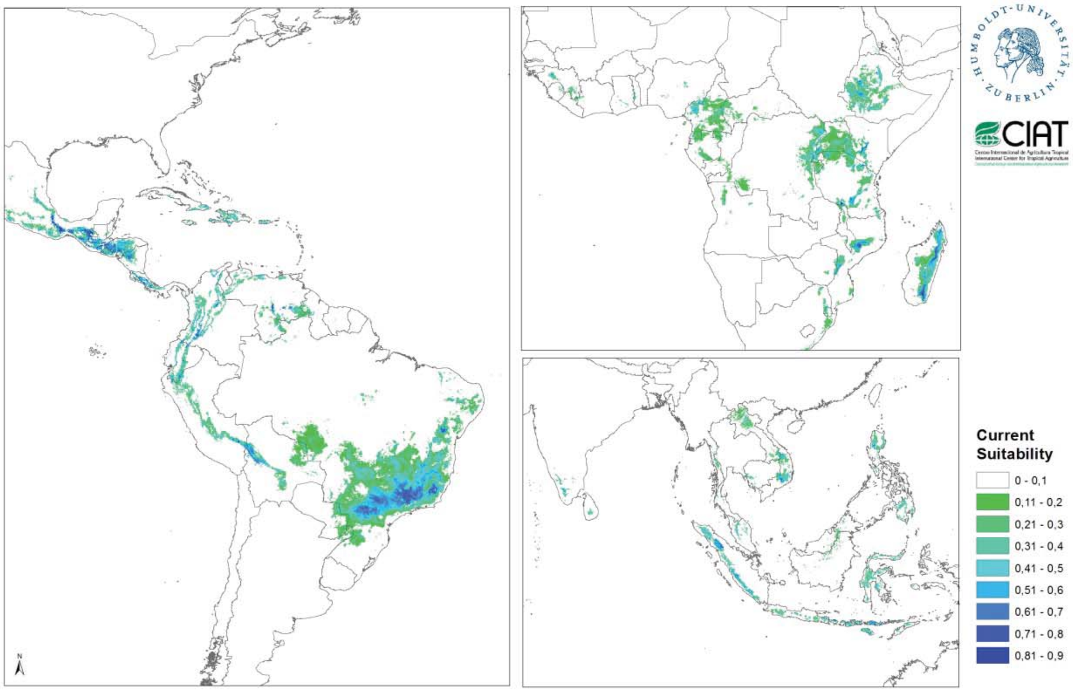
6 Appendix

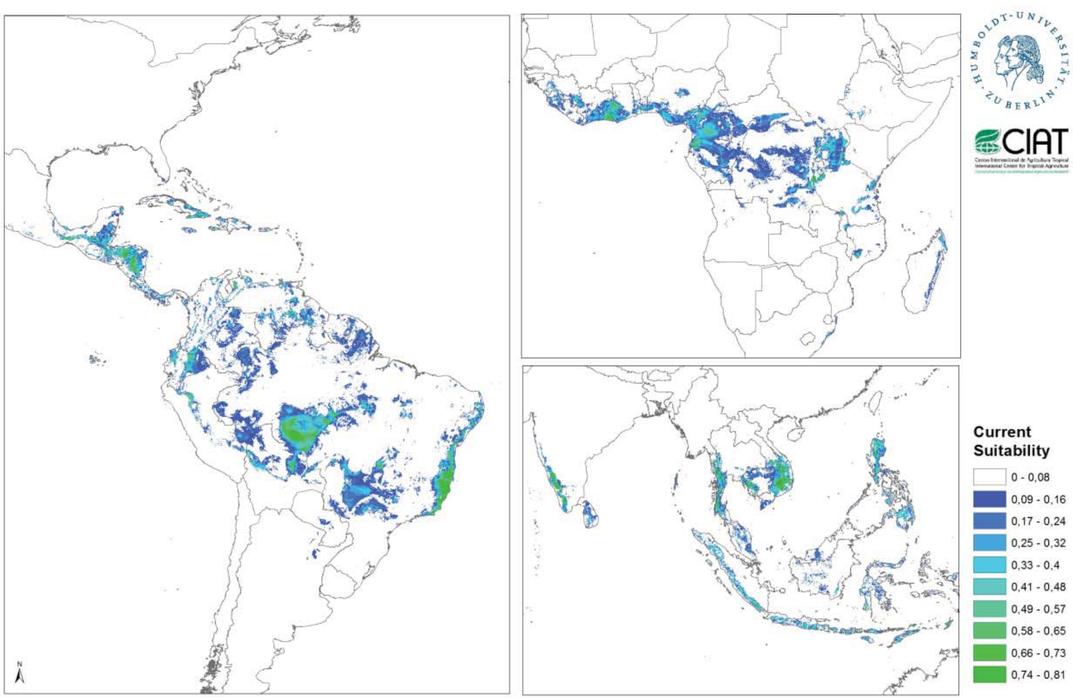
Table 1 - List of bioclimatic variables used

BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

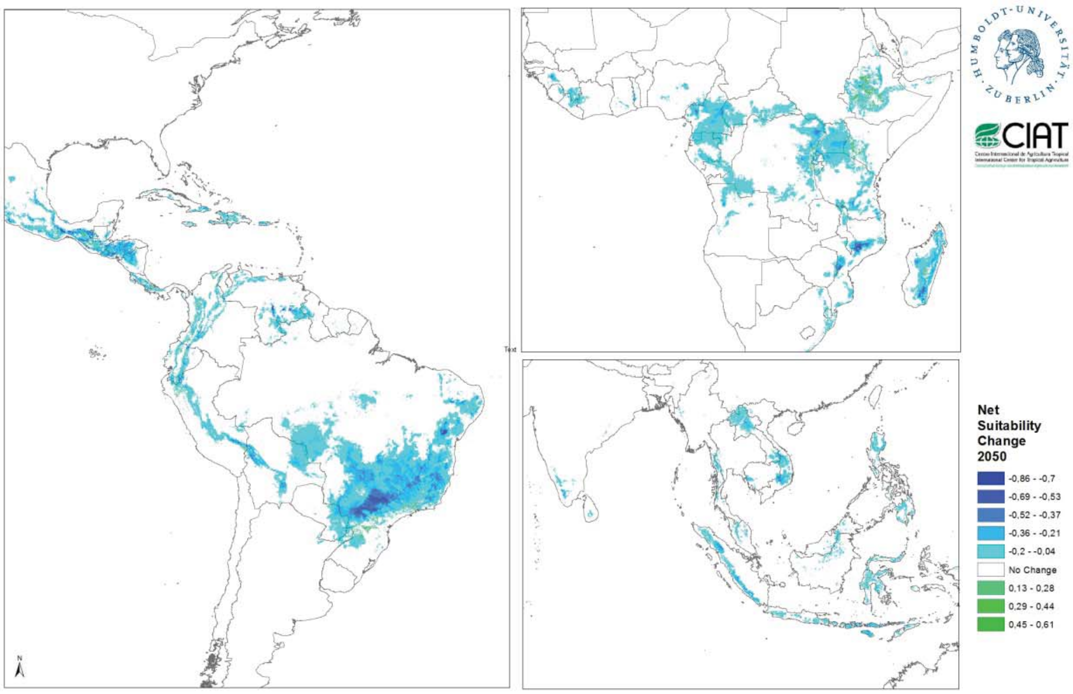
Arabica Current Suitability



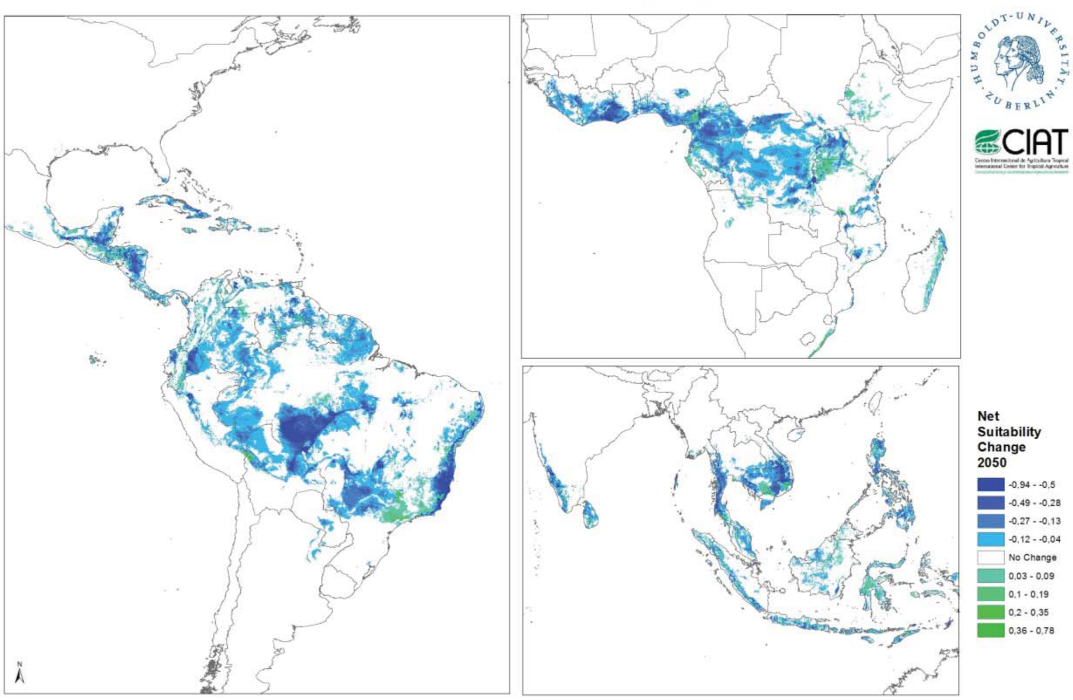
Robusta Current Suitability



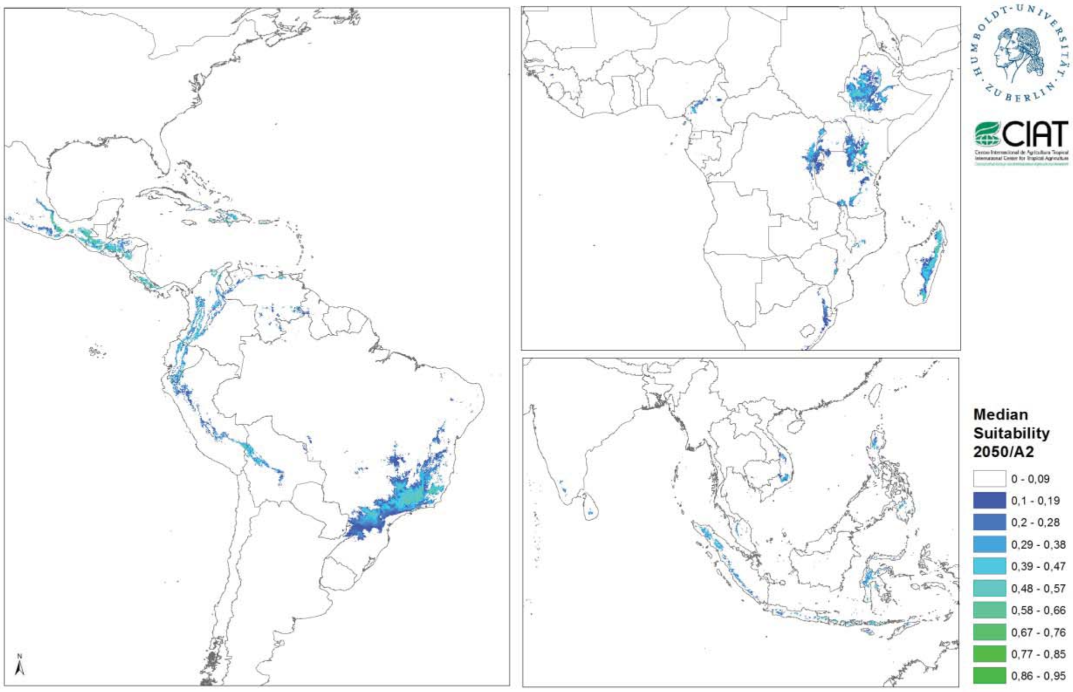
Arabica Median Change over 19 GCM projections 2050/A2



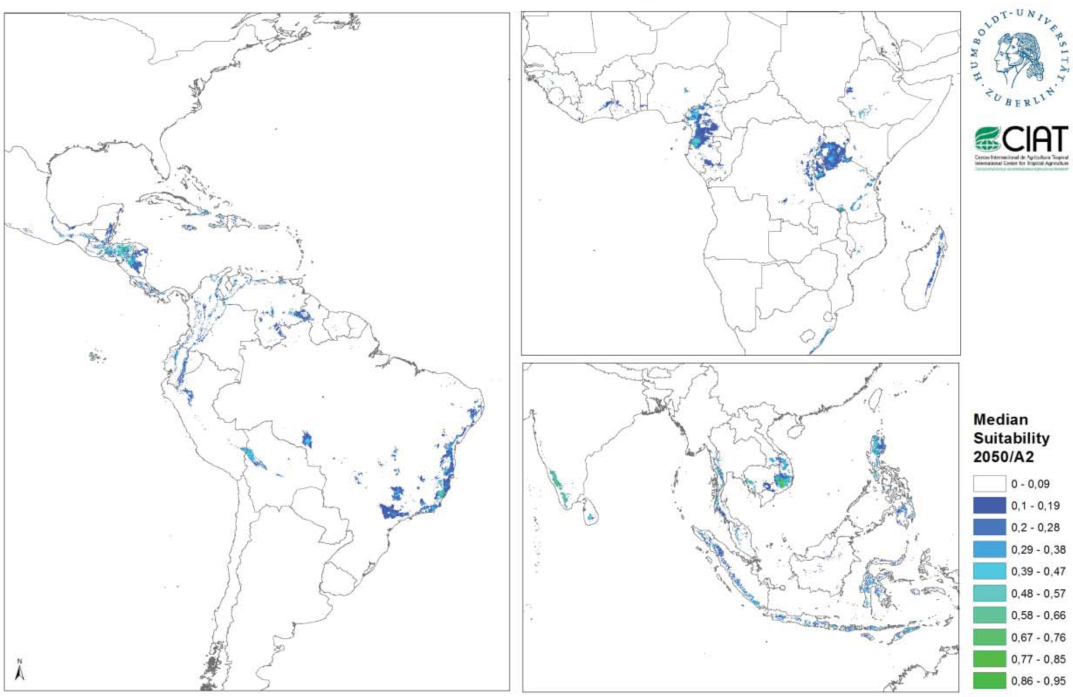
Robusta Median Change over 19 GCM projections 2050/A2



Arabica Median Suitability of 19 GCM projections 2050/A2



Robusta Median Suitability of 19 GCM projections 2050/A2



Committed Unavoidable Global Warming and Northern Hemisphere Food Security Impacts to 2100

Peter D. Carter May 2013

Abstract—This paper uses today's total minimum committed unavoidable global warming as a reliable guide to Northern Hemisphere (NH) food security vulnerability and impacts. A simple summation approach, for policy relevance and communication, includes the following unavoidable sources of warming in estimating unavoidable climate change commitment:

1. Shortest time between a rapid emergency emissions reduction to atmospheric stabilization
2. Climate system inertia (ocean heat lag)
3. Aerosol cooling (unmasking of deferred warming)
4. Positive climate system feedbacks

The lowest published ranges from all sources of unavoidable warming combined are taken and then linked to changes in food productivity (crop yield change per degree C) from climate crop models. Drought, an additional effect, is considered over and above the crop model results. The focus is on NH food security because it has been assumed to not be particularly vulnerable to global climate change impacts this century, according to past IPCC assessments. The paper relies mainly on the IPCC's Fourth Assessment Report (2007), the US National Research Council's 2010 Climate Stabilization Targets (2011), and drought projections published in 2011. We find that past reassuring NH assessments, from global temperature increase scenario projections and corresponding crop productivity yield projections, may no longer apply. An additional factor for assessment that we address is the rapid loss of Arctic albedo cooling and its impact on agriculture in the NH. The finding is that NH food security is a missing priority for the study of climate change impacts and vulnerability, and indicates that urgent action must be taken to mitigate Northern Hemisphere food productivity losses that could occur in the short term. This is most relevant to the food security of the most vulnerable populations because of the resulting effects on world food prices and food surpluses.

Climate change "commitment" is a climate change science term meaning there is more warming "in the pipe" that will happen over future decades and centuries even if no more heat is added to the climate system (IPCC 2007 AR4 WG 1 TS 5.1, Box TS 9, Committed climate change). Commitment is the result of the great climate system inertia and momentum response to an increase in radiative (heat) forcing. In other words, all future generations have been committed (or condemned) to much more warming than today's. .

This paper defines commitment as practically unavoidable even assuming a rapid emergency reduction of GHG emissions. It assumes no measures to draw down CO2 from the atmosphere.

Index Terms—committed global warming, food security, Northern Hemisphere losses in crop productivity, unavoidable climate change

————————————————————

1 Introduction

This paper presents the most policy-relevant science of committed, unavoidable global warming. Nothing is more relevant to policy than the impacts of global climate change on food productivity and its risks to food security.

It is surprising that food security is not one of the categories of the IPCC's (2007) five reasons for concern when all climate change food assessments show that under all conditions, all crops in all regions decline below baseline (present day) yields with increasing warming and a few proxies (see Fig. 1) (IPCC AR4 WG2 fig 5.2).

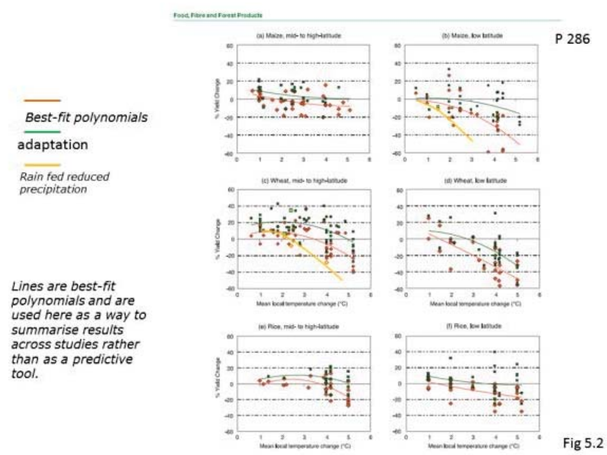


Fig. 1: IPCC (2007) Climate crop models

The world's top food-producing regions are in the temperate Northern Hemisphere (NH) (see Fig. 2), which has particular vulnerabilities to global warming: 1) faster warming in the NH than in the Southern Hemisphere because of its land masses, 2) the central continental grain belts warm faster, 3) increased tropospheric (ground level) ozone (toxic to green plants) caused by global warming, 4) loss of Arctic snow and ice albedo cooling, and 5) highly specialized industrial-scale agriculture in the NH might have particular vulnerabilities to climate change, for example, from extreme weather events that are not captured by models (Cox et al 2011).

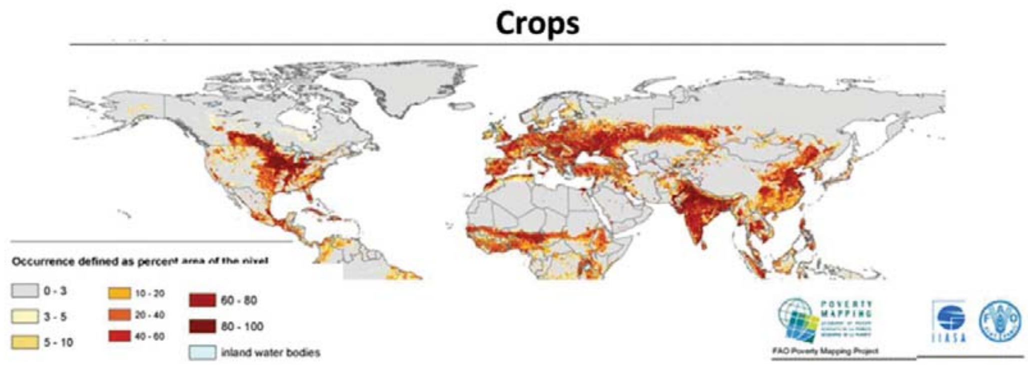


Fig. 2: Top crop-producing regions are in the Northern Hemisphere (FAO & IIASA 2006)

We find that under the best ideas for global climate change mitigation, crop yields in the Northern Hemisphere are already committed to (extremely likely) future declines of all crops below today's baseline.

2 Commitment to future global warming

The IPCC (2007) gives three definitions for global climate change "commitment," noting that none of them amounts to the real world "unavoidable" warming. "Climate change commitment as discussed here should not be confused with 'unavoidable climate change' over the next half century, which would surely be greater because forcing cannot be instantly stabilized" (IPCC AR4 WG1 10.7).

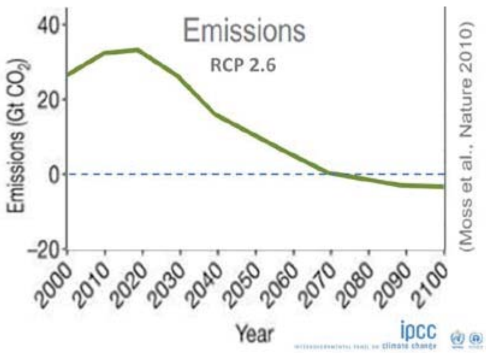
2.1 Commitment due to economic, energy and climate policy

It must be noted that commitment due to policy is much higher that the commitment due to climate system science. For example, the combined national UN pledges commit us to a warming of 4.4°C by 2100, which is a full eventual equilibrium commitment of over 8°C due to the ocean heat lag.

2.2 Commitment due to climate system science

The new AR5 IPCC scenarios are ‘representative concentration pathways’ (RCP)

(see http://www.wmo.int/pages/themes/climate/emission_scenarios.php). The most ambitious RCP scenario, RCP3-PD or 2.6 (IPCC AR5, in print) involves zero carbon emissions and reaches **1.5°C** by 2100 (see Fig. 3). It stabilizes at 1.0C after 2100. It takes 60 years to reach zero carbon from reducing emissions and 50 years from peak emissions.



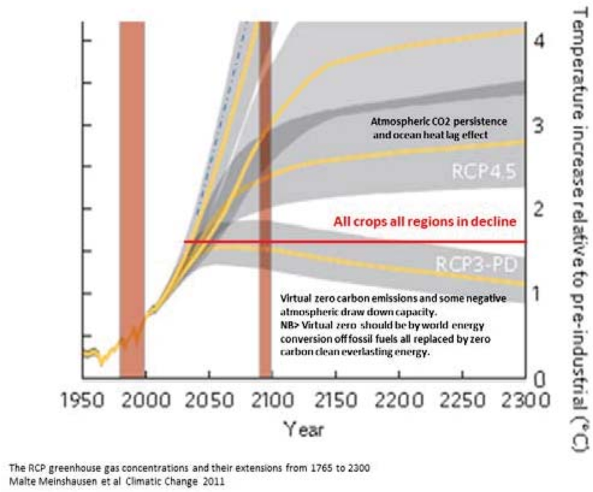


Fig. 3: The IPCC AR5 RCP scenarios and crop yield decline threshold from (underestimating) climate crop model projections

We can take this best RCP commitment as our best-case scenario (it is the only IPCC scenario that does not result in catastrophic losses in food productivity), but there are two other unavoidable sources of warming that have to be included.

First, there is a deferred warming that is a definite commitment, due to fossil fuel air pollution aerosol cooling. Acidic minute particles from fossil fuel combustion have a cooling effect. Decarbonization will result in the unmasking of this "hidden" warming. We take the proposed IPCC AR4 figure of **0.4°C** as the minimum aerosol cooling commitment. The latest climate computer model projections on this issue find a large aerosol cooling effect of 0.85 to 1.2°C (see Table 1).

Table 1: Effect of unmasking aerosol cooling

0.9°C	Ramanathan & Feng 2008
1.2°C	Hansen, Sato & Kharecha 2011
0.85°C	Huber & Knutti 2012

Next, the other source of unavoidable warming is from positive carbon feedback emissions. A positive feedback happens when global warming causes a change to the planet that increases the warming. A carbon feedback is planetary emissions of carbon dioxide (CO2) or methane (CH4). The IPCC RCP scenarios do not include the inevitable additional warming from carbon feedbacks. The IPCC AR4 (2007) recorded a figure of more than 1°C from year 2000 on the A2 scenario, which is at least **1.5°C** from preindustrial. But this accounts only for the terrestrial carbon feedback, excluding the potentially largest Arctic carbon feedbacks (UNEP 2012), making 1.5°C a minimum amount.

Global warming projections that do not account for unmasking of aerosol cooling are not policy relevant (Ramanathan & Feng 2008). Projections that do not account for all sources of unavoidable carbon feedbacks are not policy relevant.

This puts our total committed climate science warming based on minimum estimates at **1.5°C + 0.4°C + 1.5°C = 3.4°C** by 2100.

This committed warming is well within the informal estimates of climate change experts, who for several years have been warning that we are committing ourselves to a 4°C world. Warning of a 4°C commitment comes from the World Bank (2012), Betts et al (2011), and Kevin Anderson and Alice Bows (2008) who concluded: "Ultimately, the latest scientific understanding of climate change allied with current emission trends and a commitment to 'limiting average global temperature increases to below 4°C above pre-industrial levels', demands a radical reframing of both the climate change agenda, and the economic characterization of contemporary society." In other words, we are committed to a 4°C warming.

3 Global climate change risk to crop productivity

The graph below (see Fig. 4) is a composite based on the climate change crop model graphs of the US National Research Council (NRC) Climate Stabilization Targets (2011). Temperate Northern Hemisphere crops decline at much lower degrees of global warming than is generally recognized.

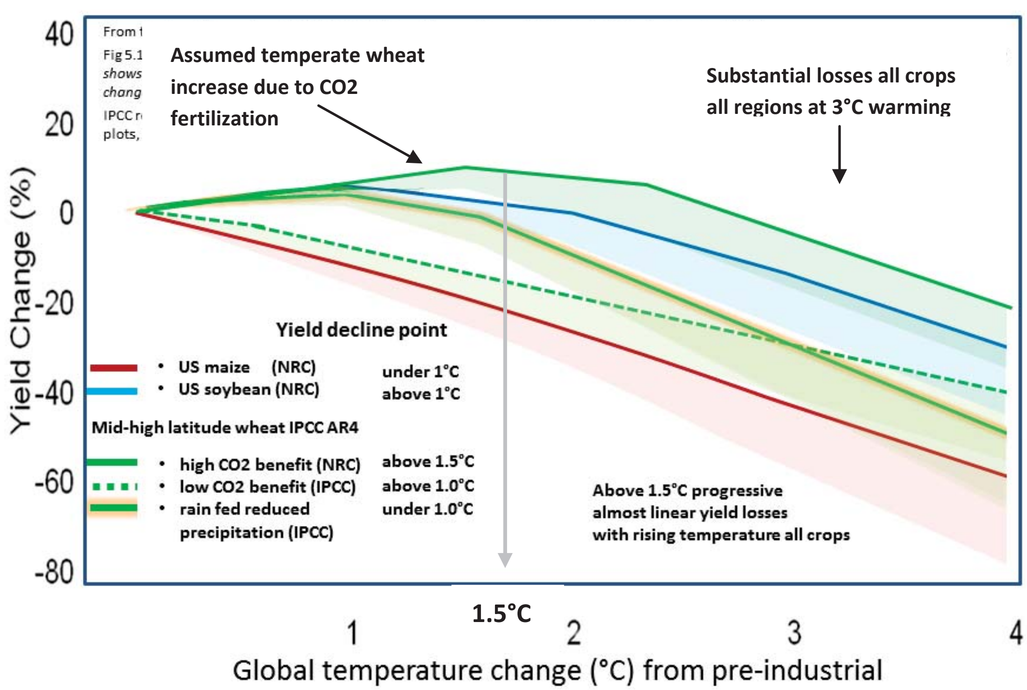


Fig. 4: Combined temperate Northern Hemisphere climate change crop yield model results (NRC 2011, IPCC 2007). NRC Fig 5.1 is "average expected impact of warming + CO2 increase on crop yields for selected crops and regions with detailed studies. Shaded area shows likely range [only greater decline range shown here]. Impacts are averages for current growing area within each region. Temperature and CO2 changes estimated for regions were computed relative to pre-industrial." IPCC plots are from AR4 2007 WG2 Fig 5.2 for mid-high latitude wheat.

Table 2 below lists the declines from the graph of crop yield reduction plots.

Table 2: Yield decline points of U.S. crops (from combined sources)

Crop	Yield Decline Point
Mid-high latitude wheat (high CO2 benefit)	above 1.6°C
U.S. soybean	above 1°C
Mid-high latitude wheat (rain fed/reduced precipitation)	above 1°C
Mid-high latitude wheat (low CO2 benefit)	under 1°C
U.S. maize	under 1°C
India wheat	under 1°C

Summing all minimum committed increases in global average temperature shows that the point when crop yields will decline will be reached sooner than projected by the mainstream crop models. Because there are so many large, inevitable impacts that are not accounted in the models, model results provide neither a guide to the risk nor the most likely real world outcomes from the multiple adverse impacts of global warming and climate change on crops. "The expected impacts are useful as a measure of the likely direction and magnitude of average yield changes, but fall short of a complete risk analysis, which would, for instance, estimate the chance of exceeding critical threshold" (NRC 2011, p. 160).

The IPCC (2007) assessment for NH food effects for policymakers is brief: "Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1 to 3°C depending on the crop, and then decrease beyond that in some regions" (IPCC AR4 Synthesis 3.3.1.). This gives the impression, as reported frequently, that temperate NH crops are not at risk of decline up to a global warming of 3°C, but this is a misinterpretation of the data.

The NRC (2011) provides the climate crop model results in the following policy informative manner in terms of the standard global average warming from pre-industrial (along with a conversion formula in the appendix):

> For C3 crops, the negative effects of warming are often balanced by positive CO2 effects up to 2-3°C local warming in temperate regions, after which negative warming effects dominate. Because temperate land areas will warm faster than the global average […] this corresponds to roughly 1.25-2°C in global average temperature. For C4 crops, even modest amounts of warming are detrimental in major growing regions given the small response to CO2. (NRC Climate Stabilization Targets 2011, p. 160)

The results of least crop yield decline for all the crops modeled (grown in the temperate NH) are for a decline in yield above 1.25 to 2°C.

We take a crop decline point from the crop health science perspective as being when a crop's yield declines, be it above or below the baseline. This gives a global warming degree of 1.5°C, above which all crops in all regions are tipped into decline, according to the model (IPCC 2007, NRC 2011) results. We are committed to 1.6°C by the ocean heat lag alone (NRC 2011).

This is an uncomfortably low degree of warming but all the other sources of the science indicate an even worse situation for NH food security because of all the adverse effects not accounted by the models. Processes not included or adequately quantified in the model projections, according to the NRC (2011, pp. 161-163), include:

- responses of weeds
- insects
- pathogens
- changes in water resources available for irrigation
- increased surface ozone levels
- increased flood frequencies
- extremely high temperatures
- sustained droughts
- year-to-year variability

Combined adverse, additive, and negative synergistic changes are not considered but would be the most devastating. This argues for not permitting any risk of more than one adverse effect.

The situation is worse still because these projections assume a questionable benefit for temperate region crops from the CO2 fertilization effect. There is no justification for including an assumed CO2 crop benefit. This assumption is based on experimental crops grown at a CO2 concentration of 550 ppm. As 550 ppm CO2 is far past global climate catastrophe and at 395 ppm we are already at the highest CO2 in 15 million years (UCLA 2009), the CO2 benefit is not valid.

One large omitted adverse effect is increased tropospheric ozone with warming, which neutralizes any potential CO2 benefit (IPCC AR4 WG2 Box 5.2) again making its assumption invalid. This effect is strongest in the Northern Hemisphere's mid latitudes due to its fossil fuel air pollution origin. Since the late 1800s, average levels of ozone in the lower atmosphere have increased by more than 30% (Lamarque et al. 2005).

4 Using crop model results to assess risk

What can we do with these model results for risk assessment? The first thing would be to assess risk based on the research of definite limiting factors like extreme temperature and prolonged drought, which are not incorporated into the climate crop model results.

4.1 Extreme temperature

Schlenker (2009) found that for United States crops, "average yields are predicted to decrease 30-46% before the end of the century under the slowest (B1) scenario," which is 2.2°C from preindustrial. So we have a 30-46% drop in yield for the NH region at a 2.2°C warming.

High regional warming projections for the summer are for heating of the food-producing regions (see Fig. 5).

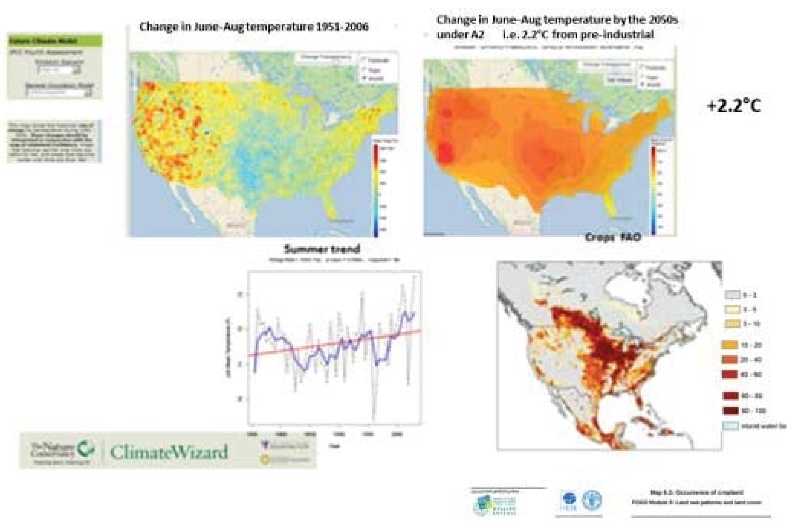


Fig. 5: Regional land warming affecting the United States summer period
(Climate Wizard, http://www.climatewizard.org)

4.2 Drought

Both heat and drought are increasing regionally in the Northern Hemisphere. There has been persistent NH regional drought recorded for the late 1990s and early 2000s (see Fig. 6).

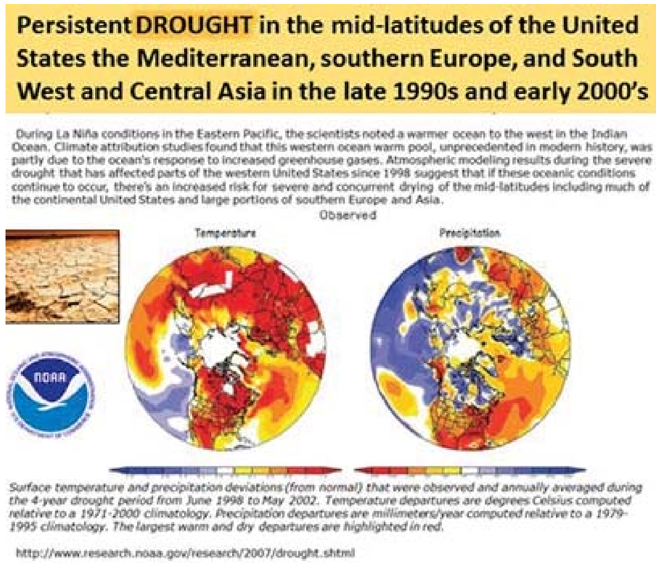


Fig. 6: Persistent DROUGHT in the mid-latitudes of the U.S., the Mediterranean, southern Europe, and Southwest and Central Asia in the late 1990s and early 2000s (NOAA 2007)

A. Dai's research (2011) provides evidence that NH food-producing regions will suffer increased drought with global warming (see Fig. 7).

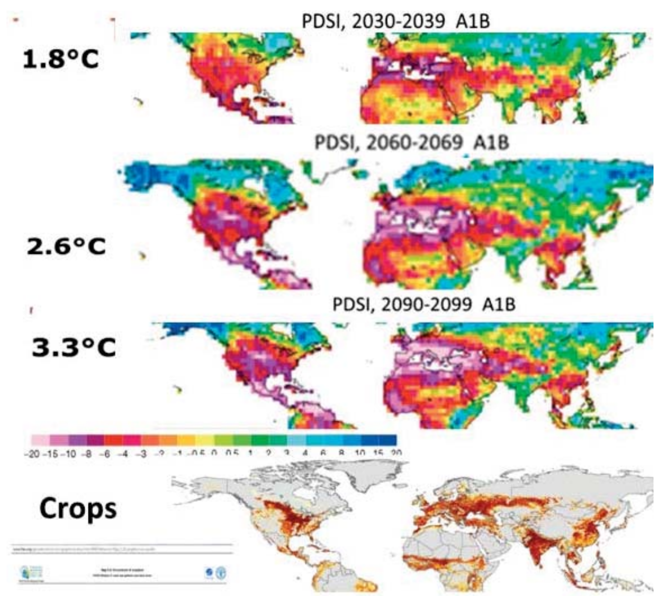


Fig. 7: Projected drought under global warming (Dai, 2011)

At a warming of 1.8°C, most of the NH croplands are under severe drought; at 2.6°C, extreme drought. This would be a catastrophic change for NH food production.

Food-producing central continental regions in the NH are currently in a three-year sustained drought at today's global warming of 0.8°C (see Fig. 8).

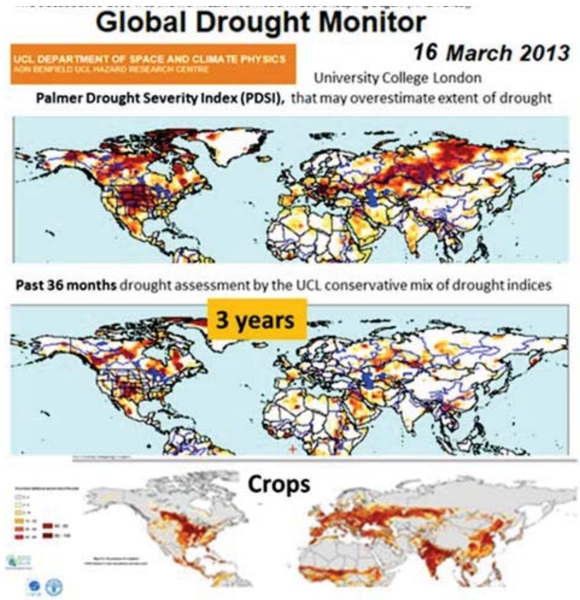


Fig. 8: Three year sustained drought (Palmer Drought Severity Index, 2013)

The U.S. grain belt is still in drought, as of March 2013 (see Fig. 9).

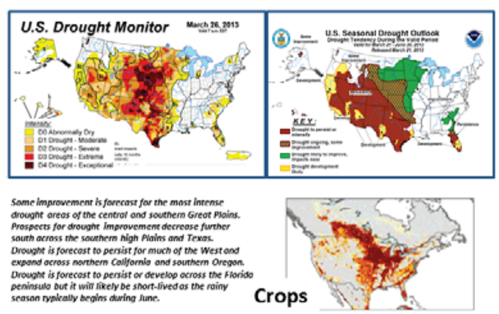


Fig. 9: Half of the U.S. still under drought, 26 March 2013 (U.S. Drought Monitor)

Drought is projected to increase in Europe under global warming (see Fig. 10).

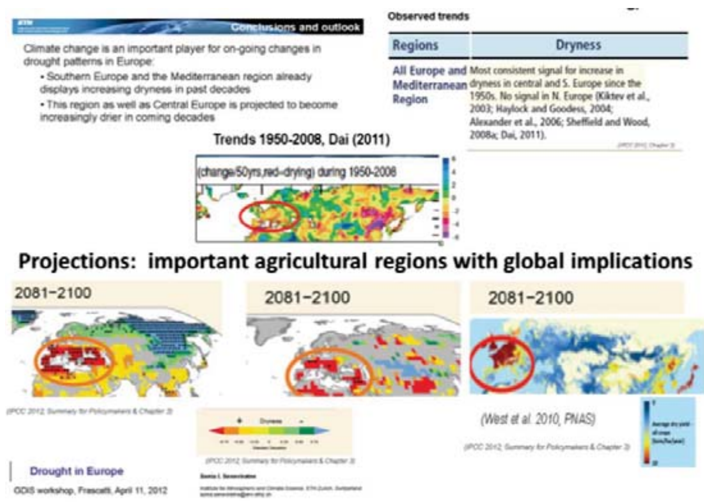


Fig. 10: Europe: Drought under climate change (without loss of Arctic albedo cooling) (GDIS workshop 2012)

4.3 Conclusions from crop models

Can we use the very incompletely programmed crop model projections to assess risk and realistic impacts? From all our approaches to crop yield impacts (and more so for impacts combined), we find that for the Northern Hemisphere (and for the most vulnerable low latitudes), any warming above 1.0°C is unacceptable for protection of food security. Indeed, the IPCC AR4 technical report (2007) records that globally, world food output is at risk above a 1°C warming (IPCC AR4 WG2 5.4.2.2).

From all approaches, we find that a warming of above 1.5°C can be expected to lead to large NH crop losses, affecting the world's best food-producing regions.

5 Arctic impacts

Finally, there is one other enormous aspect of global warming that specifically impacts Northern Hemisphere and therefore world food security. What is happening in the Arctic specifically impacts the NH with respect to extreme heat, drought, and climate variability.

5.1 Arctic albedo collapse

The Arctic is warming faster than any other region due to the Arctic amplification, which is now three times the global average (Duarte et al 2012). Scientists call the Arctic summer sea ice albedo effect the "air-conditioner" for the entire Northern Hemisphere. This albedo effect is provided by Far North snow, the summer sea ice (see Fig. 11), and Greenland ice sheet surface. All three sources of albedo are melting away fast and this is bound to have a large effect on the Northern Hemisphere's weather and climate.

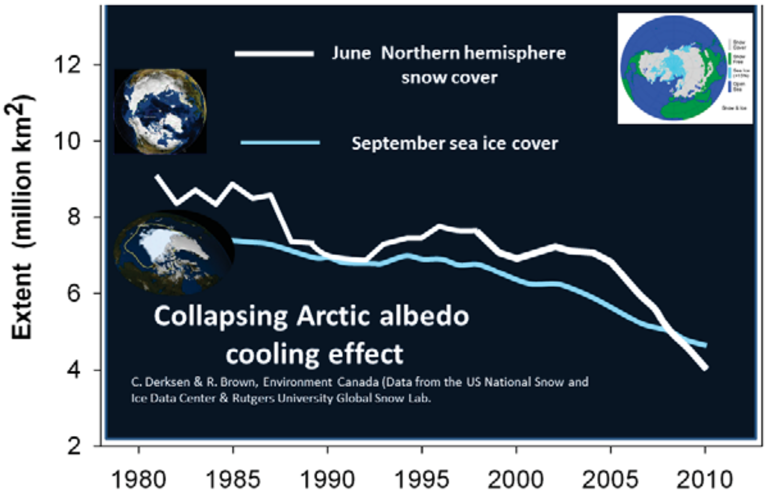


Fig. 11: Arctic albedo collapsing (Environment Canada and NSIDC)

5.2 Arctic temperature increase

While the increase in global average temperature has stalled over the past decade, the NH land temperature increase is sustained and the Arctic temperature is increasing fast (see Fig. 12). This is a very bad trend for NH food production.

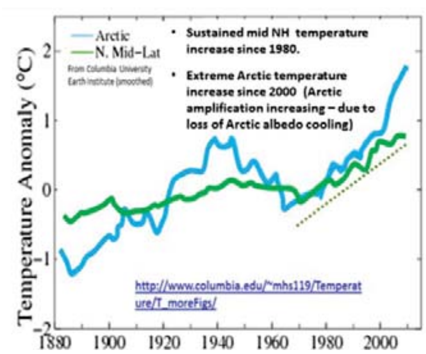


Fig. 12 Sustained mid Northern Hemisphere warming and rapidly increasing Arctic temperature increase (Columbia University)

Many experts have warned informally that the loss of the Arctic summer sea ice is a threat to Northern Hemisphere agriculture.

6 Conclusion

The evidence from the science is overwhelming. Under our best ideas of mitigation, the Northern Hemisphere is committed (already determined) by the climate science to large losses of all crops. We are clearly committed to a dire food security emergency situation in the Northern Hemisphere and, therefore, globally. What is to be done? The best-case scenario, RCP3-DP, will result in significant crop yield losses because the peak is unnecessarily delayed. The only published proposal to consider for Northern Hemisphere and world food security is Bill Hare's (2009) 1°C mitigation proposal (see Fig. 13).

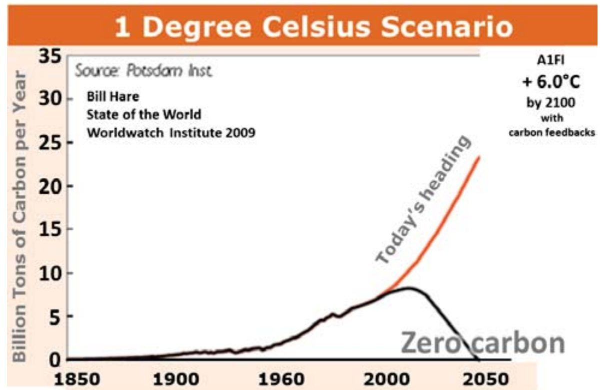


Fig. 13: Bill Hare's (2009) 1°C mitigation proposal

Author

The author (though published) is not a climate change or food production expert. He is a retired medically trained doctor with a background in environmental health protection policy development, of which global climate change is the issue of all time. He manages a suite of climate change websites, including <climatechange-foodsecurity.org> and <arcticclimateemergency.com>.

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Appendix A

NRC Climate Stabilization Targets 2010 Fi 5.1

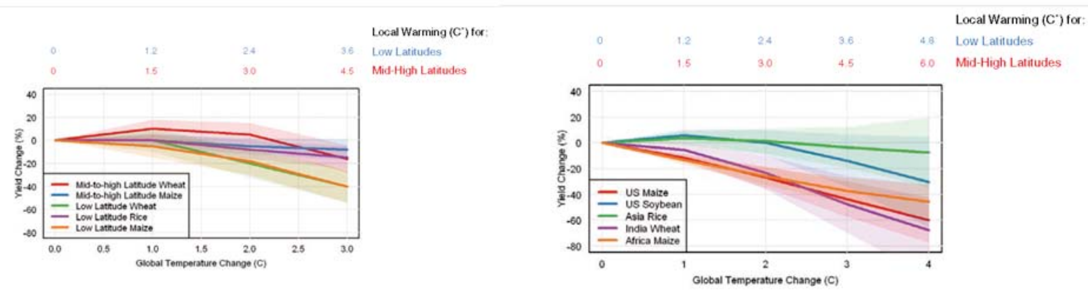

FIGURE 5.1 Average expected impact of warming + CO2 increase on crop yields, without adaptation, for broad regions summarized in IPCC AR4 (left) and for selected crops and regions with detailed studies (right). Shaded area shows likely range (67%). Impacts are averages for current growing areas within each region and may be higher or lower for individual locations within regions. Temperature and CO2 changes for the IPCC summary (left) are relative to late 20th century, while changes estimated for regions (right) were computed relative to pre-industrial. Estimates were derived from various sources (Matthews et al., 1995; Lal et al., 1998; Easterling et al., 2007; Schlenker and Roberts, 2009; Schlenker and Lobell, 2010)

NRC Appendix 5.1 FOOD PRODUCTION, PRICES, AND HUNGER
Methods summary for food figure
Left-hand panel:
For broad regions, yield losses per °C of local warming were taken from Figure 5.2 in the Working Group 2 reports of the Fourth Assessment Report of the IPCC (Easterling et al., 2007). These estimates include estimates of CO2 effects but without explicit modeling of adaptation. The mean and one standard error for each level of warming were approximated from the figure.
Local temperature changes were converted to global temperature levels using a value of 1.5°C local per global °C for mid-to-high latitudes and 1.2°C local per global °C for low latitudes.
Right-hand panel:
For each region, global temperatures were converted to local temperature change based on the patterns in Section 4.2.
CO2 levels for each temperature value were based on the values reported in Section 3.2, and assuming a ratio of
CO2 to CO2-equivalent equal to the average of the SRES scenarios (ratio is 1.05 for 1°C, 0.93 for 2°C, and 0.8 for 3°C and warmer.

NRC Appendix 5.1 FOOD PRODUCTION, PRICES, AND HUNGER

Methods summary for food figure

For broad regions, yield losses per °C of local warming were taken from Figure 5.2 in the Working Group 2 reports of the Fourth Assessment Report of the IPCC (Easterling et al., 2007). These estimates include estimates of CO2 effects but without explicit modeling of adaptation. The mean and one standard error for each level of warming were approximated from the figure.

Local temperature changes were converted to global temperature levels using a value of 1.5°C local per global °C for mid-to-high latitudes and 1.2°C local per global °C for low latitudes.

Note that since several of these studies are based on experiments where climate is allowed to equilibrate with doubled CO2 levels, while others were taken from transient simulations (e.g., based on SRES scenarios), the CO2 levels for different amounts of warming likely varied by study, with the equilibrium studies likely underestimating CO2 levels for a given warming amount.

Appendix B

IPCC AR4 climate crop model projections that are the basis of the IPCC food security assessment

Figure 5.2 provides an example of such analyses for temperature increases ranging from about 1-2ºC, typical of the next several decades, up to the 4-5°C projected for 2080 and beyond.

The results of such simulations are generally highly uncertain due to many factors, including large discrepancies in GCM predictions of regional precipitation change, poor representation of impacts of extreme events and the assumed strength of CO2 fertilisation.

Nevertheless, these summaries indicate that in mid- to high-latitude regions, moderate to medium local increases in temperature (1ºC to 3ºC), across a range of CO2 concentrations and rainfall changes, can have small beneficial impacts on the main cereal crops. Further warming has increasingly negative impacts

The low and mid-to-high latitude regions encompass the majority of global cereal production area. This suggests that global production potential,..., is threatened at +1°C local temperature change

Figure 5.2. Sensitivity of cereal yield to climate change for maize, wheat and rice, as derived from the results of 69 published studies at multiple simulation sites, against mean local temperature change used as a proxy to indicate magnitude of climate change in each study.

Lines are best-fit polynomials and are used here as a way to summarise results across studies ***rather than as a predictive tool.***

The studies span a range of precipitation changes and CO2 concentrations, and vary in how they represent future changes in climate variability. For instance, lighter-coloured dots in (b) and (c) represent responses of rain-fed crops under climate scenarios with decreased precipitation.

Food, Fibre and Forest Products **IPCC AR4 WG 2 Ch 5**

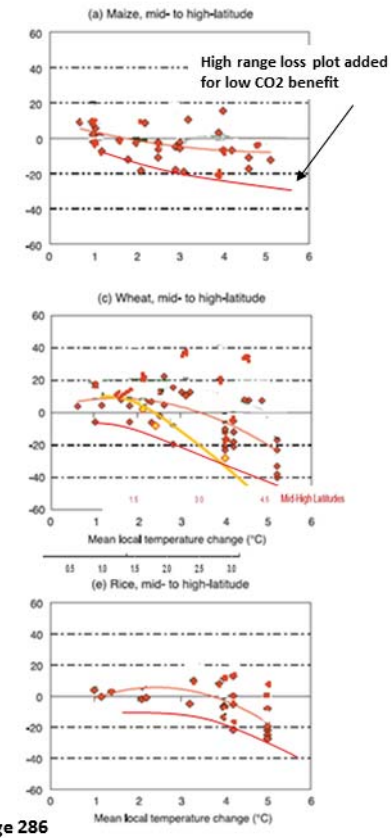

Fig 5.2 Page 286

Water requirements for maize production in Europe under changing climate conditions

A. Ceglar, O. Chukaliev, G. Duvellier and S. Niemeyer

Abstract- We use the Bio-physical Model Applications framework (BioMA) to simulate the maize yield response to water availability in current and future climatic conditions. Two different realizations of the A1B scenario from dynamically downscaled global circulation models within the ENSEMBLES project, which capture the most contrasting situations with respect to changes in precipitation and temperature, have been selected for this purpose. The CropSyst crop model has been used to simulate the water-limited and potential maize yield as well as total crop water requirement and total water consumption. The water deficit productivity index has been introduced for the purpose of the study, describing the gain in crop yield when water deficit is reduced. The results have shown that the maize yield is expected to decrease over Southern Europe as well as regions around the Black Sea during the 2030s. The water could become more productive in central and Western Europe and slightly less productive in the Southern Europe.

Index Terms— climate change, grain maize, water deficit, yield deficit

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1 Introduction

Future climate conditions are likely to intensify current agricultural water management across the Europe. Analysis of the spatial distribution of expected changes in water demand for irrigation in the near future is a prerequisite to devise appropriate water management strategies, which can stabilize crop production and increase carbon sequestration. Moreover, irrigation water requirements caused by agricultural expansion and climate change should be integrated into cross-sectoral water management. In this study we therefore aim to analyse the water requirements and consumption for growing maize in current and future climatic conditions in Europe. The change between the spatial distributions of water deficit and maize yield deficit across Europe for the baseline period (centred on 2000) and time horizon in the future (centred on 2030) is analysed. The simulations are based on a new dataset of future daily weather data that was especially tailored for crop growth applications in the near future (Donatelli et al. 2012).

2 Data and methodology

2.1 Data

The simulations require 3 data types: weather, soil and crop calendar data. Weather data for projected climate change scenarios were generated using regional climate models (RCM) nested in global circulation models (GCM) from the ENSEMBLES project (van der Linden and Mitchell, 2009). RCM simulations were bias-corrected (Dosio and Paruolo, 2011), since biased RCM simulations can lead to unrealistic crop yield simulations (e.g. Teutschbein and Seibert, 2010, Ceglar and Kajfež-Bogataj, 2012). Since the bias-correction was only done on a subset of weather variables (rainfall and temperature), this dataset was further processed by Donatelli et al. (2012)[a] to ensure that different weather variables of agronomic importance (such as global solar radiation) remained coherent amongst themselves, thus making them usable for crop simulations. This processing also included a resampling to a common 25 by 25 km grid and the use of the ClimGen weather generator (Stöckle et al., 2001) applied to data from short-term time horizons of 15 years (such as 2013-2027 and 2023-2037) in order to increase the sample size.

In our study, the priority has been given to future projections of the A1B emission scenario given by HadRM3 RCM nested within the HADCM3 GCM (HADLEY) and HIRHAM5 RCM nested within ECHAM5 GCM (ECHAM). The two realizations can be considered as warm (HADLEY) and cold (ECHAM5) according to simulated temperature in the future. These two realizations therefore represent the extremes in air temperature change within those analysed in ENSEMBLES project, allowing us to evaluate the largest range of uncertainty in weather inputs to the impact model. Two time horizons were compared in our study. Both cover a length of 30 years, centered on years 2000 (the baseline period) and 2030. Simulated changes of mean air temperature and cumulative precipitation during the vegetation period between the 2030s and the baseline period are shown on Fig. 1 and 2.

The most common soil profile across the Europe, which has a medium water-holding capacity, was used for the simulation purposes. It has to be emphasized that the simulation, limited to soil water, are sensitive to basic soil parameters derived from texture and soil depth, which influence the soil hydraulic properties. While a more detailed spatial soil database would better represent actual soil depths and areal presence in a given cell, the differences in the output would not differ markedly, except for extremely shallow soils (Donatelli et al., 2012)[b].

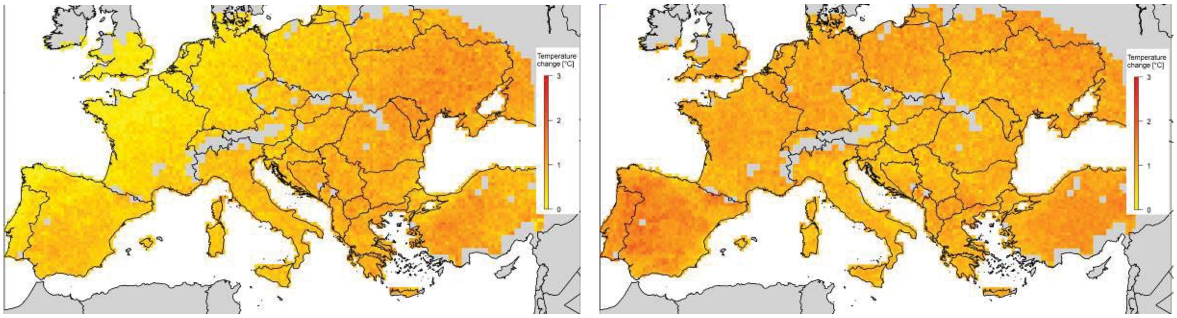

Figure 1: Simulated change of mean air temperature during the vegetation period between the 2030s and the baseline period (ECHAM5 – left and HADLEY - right).

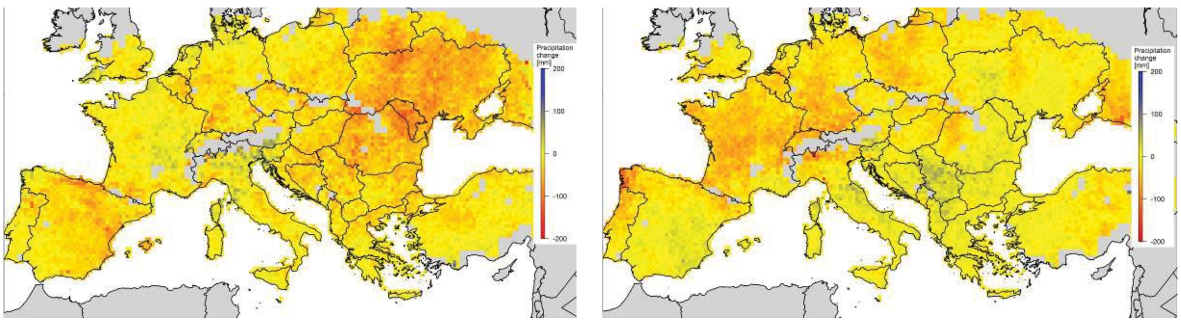

Figure 2: Simulated change of cumulative rainfall during the vegetation period between the 2030s and the baseline period (ECHAM5 – left and HADLEY - right).

2.2 Methods

The CropSyst model (Stöckle et al., 1994) was used for simulation of maize growth and development. The CropSyst is a process-based generic simulator for crops. Different crops can be simulated using appropriate parameters. The CropSyst model has already been used to study the impact of climate change and climate extremes on crop production in different locations (Tubiello et al., 2000; Moriondo et al., 2011).

Two levels of crop model simulations were used in our study: potential and water-limited (rainfed). The difference between potential and rainfed yield is called the yield deficit. Yield deficit can be reduced if additional water is applied to crops during the growing season through irrigation. We introduced an indicator of yield reduction dependence on water deficit. The latter is defined as the difference between potential and actual evapotranspiration. We defined the water deficit productivity index as:

$$WD = \frac{Y_{pot} - Y_{\lim}}{ET_{pot} - ET_{\lim}},$$

where Y_{pot} and Y_{lim} represent potential and water-limited yield, whereas ET_{pot} and ET_{lim} represent potential and actual evapotranspiration. The index value therefore represents the productivity of water which can be applied to reduce or eliminate water deficit. Index can be used as tool for vulnerability assessment in respect to water deficit; higher index value expresses higher yield reduction per unit of water in deficit.

The crop simulated in this study is grain maize. Simulations were performed for a major part of Southern, Western and Eastern Europe, in which maize can be grown. Six important maize production areas were chosen for more detailed analysis of the impact of climate change on crop production and soil water deficit (see Fig. 3). No adaptation measures have been incorporated into our simulations.

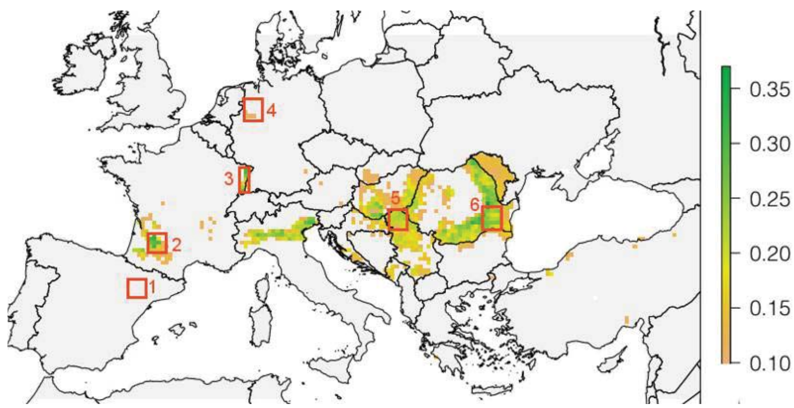

Figure 3: Maize growing areas, where more than 10 % of the cell area is occupied by maize. Shown are selected regions for the analysis (1-Zaragoza, 2-Aquitaine, 3-Alsace, 4-Lower Saxony, 5-Vojvodina, 6-Wallachian plain)

3 Results with discussion

3.1 Water deficit productivity index (WD)

WD indicates the gain in crop yield if water deficit is reduced. Figure 4 shows the dependence of maize yield deficit on water deficit for selected locations in southern Spain, Lower Saxony (Germany) and Vojvodina (Serbia). Observed weather data from the MCYFS database (daily weather data from 1982 untill 2012) (Genovese, 2004) was used to simulate yield and water deficit over those locations. Different yield deficit can be observed in the selected regions, with the highest deficit occurring over Spain and the lowest in Germany. Over the German site, potential yield is almost attained for the majority of simulated years. In several years, higher yield deficit appeared, which resulted from increasing water deficit. Moreover, accumulated water deficit throughout the growing season, which is lower than 100 mm, does not seem to significantly reduce the potential yield at the end of the growing season. Increasing water deficit tends to have the highest impact on maize yield in the interval between 100 and 300 mm. The reduction of water deficit in this case causes the most significant increase of maize yield. This can be observed for the majority of points, representing Vojvodina (Serbia). WD values decrease when the water deficit is higher (e.g. location in southern Spain), when increasing of the yield deficit becomes less significant with increasing water deficit (Fig. 4, right). Economic value of the water is therefore the highest in the interval, where the reduction of water deficit results in the most significant increase of maize yield (water deficit between 120 and 300 mm, Fig. 4).

The timing of water shortage for plant growth is important as well as the total amount of the water deficit during the growing season. To illustrate the importance of timing, we have coloured the points on the Fig. 4 according to the amount of accumulated water deficit in the period from flowering to maturity, relative to the accumulated deficit from the whole growing period. In general, high accumulated water deficit during the period between flowering and maturity causes higher maize yield deficits, which can be seen in the case of Spain (Fig. 4, left). Maize yield deficit is decreased in cases when lower accumulated water deficit between flowering and maturity occurred, which can be observed especially in Germany. The period near flowering is the most sensitive to water deficit (Ceglar and Kajfež-Bogataj, 2012). In addition, low water amount after the tasseling period can significantly reduce the grain yield production.

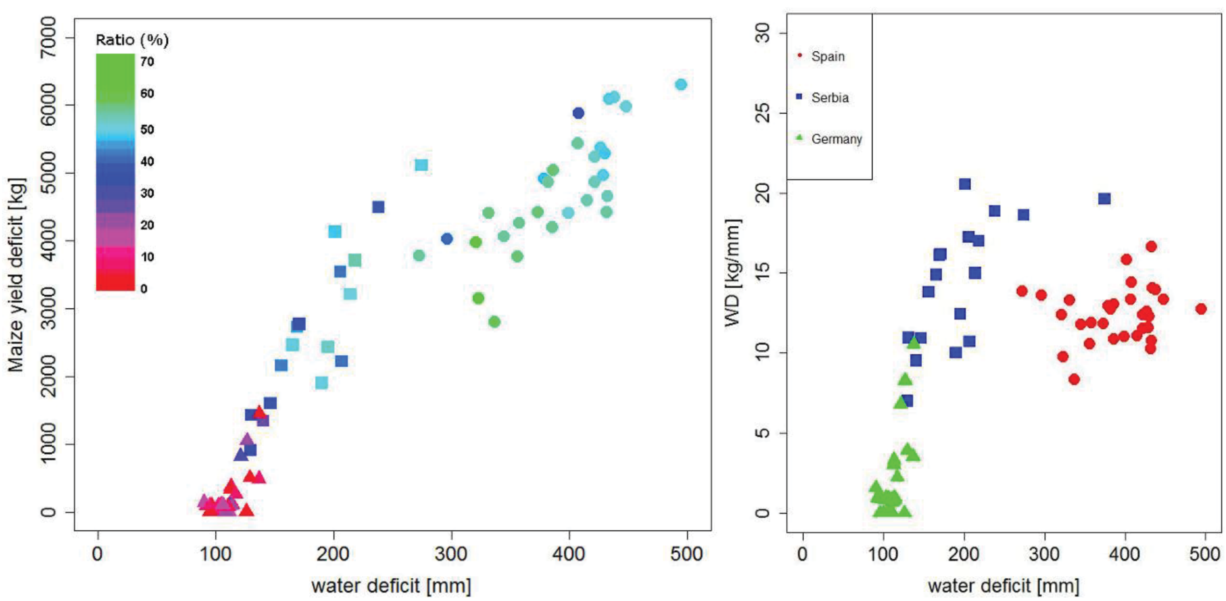

Figure 4: Left - maize yield deficit dependence on water deficit for the period between 1982 and 2012 for three different locations, characterized by a single grid point: 1) Andalusia (Spain) – circles, 2) Vojvodina (Serbia)– squares and 3) Lower Saxony (Germany)– triangles. The calculation was performend based on MCYFS data. The color represents the amount of accumulated water deficit in the period between flowering and maturity relative to accumulated water deficit over the whole growing season. Right - water deficit productivity index for the three locations.

3.2 Simulation of climate change impact on maize yield deficit and water deficit for selected regions

Figure 5 shows scatterplots of changes in water deficit and maize yield deficit in 2030s relative to water and maize yield deficits during the baseline period. Simulations from two different climate model runs are shown on each plot for all grid cells within the selected regions (Fig. 3). Little or no changes in maize yield deficit and water deficit are expected in the Lower Saxony region. Both climate models predict no significant changes in the precipitation, whereas warming between 0.4 and 1.0 °C is expected. In other places, pronounced differences can be observed between ECHAM and HADLEY model runs. In Alsace and Aquitaine, maize yield deficit is expected to increase more in case of HADLEY model run. HADLEY resulted in significantly higher temperature increase and precipitation decrease in these regions. An increase of water deficit for 50 mm could lead to increase of maize yield deficit up to 1000 kg per hectare. The maize yield deficit is expected to decrease in Wallachian plain. Water deficit increases for ECHAM, since it resulted in lower accumulated precipitation over the growing season (Fig. 2). Since both climate model runs simulate similar temperature change over the Wallachian plain, the change in yield deficit mainly depends on precipitation change, which is negative in case of ECHAM and non-significant for HADLEY model run. The potential maize yield is expected to decrease significantly over the region, mainly due to water stress and higher temperatures. Higher temperatures lead to shortened growing period and acceleration of all phenological stages, which leads to a shorter grain filling period. Negative change in maize yield deficit on the graph indicates that the reduction of potential yield is higher than reduction of the actual yield in the 2030s.

Above the diagonal line on plots in the Figure 5, the WD index change between2030s and 2000s is positive and below the line negative. This indicates that for the points above the line, water deficit will cause higher negative impact on the final yield and measures that reduce water deficit (irrigation, conservative tillage, reduced tillage, soil water conservation, …) will become more productive in 2030s than in the baseline period. Figures 6 and 7 represent the spatial distribution of WD change across the Europe. The index values generally decrease in Mediterranean and regions around the Black Sea, whereas no change or slight increase occurs in the central and part of Western Europe. Increasing of WD values can be observed in the case of HADLEY, which simulates a considerable decrease of rainfall over France and parts of Central Europe.

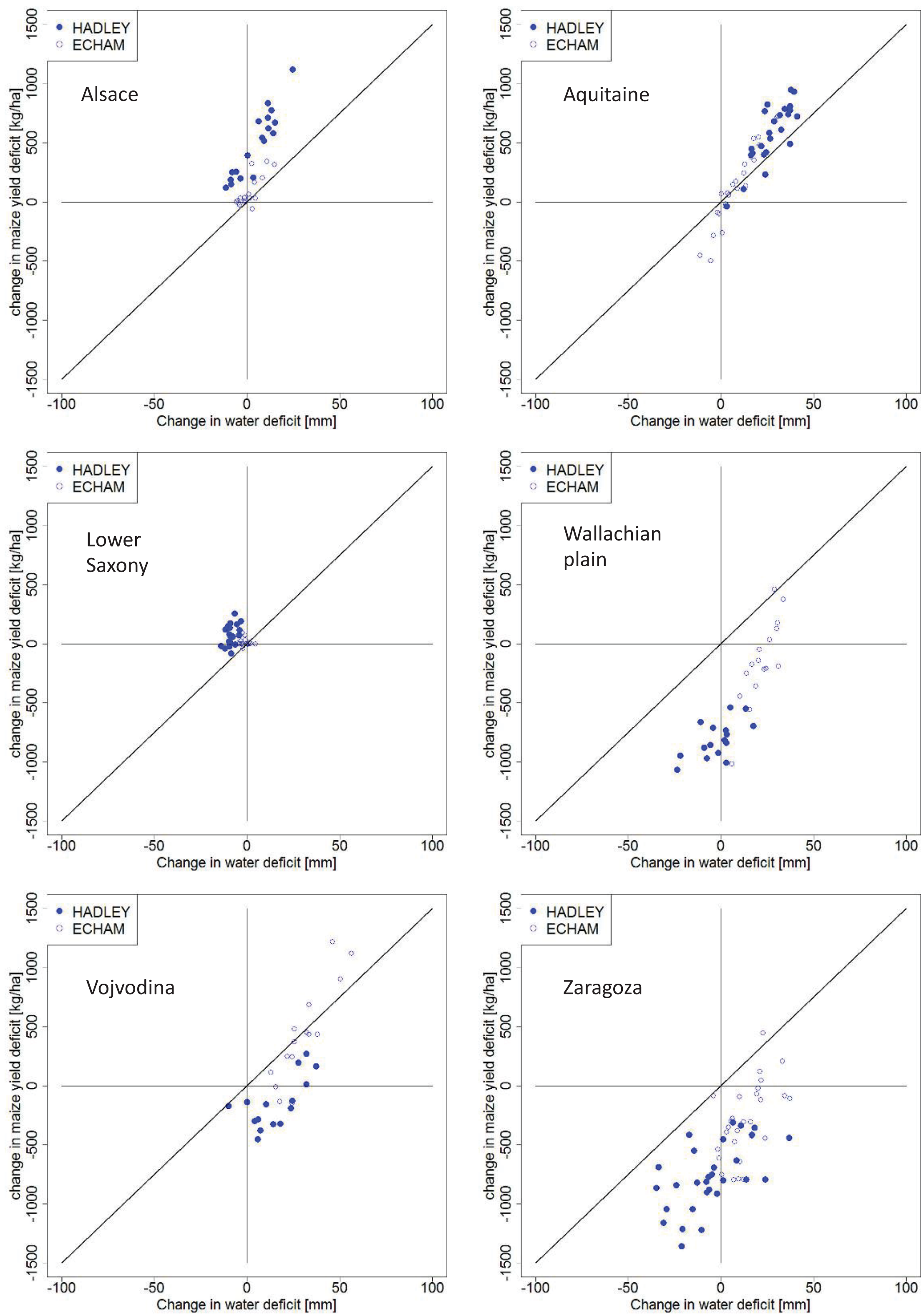

Figure 5: Scatterplots of changes in the maize yield deficit and water deficit between the 2030s and the 2000s period for Alsace, Aquitaine, Lower Saxony, Wallachian plain, Vojvodina and Zaragoza

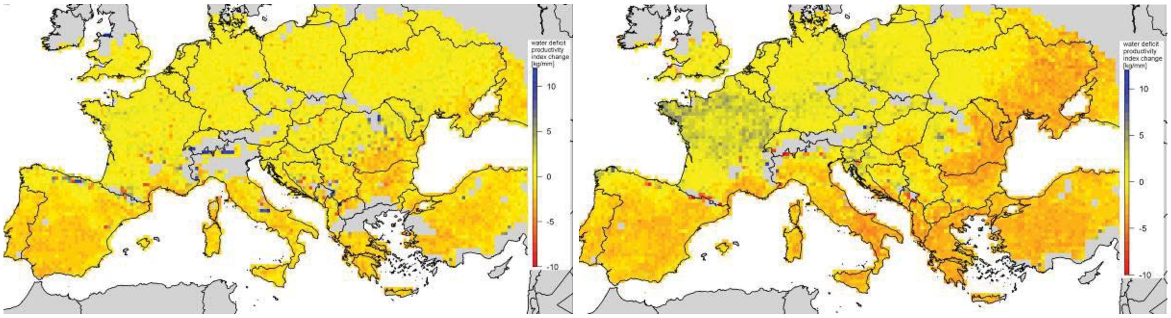

Figure 6: Simulated change in water deficit index values during the vegetation period, using the ECHAM (left) and HADLEY (right) model runs, between the 2030s and the 2000s (baseline) period.

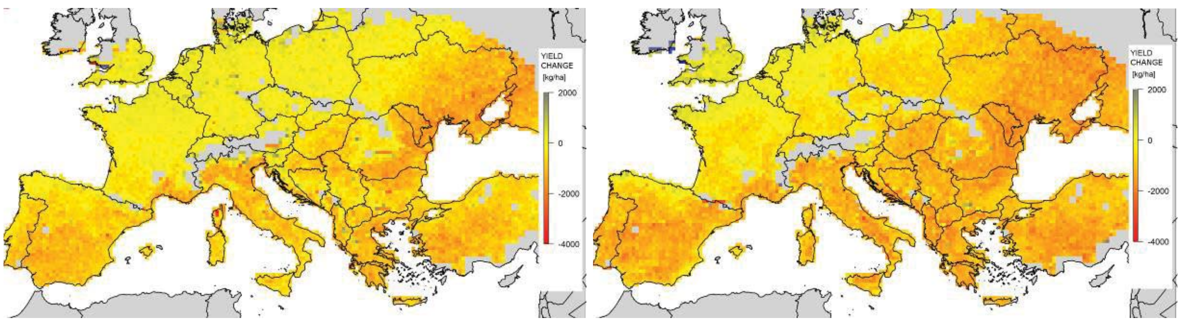

Figure 7: Simulated change in potential maize yield during the vegetation period, using the ECHAM (left) and HADLEY (right) model runs, between the 2030s and the 2000s (baseline) period.

4 Conclusions

The results of our study have shown that the maize yield is expected to decrease over the Southern Europe as well as regions around the Black Sea during the 2030s. Water deficit productivity is expected to increase in parts of Central and especially Western Europe, whereas slightly decrease in Southern Europe and regions around the Black Sea. This indicates that increase of water deficit due to climate change could increase the risk of yield reduction in Central and Western Europe and slightly less in the Southern Europe. In addition, large differences occur between two contrasting climate model runs which are reflected in the simulated water deficit productivity as well. Research activities in the future should focus on how the timing of water deficit occurrence within the growing season impacts the maize yield deficit at maturity.

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Climate impacts in Europe: an integrated economic assessment (preliminary results of the JRC PESETA II project)

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Abstract— The JRC PESETA II study integrates the consequences of several separate climate change impacts into a macroeconomic CGE model. This enables comparison of the different impacts based on common metrics (household welfare and economic activity). The study uses a large set of climate model runs (twelve) and impact categories (agriculture, energy demand, river floods, sea-level rise, forest fires, transport infrastructure).

The results show that there is a wide dispersion of impacts across EU regions, with strong geographical asymmetries, depending on the specific impact category and climate future. For instance, Northern Central Europe has negative impacts mainly related to sea level rise and river floods while Southern Europe is affected mainly by agriculture. The study also explores the significance of transboundary effects (where climate change causes economic damages outside the region directly affected.

Index Terms—climate impacts, integrated assessment modeling, climate adaptation

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1 Introduction

This article presents the methodology and preliminary results of the economic impacts assessment of the JRC PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis)[1]. The integrated methodology also benefits from other impact evidence derived from the FP7 ClimateCost project (on coastal impacts and agriculture in the 2080s).

[1] Preliminary results of the JRC PESETA II project (http://peseta.jrc.ec.europa.eu/), as published the Impact Assessment accompanying the EU Strategy on Adaptation to Climate Change, April 2013. The project uses climate data from the FP6 ENSEMBLES project, and impact estimates for agriculture and sea level rise from the FP7 ClimateCost project. The authors wish to thank Daniela Jacob for providing the E1 climate data, and the

With the proposed methodology high time-space resolution climate data feed highly disaggregated sector-specific impact models to estimate the biophysical impacts. Such structural approach, as opposed to the reduced form formulation, aims indeed to consistently integrate what is known on climate impacts in the various natural sciences disciplines into the economic analysis. With this kind of methodology it is possible to derive macroeconomic estimates of the economic effects. The main motivation of this methodology has been then to soundly integrate empirical results from biophysical models into an economic framework (Ciscar et al. 2012b). The methodology could be applied to any regional climate impacts assessment.

Regarding the economic assessment, the four main questions to be addressed are the following. Firstly, how great are the impacts of climate change under future climate scenarios, in particular, under a reference and a 2°C scenario? Secondly, what are the distributional implications of climate impacts? Thirdly, by how much can adaptation reduce climate impacts? Fourthly, are spatial (cross-country) transboundary impacts significant?

The article is organized in four sections, including this introduction. Section 2 presents the main features of the integrated methodology. Section 3 explains the climate runs used in the project. Section 4 discusses the main economic impact results. Section 5 notes a series of caveats.

2 Methodology and scope of assessment

The methodology here applied has three steps, following Ciscar et al. (2011). In the first stage the climate runs used as input to all biophysical models are selected. In a second stage, the biophysical impact models are run to compute the biophysical impacts. In a third step, those impacts are valued in economic terms using a computable general equilibrium model.

The following climate impact categories have been considered in the preliminary economic assessment: agriculture, coastal areas, energy, river floods, forest fires, and transport infrastructure. Agriculture impacts are in terms of crop productivity changes, using the DSSAT model (see Iglesias et al. 2012). The river floods assessment uses the LISFLOOD hydrological model (Feyen et al. 2012). The energy assessment computes the changes in heating and cooling demand for both residential and commercial sectors, based on the energy POLES model (Dowling et al, 2012). Coastal impacts are derived from the DIVA model (Brown et al. 2012). The forest fires analysis is documented in Camia et al. (2012), and the transport infrastructure assessment in Nemry and Demirel (2012).

The use of a multi-country general equilibrium model permits that the estimated economic impacts include both the direct impact of climate change (e.g. the losses in the agriculture sector due to lower yields) and the indirect consequences in the rest of the sectors (e.g. in the agrofood industry) and the rest of the world (considered via trade flows). The main economic output variables relate to household

members of the PESETA II project Advisory Board (J Mac Callaway, O B Christensen, C Goodess, M Hanemann, and S Waldhoff,) and JRC colleagues for their very useful comments and feedbacks.

welfare, and GDP. Economic impacts on welfare are provided in monetary terms, and are presented undiscounted, in 2005 Euros. The welfare changes are also compared to GDP.

The study evaluates a counterfactual situation: the impact of future climate on the economy of today. This approach is known as comparative static.

The results are presented dividing the EU into the following regions, according to their latitude and the relative economic size, as it was made in PESETA:

- Northern Europe: Sweden, Finland, Estonia, Lithuania, Latvia, and Denmark.
- UK & Ireland: UK and Ireland.
- Central Europe north: Belgium, Netherlands, Germany, and Poland.
- Central Europe south: France, Austria, Czech Republic, Slovakia, Hungary, Slovenia, and Romania.
- Southern Europe: Portugal, Spain, Italy, Greece, and Bulgaria.

All reported impacts assume that there is not public adaptation, unless otherwise stated. Therefore, the methodology can be useful to understand where to prioritise adaptation options.

3 Climate scenarios and runs

For the JRC PESETA II study climate simulation runs were obtained from the FP6 ENSEMBLES project (van der Linden and Mitchell, 2009). Runs were driven either by the SRES A1B emission scenario (Nakicenovic and Swart, 2000), or the so called E1 emission scenario. The E1 scenario was developed within ENSEMBLES as an attempt to match the European Union target of keeping global anthropogenic warming below 2 °C above pre-industrial levels.

It is important to note that climate model outputs may present significant errors (biases) when compared to observations: for instance, modeled summer temperatures in Southern Europe are usually overestimated, while large biases exist for precipitation. Consequently, the climate runs originally obtained from the ENSEMBLES project (12 A1B and 3 E1) were corrected for biases in temperature and precipitation by Dosio and Paruolo (2011), and Dosio et al. (2012).

The JRC PESETA II study considered four core climate runs:

- Reference Run. It is interpreted as representing well the central or average of the A1B runs. This run is interpreted as business as usual scenario. The two additional A1B runs show significant deviations from the average climate change signal, being usually warmer and drier (Reference Variant 1) or colder and wetter (Reference Variant 2) than the average;
- Reference Variant 1 is the climate run that is warmer and drier than the average;

- Reference Variant 2 is the climate run that is colder and wetter than the average;

- The 2°C Scenario. This run is an example of the E1 scenario. This run is therefore referred to as '2°C scenario' in the project.

The combination of climate models chosen for each core run is shown in Table 1. All the models driven by the same A1B emission scenario represent an equally probable projection of the future evolution of the climate. However, the selected runs show a significant variety in climate change signal for both temperature and precipitation. One can therefore expect that by using these three simulations as an input for the study of impact assessment of climate change, the main statistical characteristics of the A1B scenario as modelled by the whole ensemble of RCMs are relatively well represented.

Table 1: Climate models chosen for PESETA II core runs

	Climate Models Employed		
Core run	**Agriculture**	**Sea-level rise**	**All other impacts**
Reference run	A1B ECHAM5 (UKMO)	30 cm sea-level rise (median A1B projection)	A1B KNMI-RACMO2-ECHAM5
Reference Variant 1	A1B ECHAM5 (DMI)	30 cm sea-level rise (median A1B projection)	A1B METO-HC-HadRM3Q0-HadCM3Q0
Reference Variant 2	A1B EGMAM2006 (FUB)	30 cm sea-level rise (median A1B projection)	A1B DMI-HIRHAM5-ECHAM5
2°C run	E1 ECHAM5.4 (MPI)	18 cm sea-level rise (median E1 projection)	MPI-REMO-E4

The sea level rise projections come from the ClimateCost project (Brown et al. 2011). For the A1B scenario, the medium projection for SLR in the 2080s is 30 cm, and 18 cm for the E1 medium projection. The respective values for SLR in 2100 are 37 cm and 26 cm. The coastal impacts have been computed taking into account the projected damages for the 2080s.

4 Economic impacts

4.1 Methodology

The GEM-E3 model[2] is used to compute the overall economic impacts of climate change. The model uses a computable general equilibrium (CGE) approach that allows exploring the indirect economic consequences of climate change due to the cross-sectoral effects within the economy, on top of the direct economic impacts.

The GEM-E3 CGE model analyses the interactions between the economy, the energy system and the environment. The current EU version is based on EUROSTAT data (base year 2005), with most member states individually modelled. The countries are linked through endogenous bilateral trade flows. The GEM-E3 model integrates micro-economic behaviour into a macro-economic framework and allows the assessment of medium to long-term implications for policies.

The various impact categories are integrated by changing specific elements of the production structure and supply-side (capital and labour) of the different sectors and of the consumption structure of households. Table 2 summarizes how the different impact categories have been interpreted and implemented in the GEM-E3 model[3]. For instance, the agriculture model produces estimates of agriculture yields. They are implemented in the model as changes in productivity in the agriculture sector.

The CGE method, as it considers trade effects, can be used to estimate how impacts in one region can affect the rest of Europe. This will be applied to the assessment of the size of the possible transboundary climate impacts within Europe (see Section 4.2).

Table 2: Implementation of sectoral climate impacts in GEM-E3

Impact	**Biophysical model output**	**Model implementation**
Agriculture	Yield change	Productivity change for crops
Coastal areas	Migration cost	Additional obliged consumption
	Sea floods cost	Capital loss
River floods	Residential buildings damages	Additional obliged consumption
	Production activities losses	Capital loss
Energy	Heating and cooling demand changes	Energy demand changes in residential and service sectors

2 www.gem-e3.net

3 A similar methodology was followed in the PESETA project (see Ciscar et al., 2012b).

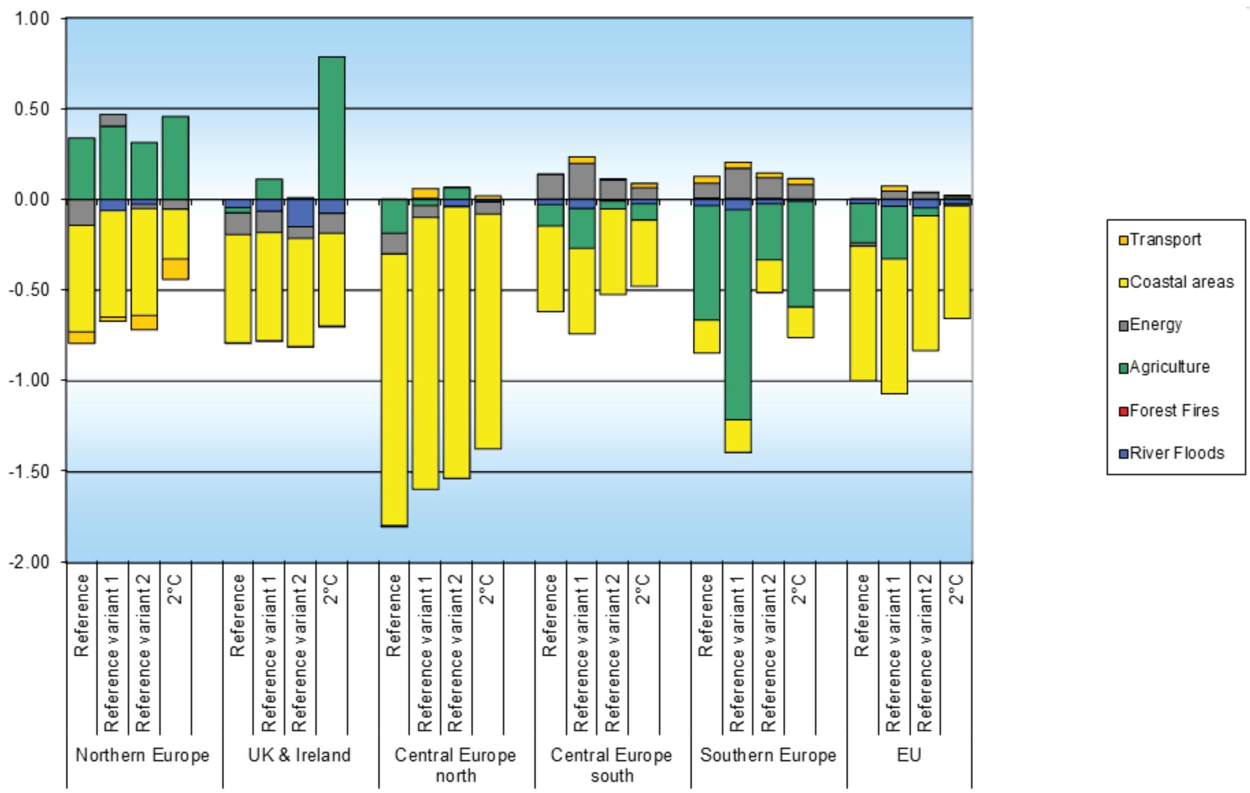
Transport infrastructure	Changes in cost of: - road asphalt binder application	Additional obliged consumption
	Net change in costs related to: - extreme flooding	Capital loss[4]
Forest Fires	Burned area damage	Capital loss
	Reconstruction costs	Obliged consumption

4.2 Results

Figure 1 shows the GDP effects for the EU, decomposed both by impact categories and EU regions. Under the reference run, losses could reach 1% of EU GDP, mainly because of impacts on coastal areas and agriculture. The overall GDP loss is reduced under the 2°C scenario. Impacts of changes in energy demand (led by reduced need for heating) are positive at EU level. Regarding the regional pattern of impacts, Central Europe north is the area most affected by GDP losses (up to 1.7% of GDP), as a consequence mainly of sea level rise. Southern Europe GDP losses are also around 1% of GDP, led mainly by agriculture impacts. In all considered regions, GDP losses become smaller when one moves from the reference run to the 2°C run.

[4] Capital loss can be negative when combined changes in winter conditions and extreme flooding create conditions that are more benign than the baseline

Figure 1. GDP impacts (% GDP)

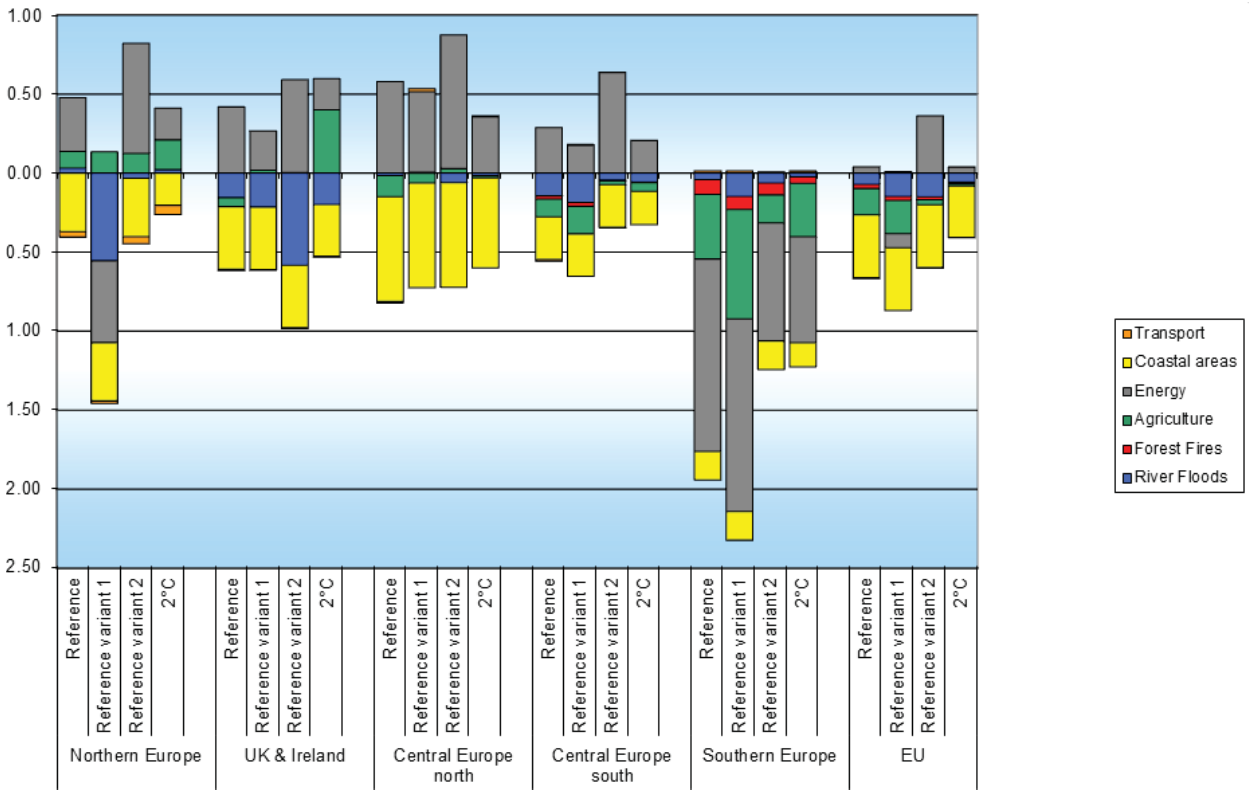


Source: preliminary results of JRC PESETA II project

Welfare change is an appropriate metrics to interpret the results of GEM-E3, as the economic model is rooted in neoclassical economics, where households pursue the maximisation of their welfare levels. Figure 2 shows welfare changes for the core runs, expressed as a percentage of GDP. For the EU as a whole (bars on the right-hand of the figure), the net welfare loss of the reference runs is estimated to be around 0.7% of GDP.

The most significant negative impacts are linked to coastal areas, agriculture and river floods. Damage from river floods is more harmful to welfare than GDP because flood damage requires spending on repairs by households. This is compulsory consumption that brings no welfare benefit (but contributes to GDP). Moving to a 2°C scenario would reduce the impact on agriculture and river floods for the EU as a whole and would reduce coastal impacts to a lesser extent.

Figure 2. Welfare impacts (% GDP)



Source: preliminary results of JRC PESETA II project

The overall EU climate impacts are disaggregated by EU region in the rest of Figure 2. Energy impacts are positive in most climate runs in all regions, expect Southern Europe. Starting with the Northern Europe region (bars on the left-hand side), the region could have welfare gains associated with lower energy expenditure and positive agriculture yield changes. Impacts in coastal areas are the main negative climate impact, and for Variant 1 run river floods could lead to substantial losses. The negative climate impacts in UK & Ireland are due to river floods and sea level rise in coastal areas. The negative impacts in the Central Europe north area are mainly provoked by sea level rise. The Central Europe south region could register negative impacts due to sea level rise, agriculture and river floods. The Southern Europe region impacts, all negative, appear to be driven mainly by changes in energy expenditure, and also to agriculture and coastal damage.

An interesting issue to analyse is to what extent climate impacts occurring in one EU region could affect the rest of the EU, via trade effects. The intuition is the following. If one region would not adapt to climate change, it would undergo welfare losses, and they would affect the rest of the EU, via trade effects, given the high degree of economic integration between the EU member states. Two preliminary simulations with the reference run setting have been made to explore these trade effects.

In the first analysis (first column of Table 3), one can imagine a counterfactual situation where only Central Europe north is affected by sea level rise, while the rest of the EU regions do not suffer any direct impact. Under such a case, the economic modelling results suggest that Central Europe north would have a welfare loss of 20.5 billion Euros. There would be an additional 30% welfare loss (5.6 billion Euros) felt in the rest of the EU due to the economic linkages between EU regions.

Table 3. Transboundary effects (reference run)

	Coast / Central Europe North	**Agriculture / Southern Europe**
Northern Europe	-491	-122
UK & Ireland	-1.677	-580
Central Europe north	-20.518	-950
Central Europe south	-1.966	-900
Southern Europe	-1.530	-10.218
EU	**-26.181**	**-12.770**

Source: preliminary results of JRC PESETA II project

A similar simulation regarding agriculture impacts has been estimated. The hypothetical case would be that only the Southern Europe region would be affected by agriculture impacts. It is then assumed that the rest of the EU does not experience any initial yield change. In that case the impact in Southern Europe could be 10 billion Euros. There would be an additional loss of 25% (2.5 billion Euros) in the rest of the EU regions, leading to an overall welfare loss estimated at 13 billion Euros (second column of Table 3).

5 Discussion

The preliminary results should be taken with care, due to the inherent uncertainties of the integrated assessment. The trajectory of GHG emissions and behaviour of the climate system are only a subset of the factors that could influence the consequences of climate change.

Additional limitations of the assessment are related to the fact that several large climate impact categories have not been considered, notably the case of all the impacts affecting ecosystems, biodiversity and human life. Abrupt climate change, including climate tipping points, has also not been considered in the analysis. It is also assumed that the rest of the world remains unchanged in spite of climate change, which is not realistic.

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Impact of Climate Change on Crop Yields with Implications for Food Security and Poverty Alleviation

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Abstract
The impact of climate changes is increasingly evident through movements of climatic variable such as temperature and precipitation. Quantification of this impact is necessary in order to better understand the economic implications these changes. Average global temperature has increased by 0.74 Celsius in the last 100 years; rainfall has trended downward during 1960–2000; and sea levels have risen between 1 to 3 millimeters per year [IPCC, 2007]. Agriculture is very sensitive to changes in the climatic variables such as temperature and precipitation as these climatic variables are direct components of the production process. This paper combines historical crop yield data on two of the major crops grown around the world - rice and maize, with the respective temperature and precipitation data from 66 countries during 1971-2002 to study the impact of changes in mean and variability of temperature and precipitation on crop yields. Using Quantile Regression, we find evidence that increases in temperature and precipitation exceeding a certain threshold can be damaging for both rice and maize yields, while increases in the variability of the climatic variables has a greater negative effect on countries with lower yields for rice.

Index Terms
Climate change, crop yields, quantile regression, impact assessment

1. Introduction

The impact of climate change is increasingly evident through movements of climatic variable such as temperature and precipitation. Quantification of this impact is necessary in order to better understand the economic implications these changes. According to the fourth assessment report of Intergovernmental Panel on Climate Change (IPCC), average global temperature has increased by 0.74 Celsius in the last 100 years; rainfall has trended downward during 1960–2000; and sea levels have risen between 1 to 3 millimeters per year [IPCC, 2007]. The report also contends that temperature and precipitation are likely to increase in most countries around the world in the next two decades.

There is evidence that crop growth and production is affected by changes in the long-term trend of the climate variables [Battisti and Naylor, 2009]. This paper provides an analysis of the effects of changes in the means and variability of temperature and precipitation on crop yields using cross-country data, where variability is computed by taking the difference from both long-run and short-run trend.

There is conflicting evidence on the possible effects of these variables on crop yields. Higher temperatures may lead to more flooding and eventually reduce crop yields; however, it may also have a favorable impact in regions with relatively cooler growing seasons or have an adverse impact in regions with already high temperature levels [Mendelsohn et al. 2007]. Precipitation affects the moisture content of soil, thus changes in precipitation can directly influence crop yields. Initial increases in precipitation allow fertilizer to mix better and increase yields; however, above a certain threshold, the absorption capacity of the soil decreases leading to an anticipated reduction in yields. Different crops have different optimal growing conditions with regards to temperature and precipitation. Movement away from these conditions may be damaging for crops, especially in countries where the current temperature and precipitation levels are already close to the tolerance limit [FAO, 2000].

This paper combines historical crop yield data on two of the major crops grown around the world, rice and maize,[1] with the respective temperature and precipitation data from 66 (Table 3) countries during 1971-2002 to study the impact of variations in temperature and precipitation. This paper finds evidence that increases in temperature and precipitation exceeding a certain threshold can be damaging for both rice and maize yields, while increases in the variability of the climatic variables has a greater negative effect on countries with lower yields for rice. The paper provides policy relevant and regional comparisons quantitative results in line with the visioning document of Impacts World. The paper also serves as a cross-disciplinary research by drawing from both economic and agricultural research.

2. Literature

The scientific community has long argued that changes in climatic variables such as temperature and precipitation significantly impact crop yields. Reilly et al. [1996] find that as temperatures move away from the favorable growing temperature of crops, the growth of the crop is adversely affected. Similarly, if variability in temperatures is high, crop yields are lower. The authors conclude that places that are too hot or are too close to the optimum temperature are likely to suffer the most.

Most agricultural economists view the relationship between temperature and crop yields as non-linear [Schlenker and Roberts, 2008]. The early papers in this discipline mostly used growth functions and incorporated weather patterns throughout the whole season instead of the average outcome usually used in simple regression techniques [Adams et al. 1995, Mearns et al. 2001]. The major

[1] From the database of FAO; Production of cereal refer to the amount of cereals produced in a given country or region each year. Cereals include wheat, barley, maize, rye, oats, millet, sorghum, rice, buckwheat, alpiste/canary seed, fonio, quinoa, triticale, wheat flour, and the cereal component of blended foods.

weakness of this literature is the assumption of homogeneity of the impact of climate change on crop yields. These studies also fail to control for the fact that climate change may affect different crops differently in different regions.

The next generation of studies uses hedonic pricing models to examine the effects changes in the climate change on crop yields; many using reduced-form linear regression models to study the impact [Mendelsohn et al. 1994, Darwin, 1999]. The hedonic models mostly does not control for critical variables such as fertilizer and irrigation which are often correlated with temperature and precipitation. As a result, the regression models used are often incorrect and provide biased estimates [Schlenker and Roberts, 2006].

This paper investigates the possible effects of changes in climatic variables on quantiles of the crop yield distribution. Thus, in this framework crop yields is a function of the climatic variables, fertilizer usage and country-specific fixed effects [Koenker, 2004] to control for unobserved district-specific, time-invariant effects (such as soil type). Quantile regression, in particular, allows the study of the effects of climate variables on agricultural production efficiency.

As can be seen from the review of the literature, there is a need for cross country analysis of the impact of changes in the climate variables on crop yields. This paper examines this relationship in a cross-country paradigm using panel data and argues that the impact of changes temperature and precipitation on crop yields across countries is not homogeneous and employs panel data analysis with country fixed effects to remedy this concern.

3. Data and Summary Statistics

The data for temperature and precipitation comes from the *Terrestrial Air Temperature and Precipitation: 1900-2006 Gridded Monthly Time Series*, Version 1.01 (Matsura and Willmott, 2007). Data on food production and agricultural land area is drawn from the database maintained by the Food and Agriculture Organization (FAO) of the United Nations.

3.1. Summary Statistics

Summary statistics of the key variables are presented in Table 1.

4. Methodology

4.1. Model

In order to investigate the impact of climate change on the agricultural crop yields, a modified version of the Mendelsohn et al. (1999) model is used;

$$lnyield_{it} = \alpha_i + \gamma_t + \beta_1 lag.g_{i,t} + \beta_2.T_{i,t} + \beta_3 T_{i,t}^2 + \beta_4.P_{i,t} + \beta_5 P_{i,t}^2 + \beta_6.F_{i,t} + \varepsilon_{it}$$

where *lnyield*$_{it}$ represents the crop yield in a given year in country *i* in year *t*, α_i represents country fixed effects and γ_t represents time fixed effects. Crop yield is expressed in log units, thus a given change in either *T* (Temperature mean/variability) or *P* (Precipitation mean/variability) will produce percent increases in crop yield, independent of the absolute levels of production. [2]

4.2. Variability

Since we are more interested in the variability of climatic variables rather than changes in the average, variability of the climatic variables along with annual deviations and the mean temperature and precipitation are used for analysis. Variability for precipitation and temperature is estimated by taking the squared difference for each annual observation, T_t or P_t for each country *i* from the mean ($\bar{P}_i$ and $\bar{T}_i$) of the centennial mean for that particular country;

For temperature: $(T_{it} - \bar{T}_i)$

For precipitation: $(P_{it} - \bar{P}_i)$

4.3. Quantile Regression

Quantile regression offers a method for inferring the conditional distribution of an outcome of interest over the entire support of its distribution. This allows us to examine the effect of covariates at different points on the distribution. If countries with lower yields are affected more by changes in climatic variables, then there is a major cause for concern. The quantile regression model can be expressed as;

$$lnyield_{it} = \alpha_i + \gamma_t + \beta_1 lag._{i,t}^{(p)} + \beta_2.T_{i,t}^{(p)} + \beta_3 T_{i,t}^{2\,(p)} + \beta_4.P_{i,t}^{(p)} + \beta_5.P_{i,t}^{(p)} + \beta_6.F_{i,t}^{(p)} + \varepsilon_{i,t}^{(p)}$$ [3]

The estimated coefficients of the explanatory variables from quantile regression also vary based on heterogeneity. However, inclusion of individual fixed effects often changes the interpretation of the coefficients of these variables. Koenker [2004] and Harding and Lamarche [2009] focused on treating the

[2] See Annex 1, Table 1 for details

[3] Where 0 < *p* < 1 indicates the proportion of crop yields below the percentile at *p*.

fixed effects in the context of a penalized estimator by separating the estimation of the fixed effects and the other covariates though an l_2-penalty[4]. Since the l_1 penalty (scalar) allows the shrinkage of the fixed effects and as a result decreases the variability in the estimation of β, this method, along with setting the penalty term equal to zero, is used in this paper.

5. Results

Apart from quantile regression, all the other regressions use heteroskedastic and correlated error structure.

5.1. Rice

When controlling for annual mean of the climatic variables, the estimation shows that the linear term of temperature is negative and significant (1 percent level) while the squared term for temperature is negative and significant at the 1 percent level. The linear term for precipitation is positive and significant at the 5 percent level, while the squared term is negative and significant at the 10 percent level.

When controlling for the variability of the climatic variables from the series mean, both temperature and precipitation variability have a positive and significant effect (5 percent level) while the squared temperature and precipitation variability have significant negative effects.

The positive and significant lagged variability coefficient of precipitation, suggesting that, at least in the short term, increased precipitation is expected to boost rice yields while the squared variability of precipitation is negative and significant at the 1 percent level.

Evidence from the agronomist literature suggests that crops such as rice and maize have the highest yields at their optimum long term condition and movement away from these conditions can be damaging to crops [Challinor et al. 2005][5]. When controlled for the variability of the climatic variables from the centennial mean, the squared measure of variability is negative and statistically significant at

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[4] L1 and L2 penalized estimation methods shrink the estimates of the regression coefficients towards zero relative to the maximum likelihood estimates. The purpose of this shrinkage is to prevent over-fit arising due to either collinearity of the covariates or high-dimensionality. Although both methods are shrinkage methods, the effects of L1 and L2 penalization are quite different in practice. Applying an L2 penalty tends to result in all small but non-zero regression coefficients, whereas applying an L1 penalty tends to result in many regression coefficients shrunk exactly to zero and a few other regression coefficients with comparatively little shrinkage [Goeman and Meijer, 2012].

[5] Agronomist literature suggests that for rice the optimum condition is between 8°C and 34°C and for maize it is between 6°C and 28°C [Schlenker, 2006].

the 1 percent level. This suggests that, as the variability crosses a certain threshold, the initial positive impact is negated.

5.2. Maize

The coefficients of variability of temperature and precipitation have the expected negative signs and are statistically significant at the 5 percent and 1 percent levels respectively. This suggests that movement away from the trend can be damaging for production of maize once temperature and precipitation cross a certain threshold.

The lagged effects are also similar to that of rice, variability being positive and statistically significant while the squared variability being negatively significant; suggesting that the effects of increased variability of temperature and precipitation are persistent for at least one year.

When controlling for variability from centennial mean, the negative coefficient on the lagged GDP suggests that during years of high growth, soil loses its fertility which has a negative effect on crop yields the following year. The coefficient for fertilizer is positive and statistically significant at the 1 percent level.

5.3. Aggregate Crop Yield

The estimation results when aggregate crop yield is used as the dependent variable are similar in direction and statistical significance. Results further suggest that while increased variability in temperature and precipitation may aid aggregate crop yields in the short run, increases in variability beyond a certain threshold are expected to have a negative impact on crop yields.

5.4. Quantile Regression Results

Quantile regression allows us to examine if some quantiles of crop yields are more affected by the explanatory variables. The value of the shrinkage parameter is an ongoing research question, thus for the purposes of this study it has been set to the simplest homogenous settings of the ratio of the scale parameters of the fixed effects and the idiosyncratic errors.

5.4.1. Rice

The results from the quantile regression on rice yields suggest that increases in temperature variability seem to have a greater effect on the countries with lower yields. While coefficients of temperature variability and the squared temperature variability are statistically significant for the 75^{th} and the 25^{th} quantile, they are not statistically significant for the median of the distribution for yield. The results also suggest that the effect of increases in precipitation variability is negative and significant for the 25th percentile but not for the 50^{th} or 75^{th} percentiles (Table 4).

Interestingly, lagged agricultural GDP growth is only negative significant for lower yield countries (τ=0.25), suggesting that countries with higher yield are also better at using technology in order to prevent soil fertility from declining.

5.4.2. Maize

The coefficients for the climatic variables show no significant differential effects between countries with high and low yields due to climate change. However, both temperature and precipitation variability are positive and significant at the 10 percent level while the squared variability terms are negative and statistically significant at the 5 percent level (Table 5).

5.4.3. Aggregate Crop Yields

The estimates from the quantile regression using aggregate crop suggest that temperature and precipitation variability are positive and significant for all the three percentiles used. Squared variability of temperature is negative but is only statistically significant for the 25^{th} percentile suggesting that as the variability of temperature crosses a certain threshold it will have a larger effect on lower yield countries compared to higher yield countries (Table 6).

6. Conclusion

The empirical estimations in this paper are consistent with both the existing literature and theory of climate change and agriculture. After controlling for changes in the climatic variables to analyze their impacts on crop yields, we find that increases in variability of both temperature and precipitation are expected to benefit crop yields up to a certain extent. However, as the variability exceeds a certain threshold which is the major cause for concern among climatologists, it is expected to have a negative impact on crop yields. As variability of temperature causes the conditions to move away from the optimum growing conditions for crops, yields are expected to fall. At the same time, as variability of precipitation increases, the optimum absorption capacity of soil is affected and this is expected to affect crop yields negatively. These results are consistent with the findings from agronomists' literature

[Battisti and Naylor, 2009]. Analysis also suggests that increasing variability of precipitation and temperature has a persistent negative effect on crop yields for at least one year.

Most importantly, results from the quantile regression for rice, the most grown crop in the world, suggest that increases in temperature and precipitation variability has greater adverse effects on lower yield countries. We find no significant differential impact of climate change on high yield and low yield land regarding yield of maize. However, there is evidence of increases in temperature variability past a certain threshold causing greater damage for lower yield countries in the case of aggregate crop yields.

Considering the results, the production of climate resilient crops should be promoted in order to minimize the loss of yields due to climate change in developing countries. It must be considered that the adverse impact on yields and subsequently food supply may lead to inflation and that a 10 percent increase in domestic food prices could push 64 million people into poverty.

The findings of the paper are policy relevant and cross-disciplinary in nature. The quantitative results are methodologically robust and provide comparisons among countries based on production efficiency. These are in line with the visioning document of the Impacts World.

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Annex 1

Table 1: Variable Definition

Variable	Definition
lnyield	Log of yield (rice, maize and aggregate)
lag.gdp	Lagged agricultural GDP growth in country *i*
T (Temperature)	Mean annual temperature in country *i*
P (Precipitation)	Mean annual precipitation in country *i*
F (Fertilizer)	Nitrogenous fertilizer consumption in country *i*
Temperature Variability	Difference from the short-run/long-run mean temperature
Precipitation Variability	Difference from the short-run/long-run mean precipitation
Squared Variability	Squared difference from the short-run/long-run mean

Table 2: Summary Statistics

Variable	*Observations*	*Mean*	*Std. Dev.*	*Min*	*Max*
Mean Temperature (°C)	2112	18.09	9.48	-4.27	146.34
Mean Precipitation (mm)	2112	88.70	148.42	0.30	577.51
Temperature Diff. from Centennial Mean	2112	4.73	8.788808	-25.39	119.39
Precipitation Diff. from Centennial Mean	2112	-98.52	169.88	-330.75	5513.16
Aggregate Yield (hectogram /hectare)	2112	27226.78	17195.55	860	89000
Rice Yield (hectogram /hectare)	1520	34105.31	17249.10	2607	93888
Maize Yield (hectogram /hectare)	1833	32506.53	28488.54	1303	203750
Fertilizer (tons)	2112	819642.20	2498275	52446	25400000
Agricultural GDP Growth (%)	2112	2.48	8.48	-43.95	78.01
Log (Aggregate Yield)	2112	9.99	0.72	6.76	11.40
Log (Rice Yield)	1520	10.29	0.59	7.87	11.45
Log (Maize Yield)	1833	10.05	0.83	7.17	12.22

Table 3: List of Countries

Algeria	Iran	Paraguay
Argentina	Ireland	Peru
Austria	Israel	Philippines
Bahrain	Japan	Poland
Barbados	Kenya	Portugal
Brazil	Latvia	Romania
Canada	Libya	Senegal
Chad	Malawi	South Africa
Chile	Malaysia	South Korea
China	Malta	Spain
Colombia	Mauritania	Sri Lanka
Costa Rica	Mauritius	Sweden
Cote D'Ivoire	Mexico	Switzerland
Cuba	Mongolia	Thailand
Denmark	Morocco	Tunisia
Ethiopia	Mozambique	Turkey
France	Nepal	UK
Germany	Netherlands	Uruguay
Greece	New Zealand	USA
Hungary	Niger	Venezuela
India	Norway	Vietnam
Indonesia	Pakistan	Zambia

Table 4: Quantile Regression Results for Rice

Quantiles	*75*	*50*	*25*
Variables	*LNRICE*	*LNRICE*	*LNRICE*
Lag Agricultural GDP	-0.00238	-0.00372	-0.00414**
	(-0.00154)	(-0.0025)	(-0.00182)
Temperature Variability	0.000008***	0.000124	0.00148***
	(-7.58E-05)	(-0.000119)	(-6.16E-05)
Precipitation Variability	3.61E-07	1.13e-06**	1.85e-06***
	(-3.78E-08)	(-4.65E-07)	(-2.56E-07)
Squared Temperature Variability	-8.78e-08***	-5.64E-09	-1.08e-07***
	(-4.46E-09)	(-8.39E-09)	(-5.55E-09)
Squared Precipitation Variability	-1.15E-14	-2.81e-13**	-2.55e-07***
	(1.04E-14)	(1.53E-14)	(8.43E-15)
Fertilizer	2.48e-08***	3.58e-08***	5.31e-08***
	(-4.24E-09)	(-7.92E-09)	(-5.54E-09)
Constant	9.82***	9.14***	8.03***
	(-0.0175)	(-0.0289)	(-0.0182)
Observations	2,046	2,046	2,046
Number of Countries	66	66	66

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Quantile Regression Results for Maize

Quantiles	75	50	25
Variables	*LNMAIZE*	*LNMAIZE*	*LNMAIZE*
Lag Agricultural GDP	-0.00414	-0.00645**	-0.00306
	(0.00261)	(0.00279)	(0.00224)
Temperature Variability	0.000820	0.00122*	0.000351
	(-0.00129)	(0.00153)	(-9.75E-04)
Precipitation Variability	1.64e-06	4.56e-07**	1.12e-05
	(6.38e-07)	(5.22e-07)	(2.62e-07)
Squared Temperature Variability	-5.38e-08	-7.81e-08*	-3.33e-08
	(9.35e-08)	(1.07e-07)	(7.16e-07)
Squared Precipitation Variability	-5.46e-14	-1.50e-14**	3.70e-13
	(2.11e-13)	(1.72e-13)	(8.62e-13)
Fertilizer	6.95e-08***	3.43e-08***	5.74e-08***
	(8.38e-09)	(9.21e-09)	(7.30e-09)
Constant	10.48***	9.891***	9.709***
	(0.0335)	(0.0306)	(0.0209)
Observations	1,798	1,798	1,798
Number of Countries	56	56	56

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Quantile Regression Results for Aggregate Crop Yield

Quantiles	75	50	25
Variables	*LNAGGREGATE*	*LNAGGREGATE*	*LNAGGREGATE*
Lag Agricultural GDP	-0.0121***	-0.0101***	-0.00517**
	(0.00202)	(0.00251)	(0.00215)
Temperature Variability	0.000850***	0.000264**	0.000833***
	(0.000102)	(0.000128)	(8.16e-05)
Precipitation Variability	1.30e-06*	1.94e-06***	1.81e-05***
	(6.67e-07)	(5.12e-07)	(2.54e-07)
Squared Temperature Variability	-5.63e-08	-1.32e-08	-6.53e-08***
	(7.45e-08)	(9.01e-09)	(5.98e-09)
Squared Precipitation Variability	-4.28e-14	-6.43e-14	-5.95e-13
	(2.19e-13)	(1.68e-13)	(8.35e-13)
Fertilizer	3.21e-08***	3.82e-08***	6.19e-08***
	(6.74e-09)	(8.57e-09)	(7.86e-09)
Constant	10.48***	10.06***	9.945***
	(0.0283)	(0.0277)	(0.0188)
Observations	2,046	2,046	2,046
Pseudo R^2	0.0336	0.0373	0.1288
Number of Countries	66	66	66

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Pastoral strategies for reducing social conflict regarding water resources in climate change context in Benin, West Africa.

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Abstract— Animal production plays a crucial role in the economy of West African countries. However, in the context of climate change, the scarcity of water resources due to drought and high spatio-temporal variability of precipitations, influences considerably pastoral activities. This has driven conflicts among herders in most arid and semi-arid areas especially in the Fourth Transhumance Corridor of ECOWAS. The study investigates the adaptation strategies of herders to spatio-temporal variability of water resources in Benin. This view will propose through multi-agents simulations, a better adaptation strategy for decision making about environment conservation policies and reducing the vulnerability of actors and productions. The data were collected with 30 flocks' keepers in northern Benin. Results reveal that three categories of herders utilize natural resources in divergent manner based on their perception, their programmed and moved distance, the abundance and the condition of the water resources. An increasing transhumant way permits to balance the number of the used water resources during pastoral season and reduces the number of conflicts among actors varying from 165 in normal season to 120 in disturbed season. The findings suggest an actor-oriented policy and local resources planning to control the movement of herbivorous livestock in open range and also enhance adaptation to climate change within the context of indigenous animal system in West Africa.

Index Terms— Climate change, Water resources, Pastoralism, ECOWAS transhumance corridor in Benin, Adaptation

1 Introduction

Stretched between the Gulf of Benin and the valley of Niger (6°17 to 12°04 North latitude), Benin Republic integrates an abrupt climatically induced rain forest fragmentation known as Dahomey gap, a forest relic characterized by a decline in annual precipitation, a reduction of sea and air surface temperatures causing climate anomaly (Bokonon-Ganta, 1987; Hayward and Oguntoyinbo, 1987; Salzmann and Hoelzmann, 2005). The country is influenced by climate change since 1970 with strong spatio-temporal rainfall variability. The consequences are soils degradation, desertification, deterioration of grasslands and water resources (Parry et al. 2007). The worrisome aspect is glaring with respect to water resources which are life-blood of the economies of West African countries (Kunstmann and Junge, 2005). Crop production and animal husbandry, the main economic activities have a hard coexistence due to an intense competition making the interactions and exchanges more difficult among actors (De Haan et al. 1990; McCarthy et al. 2001; Morton, 2006). In northern Benin, which receives each year a numerous foreign livestock from bordering countries like Niger, Burkina Faso and Nigeria, several bloody conflicts have been recorded not only between the two groups, but within each group. This paper outlines how the socio-technical knowledge used by herders to gain access to water resources is at the same time a factor that reduces the recurring clashes between them.

2 Theoretical and methodological frameworks

Our socio-anthropological research referred to action theories to provide conceptual and methodological frameworks to understand actors' logic and mechanisms in coping with climate change. Fieldworks were conducted in Alibori (north Benin), which has 692,210 out of 2,058,000 of the national bovine herd (FAO, 2013)[1]. It is also the preferred area for foreign herders from Burkina Faso, Niger and Nigeria. Data were supplied through semi-structured interviews and focus group by thirty herders partially followed along the fourth animal route of the Economic Community of West-African States (ECOWAS). The sample included five large scale herds *(≥100)*, fourteen medium scale herds *(20≤ Herd< 100)* and eleven small scale herds *(1≤ Herd < 20)*. Through CORMAS[2] and StarUML[3], a *SimWater* model was built and two scenarios were compared in relation to the access to water in normal (NCS) and abnormal (VCS) seasons during 210 days of mobility. Herds move by daily time according to water scarcity and the strategy of the shepherds. Conflicts appear in the model when two or more herds share the same restricted water resource.

3 Results

3.1 Actors and resources

3.1.1 Different Herders with specific water resources

The endogenous typology made with actors reveals that herders make a difference among them and between the water resources they use to feed animals (table1). Three classes of herders exploit three types of watering sources: "Dianpoui" available all the seasons; "Dianseeda" whose half of the number disappears after two abnormal dry months and "Dianpete" which completely dry up after an additional month of normal dry season.

[1] CountrySTAT is a web-based information technology system developed by the FAO, http://www.countrystat.org
[22] CORMAS is the Common Resources Management Agent-based System developed by CIRAD http://cormas.cirad.fr/fr/outil/outil.htm
[3] StarUML is an Open Source UML/MDA Platform, http://staruml.sourceforge.net/en

Table1. Actors and resources Characteristics

Categories	Herd size & *Fulbe* names		Water size & *Fulbe* name	
Abundance sources	Herd ≥100	Large Scale Herder (LSH) *"Owoodinaï"*	Permanent rivers, large dams	Big Water Sources (Dpo) *"Dianpoui"*
Moderate sources	20≤ Herd< 100	Medium Scale Herder (MSH) *"Owoodiseeda"*	Seasonal rivers, back-water, shadows, cas-cade, water collectors	Medium Water Sources (Dse) *"Dianseeda"*
Limited sources	1≤ Herd < 20	Small Scale Herder (SSH) *"Owooda"*	Pastoral Tanks, arte-sian wells, creeks, overdigs	Small Water Sources (Dpe) *"Dianpete"*

Source : Djohy, 2010 & 2012

3.1.2 Decision process for watering cattle herds

The main factor of water resource choice varies according to the herders (Fig.1a). LSH are influenced by the natural abundant rangeland; MSH are affected by the possibility of crop residues and supplementa-tion (Fig.1b) and SSH are affected by the access to livestock market (Fig.1c).

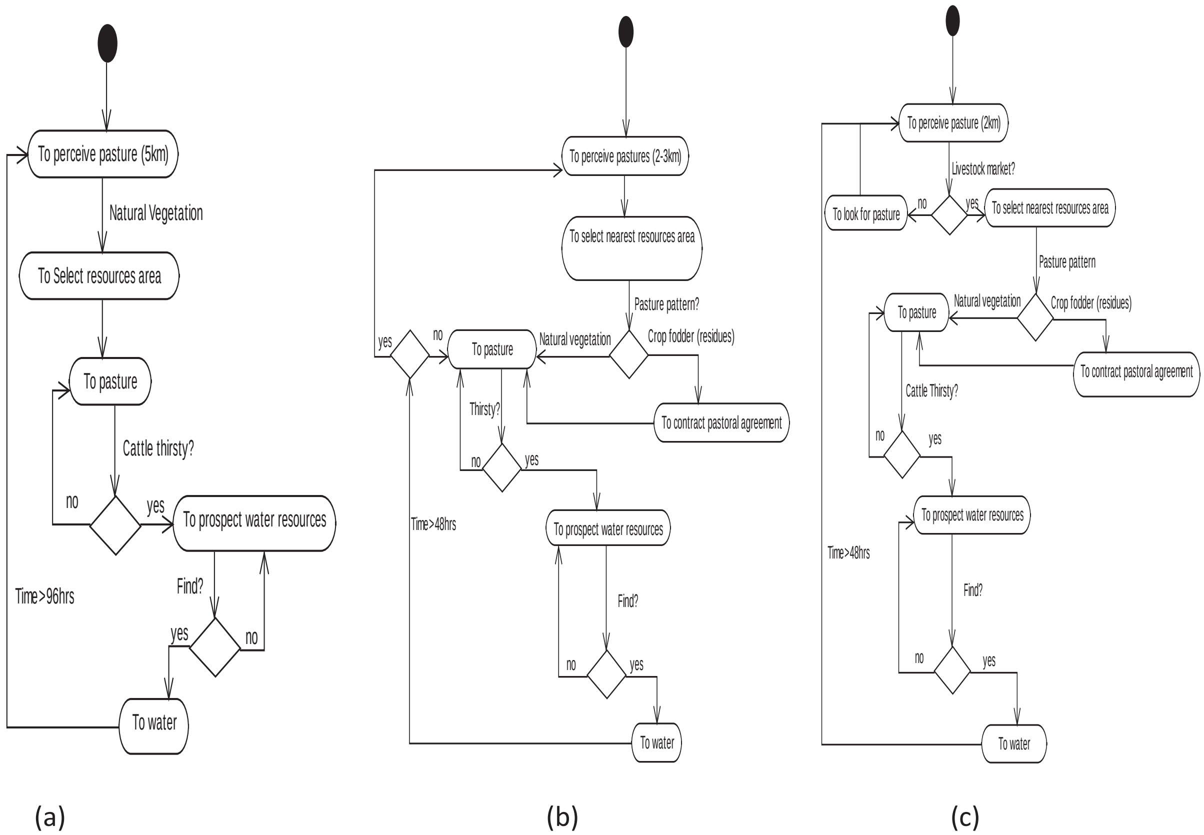


Fig.1. Herders' decision process for water resources access

3.2 Water resources access and intra-professional conflicts

Three strategies were developed according to each type of herders (Table2).

3.2.1 Large Scale Herders' watering strategy

Owoodinaï herders' movements are based on observation and assumption of water availability and access to it. This group of herders has the capability to treck long distances by choice. One LSH could observe and move up to 5 kilometers (km), select abundant grazing area and water points sufficient to cover the needs of his big flock. When the LSH realise their animals' watering need they will first look for an abundant water source. They operate a dual mode of choice depending of resources availability. Between the three categories of water points, they prefer the big and the medium water points respectively. Once they find such water points, they water animals and then continue in search of new grazing area. When resources are abundant in one area, they stay for a maximum of four days to prevent probable risks related to long stay. No matter the appetency level of the animals toward some type of fodder, the lack of water reduces their grazing duration. Thus they undertake transhumance over long distances along route N°4 and follow some secondary pathways in the forests or particular zones.

3.2.2 Medium Scale Herders' watering strategy

The MSH strategy is a combination of natural spaces and farm harvest residues *(rice and other cereals, groundnut and garden residues)* for optimal satisfaction of the herds. All guidance system of the animals toward fodder and water resources are in a dialectics of timely returning back to their semi-permanent residential huts in their communities to watch over the family and get ready for the upcoming farming season. Therefore, a typical MSH does not move beyond 2km and selects the nearest pasture and water points. In case of natural pasture, animals are left to graze adequately to meet their needs and he determines their water need by their behavior and decides to let them continue grazing or not. He stays for a maximum of three days in the same zone, for animal grazing and watering. If the rangeland is artificial (harvest residues), he contracts with farmers by paying them money (pecuniary contract) or temporary stationery so that the animals can feed on crop land (manure contract) and alternatively waters the flock.

3.2.3 Small Scale Herders' watering strategy

A key coping strategy of the SSH is to explore the possibility of combining the sale of cattle with search for pasture and water during the transhumance journeys. Many herders in this category have few herds due to the effects of successive epizooties, climatic crises and unfavourable inheritance conditions. They restrict their movement to less than 2km for grazing areas close to livestock markets. If the nearest pasture is close to a zone of harvest, he engages in a contract of pasture choosing some cattle not necessarily for selling, but especially as mediator for the merchandising of livestock. They could dig some water points for their cattle. When a SSH finds a livestock market, he will enter into a contract with farmers, leave the flock and go to the market. He stays for a day and then continues to prospect for resources and market opportunities.

Table2. Herdes' watering strategies

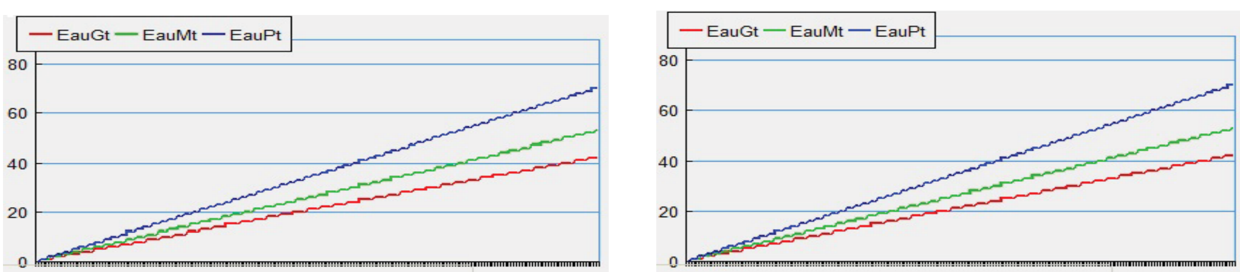
Herders	***LSH***	***MSH***	***SSH***
Strategy	Extensive	Semi-extensive	Market oriented
Move factors	Natural abundant resources position	Harvest pasturing resources position	Proximate Livestock Market position
Searching radius	5km	2-3km	2km
Stay duration	Four days	Three days	One day
Preferred resources	Dpo+Dse+Dpe=Dpo	Water resources (Dpo,	Water resources (Dpo,

	Dpo+Dse=Dpo Dpo+Dpe=Dpo Dse+Dpe=Dse Dpo=Dpo Dse=Dse Dpe=Dpe	Dse or Dpe) near harvest residues	Dse or Dpe) near livestock market

Source : Djohy, 2012

3.2.4 Maintening of watering sources from normal to changed season

To satisfy their herd's need for water under NCS, the LSH went through 42 watering sources during the entire pastoral season, while the MSH and SSH visited 53 and 70 sources respectively. These numbers remained fairly the same under VCS (Figure 2a and b). The number of browsed water points is not very different in the two scenarios, in spite of the growth of the distance in dry season. This can be explained by the fact that in terminal areas, the herders overdig some dried water points and stay much longer than they would normally have. The SSH undertake livestock trade in Gogounou district which is known as the biggest livestock market in Alibori Department. The LSH would either stabilize in the valleys of permanent rivers or deviate from the formal route N°4 of ECOWAS. It can be concluded that the increase on distance travelled is not proportional to an increase in the observed watering sources.

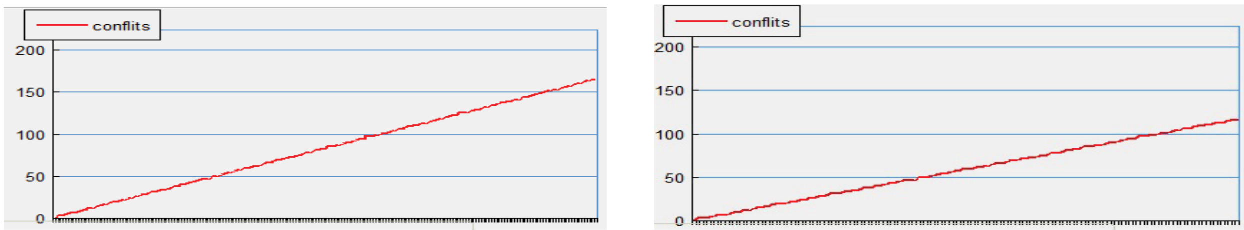


(a) (b)

Fig. 2: Number of water points under NCS (a) and VCS (b)

3.2.5 Reducing of conflict prevalence around water resources

Herders' strategies bring down the number of intra-professional conflicts (herders against herders) during the transhumance in changing season. Under the two scenarios, the curves of conflicts for 210 days of migration reveal that the increase in the number of conflicts is a function of the number of day of transhumance, but keeping in the moved water resources permit to decrease from 165 in NCS to 120 in VCS (Fig. 3, a and b).



(a) (b)

Fig. 3: Number of conflict under NCS (a) and VCS (b)

4 Discussions

Pastoralism in indigenous communities is important to properly achieve the Millennium Development Goals of the United Nations in 2015 (Cordone et al. 2009). If water is a great challenge for extensive animal production systems (Abdullaev et al. 2009; Martius et al. 2009, Winckler et al. 2012), pastoralists have to look at the future and execute a good adaptation strategy. The presence of animals in grassland around villages permits them to put up with the available resources to limit or to avoid the risk on the next kilometers during their mobility. However, it is for a relatively short period because herders for reason of distrust think indispensable not to get used to a territory to undergo other tragedies such as the flight of livestock, the poisoning of the livestock or any other teasings. The carefull management of the staying days is the technical measure for countering the crisis of trust between farmers and them. The existence of livestock markets along the route is an important factor for small scale herders' adaptation to water resources access. Regarding the precarious conditions of SSH, this new form of access to the market as "Intermediate seller" or "Intermediate purchaser" is an endogenous adaptation measure by pastoralists in the context of climate scarcity along route N°4.

5 Conclusion

Through this study we understand that the ways of thinking and acting by migratory animal herders are premised on a "make-or-break" or "do-or-die" logic. They mobilise all strategies to develop their activities and save their herds which eventually will be bequeathed to their children. Government support to pastorialists would reinforce the significance of animal husbandry in national economies. Therefore, improvement in natural resources and the enhancement of the infrastructure in animal markets must be a given priority.

6 Ackownlegment

The authors wish to thank the Institut of Resource Assessment (IRA) of the University of Dar Es Salam/Tanzania. This work was supported by a grant from African Climate Change Fellowship Program (ACCFP), and carried out in partnership between Nigerian Institute of Social and Economic Research (NISER) and the Faculty of Agronomy of the University of Parakou (FA-UP)/Benin.

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Assessing the economic impacts of climate change: an updated CGE point of view

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May 2013

Abstract:

The present research describes a climate change integrated impact assessment exercise, whose final economic evaluation is based on a Computable General Equilibrium (CGE) approach and modeling effort. Estimates indicate that a temperature increase of 1.92°C compared to pre-industrial levels in 2050 (consistent with the A1b IPCC SRES scenario) could lead to global GDP losses of approximately 0.5% compared to a hypothetical scenario where no climate change is assumed to occur. Northern Europe is expected to slightly benefit (+0.18%), while Southern and Eastern Europe are expected to suffer from the climate change scenario under analysis (-0.15% and -0.21% respectively). Most vulnerable countries are outside Europe and namely the less developed regions, such as South Asia, South-East Asia, North Africa and Sub-Saharan Africa.

Keywords: Computable General Equilibrium Modeling, Impact Assessment, Climate Change Economics

JEL CODE: C68, Q51, Q54,

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1. Introduction

A key challenge today's policy makers are facing concerns the reduction of greenhouse gases emissions, representing the major cause of climate change. The ultimate objective of the United Nations Framework Convention on Climate Change (the 1992 established UNFCCC) (Article 2) is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". This key-principle has been enhanced under the Kyoto Protocol (KP), which establishes emissions reduction targets by 2012 for most advanced countries in the world. However, a common perception is that much greater reductions are needed beyond those established by the KP to achieve the UNFCCC objective. Consistent with this, there has been significant discussion of Post-2012 action, the last during COP 17 in Doha last December 2012. If emissions continue to grow as during the last century, the consequences on the ecologic and human systems could be daunting. That also may provoke huge economic costs. This is the main reason that underlines the search for economic efficient climate policies. More precisely, policy makers should base the choice of environmental regulations on analyses allowing reliable and robust comparisons of the costs and the benefits of each given policy.

In this context, the assessment of the economic costs of climate change effects, often known as the '*Costs of Inaction*', is becoming more and more influent in the policy debate and represents the starting point to design effective and efficient strategies (both in terms of adaptation and mitigation).

A pioneering study which tried to assess the welfare impacts of climate change was developed by Nordhaus (1991), which estimated the cost of climate change for the U.S. and extended those estimates to the world. From then on, many studies have performed assessment of the global economic costs of climate change in their many aspects (for instance, Fankhauser 1995; Hope 2006; Maddison 2003; Mendelsohn et al. 2000; Nordhaus 1994, 2006; Nordhaus and Boyer 2000; Nordhaus and Yang 1996; Rehdanz and Maddison 2005; Tol 1995, 2002).

Each of these starts by some reduced form carbon cycle models linking emissions, future concentrations of greenhouse gases in the atmosphere and different levels of global average temperature change. These on their turn feed-back on the economic activity through reduced-form damage functions where each degree of temperature increase translates in a given GDP loss. Calibration of these functions derive from experts opinion and/or from aggregation of impact studies such as those related to sea-level rise, changes in the frequency and intensity of floods, changes in crops' productivity etc. and their economic consequences. If the broad methodological approach is similar across studies, these then vary on assumptions on the geographical and spatial scale, on the underlying economic context, the extent of feasible adaptation to climate change, the number of impacts considered, their nature – e.g. market or non-market, catastrophic non catastrophic -, inter-generational and intra-generational equity criteria and other crucial aspects.

Some rough comparisons of results are however possible. Tol (2010) reports main outcomes from recent research: GDP is expected to change in response to climate change from -0.4 percent (Rehdanz and Maddison 2005) to +2.3 percent (Tol 2002) for a 1 °C warming. Under a level of warming equal to 2.5 °C, the estimates of GDP change vary between -1.5 percent (Nordhaus and Boyer 2000) and +0.9 percent (Hope 2006).

2. Modeling the impacts of climate change: a CGE approach

In this background, this study aims to make an update assessment of the economic consequence of climate change in the first half of the century deriving from a wide set of climate change impacts. The reference climatic scenario is the A1b IPCC SRES scenario, implying a 1.92 °C increase in 2050 compared to the pre-industrial level.[1]

The initial inputs for the exercise are the results of a set of bottom-up partial-equilibrium impact assessments. These allow to physically quantifying climate change consequences on sea-level rise, energy demand, agricultural productivity, tourism flows, net primary productivity of forests, floods and health (in terms of reduced work capacity due to thermal discomfort).[2]

The innovative feature of the work is the application for the final economic assessment of a top-down recursive-dynamic CGE model, ICES (Inter-temporal General Equilibrium System).[3]

The appeal of such tools, with respect to other methodologies, is the explicit modeling of market interactions between sectors and regions that reduced form damage equations cannot capture.[4]

[1] 1.92 °C warming by 2050 with respect to pre-industrial temperature is the average coming from the use of 12 Global Circulation Models within the ClimateCost project (http://www.climatecost.cc/). Estimates of different impacts and the general equilibrium economic assessment share consistent assumptions with such an estimate on average global warming.
[2] The last two impacts – floods and health – only cover European Union.
[3] ICES is a recursive-dynamic model improving upon the static structure of the GTAP-E model (Burniaux and Troung 2002). The calibration year is 2001, data come from the GTAP6 database (Dimaranan 2006) and the simulation time is 2001-2050. For details please refer to Eboli et al. 2010 and http://www.feem-web.it/ices/
[4] In fact, CGE models are increasingly used to assess costs and benefits associated with climate change impacts (for a partial list, see e.g. Deke et al. 2002, Darwin and Tol 2001, Bosello et al. 2007, on sea-level rise; Bosello et al. 2006, on health; Darwin 1999, Ronneberger et al. 2009, on agriculture; Berrittella et al. 2007, Calzadilla et al. 2008, on water scarcity; Aaheim and Wey 2009, on sea-level rise, agriculture, health, energy demand, tourism, forestry, fisheries, extreme events, energy supply; Eboli et al. 2010, on agriculture, energy demand, health, sea-level rise, tourism; Ciscar et al. 2011, on sea-level rise, agriculture, tourism, river floods; Roson and van der Mensbrugghe, 2012, on agriculture, sea level rise, water availability, tourism, energy demand, human health and labour productivity).

Inter-industry and international trade flows are indeed explicitly modeled and react to any price change, be it policy driven or scarcity induced by climatic impacts. In other words, not only direct costs but also higher-order effects can be determined. It is therefore interesting to compare how the insights driven by this approach differ or are similar to reduced form results.

3. The economic impacts of climate change and the role of market-driven adaptation

Once the abovementioned impacts, appropriately translated into changes in key model variables, are imputed to ICES, global GDP losses amount to the 0.5% compared to a hypothetical scenario where no climate change is assumed to occur (Fig. 1).

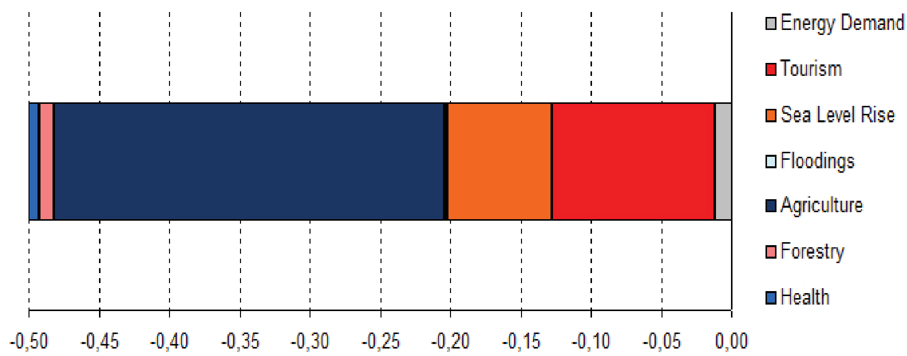

Fig. 1. Real world GDP: % change w.r.t. no climate change (ref. +1.92°C in 2050)

This result is roughly placed in the average range of benchmark studies. As a main relevant feature of the modeling framework used, it does consider market driven adaptation to climate change which partly reduces the direct impacts of temperature increases. However, it does not cover non-market impacts, such as those associated to ecosystem losses, nor catastrophic events. This implies, on the one hand, that climate change costs can reasonably expected to be higher, even when lying below the 2° C of temperature increase, recognized from many parts as the target to not go beyond as irreversible effects may occur (EU Commission, 2010; UNFCCC, 2013); on the other hand, that the working of market forces is not sufficient alone to eliminate the need for proactive mitigation and adaptation policies.

Turning to more specific results, global GDP loss is mainly driven by decreases in crop productivity, followed by the redistribution of tourism flows and land loss to sea-level rise.[5] Agriculture impacts strongly affect low-latitude regions, even at relatively low temperature increases because of their greater physical vulnerability and of the higher importance of this sector in their economy. Impacts on tourism sector determine the second highest losses, in addition to strong distributional effects. Tourism flows will be gradually re-directed away from warmer regions, becoming increasingly too hot, towards more moderate, high-latitude regions. Agriculture and infrastructures are adversely affected by sea-level rise, which due to the related land and capital induced losses, is the third major driver of economic impacts at the world level. Other impacts (on energy demand, forest primary productivity, river floods and on-the-job performance) are generally of lower importance.

Regional differences are also interesting. In the EU as a whole (Fig. 2), the overall effect on Gross Domestic Product is slightly positive (+0.01%). Gains in Northern Europe (NEUR) (+0.18%) slightly overcompensate losses in the Mediterranean (MEUR) (-0.15%) and Eastern Europe (EEUR) (-0.21%). NEUR mainly benefits from positive impacts on crop productivity and an increase in its tourism attractiveness. MEUR experiences major adverse effects from decreases in labor productivity from worsened "on the job" performance, and increases in energy demand due to the prevalence of a cooling effect. The latter exerts its negative impacts on the trade balance in a region already heavily dependent on international energy imports. Note also the positive GDP effects of impacts on agriculture and tourism. In the EEUR, adverse consequences are mostly due to a decrease in crop productivity and flooding.

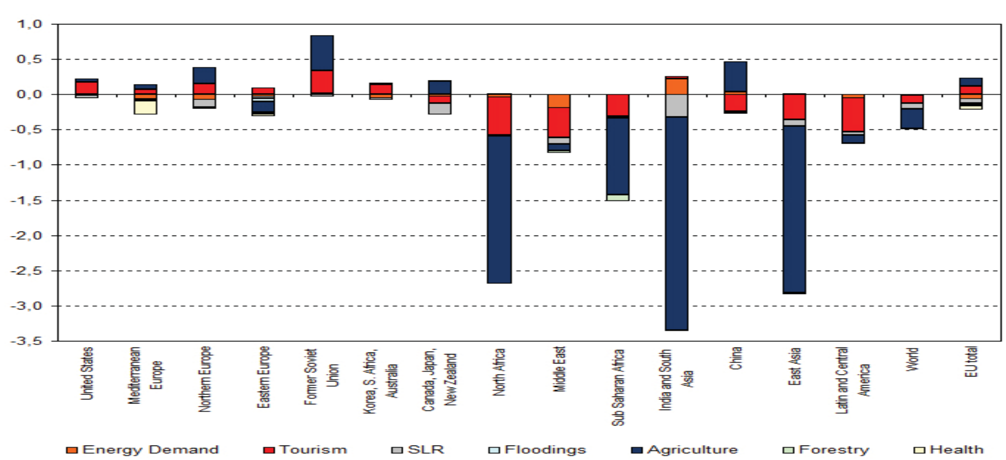

Fig. 2. Macro regional % of real world GDP change detailed by impacts with respect to no climate change (ref. +1.92°C in 2050)

[5] This is overall consistent with the recent work by Roson and van der Mensbrugghe (2012); the main differences are that they isolate agricultural productivity and water availability to explain impact on agricultural yield and consider also impact on human health induced by changes in mortality and morbidity (not available within ClimateCost).

Looking outside EU, in USA and China climate change net effect on GDP is positive. In the former the tourism effect dominates, while in the latter the major driver is the increase in crops' productivity. The research also confirms the higher vulnerability of least developed regions. The drivers of negative GDP performance (ranging from -1.5% in Sub Saharan Africa (SSA) to -3.1% in South Asia (SASIA)) are clearly the adverse impacts on crops' productivity, even enhanced by lower tourism attractiveness and land loss to sea-level rise. Both factors play a detectable role in North Africa (NAF) and SASIA, respectively. It is interesting to note that the initial impact on developing countries' agricultural sector is in magnitude comparable or smaller than that affecting Mediterranean Europe. The implications are much more negative though. This is the result of the higher dependence of developing economies on agriculture and of their lower possibility to substitute land stock with capital stock.

To conclude, it is interesting to emphasize the difference between direct impacts and final consequences on GDP. Fig. 3 provides an example for the case of sea-level rise. Generally, but not always, direct effects are larger than final effects. In fact, market-driven adaptation, primarily the possibility to substitute a scarcer production factor or consumption item with a cheaper one, provides a partial buffer against initial negative shocks. However, this general mechanism is more evident when primary factors of productions are concerned (see land losses to sea-level rise or decrease in land productivity).[6] It is more ambiguous when demand re-composition effects are involved. In the latter case, substitution mechanisms are less clear and it may well happen that a decrease in demand in a sector drives negative impacts in other related sectors with a multiplicative effect that a direct costing approach cannot capture. This is, for instance, the case of the decreasing tourism demand in China, Middle East, and Sub Saharan Africa and of the increasing one in the USA, Eastern Europe, Korea and South Africa.

[6] An additional motivation of the prevalence of direct costs on GDP costs when primary factor of production are affected, is that GDP itself is a flow measure. Therefore, large stock losses, like for instance those on land, not to mention those on labour, are only marginally reflected by the ability of a country to produce flows of goods and services, which is GDP.

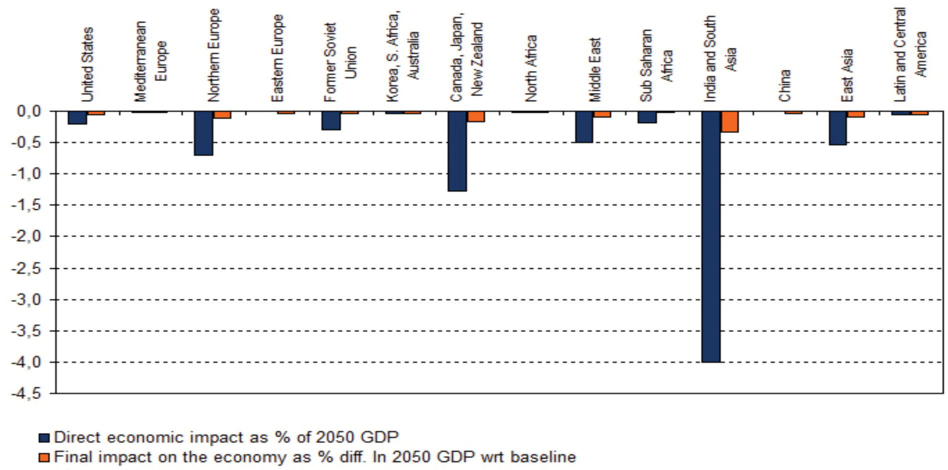

Fig. 3. Direct vs Indirect impacts in 2050: Sea-Level Rise

4. Conclusions

The present research describes a climate change integrated impact assessment exercise, of which economic evaluation is based on a CGE approach and modeling effort.

The impact assessment is partial because it only focuses on some of the market impacts, and only on 1.92 °C temperature increase. Still it represents a first step toward the development of a methodology that integrates impact assessments based on CGEs and policy analysis based on Integrated Assessment Models. Moreover, it makes use of the most recent available information.

It is worth noting that the general equilibrium estimates tend to be lower, in absolute terms, than the bottom-up, partial equilibrium estimates. The difference is to be attributed to the effect of market-driven adaptation. Markets react to climate change impacts with changes in commodity and primary factor prices that allow for adjustments in consumption and production. This induced adaptation partly reduces the direct impacts of temperature increases, leading to lower estimates. However, this general mechanism is more evident when primary factors of productions are concerned (see land losses to sea-level rise or decrease in land productivity). It is more ambiguous when demand re-composition effects are involved. In this last case substitution mechanism are less clear and it well may happen that a decrease in demand in a sector drives negative impacts in other related sectors with a multiplicative effect that a direct costing approach cannot capture.

The final message we would like to convey is that, albeit its impact smoothing potential, market-driven adaptation cannot be the solution to the climate change problem: its distributional and scale consequences need to be addressed with proactive policy-driven mitigation and adaptation strategies.

Acknowledgments

This work is part of the scientific output of the CLIMATECOST FP7 research project (Project Reference: 212774) and hereby we gratefully acknowledge EC financial support and the scientific support of CLIMATECOST research partners, which provided key scientific inputs. The authors are solely responsible for the opinions and potential mistakes expressed in this paper.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Adaptation to Climate Change: A Case Study of Rural Farming Households in Ekiti State, Nigeria.

A.I. Fatuase, A.I. Ajibefun

Abstract— Climate change is expected to have serious environmental, economic and social impacts on Nigeria, particularly on rural farmers whose livelihoods depend largely on rainfall. This study therefore investigated the factors responsible for the choices of adaptation employed by crop farming households in the study area. The study examined the adaptation choices of respondents from the two agro-ecological zones in Ekiti State. Data were collected and analyzed from a total of 40 respondents from each agro-ecological zone. Descriptive statistics and multinomial logit regression analysis were used to analyse the collected data. The study examined how farmer's perceptions correspond with climate data recorded at meteorological stations of Ekiti State. The statistical analysis of the climate data revealed that temperature and rainfall were increasing. The perceptions of farmers on temperature were in line with recorded climate data but contrary with that of rainfall which were perceived to be decreasing by the farmers. The respondents identified inadequate funds and climate information as the major serious constraints to adaptation. The study therefore concluded that educational level, farming experience, access to extension services, access to climate information and access to credit were major factors statistically affecting choice of climate adaptation measures using multinomial logit regression. Government policies and investment strategies must focus on how to intensify awareness on climate change and access to credit in order to rescue the poor rural farming households from the danger of climate change in the study area.

Key words: adaptation, climate change, multinomial logit, perception

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1 Introduction

Climate is the primary determinant of agricultural productivity. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). Fussel (2007) argues that emphasis should focus on adaptation because human activities have already affected climate, climate change continues given past trends, and the effect of emission reductions will take several decades before showing results, and adaptation can be undertaken at the local or national level as it depends less on the actions of others. Therefore, to increase management efficiency of natural resources, the perceptions of the people directly involved need to be taken along with those of experts (Kamau, 2010). Again, failure to address the issue of climate change may lead to a situation where Nigeria and other West Africa countries incur agricultural losses of up to 4% of GDP due to climate change (Mendelsohn *et al.,* 2005). Parts of the country that experienced soil erosion and operate rain-fed agriculture could have declined in agricultural yield of up to 50% within 2000-2020 due to increasing impact of climate change (IPCC, 2007). Considering the above, it is pertinent to examine farmers' perception about climate change, identify major constraints to adopt adaptation measures and determine factors influencing choice of adaptation measures among rural farming households in Ekiti State, Nigeria.

2. **Research Methodology**

2.1 Methods

The study was carried out in Ekiti State, Nigeria. Both primary and secondary data were used for this study. A multi-stage sampling technique was used for the random selection of respondents. It started by purposively selecting one Local Government Area (LGA) from each agro-ecological zone for the study which are Ise-orun and Oye LGAs in the tropical forest and guinea savanna zones respectively based on their contribution to the overall production of agricultural production in the State. Four (4) communities were randomly selected from each LGA while ten (10) respondents were randomly selected in each community. Therefore, a total of eighty (80) farming households were randomly selected for the study. The data collected were analyzed using descriptive statistics and multinomial logit regression model (MNL)

2.2.1 Multinomial Logit Regression Analysis

The standard form of the logit model is

$\text{Log}\,[P/(1-P)] = \alpha_0 + \sum \alpha_i X_i + \varepsilon$ ……………………………(1)

Where P = probability that the dependent variable Y=1;

(1-P) is the probability that Y= 0

α_s are parameter estimates for the independent variable, X

And ε is the unexplained random component.

X is a vector of socioeconomic characteristics which are Farming experience (years), Household size (numbers), Access to climate information (dummy: yes=1 and 0 otherwise), Farm size (hectares), Access to climate change information (dummy: yes=1 and 0 otherwise), Access to credit (dummy: yes=1 and 0 otherwise), Access to extension services (dummy: yes=1 and 0 otherwise), Level of education of household head (years).

Marginal effects of the explanatory variables from the above equation are given as:

$$\frac{\partial P_j}{\partial X_k} = P_j \left(\beta_{jk} - \sum_{J=1}^{J-1} P_j \beta_{jk} \right) \text{ .... (2)}$$

The marginal effects are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable from the mean.

3. Results and Discussion

3.1 Consistencies and Contradictions in Climate Perceptions and Meteorological Records

3.1.1 Perceptions about Temperature Changes

Over 95 percent of the respondents interviewed perceived long-term changes in temperature. Most of them (93.7% or 75 farmers) perceived temperature to be increasing. It was only 2.5 percent of the respondents that noticed a decrease in temperature while 2.5 percent also noticed that temperature has stayed the same over the years. Only one respondent (1.3%) does not know whether temperature is changing or not as shown in Table 1 below.

Table 1: Perceptions of farming households on changes in temperature over the years.

Temperature	**Frequency**	**Percent**
Increase	75	93.7
Decrease	2	2.5
No change	2	2.5
Do not know	1	1.3
Total	80	100.0

Source: Computed from Field survey, 2011.

The climate data recorded at meteorological stations on annual mean temperature of Ekiti between 1975 and 2007 was statistically analyzed to depict its trend over the years. The result showed an increasing trend as indicated in Figure 1. In 32 years, the temperature had risen around 0.5 degree Celsius with an average of 26.0^{0}C in the study area. Therefore, it appears that farmers' perceptions are in accordance with the statistical record in the study area.

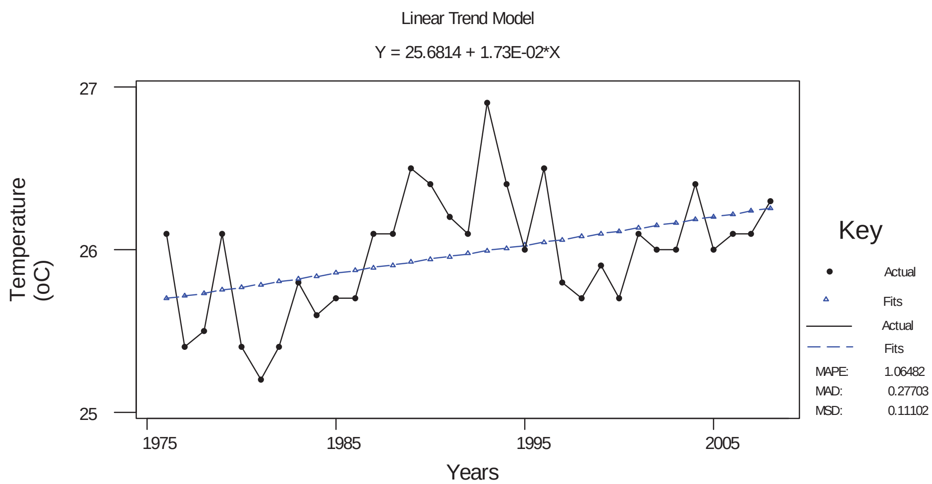


Figure 1: Trend Analysis for Annual Mean Temperature data for the study area: 1975 – 2007.

Source: Computed by author

3.1.2 Perceptions about Change in Rainfall

About 98 percent of the respondents observed changes in rainfall patterns over the years. 70 percent (56 respondents) noticed a decrease in the amount of rainfall (a shorter rainy season) over the years. In contrary, 27.4 percent observed increase while 1.3 percent said that amount of rainfall had stayed the same over the past 20 years as all indicated in Table 2 below.

Table 2: Perceptions of farming households on changes in rainfall pattern over the years.

Rainfall	Frequency	Percent
Increase	22	27.4
Decrease	57	71.3
No change	1	1.3
Do not know	-	-
Total	80	100.0

Source: Computed from Field survey, 2011.

The statistical record of rainfall data from Ekiti between 1975 and 2007 showed an increase trend over the years (Figure 2). In 32 years, amount of rainfall has been increasing by 0.312 cm per year (average of 120.6mm/year). The result from meteorological station analysis on rainfall was contrary to the view of farmers on perceptions on rainfall in the study area. A large proportion of farmers noticed a decrease in rainfall which was contrary to the outcome of meteorological trend analysis on rainfall and this could be explained by the fact that during the last few years most especially last and present years, there was a substantial decrease in the amount of rainfall. Thus, farmers' perceptions of a reduction in rainfall over the years could be explained by the fact that most of the farmers placed more weight on recent information than its efficient as also noticed by Maddison (2006) and Gbetibouo (2009).

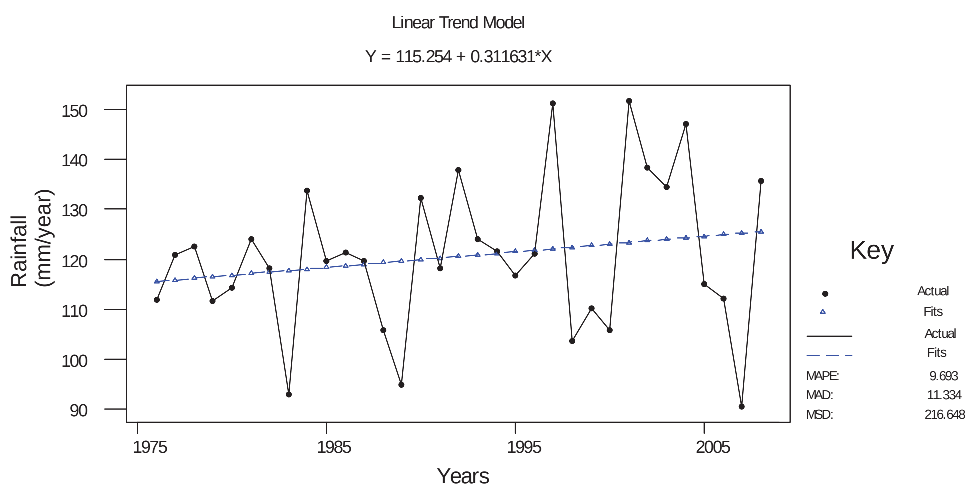


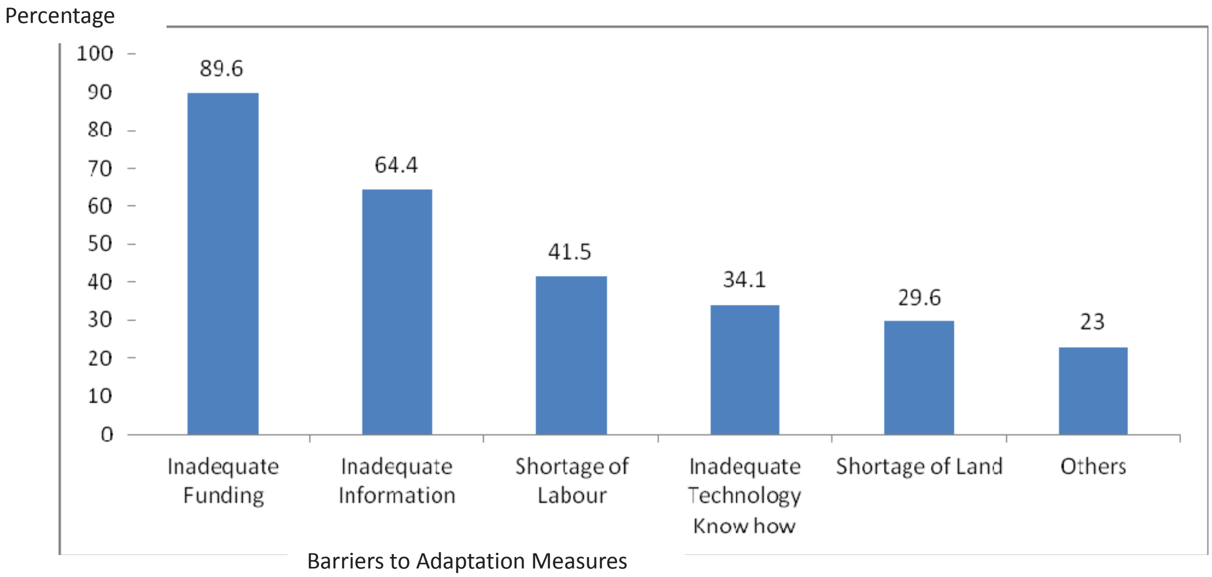
Figure 2: Trend Analysis for Rainfall Data in the Study Area: 1975 – 2007

Source: Computed by author

The issue of rainfall patterns analyzed above was in contrary with several studies but that of temperature has been in accordance with several studies carried out on perceptions of and adaptation to climate change most especially in Sub–Saharan Africa. Ishaya and Abaja (2008), Deressa *et al*. (2009), Gbetibouo (2009), Benedicta *et al*. (2010) among others have observed increased in temperature and a decrease in the amount of rainfall over the years.

3.2 Identifying Major Barriers to Adaptation Measures in the Study Area.

The result presented in Figure 3 indicated main constraints to fully adopt most of the adaptation measures identified by the farming households. The major barriers identified were inadequate funds (89.6%), inadequate information (64.4%), shortage of labour (41.5%), shortage of land (34.1%), inadequate technology know how (29.6%) and others (23%). Most of these constraints were associated with poverty and negligent of agricultural sector by the government.



*Multiple response

Figure 3: Major Barriers to Adaptation to Climate Change in the Study Area

Source: Computed from Field Survey, 2011.

3.4 Analyzing Factors Influencing Farmers' Choice of Adaptation Measures using MNL Model.

The results of MNL model showed how factors of socio-economic characteristics influence farmers' choice of adaptation measures in the study area. Therefore, the choice set in the MNL model included the following adaptation options:

1. Change Planting Date 2. Planting Different Crops 3. Planting Different Varieties 4. Other adaptations and 5. No adaptation (mono-cropping).

The estimation of the MNL model for this study was undertaken by normalizing one category, which is normally referred to as the "base category". In this analysis, the first category (no adaptation) was the base category. The likelihood ratio statistics from MNL model indicated that χ^2 statistics (83.51) are highly significant ($P < 0.0005$), suggesting the model has a strong explanatory power. Therefore, Table 3 presents the marginal effects along with the levels of statistical significance.

Educational level: educational level's coefficient has a positive and significant relationship with adaptation measure. A unit increase in the year of education of a farmer, increase the probability of choosing change planting dates, planting dfferent crops and no adaptation as an adaptation measure used in the study area. The probable reason for the positive relationship is due to the fact that educated farmers have more knowledge of climate change and already aware of various techniques and management practices that can be employed to combat effects of climate change.

Household size: This increases the likelihood of using other adaptation (i.e. crop farming to non farming, crop to livestock, use of chemical and so on) as an adaptation measure. This result is in line with Croppenstedt *et al.* (2003) and Deressa *et al.* (2011) who also noticed that the probable reason for this relationship is due to the large family size which is normally associated with a higher labour endowment and this would enable a household to accomplish various agricultural tasks especially at the peak seasons.

Farming experience: The result revealed that experienced farming households have an increase likelihood of choosing change planting date, planting different crops and planting different varieties as an adaptation measure. Experience has taught most of the farmers on the various farm management practices and techniques that can be used in the face of anticipated climate change. This has really helped farmers in the study area to switch from one adaptation measure to another based on the situation of climate variables. These results confirm the findings of Nhemachena and Hassan (2007) and Gbetibouo (2009).

Access to credit: Access to credit increases the likelihood of choosing planting different crops and planting different varieties as an adaptation measure. Lack of funds is one of the main constraints to adjustment to climate change. According to Gbetibouo (2009), he said that "in the study carried out in Tanzania, O'Brien *et al*. (2000) reported that despite the numerous adaptation options that farmers are aware of and willing to apply, the lack of sufficient financial resources to purchase the necessary inputs and other associated equipment, is one of the significant constraints to adaptation". Similar result was also found out in this study where almost 90% of the crop farming households made mention that lack of funds has been a barrier to adaptation in the study area.

Access to extension services: The coefficients of access to extension services have a significant and positive relationship with the likelihood of choosing adaptation measure such as change planting date and planting different crops. This implies that farmers who have access to extension services are more likely to be aware of climatic conditions as well as the knowledge of various management practices that they could employ to adapt to change in the climatic conditions as noticed by Gbetibouo (2009). It was also observed that extension agents do enlighten farmers on what time/period of the year that a particular crop could be best grown as a result of variation in weather conditions.

Farm size: Farm size has a significant but negative correlation with the probability of choosing change planting date and other adaptations (i.e. crop farming to non farming, crop to livestock, use of chemical and so on) as an adaptation measure. While positive relationship exists between farm size and choosing of planting different crops as adaptation measures. The negative relationship between adaptation and farm size is contrary to the study carried out by Gbetibouo (2009) but in line with Deressa *et al*. (2011) who said that the probable reason could be due to the fact that adaptation is plot-specific. This means that it is not the size of the farm but the specific characteristics of the farm that dictates the need for a specific adaptation method to climate change.

Access to climate information: This has a significant impact in using adaptation measures. It implies that access to climate information has increased the probability of using adaptation measures such as change planting date, planting different crops and planting different varieties. Information on climate variables like temperature and rainfall has really helped farmers in the study area on the time to plant a particular crop for the season. It has also prepared them to adapt easily to the changing climatic conditions.

Table 3: Result of marginal effects of explanatory variables from MNL adaptation model.

Explanatory Variables	Change Planting Date	Planting Different Crops	Planting Different Varieties	Other Adaptations	No Adaptation
	Coefficient (P-value)	Coefficient (P-value)	Coefficient (P-value)	Coefficient (P-value)	Coefficient (P-value)
Educational Level	**6.4772*** (0.001)**	**0.0729*** (0.001)**	-4.5191 (0.197)	-0.9911 (0.145)	0.0226 (0.729)
Household size	-0.1011 (0.601)	0.0018 (0.252)	-0.0012 (0.741)	**0.0141* (0.089)**	0.0011 (0.851)
Farming Experience	**0.0120** (0.012)**	**0.0022** (0.031)**	**0.0015** (0.041)**	-0.0002 (0.471)	**-0.0049* (0.057)**
Access to Credit	0.4790 (0.134)	**0.1312** (0.011)**	**0.0231** (0.041)**	-0.0551 (0.841)	-0.0551 (0.133)
Access to Extension Service	**0.0401** (0.037)**	**0.0124** (0.010)**	0.0016 (0.831)	-0.0052 (0.352)	-0.0537 (0.181)
Farm size	**-0.0015*** (0.001)**	**0.0019** (0.022)**	-0.0008 (0.110)	**-0.0048*** (0.002)**	0.0371 (1.690)
Access to Climate Information	**0.0950*** (0.001)**	**0.0311* (0.080)**	**-0.4847*** (0.001)**	0.1212 (0.711)	-0.0003 (0.880)

Note: ***significant at 1%, **significant at 5%, *significant at 10%.

Source: Computed from Field Survey, 2011

4. Summary and Recommendation

The perceptions of farmers about climate change and variability revealed that over 93% of the respondent perceived temperature to be increasing. This observation was in line with meteorological trend analysis from recorded data on the temperature. In the same vein, 70% of the respondent noticed a decrease in the amount of rainfall over the years. The rainfall observation was contrary to the trend analysis on recorded rainfall data from meteorological stations which tend to be increasing. This difference could be as a result of erratic rainfall in the last two seasons because farmers put more weight on recent information. The study also discovered inadequate funds and information on climate change as the main serious constraints faced by the farming households to be adequately adopted adaptation measures in the study area. Again, the results of MNL revealed that educational level, farming experience, access to extension services, access to climate information and access to credit were the factors enhancing the adaptive capacity to climate change among farmers in the study area.

Government policies and investment strategies must support the factors highlighted above in order to rescue the poor farmers from the danger of climate change. The policy must also be designed in such a way that farmers should have access to affordable credit as well as subsidized agricultural inputs in order to increase their ability and flexibility to change production strategies in response to the forecasted climatic conditions. Future policy could also focus on creating awareness of climate change and facilitating the development and adoption of adaptation strategies. The intensive awareness on climate change will be best achieved in the study area through extension agents, mass media, town/village cry, agricultural show, symposium and the likes.

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Assessing EPAL's Potential Vulnerabilities to Climate Variability and Climate Change

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Abstract— In southern Europe, water availability is already a concern and climate scenarios indicate a decrease in precipitation and an increase of droughts frequency and intensity for this region. This might lead to water stress conditions at a basin scale with significant impacts for the different existent water uses, including water supply. The project ADAPTACLIMA is promoted by EPAL, the largest Portuguese Water Supply Utility. It aims to provide the company with an adaptation strategy to reduce their system vulnerabilities to climate change.

The work presented here focus on the water quantity related vulnerabilities assessment for the two main EPAL superficial water resources in climate change scenarios. This assessment was based in downscaled A2 and B2 climate and water use scenarios until 2100 for the area of interest of EPAL. The generated climate, water availability and consumption time series were compiled into several indices according to EPAL's environmental, legal and operational standards. Overall results suggest a high potential future vulnerability for both water sources driven by a 20-50% decrease of water inflows in the Tagus and Zêzere basins and an increase in overall drought severity across the different climate change scenarios.

Index Terms— water supply system, climate change vulnerabilities, water availibility

1 Introduction

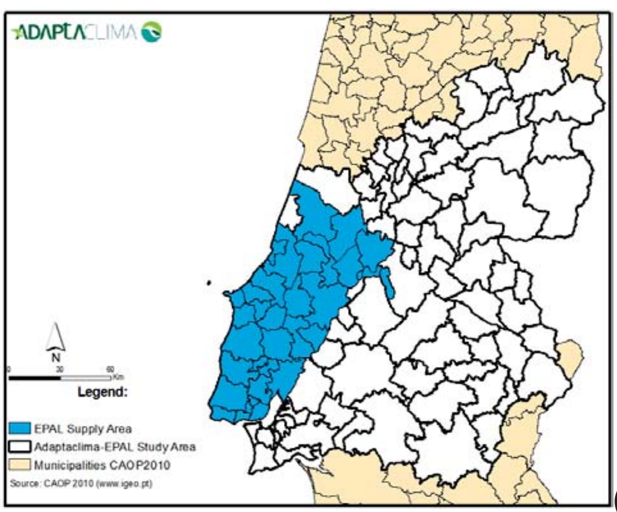
In Portugal a trend has been observed in the 20th century towards drier conditions, with decreases in rainfall and more frequent and persistent drought episodes (Nunes et al., 2008). This trend will become more severe in the future, with climate scenarios showing reductions in precipitation between 20 and 40%, during the 21st century, and an increase of the average annual temperature between 3ºC and 7ºC (IPCC WG II, 2007; SIAM, 2006). The Tagus basin, the largest Portuguese watershed (25 655 km^2), with a population of aproximatelly 3.2 million inhabitants and several concurrent water uses (e.g., water supply, irrigation, hydropower production) will be particularly vulnerable to those variations, as demonstrated in previous studies (Nunes *et al.*, 2008; Nunes and Seixas, 2011).

Nevertheless, the specific impacts to the existing water supply systems, resulting from the complex interaction between climate, hydrological and socioeconomic variables are not well known and require further study. Quantifying those impacts in a climate change context is of paramount significance because of the strategic importance of this sector and its high exposure to climatic extreme events. For this reason EPAL, the largest Portuguese Water Supply Utility, promoted the project ADAPTACLIMA, aiming to provide the company with an adaptation strategy to reduce their climate change related medium and long term vulnerabilities. The focus of this paper will be on results regarding the water quantity related vulnerabilities for the two main EPAL water resources, the Castelo de Bode Dam and the Valada-Tejo river abstraction.

1.1 Study Area

EPAL is responsible for supplying water to 34 municipalities located in the Tagus Basin (Figure 1(a)), corresponding to a total population of about 3 million inhabitants and an annual water consumption of ≈ 240 hm^3. Their water supply system relies on two main superficial water resources, responsible for 90% of the total abstractions:

1. The Castelo de Bode Dam, situated in the lower part of the Zêzere sub-catchment, is a multi-use reservoir (water supply, hydropower generation, flood protection and recreational activities), responsible for 67% (≈160 hm^3) of the EPAL's water supply. Their four uptake points are distributed along one tower, situated near the dam wall;
2. Valada-Tejo, a river abstraction with a single uptake point, situated 30 km upstream from the Tagus river mouth and responsible for 24% of the system water consumption.



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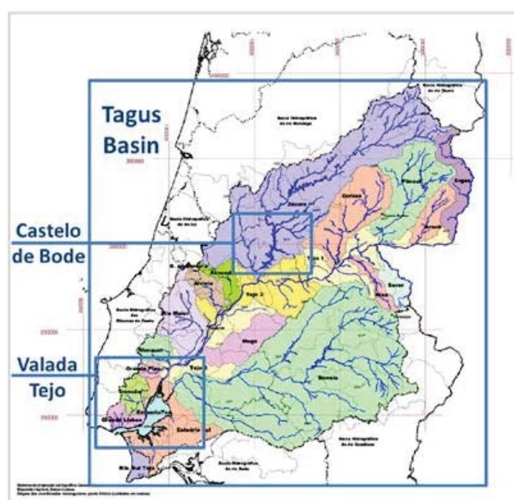

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Figure 1 - (a) Municipalities served by EPAL (marked in blue); (b) Location of the main superficial water resources of EPAL: Castelo de Bode e Valada-Tejo.

2 Methods

EPAL's potential vulnerabilities to climate variability and climate change were assessed based on the impacts to each water source calculated following the methodology shown in Figure 2.

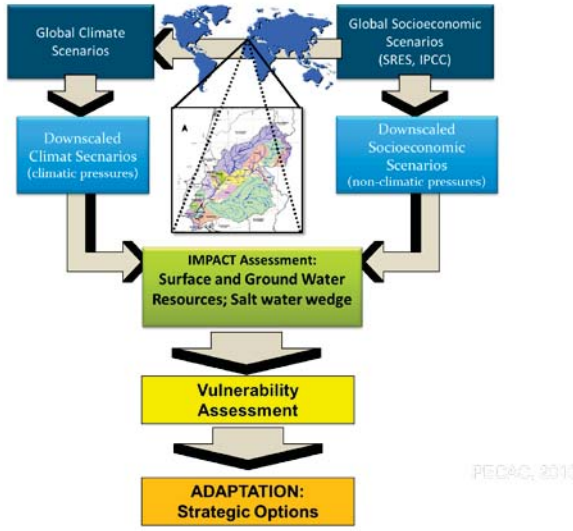


Figure 2 - ADAPTACLIMA general methodology

Precipitation, temperature, population, land use and water consumption time series were provided by statistically downscaled A2 and B2 HadCM3 climatic and CIESIN socioeconomic scenarios (Pulquério *et al.*, submitted; Jacinto *et al.*, 2013). Daily flow time series for both superficial resources were generated using the Soil and Water Assessment Tool (SWAT) model (Neitsch *et al.*, 2011). Those inflows were translated into dam hydrometric levels using a water balance model (Nunes *et al.*, 2013). Several assumptions related to the definition of minimum dam water level (100 m) and water supply, excess discharges and electricity production regimes limit the conclusions that can be reached using its results to only the definition of future dam water level trends. Water quantity impact assessement was complemented by additional information, namely:

1. A statistical analysis of flows at different time scales to identify significant trends in scenario streamflow projections
2. The calculation of a water exploitation index (WEI), defined as "the ratio of annual freshwater abstraction to long-term water availability" (EEA, 2012). Freshwater abstractions were given by estimated monthly and annual average consumption values and long-term water availability by projected annual and monthly inflows. This index identifies long term water resource overexploitation periods.
3. The estimation of the total water deficit hydrological drought index, which calculates drought severity as the product of the duration D (in years), during which flows are consistently below some truncation level and the magnitude M (in hm^3), which is the average departure of streamflow from the truncation level during the drought period (Keyantash and Dracup, 2002). The chosen truncation level was the 2005 streamflow, a historical drough year where, although the EPAL system was not affected, several national and municipal drought action plans were put into action to assure water supply. This index and its components will detect changes in typical drought characteristics.

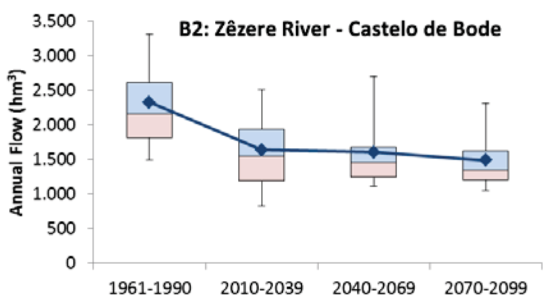
Vulnerability matrix values were then obtained through expert judgement by pondering risk, determined by the severity of an impact to the water resource, the probability of such impact and the adaptative capacity of the system to reduce the vulnerability of such an impact. Confidence values were established as the combination between impact evidence and impact agreement.

3 Results

Climate scenarios precipitation and temperature time series for the Tagus Basin indicate, for the beginning (2010-2039) and the end of the century (2070-2099): 1) an average rainfall decrease ranging from 8 to 10% (B2) and 5 to 18% (A2), respectively; 2) a temperature increase between 0.4 and 1.7° C (B2) and 0.2 and 3° C (A2). Scenario B2 usually provides higher variations in earlier periods (2010-2039), while A2 leads to extremer values by the end of the century (Pulquerio et al., submitted). Both scenarios present higher seasonal anomalies in Autumn. All socioeconomic scenarios point to a significant decrease in water consumption, driven mostly by an increase in use efficiency and a decrease in agricultural land use. To establish a worst case scenario, results incorporated in the following sections refer to current water supply and hydropower generation water consumptions.

3.1 Castelo de Bode Dam

SWAT estimated annual streamflows to Castelo de Bode show a decrease ranging from 12 (B2) and 5% (A2) in the beginning of the century to 20 and 34% by its end. Those decreases are mostly concentrated in Autumn and are characterized by the increasingly smaller annual flow variability in later periods of the century.



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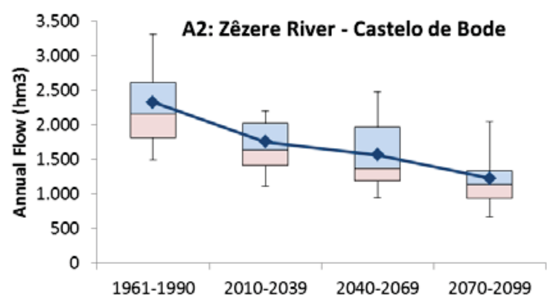
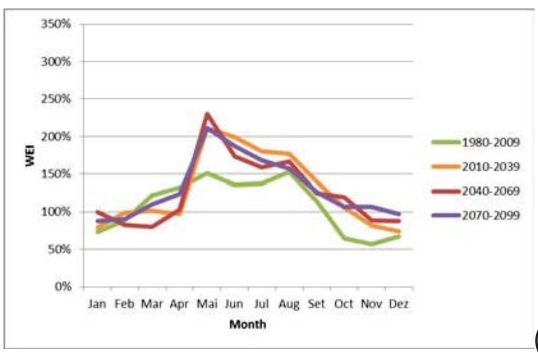


(b)

Figure 3 - Annual inflow variability to the Castelo de Bode Dam (lower and upper box limits - 25th and 75th percentiles; whiskers limits - 10th and 90th percentiles for the (a) B2 and (b) A2 scenarios

Results given by the water balance model translate those reductions in inflow into lower mean dam hydrometric levels and a higher number of months where the 100 m minimum level is reached. The percentage of such months varies from 20% in the reference period (1980-2009) to 39% by the end of the century in the B2 scenario and 67% in the A2 scenario. Unfortunately the limitations in simulating these levels restrict any conclusions related with impacts in water uptake and can only be interpreted as an indicator of a long term decrease in water availability.

Despite this expected decrease, Castelo de Bode current water supply consumptions (≈160 hm^3) only represent, in the 2070-2099 period of the A2 scenario (1225$hm^3.y^{-1}$), 13 to 45% of the average and low (given by the 10th percentile) inflows years respectively. Problems only arise when hydropower generation present consumptions (≈1400 hm^3) are included. Annual combined consumptions, which nowadays represent 85% of the average water inflows, will exceed them, varying in the end of the century between 118% in the B2 scenario and 140% in the A2. Seasonally, the water deficit period will tend to increase and include almost all months, except for December and January (Figure 4). Although priority should be given to supply needs and restrictions to hydropower generation are expected to compensate for inflow decrease, this possible water use conflict constitutes a risk that must be considered in the future vulnerabilities assessment.



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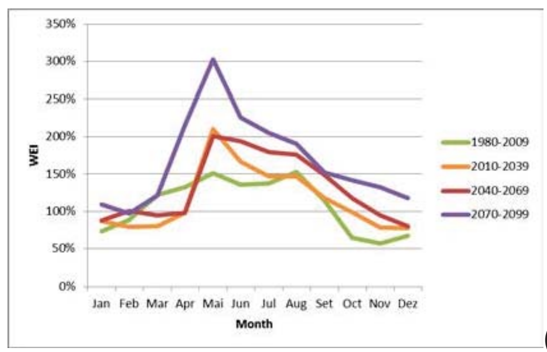

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Figure 4 - WEI monthly values (EPAL + hydropower generation) for the different future climatic periods in the (a) B2 and (b) A2 scenarios

Drought severity is also expected to intensify, especially in the A2 end of the century period (Figure 5 (b)). When compared with the 2005 drought, total water deficit drought information for the A2 end of the century results show that: 1) near miminum flows registered in 2005 will become average; 2) the number of consecutive years below the 2005 inflow threshold will increase significantly to a maximum of ≈3 years, pointing to a higher drought persistence; 3) average drought magnitude will also tend to increase, with drought periods registering yearly flow values of 20% below the 2005 level.

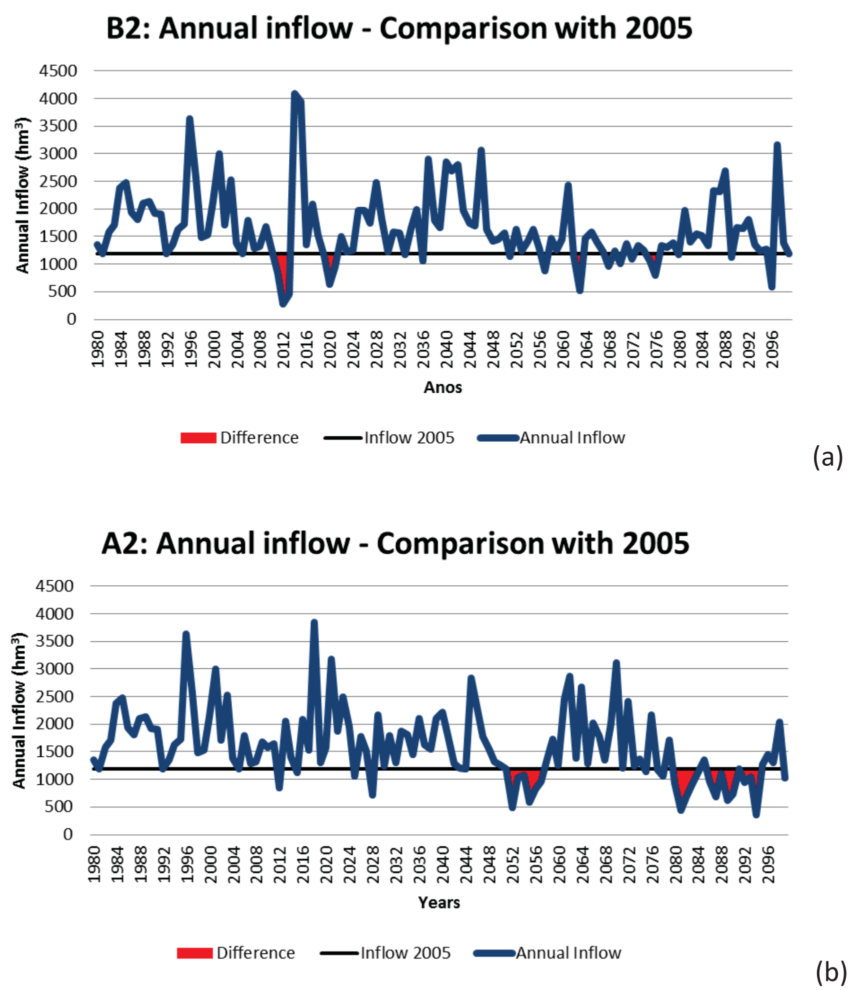
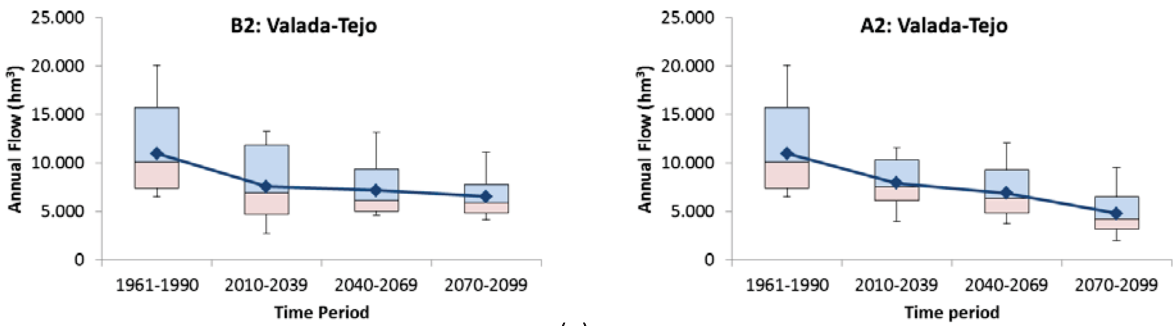


Figure 5 - Annual inflow comparison with the values estimated in 2005 for the (a) B2 and (b) A2 scenarios. The red areas refer to periods where yearly flows are lower than 2005

All these different indicators suggest a significantly higher risk to the main EPAL water resource, altough none can provide evidence of a possible disruption in water supply, due mainly to limitations in estimating realistic water dam levels. The final vulnerability index for this water resource has raised from the current low class to high, with a robust degree of confidence, since both scenarios agree on impact signal.

3.2 Valada-Tejo river abstraction

Future streamflow estimates to the Valada-Tejo river abstraction suggest an even more significant decrease in this water resource due to a high dependency on inflows coming from Spain, which are more sensitive to climate change (Nunes *et al.*, 2013). Those decreases range correspond to 20 and 16% in the in B2 and A2 scenarios (2010-2039 period) and to 31 and 49% in the end of the century and have similar seasonal characteristics as the ones estimated for Castelo de Bode.

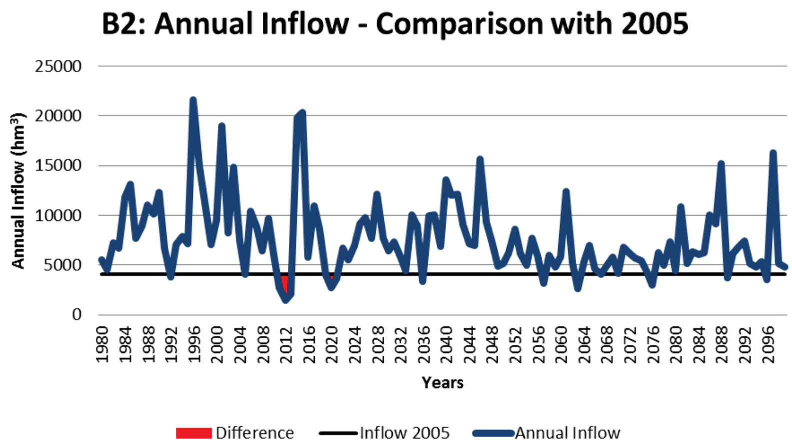


(a) (b)

Figure 6 - Annual inflow variability to the Valada-Tejo river abstraction for the (a) B2 and (b) B2 scenarios (same percentiles represented in boxplot as in Figure 3)

Despite those reductions the inflows by the end of the century (4800 $hm^3.y^{-1}$ in A2 and 6500 $hm^3.y^{-1}$ in B2) still greatly exceed EPAL water needs (≈60 $hm^3.y^{-1}$). Nevertheless this discrepancy does not reflect a higher resilience of this resource to climate change since the main constraint to water abstraction in Valada is the minimum retrieval level. However, future estimates of daily mean water levels at the uptake point, cannot be calculated since rating curves are unavailable for that river section. To partially overcome this limitation, trends in daily flows were analysed showing that the most severe impacts were on high (given by the 90th percentile) and average flows, with decreases of 49 and 65% in the 2070-2099 period of the A2 scenario. Low flow days (given by the 10th percentile) are less affected, with a reduction of 23%, by the end of the century.

Regarding drought intensity the trend and characteristics are very similar to the ones observed in Castelo de Bode with higher impacts in the A2 scenario (Figure 7(b)), an average drought duration of 2.8 years and an average magnitude with flows 26% below the 2005 estimates.



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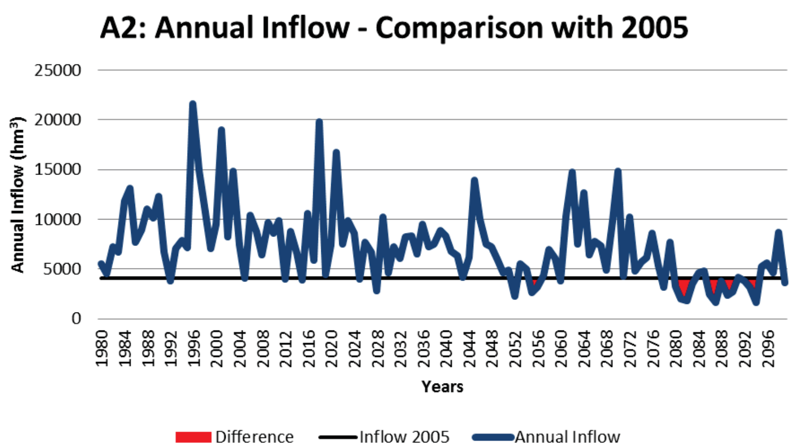

(b)

Figure 7 - Annual inflow comparison with the values estimated in 2005 for the (a) B2 and (b) A2 scenarios. The red areas refer to periods where yearly flows are lower than 2005.

Combining the information given by these different indicators, the vulnerability value increased from the current value of medium to high in future climate scenarios. However, considering the limitations in estimating river water levels, we cannot correctly assess the possibility of medium to long term breaks in EPAL water supply, and therefore our confidence in this vulnerability assessment is limitted.

4 Conclusions

The results presented in this paper confirmed an increased risk for water availability failure in the two main water resources of the EPAL system in climate change scenarios, driven by a decrease in precipitation and flows in the Tagus and Zezere basins and significant increase in drought frequency, persistence and magnitude. This apparent higher vulnerability can be minimized by a correct management of concurrent water uses such as irrigation and hydropower generation, in the case of Castelo de Bode, and through the introduction of structural changes in the Valada-Tejo river abstraction or the inclusion of new water uptake points.

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ECOSYSTEM BASED ADAPTATION (EbA) TO CLIMATE CHANGE - INTEGRATING ACTIONS TO SUSTAINABLE ADAPTATION

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Abstract

This paper is a review attempt to provide the state of the art in of Ecosystem Based Adaptation (EbA) to climate change. Present approaches of climate change adaptation are implemented mostly either as "hard" or as "soft" measures despite the recognized limitations of existing "hard engineering" solutions and the need for integrated approaches to ensure long term sustainability of adaptation. EbA is designed to integrate the fundamental but apparently conflicting building blocks of current adaptation regime within the context of sustainable adaptation to climate change. EbA to climate change balance the need for hard and soft interventions while reflecting local conditions and incorporating local knowledge. Therefore, the EbA approach has the potential to significantly increase the functionality of current adaptation practices and reduce the tension of "hard" and "soft" approach by following three major ways: a) valuing ecosystems and biodiversity in adaptation b) promoting development in adaptation and c) building long term resilience with multiple socio-economical benefits. The paper showed that increasing number of EbA is taking place for biodiversity, conservation and Disaster Risk Reduction (DRR), however, yet to be mainstreamed as one the key adaptation strategies compared to conventional "sector-based" and "hard" adaptation measures. The paper sought for expansion of EbA interventions to other sectors e.g. livelihood and incorporation of governance and participation aspects in implementing EbA practices.

Index terms: *Adaptation, Climate Change, Ecosystem Services (ES), Impacts*

1. Introduction

Climate change is a major global threat that has already had an observed impact on natural ecosystems (MEA 2005; IPCC 2007b). Early predictions and models of climate change impacts made the broad assumption that the developing world would face devastating impacts (IPCC 2007a; Bernstein et al. 2007) however latest findings firmly confirm that even developed countries are not immune to the impacts (Berkhout 2005; EEA 2012). Available climate scenarios make adaptation to climate change extremely important as some impacts cannot be avoided (Berkhout 2005). In addition, predominant “hard” adaptation measures are costly, resource intensive, obstruct natural flow and can result in mal-adaptation (IPCC 2012; Jones et al. 2012; Klein et al. 2007; Huq et al. 2003), promote “negative development” (Pérez; et al. 2010; Tschakert & Dietrich 2010), develop threats to biodiversity and ecosystems (Campbell et al. 2009; CBD 2009; EEA 2009) and do not guarantee to meet the challenges of future climate change(Jones et al. 2012; Pérez; et al. 2010).

Currently, there is an increasing interest to adapt a new approach called Ecosystem based Adaptation (EbA) which claims to have the potential to overcome mal-adaptation and the inadequate consideration of biodiversity while considering better the social part of adaptation efforts, and helping to avoid social inequality and disempowerment (Doswald & Osti 2011; Fitter et al. 2010; Everard 2009; Girot et al. 2012).

2. Ecosystem based Adaptation (EbA)

2.1 Characteristics and definition of EbA

Ecosystem based Adaptation is an approach of planning and implementing climate change adaptation considering ecosystem services and its uses for human well being (MEA 2005; Girot et al. 2012). Vignola et al. (2009) and Mercer et al.(2012) argued that EbA encourages the use of local and external knowledge about ecosystems to identify climate change adaptation approaches, recognizes the diversity of local situations and creates a facilitating environment for effective local adaptation and ecosystem management. Girot et al. (2012) highlighted that EbA also priorities natural resource conservation as one of the key principles which enhances effectiveness of adaptation. EbA is an approach that builds resilience and reduces the vulnerability of local communities to climate change (Pérez et al., 2010). It places special emphasis on ecosystem services that underpin human well-being in the face of climate change. The underlying hypothesis is that ecosystem-based solutions can contribute to address climate change adaptation through ecosystem conservation and ecosystem service provision to the society.

EbA is defined as “integration of sustainable use of biodiversity and ecosystem services into an overall adaptation strategy can be cost-effective and generate social, economic and cultural co-benefits and contribute to the conservation of biodiversity”(CBD 2009, p.41). EbA is dependent on well functioning ecosystems which are usually more able to continue to provide ecosystem services and resist and recover more readily from extreme weather events than degraded, impoverished ecosystems (Colls et al. 2009). Complete conceptualization and understanding of EbA is still in a development stage, nonetheless there are examples of ongoing EbA practices around the world. For example, Doswald and Osti (2011) identified 49 EbA projects for nature conservation covering over 17 European countries with a majority from the United Kingdom, followed by Germany and The Netherlands. The study found that nearly all case studies using ecosystem-based approaches to adapt to flooding results in benefits for both people and nature (Doswald & Osti, 2011).

2.2 Indicators and Principles of EbA

Available literature on EbA describes principles and indicators of EbA in different contexts. A literature review allowed establishing a set of EbA principles for this study which needs to be seen as a generalized list; i.e. not necessarily accounting for all place based characteristics such as the local environment, conditions, ecosystem services, institutional setting and political process. The identified indicators have gone through a systemization process resulting in clusters of principles. A total of 9 principles have been identified based on 38 indicators (Please refer Table 1).

Table1: Major principles and Indicators of EbA

No	Principle	Indicators	Literature sources
1	Flexible management structure	Adaptive management approaches Incorporate clear planning principles Promote existing best resource management practices Community based management	(Doswald & Osti, 2011) (Colls et al., 2009) (Mercer et al., 2012) (Watson 2011; Watson et al. 2012)
2	Knowledge based adaptation	Build knowledge and awareness Local science-management partnerships Best available science and local knowledge Culturally appropriate	(Doswald & Osti, 2011) (Mccarthy, 2012) (Mercer et al., 2012)
3	Maximum stakeholder involvement	Maximum stakeholders Involving local communities Multi-partner strategy Collaboration and trust	(Doswald & Osti, 2011) (Watson et al., 2012) Colls et al., 2009
4	Variety	Work with uncertainties Explore and priorities potential climate change impacts Explore a wide spectrum of adaptation options Understand trade-offs	(Watson et al., 2012) (Doswald & Osti, 2011) (Jones et al., 2012) (Mercer et al., 2012)
5	Multi Scale operation	Integration with development strategies Support sectoral adaptation planning multi-sectoral approaches multiple geographic scales	(Doswald & Osti, 2011) (Colls et al., 2009) (Travers et al. 2012) (Mercer et al., 2012)
6	Ensuring governance	Accountable Transparent decision making Gender balancing Equity Monitor and evaluate systematically	(Doswald & Osti, 2011) (Jones et al., 2012)
7	Resilience building	Resilience vs. resistance Manage climate variability Manage long-term climate change Reducing DRR vulnerability Reducing non-climate stresses	(Watson et al., 2012) (Mccarthy, 2012) (Colls et al., 2009)
8	Maintaining ecosystem	Promote resilient ecosystems Maintain ecosystem services Enhancing biodiversity Resource conservation Avoid mal-adaptation	(Travers et al., 2012) (Mercer et al., 2012) (Colls et al., 2009) (Mccarthy, 2012) (Watson, 2011) (Doswald & Osti, 2011)
9	Integrating	Providing social, economic and environmental benefit	(Colls et al., 2009) (

development	Enhancing livelihood support	Pérez; et al., 2010)
	Cost effectiveness	

3. Methodology of the research

3.1 Documents selection:

The research followed a literature review based approach and developed three relevant guiding questions to seek answers such as:

- Is EbA being implemented as adaptation intervention?
- What are the main characteristics of the current EbA practices?
- How do current EbA examples comply with sustainable adaptation to climate change?

In order to seek the answers, relevant publications on EbA were identified by using ISI web of Knowledge using the key term (Ecosyste* base* Adaptatio*) AND Topic=(Climat* Chang*) , (Adaptatio*) AND (Ecosyste*) and (Climat* Change). The initial search retrieved 1306 results on the key terms. Second round of screening included publications during the time of 2004-2013, and under the research areas “Environmental Sciences Ecology, Geography, Sociology, Meteorology, Atmospheric Sciences, Agriculture, Social Issues, Biodiversity Conservation and Forestry” and 385 numbers of articles remained. The final screening was done based on the following exclusion and inclusion criteria:

- Inappropriate studies are excluded based on title and abstract
- Presence of "EbA" in title and Abstract are included
- Relevance: To be included, a study must discuss significantly EbA as a major adaptation intervention. Ecosystem based Management (EbM) is not included
- Intervention type: Any type of EbA intervention to mitigate climate change impacts such as biodiversity, resource conservation, DRR and sea level rise is included.

After this round of selection, 17 most relevant papers on EbA were retained for review. It should be acknowledged that focusing on 17 publications might be a constraint. However, those were identified as the most pertinent publications available to date by the authors. The inclusion of further publications is envisaged in the future.

3.2 Document Analysis

The publications were analyzed using a questionnaire based on the 9 principles and 38 indicators of EbA (Table 1). Based on subjective judgment of the researchers, each publication received for each of the indicators a score. For example, indicators having empirical example was given 2, without example was given 1 and publications not dealing with the indicator was given 0.

4. Results

4.1 General overview of the papers

Among the 17 reviewed papers, 9 described EbA case studies by using empirical data, 5 dealt with conceptual understanding of EbA, while the rest (3 papers) reviewed different concepts and case study results. In terms of thematic focus, 5 papers focused on urban sectors, 3 papers on biodiversity management, 3 papers on general aspects of EbA, 2 papers on adaptation and resilience and coastal zone management, while water resource management and policies were the topic in 1 paper each. There were spatial variations as well. Among the 17 papers, 7 papers had global focus, 5 papers focused on developed countries, 3 papers on Small Island Developing States (SIDS) and 2 papers on (other) developing countries. Finally, the papers were also classified according to hazard priority; 6 papers discussed multi-hazard risks e.g. flooding, erosion etc while 8 papers did not provide specific hazard context. The hazard independent papers considered EbA necessary for mitigating the risks against climate induced hazards in general. 2 papers discussed specifically flooding and 1 fire related hazards.

4.2 Representation of the principles of EbA

Figure 1 shows the general characteristics and focus of the identified EbA literature according to the EbA principles (Table 1). 37% of all literature has a general focus on resilience building and ecosystem maintenance. Variety, development consideration, management, knowledge and scale also occupied a fair share in the literature. However, the issue of governance is often omitted. Only 3% of the papers have discussed on the governance aspects of EbA in a brief extent.

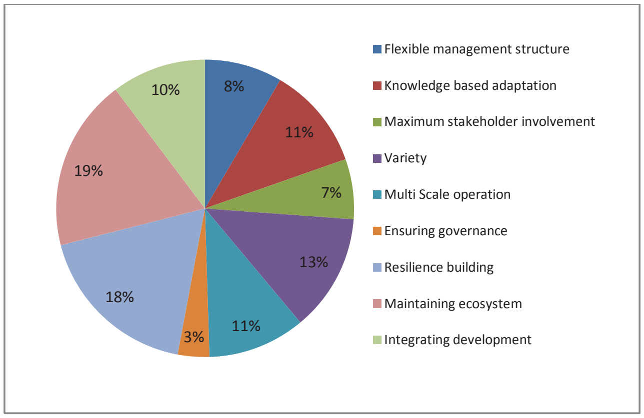

Figure 1: Representation of the principles of EbA

Although all principles were represented in the publications, not all the underlying indicators were mentioned. As shown in Figure 2, all the indicators under the principles "resilience building" and "maintaining ecosystem" are frequently referred to with or without examples by most of papers.

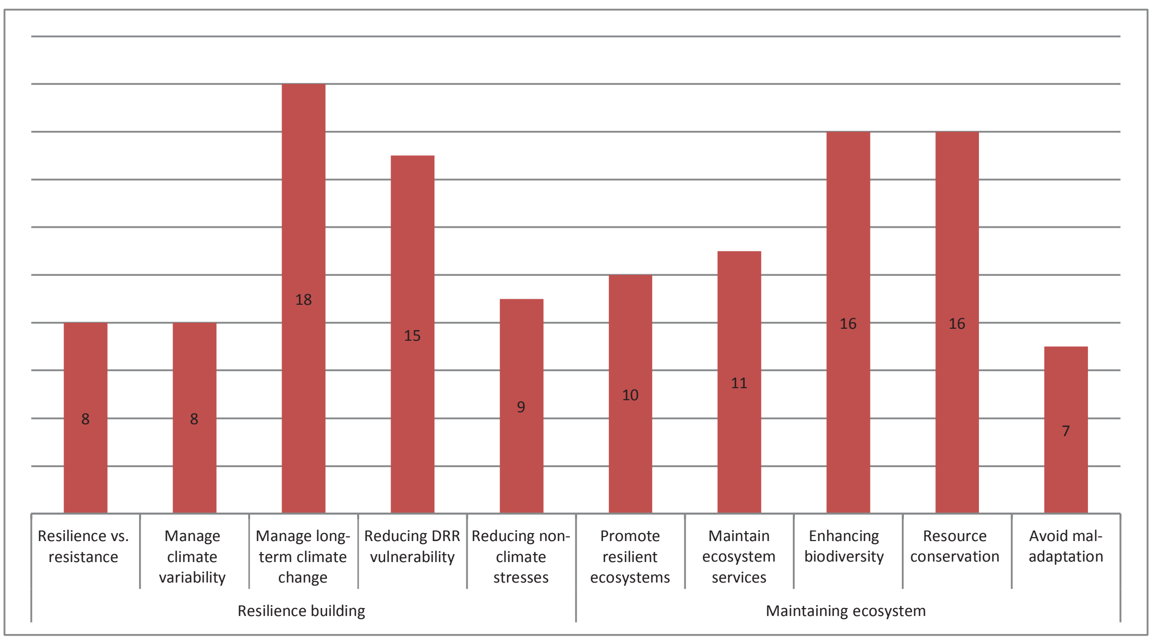

Figure 2: Cumulative scores of indicators under "resilience building" and "maintaining ecosystem"

In contrast, indicators under the principle “stakeholder participation” and “governance” were not frequently cited by the reviewed papers. Some of the underlying indicators were occasionally mentioned e.g. “local communities involvement” but some of the indicators were never cited e.g. “collaboration and trust” and “equity”. Figure 3 shows the cumulative score of the indicators “3” and “6”.

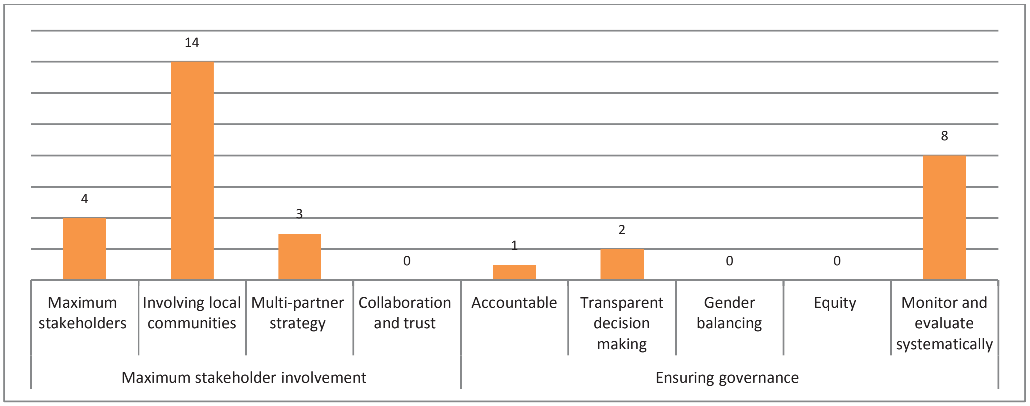

Figure 3: Cumulative scores of the indicators under the principles “stakeholder involvement” and “governance”

Table 3: Overall comparative picture of each principle, indicators and its score

Indicator with more score	Score	Indicator with less score	Score
Manage long-term climate change	18	Explore a wide spectrum of adaptation options	8
Cost effectiveness	18	Integration with development strategies	8
Enhancing biodiversity	16	Monitor and evaluate systematically	8
Resource conservation	16	Resilience vs. resistance	8
Reducing DRR vulnerability	15	Manage climate variability	8
Involving local communities	14	Adaptive management approaches	7
Work with uncertainties	13	Avoid mal-adaptation	7
Build knowledge and awareness	12	Incorporate clear planning principles	6
Best available science and local knowledge	12	Enhancing livelihood support	6
multi-sectoral approaches	12	Promote existing best resource management practices	5

multiple geographic scales	12	Maximum stakeholders	4
Maintain ecosystem services	11	Multi-partner strategy	3
Local science-management partnerships	10	Culturally appropriate	2
Explore and priorities potential climate change impacts	10	Support sectoral adaptation planning	2
Understand trade-offs	10	Transparent decision making	2
Promote resilient ecosystems	10	Accountable	1
Community based management	9	Collaboration and trust	0
Reducing non-climate stresses	9	Gender balancing	0
Providing social, economic and environmental benefit	9	Equity	0

5. Discussion

The analysis of the appearance of certain EbA-specific indicators in selected publications revealed that EbA has huge potential to mitigate long term climate risks (Table 3). Disaster risk reduction (DRR), resource conservation and biodiversity management are the three major sectors where EbA is considered as relevant and an important adaptation intervention. Conservation and biodiversity oriented papers in the EbA context focused mostly on the different conservation strategies for enhancing biodiversity and the resilience of ecosystems (Grantham, et al., 2011; Mccarthy, 2012). On the other hand, the role of EbA in achieving disaster risk reduction is also significantly emphasized by the reviewed publications. Irrespective of sectors, the analysis showed that in case EbA was implemented the process acknowledged various EbA principles such as cost effectiveness, involvement of local communities, flexible management, evidence base building, and the use of available science and local knowledge considering multiple geographic scales. However, to be an effective and sustainable adaptation management tool, EbA also needs to consider the remaining principles in the domains of governance, stakeholder participation and variety (Mercer et al. 2012; Vignola et al. 2009). The implementation of these principles were rarely reported in the publications, albeit, there are very important to accommodate the community needs and expectations (please refer to Table 3). This result might be biased though by the applied focus on publications in the selected research areas in the ISI literature search. An extension of the analysis to more social science dominated journals is needed to confirm the validity of the presented results.

One of the major review findings is that many authors e.g. Kanounnikoff et.al, (2011); Morecroft, et al., (2012),Heller & Zavaleta, (2009); James E., et al., (2013), Jones et al., (2012) and Gero et.al, (2011) unequivocally argued adapting EbA mechanisms for long term resilience building against both short term climate variabilities and long term climate impacts . They demonstrated that EbA accounted the adaptation highest potentials among the prevailing adaptation mechanisms to be sustained. The authors also argued to implement Payment of Ecosystem Services (PES) schemes for ensuring safety, funding, and rational resources use in an uncertain future. Climate change uncertainty and the risk of proactive planning in an uncertain future was an oft-repeated indicator that most of the papers emphasized (Grimsditch, (2011); Groves et al., (2012); Morecroft, et al., (2012); Roberts et al., (2011); Wilby et al., (2010)) . In response, Groves et al., (2012) and Roberts et al., (2011) emphasized EbA interventions such as “systematic conservation planning” which can minimize the “uncertainty” risks in a greater scale. Likewise, a number of papers also mentioned the importance of understanding the tradeoffs between different available adaptation options (Table 3) which hints to the need for a careful selection of adaptation choices (Groves et al., 2012; Heller & Zavaleta, 2009; Verburg, et al., 2012).

Papers also came up with entry points of EbA in disaster risk reduction (DRR). Gero et al., (2011) advocated for closer relationship of CCA and DRR. The paper showed DRR and CCA need to follow a common approach of operation so that DRR can be an entry point of a long term adaptation process (Gero et al. 2011).Not all the current DRR interventions e.g. hard, engineering options are not equally effective therefore, EbA can be a potential bridging point for DRR and CCA(Jones et al. 2012). In a different angle, Pramova, et al., (2011), showed infrequent uptake of the ecosystem services approach for adaptation mechanism in National Adaptation Plans of Action (NAPAs) (in 31% of the total projects). The author argued to encompass EbA in national adaptation plan so that EbA can bridge the gap of adaptation, development and DRR interventions. Williams, et al., (2012) and Heller & Zavaleta, (2009) extended the argument that regional ecosystem based planning, land use planning (Verburg et al., 2012) water management planning (Wilby et al., 2010) and other sectoral development planning can also be the potential entry points of EbA to take place in longer term resilience building for the community. The papers also suggested for a greater need of strong evidence base for proactive and efficient planning.

6. Conclusion

The review research was aimed to get answers of three guiding questions. The research showed that EbA is taking place in different parts of the world for long term adaptation intervention to climatic and non-climatic stressors. The results also showed that the current EbA practices are still skewed towards biodiversity and conservation related interventions along with increasing expansion to the DRR area. EbA tools are yet to be mainstreamed as one of the key adaptation interventions for managing missing sectors e.g. livelihood. The main challenge is to mainstream EbA as key adaptation process from the domain of mere conservation regime. The incorporation of governance and participation aspects is particularly important in EbA practices and absence of these principles may provoke top-down conventional planning regime, which are highly ineffective. In a nutshell, EbA has high potential of building sustainable adaptation practices; however, the principles need to be effectively materialized across spatial, temporal and administrative scales with larger community involvement.

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1. Topic=(Ecosyste* base* Adaptatio*) AND Topic=(Climat* Chang*)
Refined by: Research Areas=(ENVIRONMENTAL SCIENCES ECOLOGY OR SOCIAL ISSUES OR METEOROLOGY ATMOSPHERIC SCIENCES OR SOCIAL SCIENCES OTHER TOPICS OR MARINE FRESHWATER BIOLOGY OR URBAN STUDIES OR GEOGRAPHY OR BIODIVERSITY CONSERVATION OR FORESTRY OR SOCIOLOGY OR AGRICULTURE OR ANTHROPOLOGY OR WATER RESOURCES OR PHYSICAL GEOGRAPHY OR OCEANOGRAPHY OR FISHERIES)
Timespan=2004-2013.

351 results

2. Topic=(Ecosyste* base* Adaptatio*) AND Topic=(Climat* Chang*)

Refined by: Research Areas=(ENVIRONMENTAL SCIENCES ECOLOGY OR SOCIAL ISSUES OR METEOROLOGY ATMOSPHERIC SCIENCES OR SOCIAL SCIENCES OTHER TOPICS OR MARINE FRESHWATER BIOLOGY OR URBAN STUDIES OR GEOGRAPHY OR BIODIVERSITY CONSERVATION OR FORESTRY OR SOCIOLOGY OR AGRICULTURE OR ANTHROPOLOGY OR WATER RESOURCES OR PHYSICAL GEOGRAPHY OR OCEANOGRAPHY OR FISHERIES) AND Research Areas=(ENVIRONMENTAL SCIENCES ECOLOGY OR FISHERIES OR SOCIAL ISSUES OR GEOGRAPHY OR BIODIVERSITY CONSERVATION OR SOCIOLOGY OR FORESTRY OR ANTHROPOLOGY OR AGRICULTURE OR WATER RESOURCES)
Timespan=2004-2013.
321 results

3.

Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Food security — is climate important at all?

Martin Köchy, Martin Banse

Abstract— This question seems odd at first glance. Climate in its short-term realization as weather noticeably affects crops and hence food production. The right timing of rain and favourable temperatures results in bumper crops, whereas droughts, flooding, frost, and hailstorms can ruin a harvest.

Recent years have seen a tremendous increase in projects, conferences, and networks addressing food security and also food security and climate change. In a new project, FACCE MACSUR, set up by 17 countries in June 2012, we target one and a half components of food security with a focus on Europe: availability and prices. One of the greatest challenges is the integration of models of crop and livestock production, food markets, and farm economics across spatial, temporal, and organizational scales, their methods and assumptions, and in their progress with respect to incorporating climate impacts in their models.

MACSUR started the integration with inventories and descriptions of existing models and the types of scenarios used so far. The next step will be to identify how the output of one type of model can feed into another type of model and how one can incorporate feedbacks between physical scales and organizational units. The third step will be to apply a setup of joint crop-livestock-economics models to regional pilot studies. An alternative approach using Bayesian networks for assessing uncertainties is described.

Index Terms—food security, linking socio-economic and production models, food prices, integration

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1 Introduction

A common joke about farming goes "what is the worst season for farmers? Spring, summer, fall, and winter!" Weather has been the plight and benefactor of farming since the dawn of times. The germination of seeds is controlled by the sum over days of soil moisture and temperature above a certain level (Bradford 2002) and may require additional environmental cues. Maximum shoot (and root) growth rates of most plant species are restricted by ambient temperature and available water (and other factors like light and nutrients). The timing of flowering and pollination are tuned to favourable weather conditions. Also the ripening of fruits is in many species controlled by temperature and water conditions. Moreover, weather conditions determine the growth and dispersal of pests (fungi, weeds, bugs). Weather conditions may also control whether a piece of land is at all accessible by farmers and machinery or whether ripe crops can be harvested and stored without loss. Meat and dairy production can also be affected by weather. Animals kept outdoors are directly exposed to weather and indirectly affected by weather effects on feedstock growth and disease vectors. Animals kept indoors are affected by weather-dependent feed quality and indoor climate (unless regulated). In many instances unfavourable weather will delay the growth process of a crop, but extreme weather events –frost, drought, extreme heat, hail, flooding– may kill a plant. Extreme weather events may also cause economic disturbances at the macro-economic level (Hallegatte et al. 2007) with effects on farmers' income and food prices.

2 Extreme weather events and food security

The vagary of weather in one place shows central trends over decades that we recognize as climate. Climate is typically characterized by average annual mean temperature and mean annual precipitation. We know that these averages are going to change over the next decades due to the increasing concentration of greenhouse gases in the atmosphere (IPCC 2007). What is less clear is to what extent the averages will change and where (Randall et al. 2007). Even more difficult to predict are regional changes in the frequency, extent, and seasonal timing of extreme weather events (Kharin et al. 2007; Chen and Knutson 2008) that are decisive for the yield or quality of crops (Van Oort et al. 2012; Skaggs and Irmak 2012). The effect of weather is an important issue for an assessment of food production. This is expressed in a growing number of studies on the quality of prediction of extreme events, on the change in the probability distribution of extreme events (Kharin et al. 2007), and on the effects of extreme events.

The great variability of weather in one place would cause similar variability in food production if food is produced (and consumed) in the same place. When food is traded over greater distances, crop failures in one place can be balanced by surplus from crops in other places. This effect, however, works only at distances at which weather is not (or only weakly) correlated. But even at the global scale, weather extremes can coincide across large distances. In e.g. 2003, droughts occurred at the same time in the major grain production regions in North America, western Asia, and Europe (Herweijer and Seager 2008). With respect only to numbers there was still enough grain produced and in storage around the world to feed the world population but the great demand for grain let to increasing grain prices and sufficient food was not accessible or affordable in some parts of the world.

Food security comprises availability, affordability, accessibility, and adequacy (United Nations 1975). The food must reach the people, they must be able to pay for it and it must be nutritious. Based on this definition, high world market prices for food reduce the affordability and hence food security. Since world market prices strongly affect local prices, local food security is to some degree affected by weather elsewhere.

3 The MACSUR project

Several European countries have got together to assess European food security under climate change. They commissioned a project, MACSUR, comprising 71 institutions from 17 countries to link existing models of crop production, livestock farming, farm economics and trade models. The project started in June 2012 and is coordinated by the Thünen Institute together with the University of Reading. The first three years of the project are intended as a proof-of-concept showing how existing models could be linked, with examples of application. The research activities in MACSUR are informed by similar activities at the global scale in research networks AgMIP and Global Research Alliance. If possible and meaningful, existing approaches and scenarios will be adopted from the global networks and adjusted or refined for use in MACSUR.

An appropriate assessment of future regional food security should address future weather (i.e. climate including its full variability) not only in the target region but worldwide, the effect on regional crop production, global trade and global prices, the effect of government regulations that affect local prices and restrictions on the area that can be used for crops, and the reaction of farmers in farm management to expected food prices and local weather. A full assessment should further include a comparison of food prices in relation to available income and account for food distribution and food quality. The inclusion of all of these aspects, however, was not feasible in the first (three-year) phase of our project that is concentrating on linking models.

4 Linking climate, production, and economic models across scales

One of the challenges of the project is to link existing models of crop and livestock production, farming and trading that come from diverse scientific areas with basically two different approaches. (Climate models are not included directly in the project but their projections are used as input for crop models). On the one hand side are the more process-oriented models of crop and feed production, on the other hand side are the market models with endogenous price formation.

Physiological plant production models capture the most relevant known (or presumed) processes to predict the next state of a plant from the preceding state. Since the mechanisms of crop growth and the major crops (cereals) are mostly identical over large regions and even continents, crop models can be applied flexibly. Crop models are usually applied to environmental (climate and soil) conditions in a single point or small area and yields are extrapolated to larger regions assuming heterogeneous environmental conditions. This assumption is usually only valid at regional but certainly not at country level.

Regions with diverse environmental conditions require separate simulations. The aggregated yields over several larger regions to the country scale are required for deriving world market and regional prices by economic models because economic price models rely on the calibration based on national statistics and require input at this scale. Simulated crop production scaled and aggregated to the national level should also correspond to national harvest statistics. Often, however, crop models overestimate national production because they assume near-optimal crop management in method and timing (field preparation, fertilization, irrigation, pest treatment, environmental hazards, harvest). The difference between simulated and reported yields (“yield gap”) must be accounted for when crop model results are scaled and aggregated to larger spatial units. Appropriate scaling (from point to region) and aggregation (across regions) procedures will be developed in MACSUR.

Trade models focus on the finding of expected prices based on historical observations of, not necessarily causal, correlations among available amounts of goods, demand for the goods, and resulting prices. One of the reasons for the focus on expected prices is that prices for a major part of the expected yield are negotiated between buyers and sellers before the harvest. For determining the world market price for crops, trade models must be informed about the yields in all parts of the world, which requires simulations of crop yields outside Europe in adequate detail. The trends of world market prices for individual crops will influence a farmer’s decision what proportion of the land he will use for which crop or proportion of livestock. This decision process is simplified in many trade models by assuming that a whole country corresponds to one farm with one farmer who allocates crops to pieces of land. This simplification glosses over regional differences in climate, soil, and other environmental and socio-economic differences. Specialized (small-scale) farm models can take better into account income generated, legal requirements, government subsidies, allocation of area to crops, pasture or meadows, crop rotations, and livestock farming.

5 Concept for model linking in MACSUR

The partners involved in MACSUR develop or apply 25 economic models, 53 crop models (not including different versions), and 11 farm models (including livestock production). Nine pairs of these models have already been used together in the past (linked) where crop models provided input for economic models. These links exist at global, European, country, or regional scales providing the backbone for an integrated assessment of food security in several European regions.

Scenarios of climate change and socioeconomic pathways (subsampled from IPCC) will provide a minimum framework for all assessments. Our suggestion is to establish annual production and prices for the whole world using these storylines and feeding simulated weather from Global Circulation Models (GCMs) to vegetation models (Fig. 1). The general vegetation model LPJmL is linked to the global market model MAGPIE and the crop, grassland, and forest models EPIC, Century, and G4M are linked to the global market model GLOBIOM. In the following step, the coarser global projections will be refined by regional models. Candidate models for downscaling world prices are CAPRI and SFARMOD with their linked crop models SimplACE and Mendelu. The annually-stepped output of these crop models should be in line with the weather output of the GCMs. It is desirable that these crop models do not use the output of GCMs directly but the output of Regional Climate Models that can take into account topographic and geographic variation within the coarse modelling units of GCMs. The country scale would be appropriate for additional scenarios with respect to e.g. EU agricultural policies, national GHG reduction policies, regional price variation, or urban sprawl. Within the national price scenario, farm-scale models would be able to account for even more detailed environmental effects of climate change, and could address further scenario variants like adaptation measures, crop rotations, management options, allocation to livestock operation, expansion of areas for biofuel crops. This scale of simulation of crops would again have to be in line with the global and national outputs of climate models and associated vegetation models. At each scale the aggregated sum of crop yields should ideally be the same. The added environmental and economical heterogeneity at finer scales and the use of stochastic functions will, however, create variation across scales that could be minimized by calibration in iterative runs so that the global crop and trade models better reflect the aggregated production and decisions by farmers. Although this fine-tuning cannot be done for each region within the timeframe of the project, it can indicate the uncertainty arising from small-scale variation. The quantification of uncertainty of food security projections is an important task of MACSUR. The suggested integrated multi-scale approach allows assessing uncertainty at different scales, contributions to uncertainty through scaling, model setup (by comparing different models), parameter variation, and stochasticity. Projections and uncertainties can also be compared in space by selecting several geographic focus regions that reflect the dominant farming types and expected stronger climate impacts.

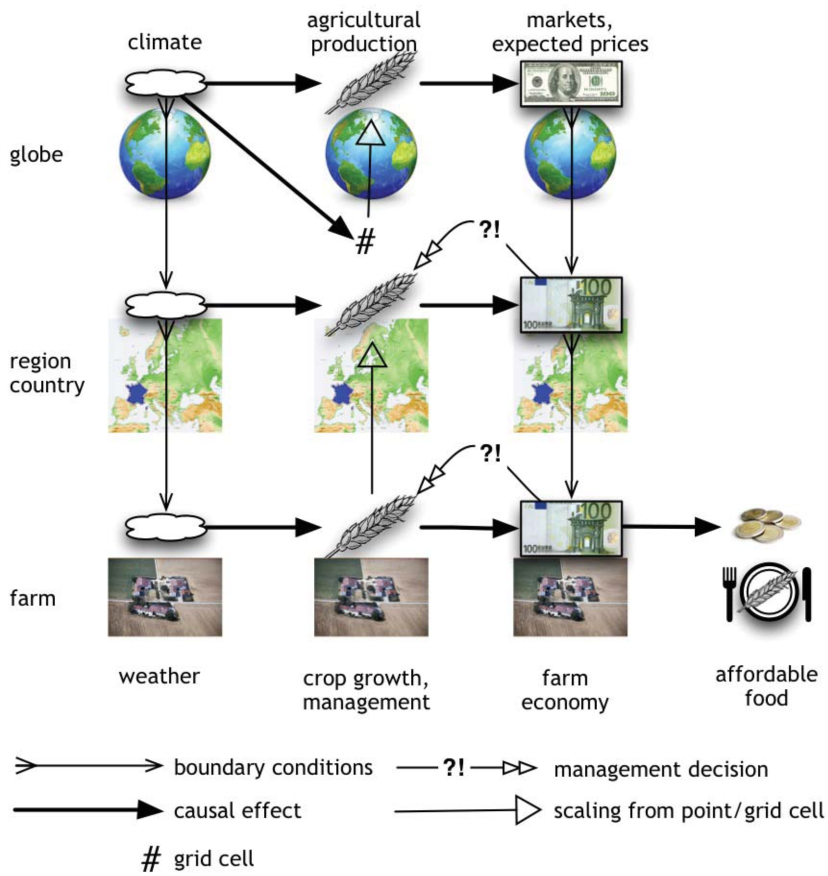

Fig. 1. Suggested concept of linking in- and output of climate, crop, farm and food market models across global, regional, and farm scales to food prices in the MACSUR project.

The above approach for assessing future food security focuses on mechanistic simulations of food production and prices. An alternative approach could focus on the probability of changes in food production and prices. This could be achieved by generating probability density functions from unlinked model runs for food production, food markets, and farm management with variations in external (boundary) conditions. The probability density function could be implemented in a Bayesian network that reflects the dependencies among effects on food security (Fig. 2). The network can be used for exploring the effects of changes in the probability of, e.g., summer droughts, on the likelihood that food availability is low or high conditional on global correlation of weather events. This approach has the great advantage that models do not need to be linked directly but can nonetheless capture the uncertainty and effects across scales.

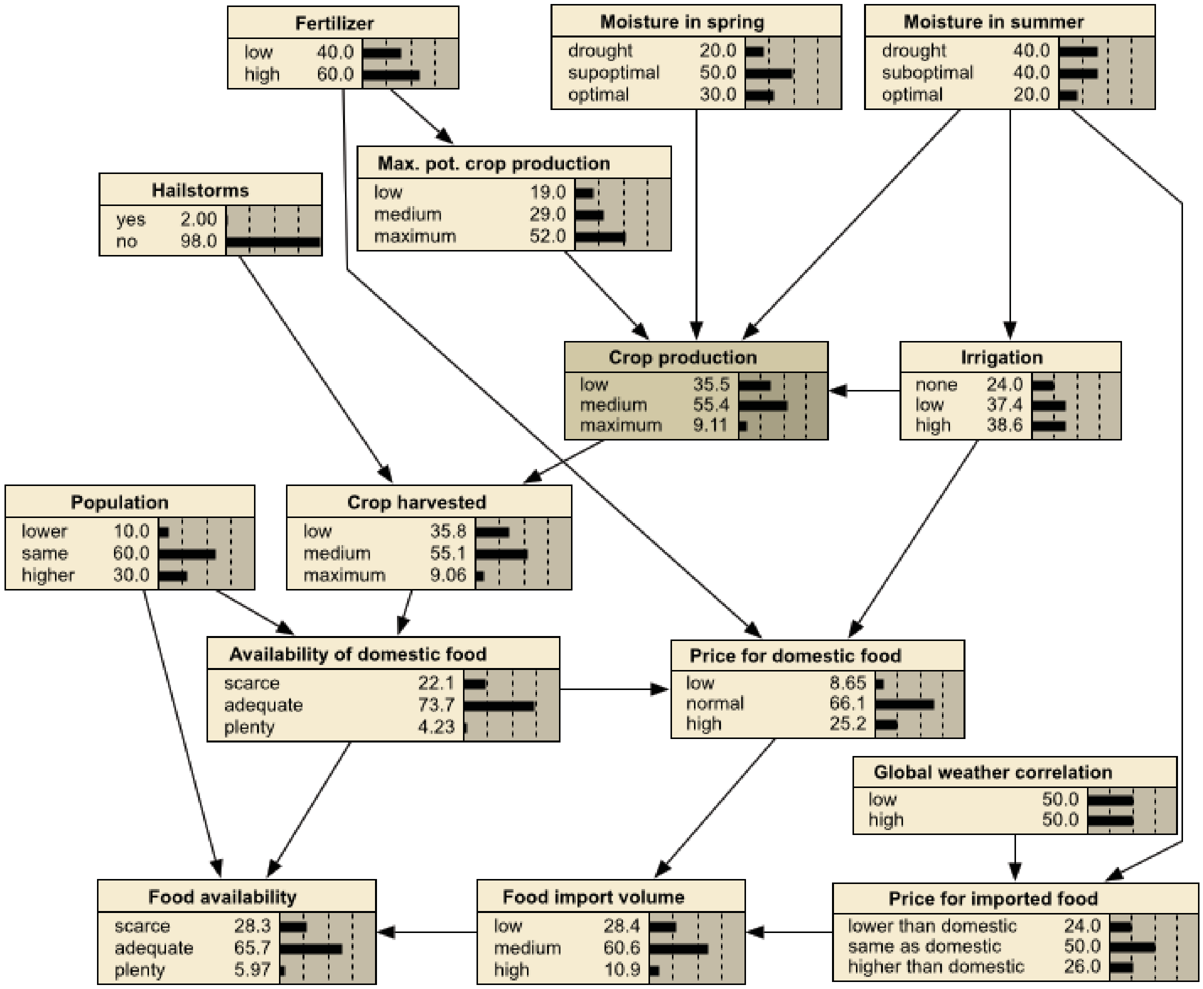

Fig. 2. Illustrative example of a Bayesian network of effects on food availability. Bars indicate values of probabilities of each state (row) of an effect (box) given the probabilities of all 'ancestor' boxes. Default probabilities of states (dependence on only the 'parent' boxes) can be changed to probabilities derived from simulations, observations or expert knowledge. The network can be used to analyze cumulative uncertainties and importance of effects (sensitivity to changes in states).

6 Conclusions

Existing climate, crop, farm, and market models have evolved separately and mostly independently. An assessment of future food security under climate change requires linking these models including feedbacks across scales and organizational units. For consistency, the linked models must use the same storylines and should use the same 'weather' across linked model runs. Models may be linked via output and input of simulation results for a more quantitative assessment or via aggregation in a Bayesian network for emphasis on uncertainties.

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Impacts World 2013, International Conference on Climate Change Effects,
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El Nino Cycles and variability of the Blue Nile annual flow in the Sudan

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Abstract— Impacts of climate change on Africa hydrological systems have already become visible and manifested in variability in rainfall patterns and flows of major rivers. In this paper, El Nino Southern Oscillation Index (ENSO) is used as proxy for investigating climate change impacts in the Sudan hydrologic systems, as the phenomenon cycle has intensified in recent years. Links between ENSO and variability of the annual Blue Nile flows are investigated. A series of annual flow for 96 years for the Blue Nile at El-Deim station together with the ENSO SST index have been used in the analysis. Coexistence between years of low flows and El Nino years was found. Based on the relationship found a probabilistic model for forecasting the annual Blue Nile flow at El-Deim station is developed. The model is tested and is found to be adequate in predicting annual flow of the River at the station. This model can be useful as planning tool for developing adaptation polices and water resource management in the Blue Nile Basin.

Index Terms—Blue Nile, El Nino Southern Oscillation Index, Sudan, Qualitative Probabilistic model

1 Introduction

The Blue Nile is one of the main tributaries of the River Nile, which is the longest river in the world. It rises from Lake Tana in the Ethiopian plateau and flows through Sudan where it joins the White Nile at Khartoum (capital of Sudan) to form the main River Nile. It contributes about 59 % of the annual flow of the River Nile 84 km^3 annual flow. Two mult-purpose reservoirs have been constructed on the river reach in Sudan downstream El Deim Station; the Sennar and Roseries reservoirs. Water stored in these two reservoirs is mainly used for water supply, hydropower generation and for supplying water to the Gezira-Managil irrigation scheme located between the Blue Nile and the White Nile. The Gezira-Managil scheme contributes significantly to the export earnings in Sudan. Thus, the study of the variability of the Blue Nile flows is important for its sustainable water resources management and the economic prosperity of Sudan. It is within this context that the present study has been carried out.

The El Niño-Southern Oscillation (ENSO) results from interactions between large-scale ocean and atmospheric processes in the Pacific Ocean (Chiew et al., 1998). The warm phase of the ENSO is known as El Niño while its cold phase is known as La Niña (Nazemosadat, 2000). The ENSO is described by numerical indices, which utilize the changes in the sea-level pressure or the anomalies of the sea surface temperature (SST) in the Pacific Ocean (Kawamura, 1998). In the present study, the Wright (1989) index of the ENSO sea surface temperature is used. A number of studies have demonstrated that droughts and floods in many parts of Africa are linked to the El Niño-Southern Oscillation (ENSO) (e.g. Mackenzie, 1987; Janowiak, 1988; Ogallo, 1988; Beltrano and Camberlin, 1993; Seleshi et al., 1993; Seleshi and Demaree, 1995; Hastenrath et al., 1995; Camberlin, 1995 & 1997; Eltahir 1996; Osman et al, 2001; Osman & Shamlseldin, 2002; Reibeek, 2011).

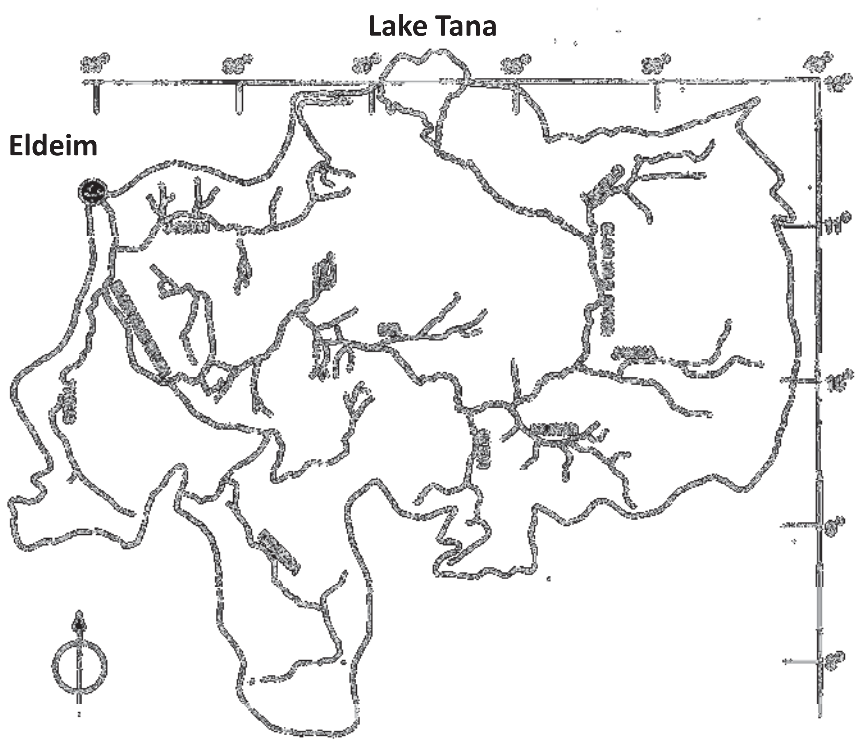

Fig 1 The Blue Nile catchment at ElDeim

In the present study, the effects of the El-Niño Southern Oscillation (ENSO) on the annual flow variability of the Blue Nile are examined and compared. A qualitative probabilistic model for prediction of the annual flow of the Blue Nile is developed using the Wright (1989) index of the ENSO sea surface temperature (SST). The model developed provides qualitative forecasts about the annual flow condition (e.g. dry, normal or wet).

2 Data

In this study, the Blue Nile annual flows for the period 1914-2009 (96 years) at El Deim gauging station are used. A typical monthly flow distribution for the Blue Nile at El Deim guguing station is shown in Figure 2. The index of ENSO used in the present study is the homogenised monthly series of mean sea surface temperature (SST) anomaly, averaged over the region bounded by 6 - 2^{o} N, 170 - 90^{o} W; 2^{o} N - 6^{o} S, 180 - 90^{o} W; 6 - 10^{o} S, 150 - 110^{o} W. The ENSO-SST values are obtained from a published paper by Wright (1989), in which the ENSO-SST values are only available until 1986. The ENSO-SST values for the period (1987-2009) are obtained by linear regression of these available values with the Eastern Equatorial Pacific index, which is available for the period 1845-2011. The later index is also known as the Cold Tongue Index (CTI) and it is defined as the sea surface temperature anomaly averaged over the region 6 N-6^{o} S and 180-90^{o} W (JISAO, 2013). The ENSO index is hereafter referred to as “ENSO-SST”.

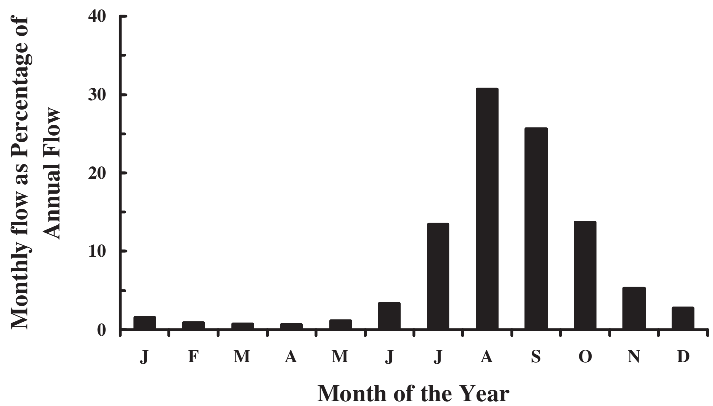

Fig 2 Monthly flow distribution of the Blue Nile at El Deim

3 Correlation of Annual Flow with ENSO-SST index

Due to the uni-modality of the Blue Nile flow hydrograph (see Figure (2)) the analysis presented in this paper uses the annual flow values. The annual flow of the Blue Nile is standardized to obtain the annual flow index (AFI). The monthly ENSO-SST values are averaged seasonally by dividing the year into four seasons, namely, (1) The winter season ($D^{-}JF$) which extends from December of the last year to January and February of the concurrent year, (2) The spring season (MAM) which extends over March, April, and May, (3) The summer season (JJA) which extends over June, July and August and (4) The autumn season (SON) which extends over September, October and November.

The time series of 6 seasons are used in establishing the correlation with the AFI time series. These seasons are the preceding summer ($J^-J^-A^-$), the preceding autumn ($S^-O^-N^-$), the concurrent winter (D^-JF), the concurrent spring (MAM), the concurrent summer (JJA), and the concurrent autumn (SON).

Statistical links between the annual flow index (AFI) and the ENSO-SST are assessed using linear correlation methods by calculating the corresponding correlation coefficients. These correlation coefficients provide quantitative measures of the effects of the ENSO-SST on the annual flow of the Blue Nile.

Table (1) shows the values of the correlation coefficients between the annual flow index (AFI) and the ENSO-SST index and the seasons in which these coefficients are obtained. Examination of data in Table (1) indicates that the AFI is negatively correlated to the ENSO-SST index. Further examination of the table shows that the JJA ENSO-SST season has the highest correlation with the AFI. The two-tailed t-test is used to examine the statistical significance of the highest correlation. The results of the t-test indicate that the correlation coefficient is significant at the 1 % level of significance.

Table 1 Coefficient of correlation of the AFI with the ENSO-SST index

Season	J-J-A-	S-O-N-	D-JF	MAM	JJA	SON
Correlation coefficient (AFI and ENSO-SST index)	-0.126	-0.180	-0.256	-0.342	-0.428	-0.372

Figure (3) displays the time series of the annual flow index (AFI) and the ENSO-SST index for the period 1914 to 2009. The ENSO-SST index is that of the season having the highest correlation with the AFI.

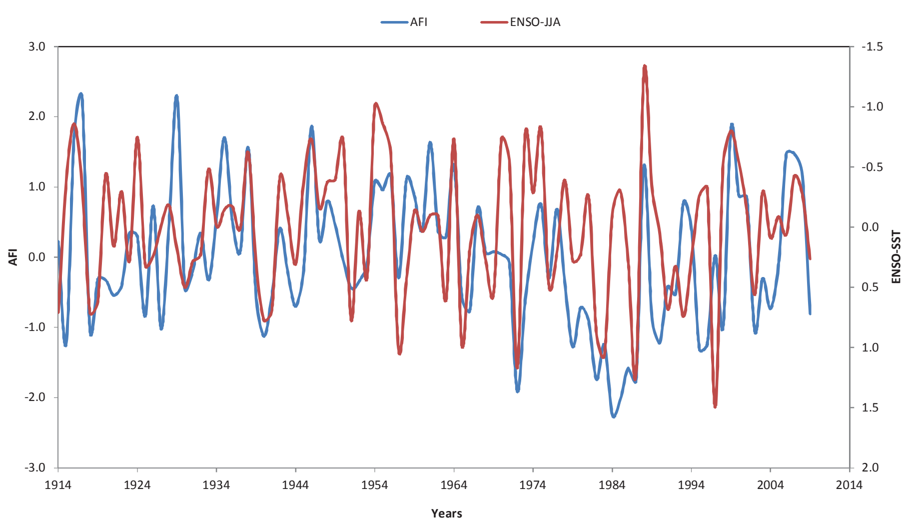

Fig 3 Time Series of the Blue Nile AFI and ENSO-SST

It can be observed in the figure that dry years are usually associated with the warm ENSO-SST and wet years are associated with cold ENSO-SST. This co-existence suggests that in the development of a prediction model for annual flow in the Blue Nile, inclusion for the effect of the ENSO-SST index will be essential.

4 Qualitative Probabilistic Model

4.1 Model development

The development of the qualitative probabilistic prediction model of the annual flow of the Blue Nile is prompted by the correlation results presented in the previous section. The model uses the ENSO index for the JJA season as predictor for the annual flow. The model provides qualitative prediction about the annual flow condition (e.g. dry, normal or wet) together with the corresponding probability of observing the condition. When the medium and long-range predictions of the ENSO-SST conditions are available then the model can provide medium and long-range predictions for the annual flow condition. Model development involves the following steps:

(i) Plotting of scatter diagram for the AFI with the ENSO-SST index using data of the period 1914 – 1986 (see Figure (4) below),

(ii) Drawing of windows on the scatter plot according to the following subjective classification rules:

a) For ENSO-SST values =< - 0.2, the corresponding ENSO condition is regarded as being cold (denote by C) and for ENSO-SST values >= 0.2, the condition is considered as being hot (denote by H). For ENSO-SST values between these two limits, the condition is considered as being normal (denote by N).

b) For AFI values =< - 0.4, the annual flow condition of the year is considered as being dry (denote by D), for AFI values >= 0.4, the condition is regarded as being wet (denote by W) and for AFI values between these two limits the condition is considered as being average (denote by A).

Following the above rules, the scatter diagram in Figure (4) is divided into a set of nine windows.

(iii) For each window in the scatter diagram, the conditional probability of having a dry, average or wet year, given a certain ENSO-SST condition (i.e. hot, normal or cold) is found by dividing the number of data points in the corresponding window by the total number of data points which are associated with the ENSO-SST condition. In Figure (4), the conditional probability is shown as a percentage in the corresponding window.

(iv) The prediction of the probabilistic model for the category of the annual flow (i.e. dry, average or wet) given a particular ENSO-SST condition is that which has the highest conditional probability.

Table (2) displays the conditional probability of the annual flow category given a certain ENSO-SST condition as obtained from Figure 4. The probabilities of having a dry, an average or a wet year in the Blue Nile, without knowledge of ENSO-SST conditions, are also derived and shown in Table (3). Inspection of Table (3) shows that the most likely predication of annual flow category in the Blue Nile is 'average' (the probability of an average year being 36 %).

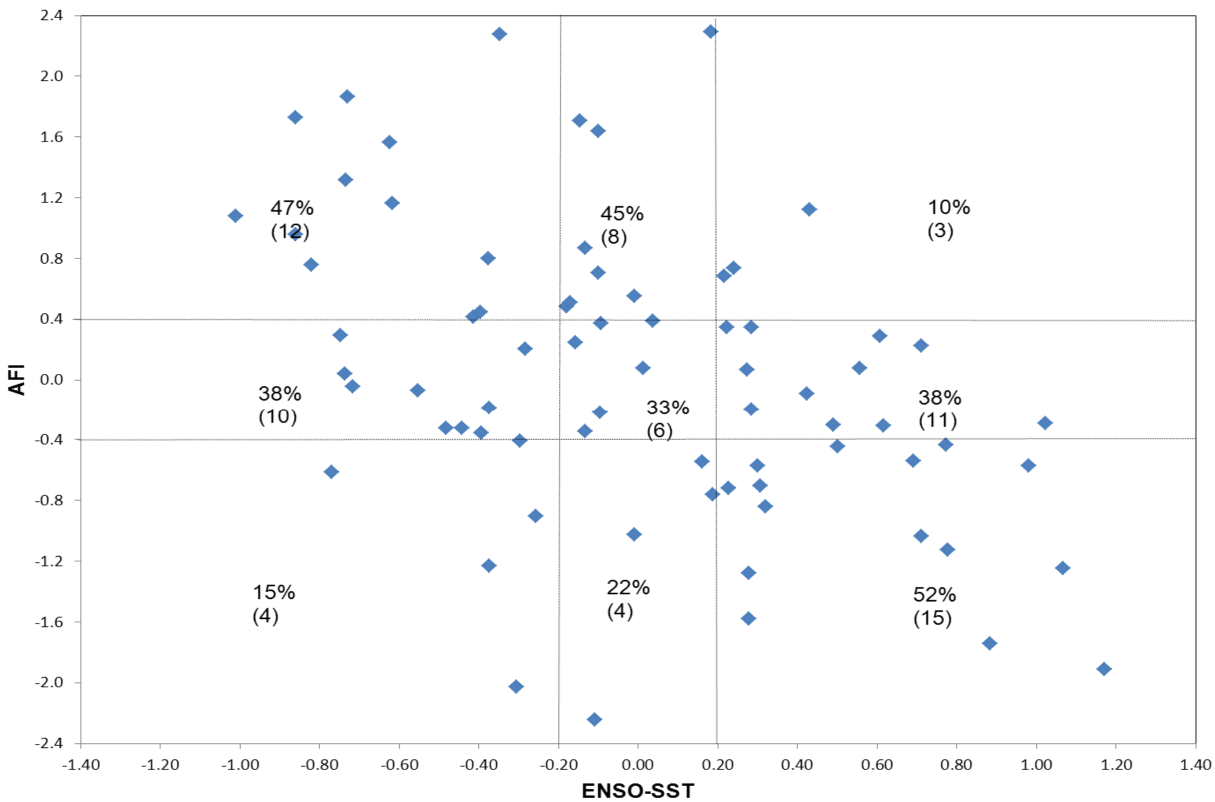

Fig 4 Scatter Diagram of AFI with the ENSO-SST index.

Figure (4) can be viewed as graphical forms of contingency tables of categorical data. Thus, they can be used to test the statistical significance of the dependence between the AFI with the ENSO-SST index using the chi-square (χ^2) test of independence. The results of this test confirm that the relation between the AFI and the ENSO-SST are statistically significant at the 1 % significance level.

Table 2 Conditional Probability of the annual flow category given the ENSO-SST index.

	ENSO SST category		
Annual flow category	C	N	H
D	0.15	0.22	0.52
A	0.38	0.33	0.38
W	0.47	0.45	0.10

Table 3 Probability of the annual flow category without the knowledge of the ENSO-SST index

D	A	W
0.32	0.36	0.32

4.2 Performance of the model

To verify the adequacy of the probabilistic model developed in the previous section, the observed AFI, ENOS-SST time series for 23 years (1987-2009) are used. A summary of the data used in the verification of the model is shown in Table (4).

Table (4) shows the results of the qualitative probabilistic model with the ENSO-SST condition being used as the predictor variable. On the basis of the AFI classification, there are 11 ‘D’ years, 9 ‘W’ years and 3 ‘A’ years in the observed data. The classifications of the verification years are shown on the third column of the table. The model predictions for the conditions of the verification years with the knowledge of the ENSO-SST conditions are shown on the fifth column of the table. Examination of this column shows that the model predicts 8 ‘D’ years and 15 ‘W’ years. Comparison of the model predictions and the observed conditions (see column seven) shows that the model predictions are correct in 14 out of the 23 years of the verification period (i.e. the model efficiency is 61 %). In the absence of the ENOS-SST information, the prediction of the annual flow condition is average ‘A’ for all of the verification years (see Table (3)) which is correct only for 3 years out of the thirteen verification years, as shown in column 9 of Table (4) (i.e. the efficiency is 13 %).

The results presented in Table (4) suggest that the performance of the probabilistic model when the EN-SO-SST conditions are used is better than the model which is not used it.

Table (4): Results of the probabilistic model in the verification years

Year	Annual Flow Index		ENSO-SST		Model prediction using ENSO-SST		Model prediction without ENSO-SST	
	Value	Category	(C^o)	Category	Category	Evaluation	Category	Evaluation
1987	-1.8	D	1.22	H	D	T	A	F
1988	1.3	W	-1.30	C	W	T	A	F
1989	-0.8	D	-0.34	C	W	F	A	F
1990	-1.2	D	0.05	N	W	F	A	F
1991	-0.4	D	0.68	H	D	T	A	F
1994	0.4	W	0.26	H	D	F	A	F
1995	-1.3	D	-0.26	C	W	F	A	F
1996	-1.2	D	-0.33	C	W	F	A	F
1997	0.0	A	1.50	H	D	F	A	T
1998	-1.0	D	-0.52	C	W	F	A	F
1999	1.8	W	-0.80	C	W	T	A	F
2000	0.9	W	-0.53	C	W	T	A	F
2001	0.9	W	-0.14	N	W	T	A	F
2002	-1.1	D	0.56	H	D	T	A	F
2003	-0.3	A	-0.29	C	W	T	A	T
2004	-0.7	D	0.09	N	W	F	A	F
2005	-0.1	A	-0.09	N	W	T	A	T
2006	1.5	W	0.06	N	W	T	A	F
2007	1.5	W	-0.42	C	W	T	A	F
2008	1.2	W	-0.27	C	W	T	A	F
2009	-0.8	D	0.26	H	D	T	A	F

* F denotes false prediction
** T denotes correct (true) prediction

5 Concluding remarks

In the present study, the influences of the El Niño-Southern Oscillation (ENSO) on the annual flow variability of the Blue Nile River have been investigated. The following concluding remarks have reached:

- The Blue Nile annual flow index (AFI) is negatively correlated to the ENSO-SST index. Dry years coincide with warm ENSO and Wet years coincide with cold ENSO.
- Verification results of the qualitative probabilistic model developed, which uses ENSO as predictor, out-perform the model which does not use ENSO.
- The developed model can be used to give forecast of flow at planning stages.

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Framework for multi-scale integrated impact analyses of climate change mitigation options

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Abstract— Tropical forest ecosystems are hotspots for biodiversity and represent one of the largest terrestrial carbon stocks, making their role in climate change mitigation (CCM) programmes increasingly important (e.g. REDD+). In Latin America these ecosystems suffer from high land use pressures that have resulted in a dramatic biodiversity loss. Little is known about how CCM options may impact on biodiversity and how this in turn may affect ecosystem carbon storage. Within this context, the FP7 ROBIN (Role Of Biodiversity In climate change mitigatioN) project developed a framework for multi-scale integrated analysis of the impacts that land use change may have on the ecological and social-economic processes of these ecosystems. The framework represents a continuous feedback loop in which changes in CCM options modify land use, that results in biodiversity change, affecting ecosystem functions, leading to changes in ecosystem services that affect human outcomes and societal behaviour, and which then affect the main drivers and pressures on biodiversity and ecosystems, and so on. We have constructed an indicator framework that allows to quantify, link and assess these interactions at three spatial scales: regional (Central and South America), national (Bolivia, Brazil, Guyana and Mexico) and sub-national (study sites representing multifunctional landscapes). Indicators are selected through a demand-driven approach, by directing modelling and assessment efforts towards end-user relevant issues using stakeholder participatory processes. Indicator values are grounded on field data, statistics and model outputs. The framework provides a basis for understanding potential tipping points and unexpected consequences that may arise from the implementation of climate change mitigation policies, or management options (e.g. reducing deforestation and burning, or expansion of areas of biofuel crops in illegal areas). An illustrative example, showing how the framework helps to identify the appropriate indicators to synthesise the impacts of afforestation (one of the CCM options) across the ecological and socio-ecological processes and regions is presented.

Index Terms—Biodiversity, climate change mitigation (CCM), framework for multi-scale integrated impact analysis, tropical forest ecosystems, social-ecological systems.

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1 Introduction

Tropical forest ecosystems are hotspots for biodiversity and represent one of the largest terrestrial carbon stocks (IPCC 2007), making their role in climate change mitigation (CCM) programmes increasingly important (e.g. REDD+). In Latin America these ecosystems suffer from high land use pressures that have resulted in a dramatic biodiversity loss (Higgins, 2007). Little is known about how CCM options may impact on biodiversity and how this in turn may affect ecosystem carbon storage. Furthermore, it is also unknown how these changes in the ecological system will affect the underpinned ecosystem services, their benefits to human beings and finally result in changes in human behaviour and societies (mitigation and adaptation measures). The assessment of this complex social-ecological process requires analytical frameworks that are able to deal with the multi-scale, multi-sectoral interactions. Within this context, the FP7 ROBIN (Role Of Biodiversity In climate change mitigatioN) project has developed a framework for multi-scale integrated analyses of the impacts that land use change may have on the social-ecological processes of these systems. The objective of this paper is to contribute to the conference discussions on "Can we integrate our existing knowledge across sectors?" by introducing the ROBIN framework for multi-scale integrated impact analyses of climate change mitigation options, and illustrating how it can be applied.

2 Analytical framework for multi-scale integrated impact analyses

The ROBIN analytical framework (Fig. 1) is based on the Integrative Science for Society and Science ISSE framework (Collins et al. 2010). It has been designed to address the following key research questions:

1. **Q1**: How do changes in biodiversity affect key ecosystem processes that then affect the capacity of ecosystems and multi-functional landscapes to mitigate climate change?
2. **Q2a** and **Q2b**: How do changes in biodiversity and linked ecosystem structure and functions affect (Q2a) climate change mitigation capacity and (Q2b) other key ecosystem services?
3. **Q3**: How do changes in climate mitigation capacity affect human outcomes (i.e. benefits to society) and what is the effect of taking into account other ecosystem services in this evaluation process?
4. **Q4**: How do changes in human outcomes affect societal behaviour?
5. **Q5**: How do changes inglobal drivers, policies and management options affect climate change and land use change?
6. **Q6**: How do changes in climate and land use affect the biodiversity and ecosystem functions?

The framework represents a continuous feedback loop in which changes in CCM options modify land use that result in biodiversity changes, affecting ecosystem functions, leading to changes in the provision of ecosystem services that affect human outcomes and societal behaviour, and which then affect the main drivers and pressures on biodiversity and ecosystems and so on.

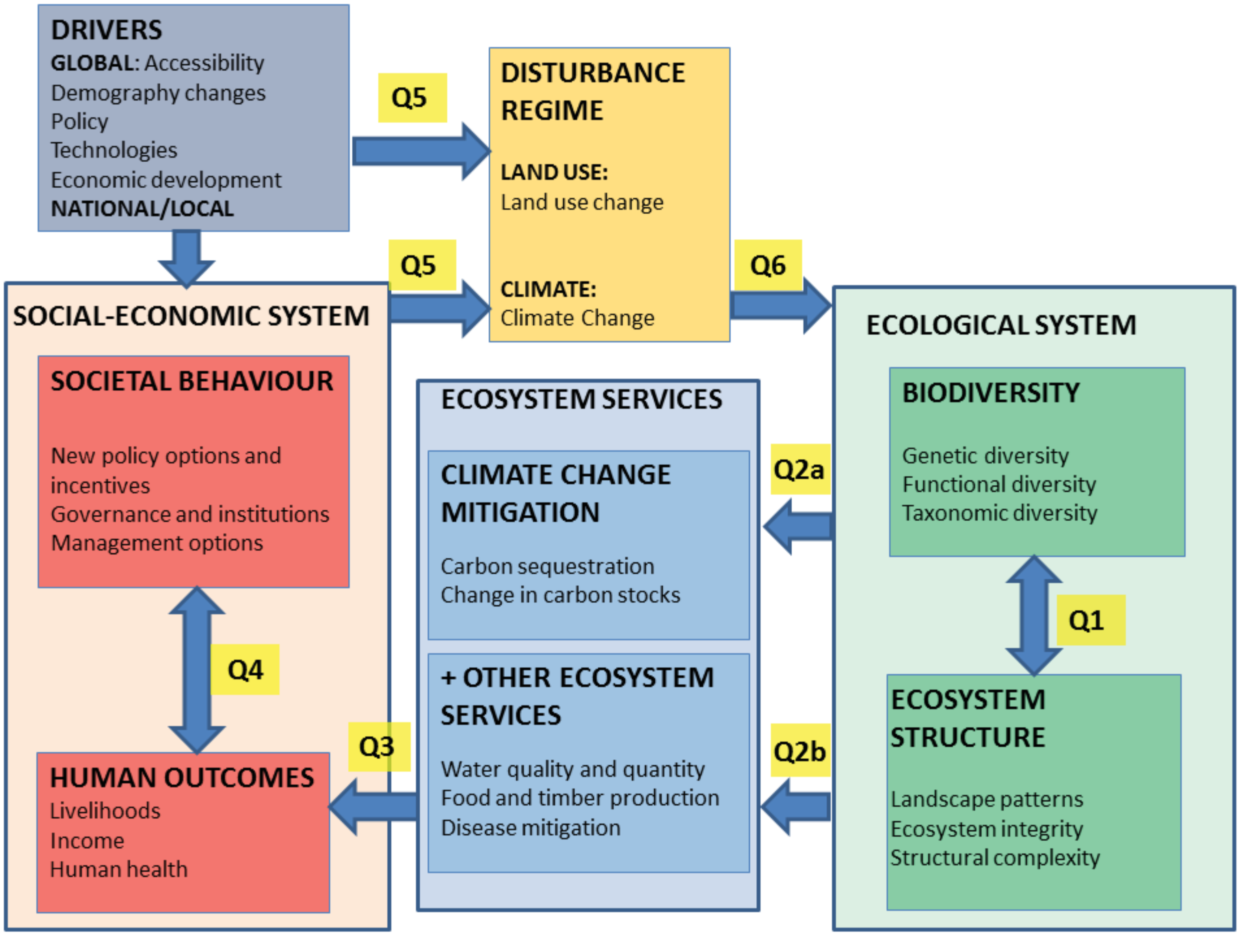

Figure 1. ROBIN analytical framework showing the main *Categories* as coloured boxes (e.g. DISTURBANCE REGIME), *Themes* within the boxes (e.g. LAND USE) and *Variables* (e.g. Land use change).

3 Indicator framework

The analytical framework is connected to an indicator framework for quantifying the interactions at three spatial scales: regional (Central and South America), national (having as example countries Bolivia, Brazil, Guyana and Mexico) and sub-national (study sites representing multifunctional landscapes). Indicators are selected ensuring a demand-driven approach, by directing modelling and assessment efforts towards end-user relevant issues, using stakeholder participatory processes. Indicator values are grounded on field data, statistics and model outputs. The framework provides a basis for understanding potential tipping points and unexpected consequences that may arise from the implementation of climate change mitigation policies, or management options (e.g. reducing deforestation and burning, expansion of areas of biofuel crops in illegal areas).

3.1 Structure of the indicator framework

The indicators selected for the ROBIN indicator framework are linked to the ‘boxes’ in the analytical framework presented in Figure 1. The indicator framework is structured into four divisions: categories, themes, variables and indicators, defined as follows:

- CATEGORIES: Broad group of issues to be assessed and analysed in the context of the ROBIN indicator framework. These issues are linked to the continuous flow between the ecological and social-economic systems, i.e. global and national drivers cause changes in land use and climate that affect eco-systems and particularly their biodiversity, which in turn impact their provision of ecosystem services, with direct and indirect impacts on the social-economic system (human outcomes affecting societal be-haviour) that drive changes, etc. They can be identified as the ‘boxes’ with different colours in Figure 1.

- THEMES: Main particular issues to be tackled within each category in order to assess and analyse the key research questions. For example, within the category ecosystem services, there are two themes: climate change mitigation (main focus of ROBIN) and other ecosystem services.

- VARIABLES: topics under each theme which value varies in time and/or space according to their current state, dynamics and trends. An operational variable is a representation of an attribute (quality characteristic, property) of a system. The pragmatic interpretation of a particular variable as an indicator is usually made on the basis that this variable carries information about the condition and/or trends of the considered system attribute.

- INDICATORS/INDEXES: They help to characterise the state, dynamics and trends of variables to be monitored, assessed and analysed. Overall, an indicator is an empirical observation or statistical esti-mation that synthesizes aspects of one or more events that are important to one or more analytical or user requirements purposes over time.

3.2 Selection of indicators

In ROBIN the selection of indicators follows a stepwise approach. In the first step, a preliminary selection is based on an extensive review of available and relevant datasets and frameworks in Latin America, which are linked to impact assessment of land use change, climate change and the sustainability of so-cial-ecological systems, particularly biodiversity, using international, regional, national and local sources. Indicators are selected 1) considering the different spatial and temporal aspects of ecosystem dynamics in climate change mitigation; 2) ensuring that both the socio-economic and environmental dimensions of land-use are covered; 3) helping to relate main policy questions to diagnostic criteria on system sustainability.

Once the data sources are reviewed and potential indicators identified, a consistent selection of the indicators is done by a few key criteria. 1) A maximum of three key indicators are selected per VARIABLE (e.g. land use change) for the regional and national scales; the number of key indicators for the local scale is not fixed since it will be regularly updated throughout the project based on the input from the local stakeholders and the participants in the project as it evolves. 2) The key indicators are ideally the same for the three spatial scales. 3) Data are available in international, national and local data sources, and if possible at different time periods.

Applying these criteria, tables were produced for the six main categories in the analytical framework, i.e. drivers, disturbance regime, ecosystem, ecosystem services, human benefits and human behaviour. The tables are structured according to categories, themes, variables and indicators/indexes, as defined above. See Table 1 as an example of the current selection of indicators for the Category "DISTURBANCE REGIME".

In a second step, end users will revise the preliminary list ensuring a demand driven approach. By end-users we mean scientists within and outside the project, and policy and decision makers at different decision levels: government officers (national, sub-national and local authorities), land use managers (national and local), NGO's, cooperatives, farmers, wood producers, etc. Then the revised indicator list will be operationalised by using the framework to assess the impact of some climate change mitigation options in case studies. This activity will test and improve the validity of the established framework.

Table 1. Indexes and Indicators for the DISTURBANCE REGIME category

CATEGORY	THEME	VARIABLE	INDICATOR/INDEX		
			REGIONAL (Meso-America and South-America)	NATIONAL (Bolivia, Brazil, Guyana and Mexico)	SUB-NATIONAL (case studies:Tapajos, Guarayos, Cuitzmala)
DISTURB-ANCE REGIME	LAND USE	1. Land use change (including land management)	1a. Forest risk index	1a. Forest cover change (by type) 1a. Deforestation rate (%, has, by type of forest)	1a. Forest degradation index 1a. Phenology/ disturbance index (derived from Remote Sensing)
			1b. Land use index	1b. Land Use Land Cover Change 1b. Land use potential	1b. Land degradation index 1b. Carrying capacity index (Animal Units/ha) 1b. Fraction of functional crop types 1b. Harvested biomass 1b. Residual biomass after harvesting 1b. Land use carbon change in soils 1b. Land use carbon change in biomass
			1c. Crops affected by pest and diseases	1c. Use of pesticides per ha	1c. Location of crops diseases 1c. Location of livestock diseases 1c. Location of forest diseases 1c. Location of human diseases
			1d. Invasive species	1d. # of alien plants species	1d. Location of alien plants species
	CLI-MATE	2. Climate change	2a. Climatic risk index	2a. Precipitation/ temperature change 2a. Drought events (#, areas affected, economic losses) 2a. Flood events ((#, areas affected, economic losses)	2a. Economic impact of ENSO[1] 2a. Evapo- transpiration change 2a. Precipitation/ temperature change 2a. Area affected by drought 2a. Area affected by flood
			2b. Fires location/extension	2b. CO_2 emissions by land use change 2b. Fire location 2b. Fires risk	2b. Area affected by fires 2b. CO_2 emissions by land use change 2b. CH_4 emissions by land use change

4 Example illustrating the analytical framework application

The example in Figure 2 shows how the ROBIN framework (see Fig. 1) helps to identify the appropriate indicators to synthesise the impacts of afforestation (one of the CCM options) across the ecological and socio-ecological processes and regions. The framework can be consistently applied to address the key research questions (see section 2 above) at three different scales (regional, national and sub-national, and provides a logical and functional link between the different conceptual compartments and integration between the three spatial scales. It is interesting to see how the different indexes and indicators are used at different scales depending on their relevance and availability.

[1] ENSO = El Niño-Southern Oscillation

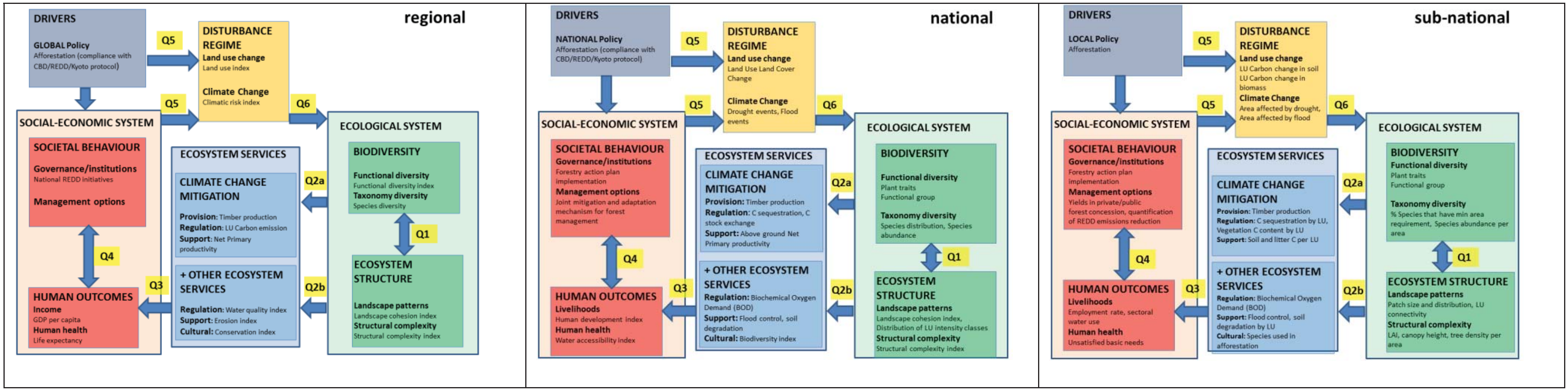

Figure 2. Example illustrating the application of the analytical framework integrating the different conceptual compartments at three scale levels: regional, national and sub-national.

5 Conclusions

One of the biggest challenges to define efficient and effective climate change mitigation options is to integrate our existing knowledge across sectors and scales. Achieving understanding on the interactions and feedbacks between sectors at different spatial levels as well as across ecological and social structures, could have a profound influence on the global mitigation capacity. We introduce here a generic analytical framework based on a circular model, where the links between the sectors within the social-ecological system are made explicit and measurable through a set of key indicators. This framework can be applied at different spatial levels in a consistent and flexible manner, allowing a multi-scale integrated assessment. The framework can also provide an understanding of the potential effects of changes in other 'land-use-related' policies than climate change, such as environmental and agricultural policies. Our framework thus provides the basic building blocks for a better understanding of the feed-back loops in the system, the interaction between scales and the testing of mitigation options.

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Cross-sectoral conflicts for water under climate change: the need to include water quality impacts

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Abstract— Climate change is expected to increase pressures on water use between different sectors (e.g. agriculture, energy, industry, domestic uses) and ecosystems. While climate change impacts on water availability have been studied widely, less work has been done to assess impacts on water quality. This study proposes a modelling framework to incorporate water quality in analyses of cross-sectoral conflicts for water between human uses and ecosystems under climate change and socio-economic changes. We illustrate this with an example that shows that increasing river temperatures and declines in summer low flow under climate change are likely to increase environmental restrictions on cooling water use, with substantial reductions in power plant capacities in Europe and the US. Hence, conflicts between environmental objectives and electricity supply are expected to increase due to both changes in water availability and water quality (water temperature) under climate change. A new impact modelling framework is proposed, which integrates relations between water availability, water quality and cross-sectoral water uses, including water requirements for ecosystems. This could provide improved understanding of how climate change and socio-economic developments will affect the 'water-energy-food-ecosystem nexus'.

Index Terms—river flow, water temperature, water quality, climate change, socio-economic developments, human water use, ecosystems

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1 Introduction

Climate change in combination with other anthropogenic changes is expected to contribute to an increasing pressure on water between human water use sectors (e.g. agriculture, energy, industry, domestic uses) and ecosystems (Alcamo et al., 2003). In addition, water demand is expected to increase with a growing and more prosperous global population (Vörösmarty et al., 2000). Sufficient water of suitable quality to guarantee human uses and ecosystem health could therefore become a main challenge in the next decades.

The increasing awareness that climate change may affect water resources has greatly stimulated the study of the hydrological impacts of a changing climate. While impacts on water quantity have been studied widely on different scales, varying from catchment (e.g. van Roosmalen et al., 2009) to continents (e.g. Feyen and Dankers, 2009) and the world (e.g. Döll and Müller Schmied, 2012), considerably less work has been done to assess climate change impacts on water quality. However, most sectors require not only sufficient water availability (quantity), but also suitable water quality. For instance, water temperature is a critical parameter for cooling water use in the energy and industrial sector, while salinity and nutrient concentrations are important for agricultural and drinking water uses. The need to expand hydrological impact assessments to incorporate water quality issues has therefore been increasingly recognized (Kundzewicz and Krysanova, 2010; Whitehead et al., 2009).

In this paper, we propose a modelling framework to incorporate water quality, in addition to water availability, in studies of cross-sectoral water stress under global change. We illustrate the need to include water quality by focussing on water temperature, which is most directly affected by climate change. Water temperatue also influences several other water quality parameters, such as dissolved oxygen and nutrient concentrations and toxicity of heavy metals (Ducharne, 2008; Murdoch et al., 2000). Water temperature and river flow are also major parameters that characterize the physical conditions of freshwater habitats (Carpenter et al., 1992; Rahel et al., 1996), and are of economic importance for cooling water use for thermoelectric power production and manufacturing (Manoha et al., 2008). We highlight cross-sectoral conflicts for water availability and quality, by focussing on impacts of changes in river flow and water temperature on cooling water use in the energy sector and freshwater ecosystem health.

2 Modelling of conflicts for water availability and water temperature between energy sector and freshwater ecosystems

To simulate large-scale conflicts for water between cooling water use in the energy sector and freshwater ecosystems, we worked on the development of a large-scale water temperature module linked to a macro-scale hydrological model. We used a physically-based modelling framework, consisting of the stream temperature River Basin Model (RBM) (Yearsley, 2009; Yearsley, 2012) and the Variable Infiltration Capacity (VIC) macro-scale hydrological model (Liang et al., 1994). RBM was further developed for applications to large rivers worldwide, including human impacts of thermal pollution and reservoir impacts on water temperature (van Vliet et al., 2012a). The resulting framework simulated observed conditions realistically (van Vliet et al., 2012a). It was then forced with an ensemble of bias-corrected general circulation model (GCM) output for the 21st century (Hagemann et al., 2011) provided within the EU FP6 WATCH project. Overall, water temperature sensitivities are exacerbated by projected declines in low-flows, resulting in a reduced thermal capacity (van Vliet et al., 2011). Strong increases in water temperature and reductions in low flows are mainly projected in the south-eastern United States, southern and central Europe and eastern China (van Vliet et al., 2013) (Fig. 1). These regions could therefore be potentially affected by increased deterioration of water quality and freshwater habitats, and reduced potentials for human water uses under future climate.

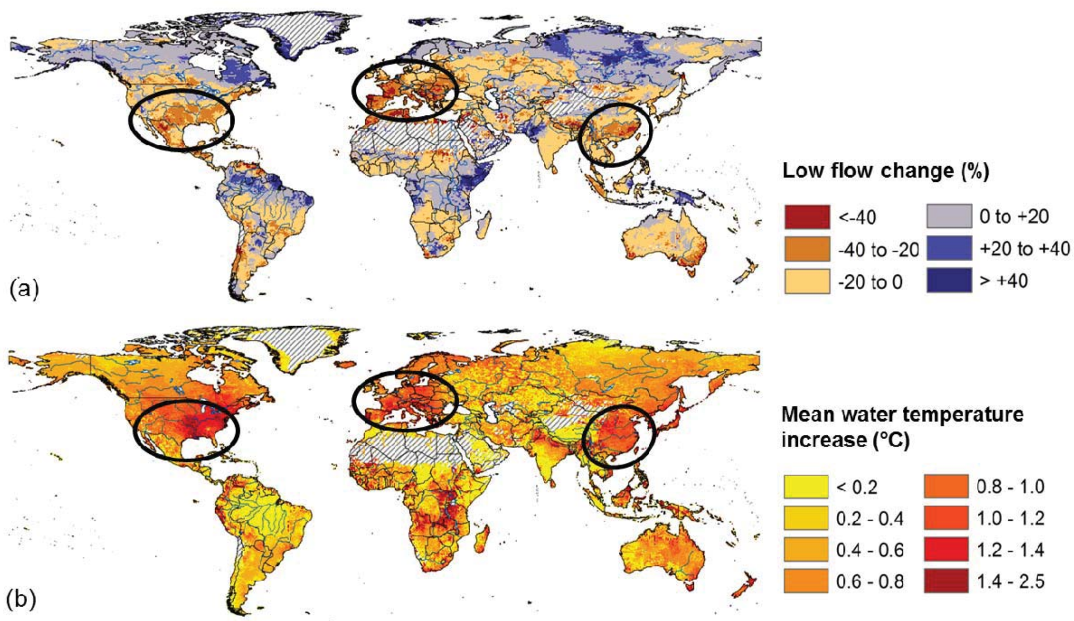

Fig. 1: Impact of climate change on low river flows (10-percentile daily flow)(a) and mean water temperatures (b) for 2031-2060 relative to 1971-2000 using the GCM ensemble mean simulations for SRES A2. The results are masked (hatched areas) for regions with very low (<1 m^3s^{-1}) river flow.

Impacts of projected changes in river flow and water temperature on cooling water use in the energy sector and freshwater ecosystems (i.e. fish habitats) were assessed in more detail. The frequency and magnitude of exceeding maximum temperature tolerance values of several fish species increased significantly for considerable areas of current suitable habitats (van Vliet et al., in revision). This could, in combination with changes in flow regime, affect the distributions of freshwater species. To maintain and protect current freshwater ecosystems, environmental standards are defined with regard to the volume and temperature of water for cooling water use (European Water Framework Directive and Fish Directive, and U.S. Clean Water Act). In Europe and the U.S., most electricity (91% and 78%, respectively) is currently produced by thermoelectric power plants depending on cooling water, and large fractions of water for cooling are extracted from rivers. Projected increases in river temperatures and declines in low summer flow for both regions are expected to increase environmental restrictions on cooling water use. This could result in substantial reductions in summer mean usable capacity of 6–19% for Europe and 4–16% for the US (depending on cooling system type and climate scenario for 2031-2060 relative to 1971-2000) (van Vliet et al., 2012b) (Fig. 2). Conflicts between environmental objectives and economic consequences of reduced electricity production are thus expected to increase in both regions due to the combination of increases in water temperatures and declines in summer low flow under climate change.

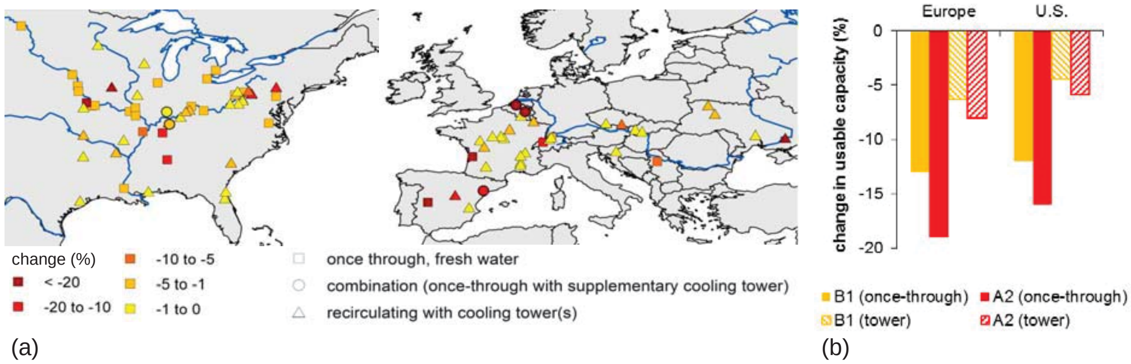

Fig. 2: Changes in summer mean usable capacity of thermoelectric power plants in the U.S. and Europe for SRES A2 emission scenario for 2031-2060 relative to 1971-2000 assuming current environmental regulations to protect ecosystems (figure panel of van Vliet et al. (2012b), with permission of Nature Climate Change) (a). Histograms present the regional average changes in usable power plant capacity for power plants with once-through and combination cooling systems and power plants with recirculation (tower) cooling systems for both the SRES A2 and B1 scenario (b). For more results see van Vliet et al. (2012b).

3 Conceptual modelling framework including water quality impacts

Most of the modeling frameworks that are currently used for climate change impacts analyses on water resources focus on water quanity and ignore water quality. Global water stress was commonly estimated by calculating the withdrawals-to-availability ratio (e.g. Alcamo et al., 2007; Arnell et al., 2011) using only river discharge and water withdrawal simulations. However, most water use sectors require not only sufficient water availability (quantity), but also suitable water quality.

The proposed modelling framework (Fig. 3) consists of a multi-model ensemble of both climate change scenarios (based on representative concentration pathways (RCPs) (Moss et al., 2010) and shared socio-economic pathways (SSPs) (Kriegler et al., 2012). These climate and socio-economic scenarios are used in global hydrological models with linked water quality modules and sectoral water use modules. To integrate relations between water availability, water quality and cross-sectoral water uses, both surface water availability and water quality will be simulated. In addition, water demand for different sectors and water requirements for freshwater ecoystems will be calculated with regard to both water availability and water quality.

Water quality parameters that are relevant for agriculture, domestic uses and ecosystem health are for instance salinity, nutrients, heavy metals and PAHs (polycyclic aromatic hydrocarbon). Water temperature is mainly important for energy and industrial uses, and also for human health (drinking water) and ecosystem functioning. For most of these water uses, specific threshold values that reflect a deterioration or reduction in water usage potential are defined. For instance, for drinking water production, the World Health Organization (WHO, 2011) defined water quality standards, like the 25°C water temperature limit for which thermophilic pathogens (e.g. Legionella Campylobacter and Vibrio cholerae) in surface waters with low residual concentrations of chlorine proliferate. The focus should therefore be on the availability of water of suitable water quality for each water use function. In addition, water quality can also influence water demand and these impacts could also be included in water stress analyses. For instance, the water demand for thermoelectric power strongly increases when water temperature rises (van Vliet et al., 2012b). Changes in thermoelectric water demands and water stress under future climate could therefore be underestimated if impacts of water temperature increases are ignored. Davies and Simonovic (2011) also showed that inclusion of dilution capacity for pollutants in water demands has large impacts on calculated water stress levels. Future changes in water quality under climate change and socio-economic changes would therefore be important to consider. The use of simulations of river flow, water quality and water demand (with regard to both availability and quality), is therefore highly recommended to improve the assessment of water stress under global change.

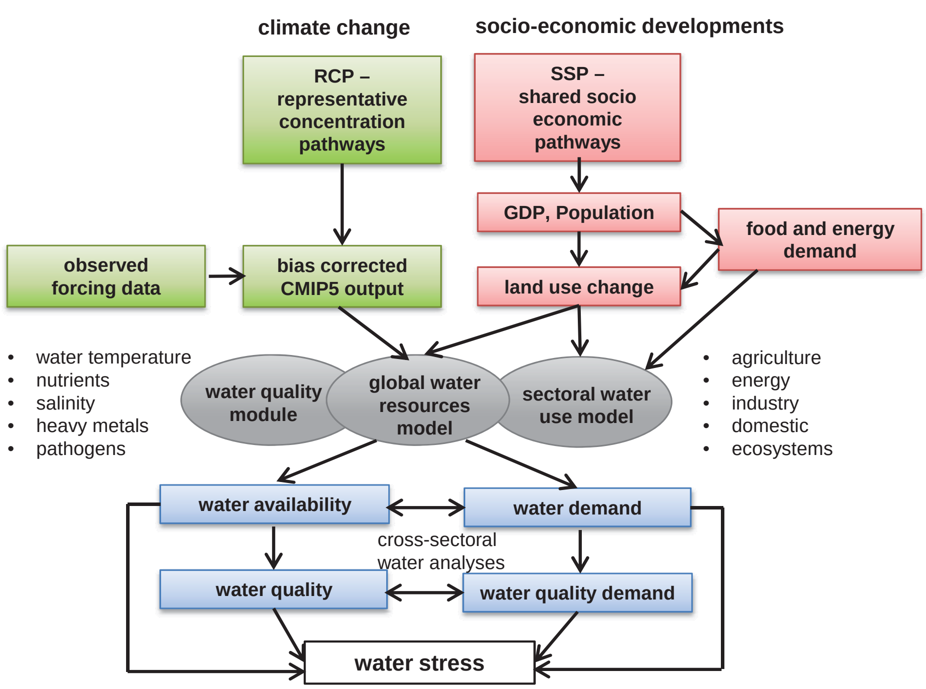

Fig. 3: Proposed modelling framework to integrate relations between water availability, water quality and cross-sectoral water uses under climate change and socio-economic developments.

4 Conclusions

Most water use sectors require not only sufficient water availability (quantity) but also suitable water quality. As pointed out in Section 2, the pressure on water between cooling water use in the energy sector and freshwater ecosystems in Europe and the U.S. will increase under climate change, because of changes in both summer flow and water temperature. Ignoring water temperature increases could result in an underestimation of the pressure on water between the energy sector and freshwater ecosystems.

For assessments of water stress and cross-sectoral conflicts for water under future climate and socio-economic changes, we therefore propose a modelling framework that includes both water availability and water quality.

Although the focus of our study has been limited to climate change impacts on global river flow and water temperature, the hydrological - stream temperature modelling framework (VIC-RBM) used in this study has potential to include other water quality parameters (van Vliet et al., 2013; Yearsley, 2009). An extension of the modelling framework to other water quality parameters affected by water temperature (e.g. dissolved oxygen), streamflow (e.g. conservative substainces) or both (nutrients, pathogens) could be a next step. Analysis of the competition for water between different water use sectors and freshwater ecosystems including water quality impacts, could contribute to improved understanding of the developments of the 'water-energy-food-ecosystem nexus' in the 21st century.

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Topic 2:

Is anybody listening?

Climate Change Implications for Smallholder Agriculture and Adaptation in the White Volta Basin of the Upper East Region of Ghana

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Abstract

In this paper we use the TOA-MD model to test climate change impacts and adaptation strategies with socioeconomic, survey data from the upper White Volta Basin of Ghana. Combining simulated and expected crop and livestock yields under three different climate scenarios, the economic impact of climate change to 2050 is analysed. We find that livelihood outcome variables like income and poverty levels as well as adoption rates are sensitive to the different climate scenarios. Most particularly, introducing an I&E technology as climate change adaptation strategy offsets some negative impacts and improves income but not poverty rates in the area. The results are useful in providing spatiotemporarily-specific policy recommendations on the potential impacts of climate change and the economic outcomes associated with different adaptation strategies.

Key words: adaptation, climate change, Ghana, white volta basin

While modeling tools and assumptions are global, we only report results for Sub-Saharan Africa.

(1) direct effects on rainfed yields through changes in temperature and precipitation; (2) indirect effects on irrigated yields from changes in temperature and in water available for irrigation (including precipitation); and (3) autonomous adjustments to area and yield due to price effects and changes in trade flows in the economic model.

When IMPACT projections are compared with and without climate change scenarios, the "net" effects of climate change on agricultural production, demand, trade, and prices can be obtained.

The direct and indirect effects of climate change on agriculture play out through the economic system, altering prices, production, productivity, food demand, calorie availability, and, ultimately, human well-being.

1.Introduction

Climate change is projected to intensify the challenges already faced by Sub-Saharan Africa's (SSA) smallholder farmers. Changes in rainfall levels and distribution, rising temperatures and variations in soil carbon utilization by crops due to climate change etc are expected to negatively influence the growing conditions and the potential yields of many crops in SSA. The decline in output and yields will in turn aggravate the food security status and poverty incidence of smallholders whose livelihood is solely dependent on agriculture.

In arid and semi-arid tropical regions of the world like the Savannah and Sahel zones of West Africa, agriculture is largely rain-fed, and farmers commonly plant local crop varieties with little resilience to the immediate effects of climate variability - drought, flooding and high temperatures.

Though few in number, the increasing concern about climate change is attracting a considerable number of climate impact assessments across SSA e.g. Hijmans, 2003; Jones and Thornton, 2003; Thornton et al, 2009a and 2009b; Claessens *et al*, 2011 etc. The general conclusion from these studies is that SSA's crop and livestock yields will decline if there is no adaptation to future climatic conditions.

Most previous studies exclude economic impacts from estimated yield impacts, or use statistical methods that require costly multi-year farm-level surveys, and neither considers the adaptation or the cost of it, nor downscales the results to permit site-specific impact assessments (Claessens et al 2011). Because of these deficiencies, the findings of existing climate impact studies are often not uniform everywhere, and lack farm level-specific relevance and quantitative economic value.

To address some of the empirical weaknesses of previous studies, this study quantifies the potential economic impacts of climate change on technology adoption, gross and net farm revenues, and poverty rates among heterogeneous farm populations in the upper White Volta Basin (WVB) in the upper east region (UER) of Ghana. The objective is to assess how climate change, with and without adaptation, will impact on the above livelihood parameters and how farmers might respond to these impacts via the implementation of adaptation strategies. This study particularly examines how farmers' wellbeing might be affected if future climatic conditions reduce precipitation and increase temperature trends.

The analysis is implemented using the Tradeoffs Analysis for Multi-Dimensional Impact Assessment (TOA-MD) model and socioeconomic survey data obtained from households under the **C**limate change **I**mpacts on **W**est African **A**griculture: a **R**egional **A**ssessment (CIWARA) Project.

2. Study Area and Dataset

The study is undertaken in the Anayari (200km^2), Atankwidi (270km^2) and Yarigatanga (200km^2) sub-catchments of the upper White Volta River Basin in the UER of Ghana (Fig. 1). These occur respectively in the Kasena-Nankana East, Kasena-Nankana West and Bongo districts of the UER in Ghana, and extend northward into Burkina-Faso. Average rainfall in the WVB ranges from 645mm to 1250mm per annum, which is distributed from May to October/November yearly. Mean rainy season temperature averages about 28.6°C.

Rain-fed, semi-subsistence agriculture comprising "compound farms" of millet and sorghum systems with mixtures of cowpea, maize, and vegetables located near the homestead; and "bush farms" located some distance away from the village with rice, groundnuts and other monocrops, and the rearing of livestock is the most predominant source of livelihood in the study area. The average poverty line income in Ghana is about GHC330.00, circa $170.0 per annum.

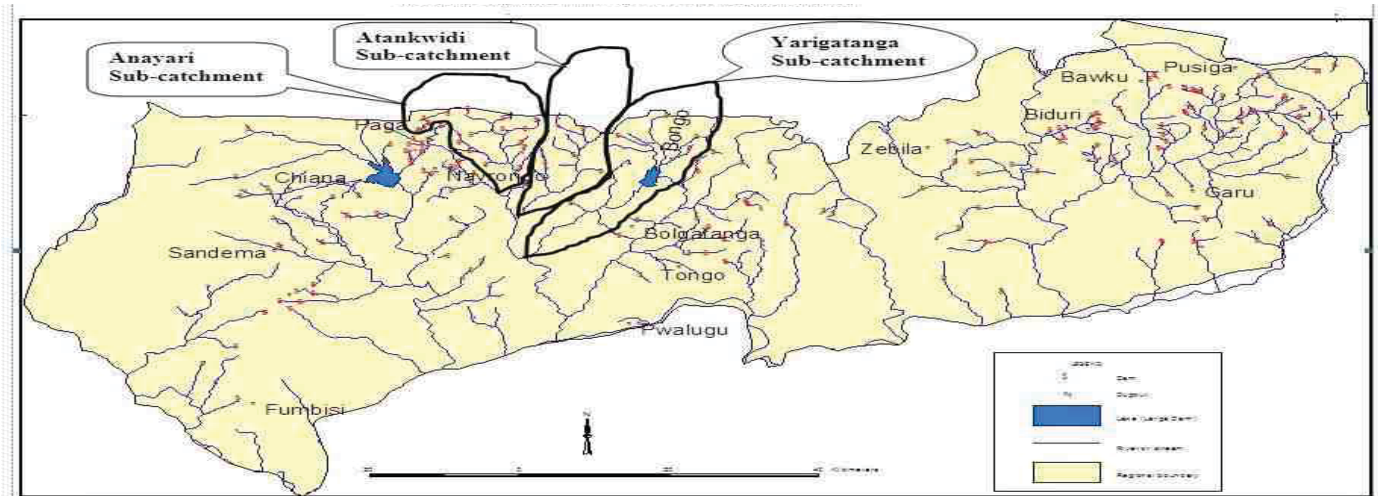


Fig. 1: A map showing the Anayari, Atankwidi and Yarigatanga sub-catchments of the upper WVB
Source: Laubel et al, 2012.

The analysis is conducted on a total of 300 farm households sample across the three sub-catchment areas. The data included variables like farm size, household size, land use and farm management activities, off-farm income etc obtained from farms with millet, sorghum, maize, rice and livestock enterprises. A summary of the key variables used to estimate the TOA-MD model parameters is presented in Table 1.

Table 1: Key descriptive statistics of base system variables used in TOA-MD analysis

Parameter/Strata	*1. Farms without Irrigation*			*2. Farms with Irrigation*		
	Mean	***Stand. Dev.***	***CV (%)***	***Mean***	***Stand. Dev.***	***CV (%)***
Farm Characteristic						
Household size	8.63	4.46	51.62	8.87	4.33	48.75
Farm size	2.78	1.97	70.79	2.93	2.34	79.70
Herd size (UBT)	14.74	18.36	124.57	30.54	39.60	129.68
Off-Farm Income	1034.53	1887.52	182.45	1816.70	3850.69	211.96
Maize						
Yield/farm (kg)	328.44	243.23	74.05	646.99	1239.50	191.58
Var. Cost/farm (GHC)	226.54	163.23	72.05	313.31	380.80	121.44
Net Rev./farm(GHC)	74.65	268.14	359.22	241.55	660.51	273.44
Price (GHC/kg)	0.96	0.27	28.63	0.92	0.32	39.91
Millet						
Yield/farm (kg)	152.88	209.41	136.97	266.33	256.91	96.46
Var. Cost/farm (GHC)	226.54	119,40	78.43	155.49	119.74	77.00
Net Rev./farm(GHC)	74.65	225.62	381.84	173.96	350.08	201.24
Price (GHC/kg)	1.29	0.56	43.01	1.10	0.21	19.12
Sorghum						
Yield/farm (kg)	230.65	309.19	134.05	482.46	764.39	158.44
Var. Cost/farm (GHC)	106.05	86.41	81.48	122.76	99.55	81.09
Net Rev./farm(GHC)	109.27	247.61	226.63	375.54	787.08	209.58
Price (GHC/kg)	0.91	0.26	29.85	1.01	0.14	14.88
Rice						
Yield/farm (kg)	312.65	355.61	113.75	609.09	570.37	93.64
Var. Cost/farm (GHC)	185.29	168.76	91.06	306.86	208.79	68.04
Net Rev./farm(GHC)	161.03	466.99	290.00	348.04	579.62	166.54
Price (GHC/kg)	1.20	0.51	42.61	1.09	0.35	39.91
Livestock						
Var. Cost (GHC)	144.79	267.86	185.00	252.01	411.34	163.22
Net Rev./farm(GHC)	554.25	974.60	175.84	538.15	1576.07	292.87

Two sub-systems of farms are considered under this study. Farms belonging to the first sub-system hereafter called system 1 are purely rain-fed farms that lack access to irrigation; while farms in the other sub-system hereafter called system 2 are those with access to irrigation facilities. The assumption is that farms with access to irrigation will be better-off under reduced precipitation and increased temperature following changed climate. Irrigation will be an important adaptation strategy and determinant of the economic outcomes for these farms under climate change since Irrigation mutes the negative impact of reduced precipitation.

Particularly intensified and expanded use of ground water irrigation will be a practical, least-cost strategy for climate change adaptation (Laube et al, 2012) because irrigated farms are less vulnerable to climate change. We assume no 'carbon fertilisation' which though has a critical effect on crop growth and yields, is not a common practice by most WVB farms.

3. Methodology: The TOA-MD Model

The theoretical framework of the TOA-MD model (Antle, 2011a) assumes that, farmers as economically rational people, choose from a set farm systems that yield positive expected net returns. In this climate analysis, the economic outcomes associated with each of two systems - base system (system 1) and an adapted system (system 2), are simulated and compared for three different climate scenarios. It is expected that changes in climatic conditions will affect the economic outcomes of the system 1 causing some farmers to adopt system 2 where they will employ improved technology. By so doing, both adopters and non-adopters of system 2 and thus the entire population of farms may gain or lose in terms of changes in their income and poverty levels.

In the TOA-MD model, a farmer at a site s using a production system h earns per-hectare returns equivalent to $v_t = v_t(s,h)$ each season/period. Let: System 1 = Farmers with base technology and base climate, and System 2 = Farmers with adapted technology under changed climate. Now if $\omega = v_{1-}v_2$ measures the difference in income between systems 1 and 2; then $\omega = v1 - v2 > 0$, means climate change leads to a gain for farms that continue to use the base technology, but if $\omega = v1 - v2 < 0$, then climate change implies a loss for the farms that continue to use the base technology.

When the production system changes for instance from j to k following climate change, the expected economic returns (gain or loss) as a result of this change is given by:

$$\omega(p,s,j,k) = V(p,s,j) - V(p,s,k) \tag{1}$$

Where a positive $\omega(p,s,j,k)$ denotes the loss associated with changing from system j to k while a negative $\omega(p,s,j,k)$ denotes a gain from changing from system j to k.

If we let $\varphi(\omega \setminus p,j,k)$ be the spatial distribution of gains or losses in the population of s farms, the percentage of farms with $\omega(p,s,j,k) < a$ is:

$$r(a,p,j,k) = 100\int_{-\infty}^{a} \varphi(\omega \setminus p,j,k)\,d\omega \tag{2}$$

Where a is returns/ha.

3.1 Climate Change Projections

The analysis explores three principal scenarios - the CSIRO, NCAR and the I&E. The first two climate model runs, national centre for atmospheric research (NCAR) and the commonwealth scientific and industrial research organization (CSIRO) models, are used to simulate the potential effects of climate change on crop yields using the A2 inputs of the IPCC's 4th assessment report (IFPRI, 2009). Both models project higher temperatures, high evaporation, increased precipitation and reduced crop yields without CO2 fertilisation for SSA by 2050 (fig. 2). The intensive and expanded (I &E) model, based on the assumption that irrigation water from aquifers within the WVB will be used as an adaptation strategy to bring yields levels up to 95% of their baseline values, is tested as an adaptation strategy under a third scenario. In all three scenarios, we test a recommended 10% reduction in yield of livestock caused by declines in feed intake and availability.

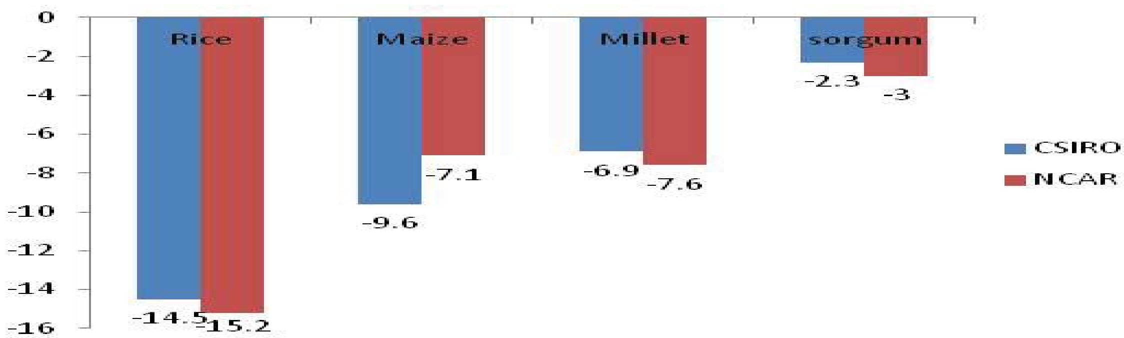


Fig. 2: Mean yield change of major crops for the CSIRO and NCAR A2 Scenarios
Source: Authors' plots from IFPRI (2009) projections.

4. Results

The results based on the three scenarios are presented in Table 2. They show the effects of different climate scenarios on adoption rates for new technologies (economic feasibility of adaptation strategies), and on potential income gains and losses, and poverty rates as a result of farm households switching from system 1 to 2 under climate change. The results are disaggregated across the two strata of farms – those with and those without access to irrigation; and aggregated for the entire farm population.

First, the results on the adoption rates for system 2 show in all three scenarios that farms with access to irrigation have higher adoption rates than farms without irrigation access. The adoption rates for the entire population of farms are 27%, 22% and 35% respectively for the CSIRO, NCAR and I&E irrigation scenarios respectively. Therefore, availability of water for intensive and expanded irrigation following climate change is expected to have a profound effect on the rate of adoption of system 2.

Next, net farm incomes are shown to be sensitive to climate change. The results of the percent gains, losses and thus net losses by farms with and without irrigation access as a percentage of net mean farm income mirror those of the adoption rates. As may be seen across all scenarios, farms with irrigation access gain more but lose less due to climate change. The aggregate net losses are 14%, 21% and 26% respectively under the I&E, CSIRO and NCAR scenarios respectively. This means, irrigation reduces the percentage of average, net farm income losses for the entire population of farms from 26% under the NCAR scenario to 14% under the I&E scenario. As noted above, irrigation buffers farms from the negative effects of reduced precipitation on farm productivity.

Table 2: Climate simulation results across scenarios in the upper WVB in Ghana (A2: 2050)

Scenario/Stratum				
	Adoption Rate (%)	**Gains (%)**	**Losses (%)**	**Net Loss (%)**
CSIRO				
Farms without Irrigation	25.00	11.91	35.74	23.83
Farms with Irrigation	30.49	14.59	33.26	18.67
All Farms	27.1	13.24	34.51	21.27
NCAR				
Farms without Irrigation	20.04	9.44	37.65	28.21
Farms with Irrigation	24.94	11.76	35.39	23.63
All Farms	21.94	10.59	36.53	25.94
I&E Irrigation				
Farms without Irrigation	33.45	16.23	32.28	16.05
Farms with Irrigation	36.35	17.64	30.89	13.25
All Farms	34.57	16.93	31.59	14.66

Notes: Gains, losses and net losses are expressed as a percentage of mean agricultural income in the base system.

In addition to the effects on income, we also estimate poverty rates (% of the farm population living on less than s $1.00/day) due to climate change under the 3 scenarios at the disaggregated and aggregated levels (Fig. 3a and b).

Fig. 3b: Poverty rates of farms under system 2 (% of farms with < $1.00/day)

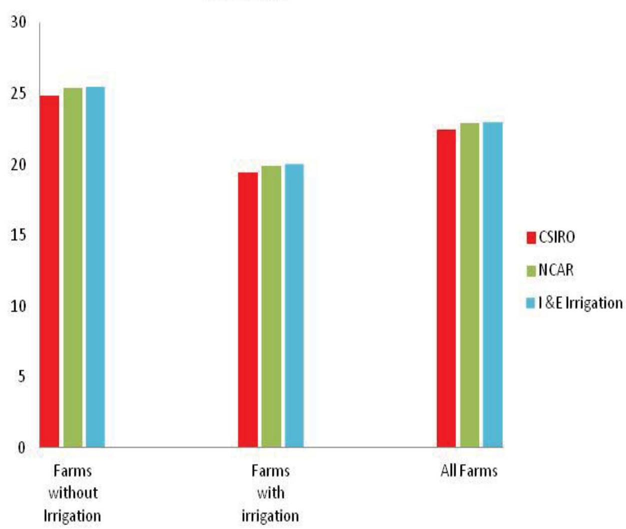
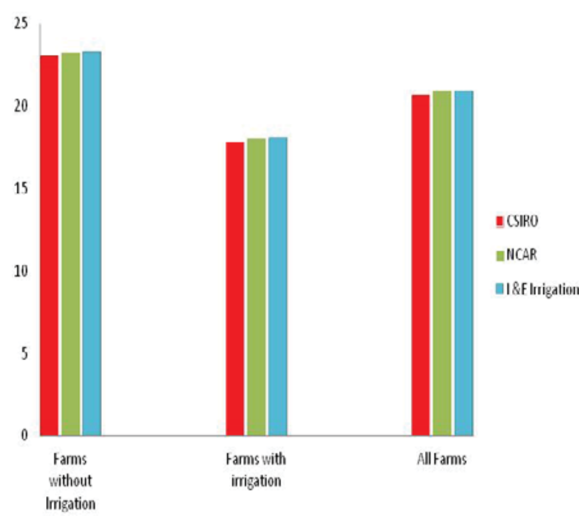


Fig. 3a: Poverty rates of farms under system 1 (% of farms with < $1.00/day)



As expected, the different climate scenarios produce different poverty impacts on farms. The results show that overall poverty rates under system 1, the base system are lower than those under system 2, the adapted system. Surprisingly, the I&E scenario has a less profound effect on the simulated poverty rates than the SCIRO and NCAR scenarios. It appears that off-farm income will play an important supplementary role in reducing future poverty rates in the WVB.

5. Conclusion

By assessing climate impacts at the farm household level, the study reveals that net farm incomes and poverty rates are sensitive to climate change; with irrigated and rain-fed farms having different responses to climate change. Irrigation access appears to benefit the production of rain-fed crops either directly via supplementary irrigation during drought events within the production season and indirectly via increased financial access of farms with irrigation to obtain other yield-improving farm inputs. Since surface water for irrigation is not available everywhere in the study area, it means future climate changes that result in reduced precipitation and high temperatures will negatively affect livelihood outcomes. An important adaptation strategy for farmers and policy makers will be to introduce an I&E technology to offset some of the negative climate change impacts on agricultural productivity, improve net farm incomes and reduce poverty rates in the WVB.

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Quantifying Uncertainties in Modeling Crop Water Use under Climate Change

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Abstract— In this study, we present an intercomparison of 26 wheat crop simulation models aimed at quantifying uncertainties in modeling water use under climate change. We used field experimental data from four contrasting sites, located in the Netherlands, India, Argentina, and Australia, to represent a wide range of growing conditions of wheat. An A2-2040-2069 (Mid- Century) scenario was used with 16 different General Circulation Models (GCM). For each GCM the 2050s period was compared to the baseline period. Commonly used delta changes were then applied to the observed 30-year baseline at each location on a monthly basis, in order to obtain input data on future climate. Results of this study show that the variability in simulated water use was similar for baseline and future climate (both have a coefficient of variation of 18%), despite the fact that the variability in the future simulations comes from variability in both the crop models and the GCMs. The variability between GCMs contributed little to the overall variability, no doubt related to use of the delta method. 78% of the uncertainty in climate change impact comes from variability among crop models and 15% from GCM's and the remainder from interaction between crop models and GCMs.

Index Terms — Crop simulation models, evapotranspiration, uncertainty, wheat.

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1 Introduction

At global scale, agriculture is the largest user of water. About 70% of the world's freshwater withdrawals are used for irrigation purposes. Future growing populations, urbanization and industrialization will increasingly compete for this water (Howell, 2001). In rainfed agricultural systems, where crops rely on precipitation only, future changes in rainfall patterns, which can become more favorable or unfavorable, in conjunction with warming and enhanced atmospheric CO_2 concentrations will affect crop production positively or negatively, depending on their geographical location (Rötter and van de Geijn, 1999; Nelson et al., 2010). More generally, as global food demand will approximately double by 2050 (Tilman et al., 2011) and water is getting a scarcer resource (Siebert & Döll, 2010), it is important to estimate the crop water use under current and future climatic conditions. This is to increase understanding of how much water is needed to produce a certain amount of food. Crop simulation models (CSMs) are increasingly applied in assessing agricultural impacts of climate change (Angulo et al., 2013; Osborne et al; 2013; White et al., 2011). CSMs take into account multiple interactions between climate, crop, soil and management, but the uncertainties of both simulated yield and water use due to imperfect crop models have rarely been quantified. Uncertainties have been studied in climate science using probabilistic projections based on global and regional climate model ensembles (Mearns et al., 1997; Tebaldi & Knutti, 2007). However, climate change impact studies have often used single crop models (White al., 2011), which do not allow any quantification of crop model uncertainty. To overcome this short-coming, the use of multi-crop model simulations has been suggested (Rötter et al. 2011). This is a critical point because CSMs differ in the way they simulate soil-plant-atmosphere processes and in the number of parameters and inputs required. Recently, Palosuo et al. (2011) reported large differences in simulations of grain yield between CSMs, but no comparison was made for crop water use. Wiltshire et al. (2013) used an ensemble of climate simulations to study the implications of changes in climate on food and water availability at a global level. Previous studies of model intercomparison have showed that the different potential evapotranspiration formulae yield significant differences because of their sensitivities to temperature and other climate inputs (McKenney and Rosenberg, 1993). Potential evapotranspiration is the first step used by crop models to simulate the water balance in a crop. Actual evapotranspiration differ from the potential one in many situations when the soil moisture is limiting, or where vegetation features differ from those used for the definition of the potential evpotranspiration. Therefore, significant differences in potential evapotranspiration simulations can be reflected in the simulation of actual evapotranspiration. Rötter et al. (2012) showed that there is uncertainty in simulation of actual evapotranspiration. The need for a coordinated effort in assessing uncertainty in climate change impact projections on crop production, and contributing these to climate and crop models has been recognized by the Agricultural Model Intercomparison and Improvement Project (AgMIP; www.agmip.org, Rosenzweig et al., 2013).

Therefore, we analyzed differences among models (i) due to the calculation of reference ET, (ii) due to the partitioning of simulated ET between soil evaporation and plant transpiration, (iii) with respect to the within-season variability of ET, and (iv) for the simulated impact on ET under future climatic conditions.

2 Materials and Methods

Twenty six different wheat crop simulation models were used. In most cases the group that developed the model carried out the model simulations. The models varied in their structure, complexity and functionality. Simulations were carried out for single treatment experiments located at four contrasting sites in the Netherlands (Wageningen), India (New Delhi), Argentina (Balcarce), and Australia (Wongan Hills). The locations were chosen to represent a wide range of growing conditions of wheat (Asseng et al., 2013). The 30-years averages of the growing season temperature and precipitation were 8.5 °C, 12°C, 18.9°C, 16.2°C, and 716 mm, 395 mm, 467 mm, 246 mm, for the Netherlands, Argentina, India, and Australia, respectively. For India the 467 mm were applied as irrigation as the growing season rainfall is negligible. The reference ET (ET_0) was calculated for the 4 sites using the standard FAO approach for the experimental years used in this study (Allen et al., 1998). The ET_0 was 837 mm for the Netherlands, 532 mm for Argentina, 773 mm for India, and 689 mm for Australia. The data provided to the modelers were soil characteristics, initial soil water and soil N contents, and crop management (N fertilizer application, irrigation, and sowing). For the baseline, location-specific daily climate data for the period 1981-2010 were used for each location. For India, solar radiation was obtained from the NASA POWER (Stackhouse, 2010) dataset that extends back to 1983. Missing data for 1981 to 1983 were filled using the Weatherman tool included in DSSAT 4.5 (Hoogenboom et al., 2010). In addition, 2-meter wind speed (m s^{-1}), dew point temperature (°C), vapor pressure (hPa), and relative humidity (%) were estimated for each location from the NASA Modern Era Retrospective-Analysis for Research and Applications (MERRA). The models were calibrated using anthesis dates, maturity dates, within-season and final biomass, water and N uptake, soil water and soil nitrogen, and grain yield and yield components. Information on differences in implementing the reference ET (ET_0) calculation approaches, Penman (P; Penman, 1948), Penman-Monteith (PM; Allen et al., 1998) and Priestley-Taylor (PT; Priestley and Taylor, 1972) in the 26 wheat models is given in Table 1. Two models (STICS and FASSET) used other methods; one method (SW in Table 1) uses a modification of the PT (Brisson et al., 1998), and the other the Makkink equation (Hansen, 1984). Both models were considered in the group of the PT for this study. Analysis of Variance (ANOVA) for unbalanced design is used to test the differences between the 3 different ET_0 formulae in each location. Of these 26 models, 19 provided simulated values of plant transpiration (Ta) for the Netherlands, India, and Argentina, while 18 models provided these outputs for Australia. Soil evaporation (Es) was calculated as difference between simulated ET and simulated Ta for each of the available crop models.

Table. 1. Different approaches used to simulate reference evapotranspiration (ET_0) by 26 wheat crop simulation models.

#	Model	Evapotranspiration
1	APSIM-Nwheat	Priestley –Taylor
2	APSIM-wheat	Priestley –Taylor
3	AquaCrop	Penman-Monteith
4	CropSyst	Penman-Monteith
5	DSSAT-CROPSIM-CERES	Priestley –Taylor
6	DSSAT-CROPSIM	Priestley –Taylor
7	EPIC wheat	Penman-Monteith
8	Expert-N – CERES	Penman-Monteith
9	Expert-N – GECROS	Penman-Monteith
10	Expert-N – SPASS	Penman-Monteith
11	Expert-N – SUCROS	Penman-Monteith
12	FASSET	Makkink
13	GLAM-Wheat	Priestley –Taylor
14	HERMES	Penman-Monteith
15	InfoCrop	Penman-Monteith
16	LINTUL-4	Penman
17	LINTUL-FAST	Penman
18	LPJmL	Priestley –Taylor
19	MCWLA-Wheat	Penman-Monteith
20	MONICA	Penman-Monteith
21	O'Leary-model	Penman
22	SALUS	Priestley –Taylor
23	Sirius	Penman
24	SiriusQuality	Penman
25	STICS	Shuttleworth and Wallace
26	WOFOST	Penman

An A2-2040-2069 (Mid- Century) scenario was used with 16 different General Circulation Models (GCM; Randall et al., 2007). For each GCM the 2050s period was compared to the baseline period. Commonly used delta changes were then applied to the observed 30-year baseline at each location on a monthly basis, in order to obtain input data on future climate. For this step only 25 CSMs provided simulated ET data.

The difference between simulated ET with the GCMs and simulated ET with baseline weather is calculated as follows:

$$Diff\,ET_{i,j} = ET_{i,j}^{future} - ET_{i}^{baseline} \qquad (1)$$

where $ET_i^{baseline}$ (mm) and $ET_{i,j}^{future}$ are sowing to physiological maturity ET simulated with model i and averaged over the 30 years of baseline weather or over 30 years of future weather simulated with GCM j respectively. $DiffET_{i,j}$ (mm) then is the difference in ET (future minus baseline) for CSM i and GCM j.

Diff ET is treated as a discrete random variable, whose value depends on the choice of crop model and of

GCM. The distribution of this variable is:

$$P(DiffET = DiffET_{ij}) = \frac{1}{nCSM * nGCM} = \frac{1}{25*16} = 0.0025 \quad (2)$$

The total variance of *DiffET* can be decomposed into:

$$\mathrm{var}(DiffET) = \mathrm{var}[E(DiffET \mid CSM) + \mathrm{var}[E(DiffET \mid GCM)] + \text{Interaction} \quad (3)$$

The first term on the right, the variance of the expectation of *DiffET* for a fixed crop growth model is the first order contribution of variability between crop growth models, the second term is the first order contribution of variability between GCMs and the last term is the interaction between them.

3 Results

Simulated cumulative ET for the experimental year and for the four locations is shown in Fig. 1. The three main different approaches used for calculating ET are shown by different symbols as reported in Fig. 1. Each of the ET_0 formulae used to simulate actual ET (ETa) showed high variability and a significant difference between location and ET_0 formula. No measured data were available for NL and AR.

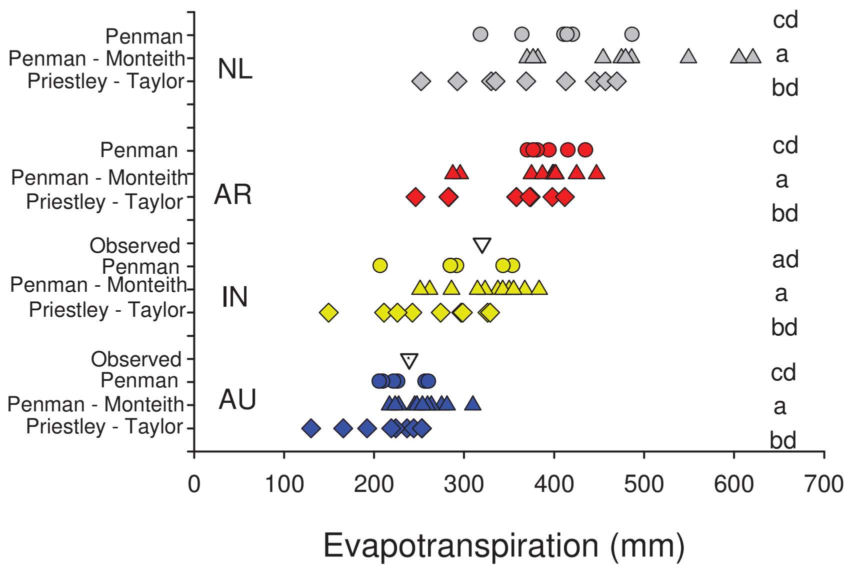

Fig. 1. Observed (black circle for NL and AR, and black triangle for IN and AU), and simulated cumulative actual growing season evapotranspiration (ETa) for the Netherlands (NL, grey symbols), Argentina (AR, red symbols), India (IN, yellow symbols), and Australia (AU, blue symbols) for models using the Penman (dots; n=6), Penman-Monteith (triangle; n=11), and Priestly-Taylor (diamonds; n=9) equations for the reference ET calculation. The letters next to the symbols represent the Least Significant Difference (LSD) at 0.05.

The ratio between soil evaporation (Es) and Ta is shown for the Netherlands and Australia in Fig. 2a-b because of the contrasting environmental factors. Overall, there was a high variability in Es/Ta among CSM for Australia and less for the Netherlands. Models that used the PT or PM approaches showed a high ratio of this index indicating high Es and lower Ta for the growing season.

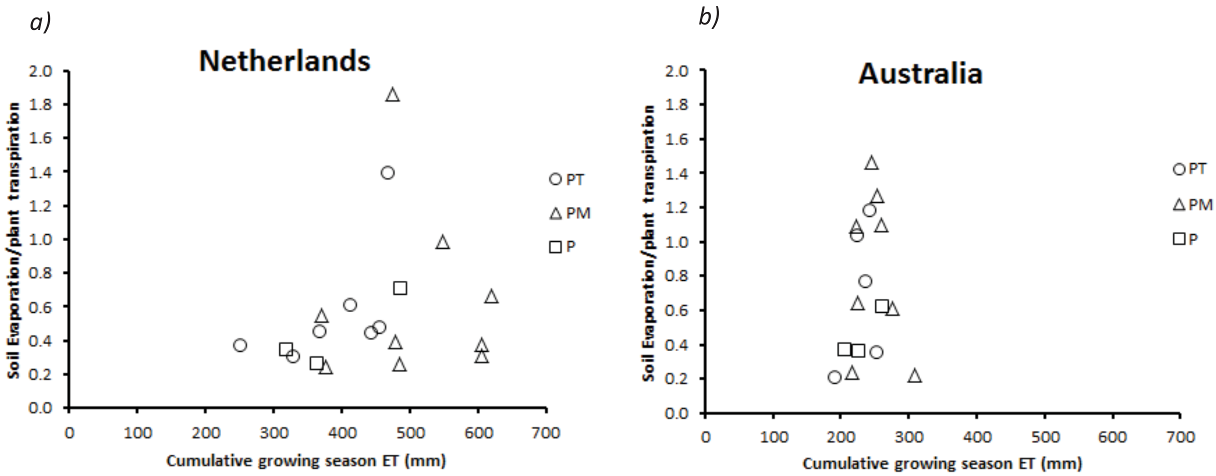

Fig. 2. The ratio between simulated soil evaporation (Es) and plant transpiration (Ta) vs. simulated actual cumulative ET calculated from reference ET_0 calculated with the Priestley-Taylor (PT, open circle), Penman-Monteith (PM, open triangle), and Penman (P, open square) is shown (***a***) for the Netherlands (19 models; PT n=7; PM n=9; P n=3), and (***b***) for Australia (18 models; PT n=7; PM n=8; P n=3). Note, 7 and 8 out of the 26 models provided no partitioning of ET into Es and Ta for the Netherlands and Australia, respectively.

The boxplot of the difference between observed ET and simulated ET, for the 26 CSM, is shown in Fig. 3 for Australia. The variability among models varies during the growing season. It is low from tillering (Decimal Code DC 20-29; Zadoks et al., 1974) until the beginning of booting (DC 40-49). Then, the discrepancy is high at the end of booting, at anthesis (DC 60-69) and at the beginning of grain filling (DC 70-79) to decrease again later during the grain filling period (DC 70-79 and 80-89) as shown in Fig. 3. However, the highest deviance from the observed ET is only about 20 mm, which is small if compared to the absolute ET measured values (Fig. 3). India showed a similar pattern as Australia (results not shown).

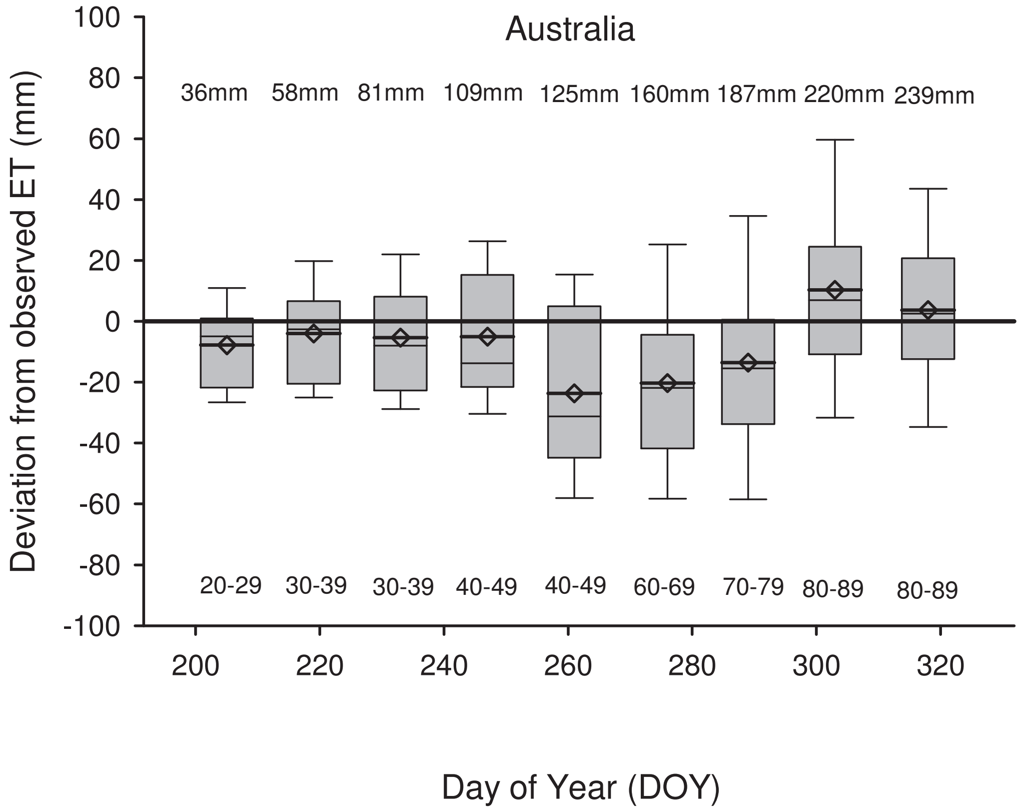

Fig. 3. Box-plot of the difference between observed and simulated cumulative ET for the 26 crop models for Australia from sowing to physiological maturity. Lower side of box = 75%-tile, upper side of box = 25%-tile, thin horizontal line in box = median, horizontal line with open diamonds in box = average, lower whisker extends to 95%-tile and upper whisker to 5%-tile of simulations based on 26 models. The black horizontal line is y = 0. The numbers above the x-axis represent the Decimal Code (DC) according to Zadoks et al. (1974) and defined as: DC 20-29 = Tillering; 30-39 = Stem elongation; 40-49 = Booting; 60-69 = Flowering; 70-79 = Milk development (grain filling); 80-89 = Dough development (grain filling).
The numbers above the box represent the observed cumulative ETa.

The baseline and future simulated cumulative ET is shown in Fig. 4a. Overall, there was a small, statistically non-significant, reduction in simulated ET between future and baseline for all the locations (both have a coefficient of variation of 18%). The variability of the simulated ET for baseline and future conditions was similar for all the locations, except the Netherlands where the simulated baseline ET variability is lower (Fig. 4a). Most of the total variance (eq. 3) is due to the variance from the CSMs (78%). The GCMs contribute only 15% to the total variance with a substantial contribution only in Australia and the interactions contribute 7% to the total variability (Fig. 4b).

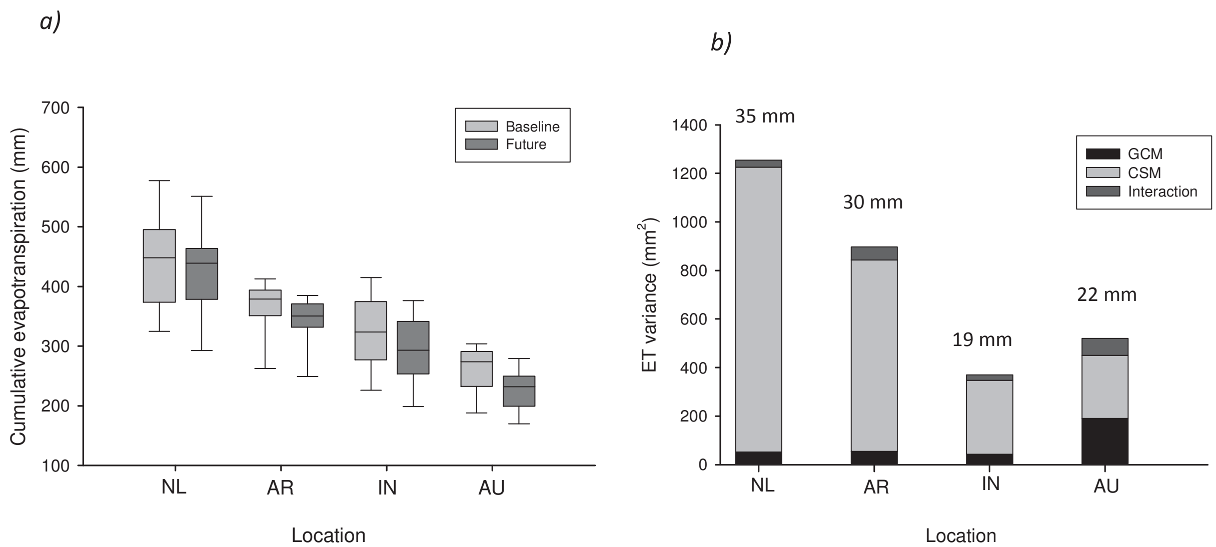

Fig. 4. (***a***) Box-plot of simulated baseline ET (grey boxplots) and future simulated ET (dark grey boxplots) for the Netherlands (NL), Argentina (AR), India (IN), and Australia (AU) for 25 crop models. Lower side of box = 75%-tile, upper side of box = 25%-tile, thin horizontal line in box = median, lower whisker extends to 95%-tile and upper whisker to 5%-tile of simulations based on 25 models; (***b***) Variance (mm^2) of the difference in ET between simulated baseline and future ET (stacked bars) decomposed into variance due to crop models (CSM-light grey portion), GCMs (black portion), and interaction between GCM and CSM (dark grey portion). The numbers above the stacked bars represent the total standard deviation.

4 Discussions

In this study, future crop ET was predicted to decrease across the study sites, although the decrease is slight and less than the variability in baseline or future ET. A future decrease of simulated ET is expected due to an increase in atmospheric CO_2 concentration which increases crop water use efficiency through two mechanisms: (i) an enhancement of leaf and biomass production, leading to faster and more complete canopy closure and a reduction of soil evaporation, and (ii) a reduction in crop stomatal conductance, causing a decline in ET (Rötter & van de Geijn, 1999). This agrees with Wall et al. (2006) who reported for wheat a reduction of stomatal conductance resulting in unchanged or less water use despite an increase in crop growth and yield under water-limited conditions.

In order to quantify uncertainty in future simulated crop water use we addressed separately the uncertainty from variability. The simulated ET variability between models is a quantitative description of the spread of simulated ET as shown in Fig. 1 and 3. Such variability represents the heterogeneity across crop models. On the other hand, the uncertainty is a lack of precise knowledge of the assessment process of future ET simulations.

We examined two possible sources of variation in simulated ET, namely the use of different reference ET_0 to simulate actual ET and the partitioning between soil evaporation and crop transpiration. For the baseline simulations, the uncertainty in simulated ET is relatively high even among models that use the same approach to estimating ET_0, suggesting that other components of the soil-plant-atmosphere system, e.g. the partitioning of ET into evaporation and transpiration, add to uncertainty in the ET calculation (Fig. 1 and 2). The partitioning into Es and Ta is critical for crop growth and final yield simulations. Note that models varied widely in their partitioning into Es and Ta (Fig. 2a-b).

Variability in simulated water use was similar for baseline and future climate, despite the fact that the variability in the future simulations comes from variability in both the CSMs and the GCMs. It seems that the variability between GCMs contributes relatively little to overall variability. This is probably related to the fact that the GCMs were not applied directly, but their monthly projected deltas were used together with the historical climate data for the future projections. This no doubt reduced the uncertainty in the resultant projections. Other down-scaling methods might have generated higher uncertainties due to the variations among climate change projections.

We have examined the relative contributions of CSMs and GCMs to the uncertainty in predicted *DiffET*. The GCMs had a relatively small impact on the simulated ET uncertainty. Thus most of the uncertainty was due to variations among CSMs, and to the interaction between crop and climate models (Fig. 4).

In climate science, multi-model ensembles have been used to increase the prediction skill as errors tend to cancel out due to the non-linear nature of the climate models (Mearns et al., 1997). It has been observed that even with the inclusion of the worst models, the average of many models improve the prediction skill (Weigel et al., 2008; Palosuo et al., 2011; Rötter et al., 2012). If only final cumulative ET is considered, the error of the average of the 26 models and the variability between models is relatively low. However, if ET dynamics during the growing season are considered, the variability of simulated ET can become relatively large especially around anthesis (Fig. 3). This suggests that an ensemble mean might not always be a good predictor throughout a growing season.

Results of this study are preliminary and some of these aspects are being further elaborated and will be reported in the future. However, in support of multi-model approach Asseng et al. (2013) and Rötter et al. (2012) found that for grain yield simulation the multi-models ensemble mean did better than any single model across the sites, and that the yield variability was better predicted by the ensemble mean.

In conclusion, despite a calibration of CSMs at each location (based on information of crop developmental stages, yield and yield components, dynamics of biomass, LAI, and for two sites of ET, soil water content and nitrogen) there remains uncertainty in simulating ET, due to different ET_o functions used, different partitioning of Es and Ta and remaining differences in other processes and parameters used in crop models, which were not examined here. Crop simulation models require further systematic evaluation of model intercomparison results, and improvement to accurately estimate crop water use under current and future climates.

Acknowledgments:

All the co-authors performed crop simulation experiments and discussed the results of the simulations. The authors would like to thank the anonymous reviewer for constructive comments.

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Estimation of Sub-Daily IDF Curves in Singapore using Simple Scaling

C. W. Chang, S. Hiong

Abstract - In Singapore, the Intensity-Duration-Frequency (IDF) curves is one of the tools adopted in the Code of Practice to guide the design of urban drainage systems, as the IDF curves provide information on the intensity of extreme short-duration rainfall that is expected in Singapore. When studying climate change, a method to scale the projected annual maximum 24-hour rainfall to maximum hourly and sub-hourly rainfalls is required, in order to study the effects of climate change on extreme short-duration rainfall. Through analysis of historical rainfall data from 4 rainfall stations in Singapore, this paper shows that the rainfall in Singapore displays scale-invariance property and the simple scaling model is thus applicable to Singapore rainfall. Hence, the simple scaling model is a viable approach to estimate IDF curves of hourly and sub-hourly rainfall from daily rainfall projections.

Index terms - Climate change; downscaling methods; extreme rainfall; IDF curves; scale invariance; stormwater management

1 Introduction

When designing urban drainage systems, knowledge of short duration rainfall is important. The Intensity-Duration-Frequency (IDF) curves are an effective representation of the extreme rainfall that is expected of the region of interest, because it reflects the average rainfall intensity at every return period for all rainfall durations. The IDF curves are derived typically by performing annual maximum analysis of historical rainfall data, based on the assumption that the climate remains stationary. In Singapore, a highly urbanised city-state located in the tropics, the Code of Practice on Surface Water Drainage contains a set of IDF curves representing the rainfall of Singapore which provides information on average rainfall intensity to guide the design of drainage systems in Singapore (Figure 1). Furthermore, the Code of Practice (6th Edition) also stipulates the minimum return period of rainfall in the drainage design, determined by the area of catchment served.

In lieu of climate change, understanding the extent of increase in intensity of rainfall, in particular the short-duration rainfall, is critical in the adaptation planning of drainage infrastructure to cope with these extreme events. Often, general circulation models (GCMs) are used to project the global climate in the long run, in terms of the main climate variables including rainfall, temperature, wind direction, and sea level, based on the various IPCC greenhouse gases emission scenarios. These dynamical models typically produce monthly or daily series, as the generation of data of even higher resolution will require enormous computing powers. Due to the coarse spatial resolution of GCMs as large grid size are used, the outputs of the GCMs are often further dynamically or statistically downscaled to generate projections for a specific site. Nevertheless, daily rainfall projections for the site in question are still not sufficient to construct the IDF curves for future periods. Hence, a method of scaling the annual maximum 24-hour rainfall to maximum hourly and sub-hourly rainfalls is required.

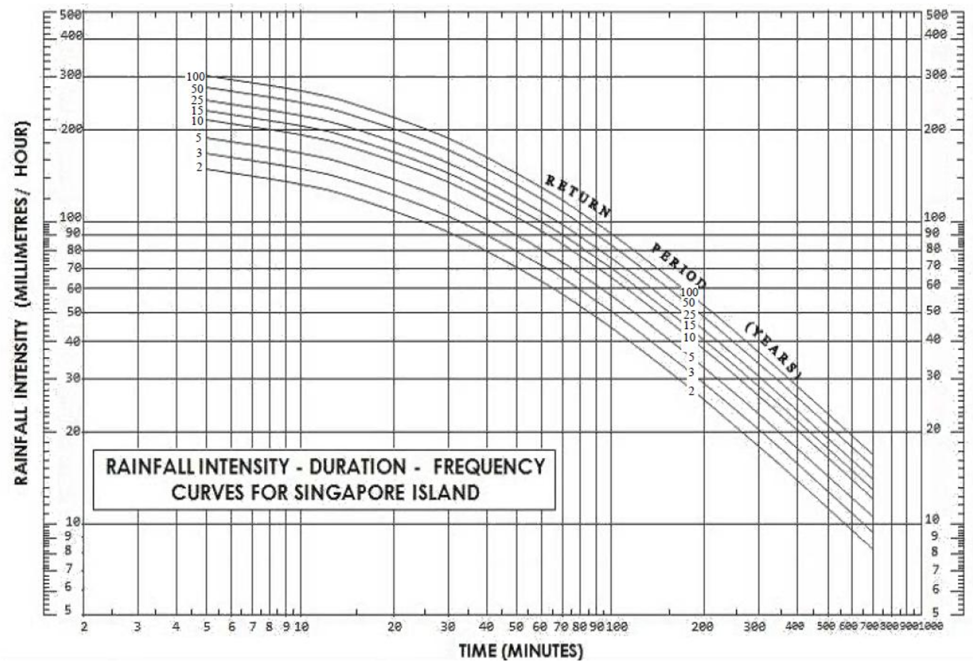

Figure 1: IDF curves for Singapore from Code of Practice on Surface Water Drainage (6th Edition)

Menabde et al (1999) proposed a simple scaling model that enables the calculation of rainfall amounts of any return period and duration shorter than a day using the historical daily rainfall information, after verification of the scale-invariance property of rainfall patterns. This model was further explored by Nhat et al (2008) whereby the scale-invariance property of rainfall was proven based on recorded data at 4 stations in Nagoya (Japan), Daegu (Korea), Geraldton (Australia), and Malaysia. The IDF curves for 10-min and 1-hour rainfall that are constructed by simple scaling of 24-hour maximum rainfall have a Mean Absolute Percent Error (MAPE) of less than 5% when compared to observed data. The simple scaling method has been used by several countries to estimate sub-daily rainfall using daily rainfall to overcome the problem of incomplete (or non-existent) sub-daily rainfall data.

This study seeks to verify the scale-invariance property of Singapore rainfall, based on past rainfall data at 4 stations – Changi, MacRitchie, Tengah, and Paya Lebar – and to validate the capability of the simple scaling model to reproduce the IDF curves of current Singapore rainfall. Once validated, the scaling exponent derived from historical rainfall data and assumed to be constant with time can then be applied to daily rainfall projections to derive future periods sub-daily IDF curves.

2 Methodology

2.1 Simple scaling

In the model proposed by Menabde et al (1999), rainfall intensity I(d) of duration d is said to exhibit simple scale invariance behaviour if

$$I(\lambda d) \overset{\text{dist}}{=} \lambda^{H} I(d) \tag{1}$$

holds true. The equality refers to identical probability distributions on both sides of the equation; λ denotes a scale factor and H is a scaling exponent. It follows that by raising both sides of Equation 1 to the power of q and taking the ensemble average, that is, taking the q-th moment of both distributions, the q-th moments are related in the following manner:

$$\mathrm{E}[\mathrm{I}(\mathrm{d})^{\mathrm{q}}] = \lambda^{-\mathrm{Hq}}\mathrm{E}[\mathrm{I}(\lambda\mathrm{d})^{\mathrm{q}}] \tag{2}$$

When the moments $E[I(d)^q]$ are plotted on a logarithmic chart versus the scale λ for various moments order q, each slope will represent Hq for the respective q. The various slopes Hq are then plotted against q: if the graph is a straight line, it implies that H is a constant and I(d) exhibits characteristics for simple scaling; otherwise a multi-scaling approach has to be considered.

In a case of simple scaling, and when the cumulative distribution function (CDF) of extreme events is assumed to be independent of d (Menabde et al, 1999), it was shown that the mean μ and standard deviation σ of different d are related by:

$$\mu_d = \lambda^{-H}\mu_{\lambda d} \tag{3}$$

$$\sigma_d = \lambda^{-H}\sigma_{\lambda d} \tag{4}$$

By further assuming that the CDF follows a Gumbel Extreme Value distribution (also known as EV I distribution), the following IDF relationship can be derived:

$$I = \frac{\mu_d + \sigma_d\left(-\ln\left(-\ln\left(1-\frac{1}{T}\right)\right)\right)}{d^{-H}} \tag{5}$$

where I is in mm/h, T is the return period, and d is in hours.

2.2 Station-year method

The station-year method was proposed primarily to overcome the hydrologic design problem of estimating return periods that are much longer than the length of rainfall data available at a single rainfall station. As long as the rainfall stations satisfy the 3 conditions – (i) the area is meteorologically homogenous, (ii) the stations have a satisfactory length of record, and (iii) the rainfall observations at each station are independent – the *n* years of records from *m* stations may be combined and treated as *m x n* station-years of records of a single station (Huff and Neil, 1959).

In Singapore, the IDF curves found in the Code of Practice is derived by combining rainfall records of 35 rainfall stations, each with varying length of rainfall data, using the station-year method. As a result, over 1300 station-years worth of annual maximum rainfall data is available. In this study, data from only 4 rainfall stations are used. These stations are roughly evenly spread across Singapore – their approximate locations are shown in the map Figure 2. For consistency in methodology, the station-year method will also be applied in the analysis of the rainfall data from the 4 stations.

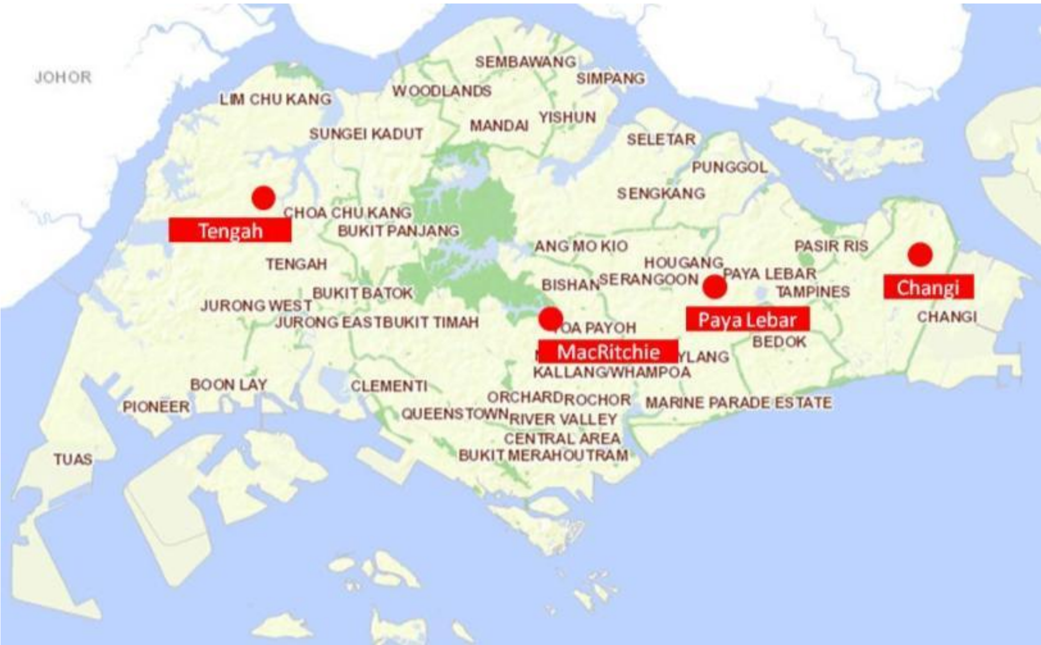

Figure 2: Map showing approximate locations of Tengah, MacRitchie, Paya Lebar, and Changi rainfall stations, denoted by red circles

3 Data used

For the verification of scale-invariance property and derivation of the scaling exponent, H, for the rainfall in Singapore, annual maximum 15-min, 30-min, 45-min, 1-hour, 2-hour, 3-hour, 6-hour, 12-hour, and 24-hour rainfall data from Changi, MacRitchie, Tengah, and Paya Lebar rainfall stations are used. Each station provides 36-55 years of moving-maximum data for each rainfall duration, which gives a total of 171 station years.

4 Results and Discussion

4.1 Verification of scale-invariance property

Equation 2 can be checked using empirical data by replacing the ensemble average by the sample average (Menabde et al, 1999). The sample moments are plotted against duration, d, on a logarithmic scale as shown in Figure 3. It can be observed from Figure 3 that log(moment) and log(duration) have a linear relationship with 2 distinct gradients for 2 regimes and the change in gradient occurs at around 45 min – this phenomenon is also observed by Nhat et al (2008). This suggests a "transition in the rainfall dynamic" (Nhat et al, 2008) but is not confirmed by a physical model yet. Linear regression performed separately for each of the two regimes confirmed the linear relationship – the correlation is consistently strong with coefficient of determination R^2 values greater than 0.98 for both sections.

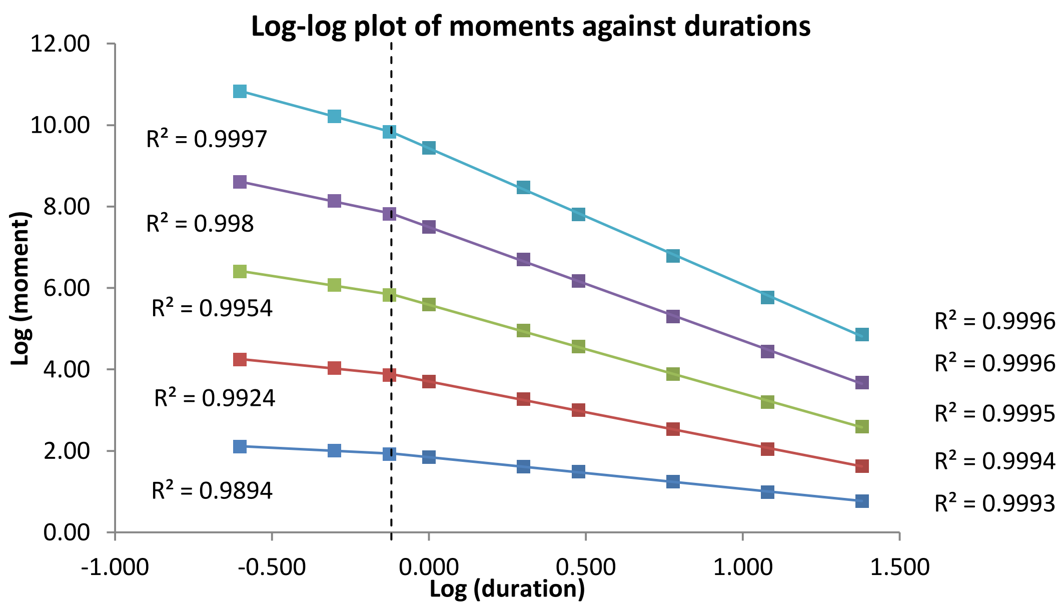

Figure 3: Log-log plot of moments (of orders 1 ≤ q ≤ 5) versus durations

The slopes of all the best-fit straight lines, Hq, are then plotted against q up to 3rd order, as shown in Figure 4. The plots show that the relationship is linear with very high values of R^2 of close to 1, thus justifying the using of simple scaling. The slopes, obtained by linear regression, are the values of the scaling exponent H for the two different regimes – 45-min to 24-hour and 15-min to 45-min. Based on the rainfall data of the 4 stations used, the scaling exponent is -0.7272 and -0.4012 for 45-min to 24-hour range and 15-min to 45-min range respectively.

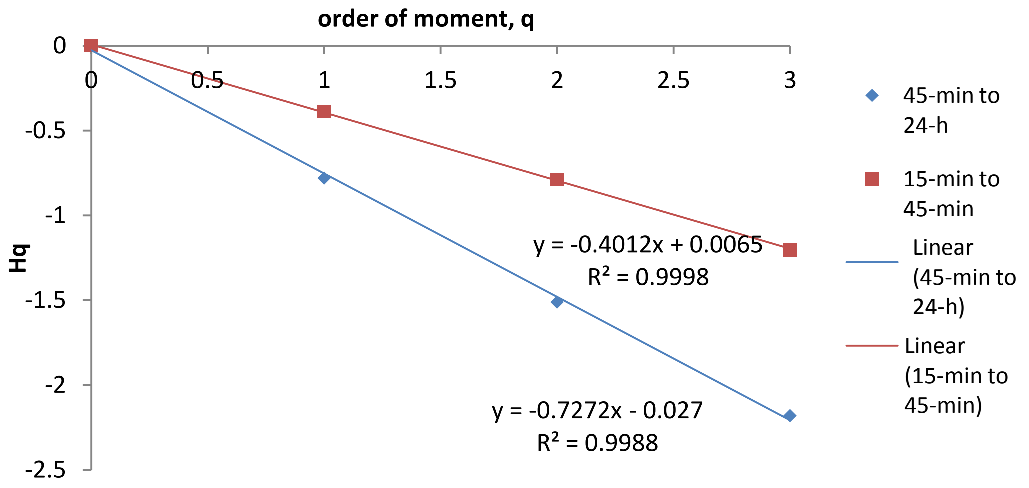

Figure 4: Relationship between Hq and order of moment q for two ranges, 1-hour to 24-hour and 15-min to 1-hour at Changi Station

4.2 Estimation of IDF curves and evaluation of model performance

The mean μ_{24} and standard deviation σ_{24} are estimated from the sample of annual maximum 24-hour rainfall data using the L-moment method: this method is said to be more robust (relative to conventional moment method) against outlying points when estimated from a sample (Sattar and Wan, 2009). The L-moment is estimated by using plotting position, which is a distribution-free estimator of cumulative distribution function $F_d(i)$ – in this study, the form $F_d(i) = (i-0.35)/n$, as proposed by Hosking (1999), is assumed.

Subsequently, the mean μ_d and standard deviation σ_d for various sub-daily durations d are calculated from μ_{24} and σ_{24} using Equations 3 and 4 in 2 steps: first applying a scale exponent H of -0.7272 for the 45-min to 24-hr range then applying H = -0.4012 on $\mu_{d=0.74}$ and $\sigma_{d=0.75}$ for the 15-min to 45-min range. Knowing μ_d and σ_d enables IDF curves of durations d to be estimated based on Equation 5.

The estimated IDF curves are then plotted together with the actual observed data, as in Figure 5, to evaluate the goodness-of-fit graphically. Also, the IDF curves derived by fitting Gumbel Extreme

Value distribution to actual observed data (of various durations d) are plotted on the same graphs for comparison. It can be observed that the estimated IDF curves of the short-duration rainfall by simple scaling fit the observed data point very well at lower return periods (T<50 years) but not as well at higher return periods. This is observed for the IDF curves that are fitted to the actual short-duration rainfall data as well, which suggests that the annual maximum (AM) rainfall distribution does not exactly follow the Gumbel distribution at higher return periods in the first place, due to the presence of some outliers.

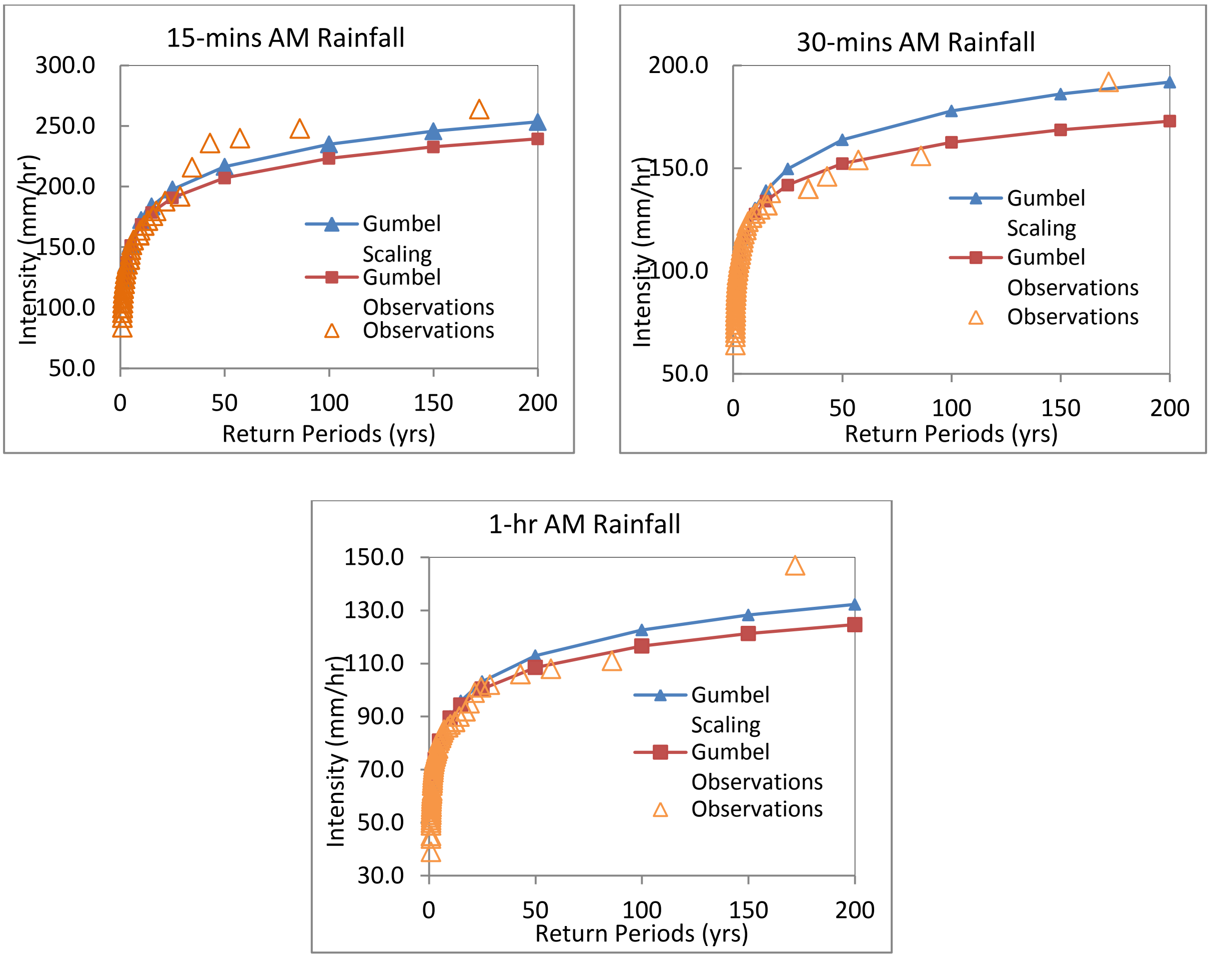

Figure 5: IDF curves estimated by simple scaling and by fitting Gumbel distribution to the observations -for 15-min, 30-min, 1-hour rainfall

In addition, evaluation statistics Root Mean Square Error (RMSE) and Mean Absolute Percent Error (MAPE) are also used to evaluate the performance of the simple scaling model. Table 1 shows the computed RMSE and MAPE values for 15-min, 30-min and 1-hour IDF curves estimated by simple scaling. The MAPE values are in the range of 5-7% which is only slightly higher than the MAPE values when fitting Gumbel distribution to the observed data points which is the range of 2-4%. These results validate the performance of the simple scaling model in estimating the IDF curves of short-duration rainfall in Singapore.

Table 1: The Root Mean Square Error and Mean Absolute Percent Error for 15-min, 30-min and 1-hour IDF curve estimates

	By Simple Scaling and assuming Gumbel distribution		**By fitting Gumbel distribution to observed data**	
	RMSE	**MAPE**	**RMSE**	**MAPE**
15-min	6.5	4.9%	6.3	3.8%
30-min	8.2	8.9%	2.5	2.1%
1-hour	4.3	6.7%	2.3	2.6%

In order to test how representative the rainfall data from the selected 4 rainfall stations are of the rainfall observed in whole of Singapore, the IDF curves estimated from the 24-h annual maximum rainfall series of the 4 stations via simple scaling are plotted together with the IDF curves from the Singapore Code of Practice, estimated by fitting Gumbel distribution to 35 stations of rainfall data. Figure 6 shows that IDF curves estimated by simple scaling can reproduce the IDF curves for Singapore reasonably well. The absolute percentage difference is in the range of 1-6% for 15-min, 30-min and 1-hour rainfall of 10 to 100 years return period.

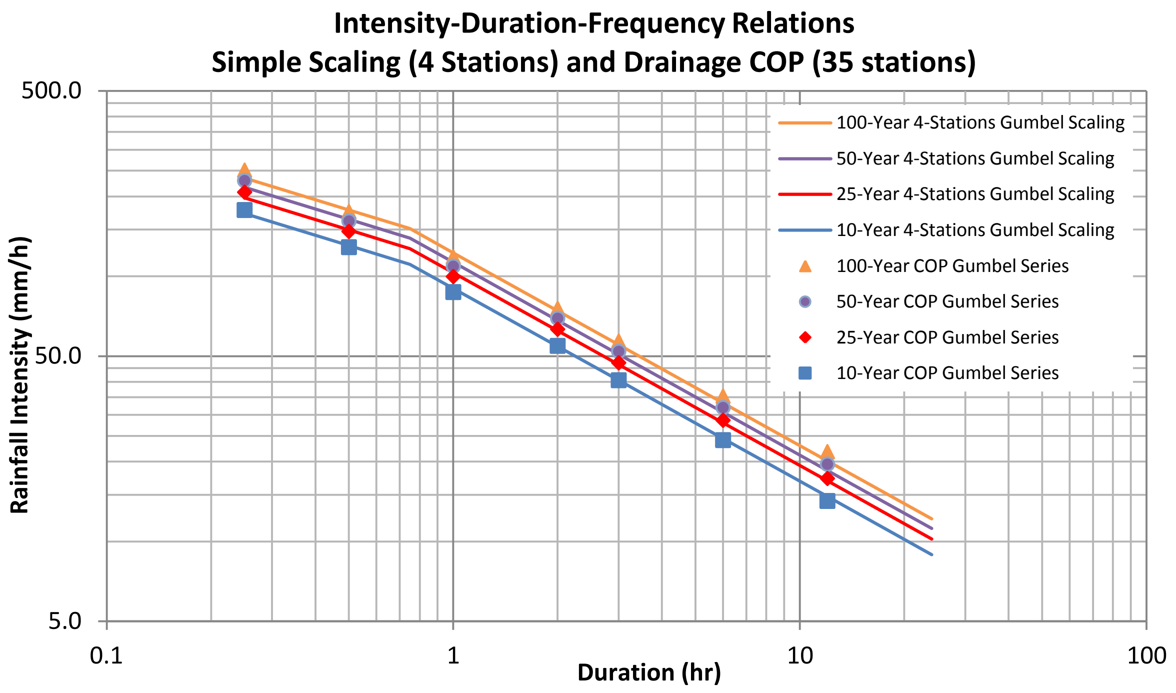

Figure 6: IDF curves estimated by simple scaling and IDF curves of Singapore from the Code of Practice

5 Conclusions

The results of this study show that the Singapore rainfall displays scale-invariance property in 2 scaling regimes – from 45-min to 24-hour and from 15-min to 45-min. Relying only on the statistical properties of the annual maximum 24-h rainfall, the IDF curves of short-duration rainfall could be estimated and they are shown to match the actual observations reasonably well, especially in the lower return period. Furthermore, the IDF curves estimated from data of 4 selected rainfall stations are similar to the IDF curves derived from fitting Gumbel distribution to the data from 35 stations and currently being used for drainage design in Singapore. Hence, the simple scaling model is shown to be applicable to Singapore rainfall.

The findings are of significance to work related to IDF relations of extreme storms. The key advantage is that IDF curves of shorter rainfall durations that are not measured or unavailable can be derived solely based on the statistical properties of the annual maximum 24-h rainfall. This is important because daily rainfall projections are more commonly available in the downscaling of GCMs results in climate change studies but not sub-hourly rainfall projections. Until computing powers allow dynamical downscaling to produce time-series of rainfall projections in short time intervals (for example every 15 minutes), the simple scaling model is a viable and reasonable approach to scale daily rainfall projections to hourly and sub-hourly rainfall in order to study the effects of climate change on extreme short-duration rainfall.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Changes in flood hazard in the JULES ISI-MIP simulations

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Abstract— Climate change due to anthropogenic greenhouse gas emissions is expected to increase the frequency and intensity of precipitation events, which is likely to affect the probability of flooding into the future. An earlier analysis of river flow simulations from nine global hydrology and land surface models participating in the InterSectoral Impacts Model Intercomparison Project (ISI-MIP) explored the uncertainties in the potential impacts of climate change on flood hazard at global scale. Here we use additional simulations from the JULES model to investigate the impact of climate mitigation, and the influence of bias correction of the climate simulations on the projections. Under the most aggressive mitigation scenario (RCP2.6), the projected changes to the flood hazard are generally smaller, and some of the more extreme increases in flood hazard are prevented. At the global scale, the use of bias correction has a small impact on the projections, but regionally it adds to the uncertainty arising from climate and modeling uncertainty.

Index Terms—Bias correction, climate impacts, floods, JULES

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1 Introduction

In a warming climate, the frequency of flooding is likely to change. Anthropogenic climate change is expected to alter the distribution and variability of precipitation (Meehl et al., 2007). As the water holding capacity of the atmosphere is increasing with temperature, global warming is expected to increase the intensity of precipitation events (Allen and Ingram, 2002). Other climate characteristics that are relevant to flooding, such as the timing and duration of the snowmelt season, are expected to change as well.

Although an increase in flooding under climate change is often speculated upon, few studies have actually provided projections of fluvial flooding at a continental or global scale (examples include Hirabayashi et al., 2008; Dankers and Feyen, 2008; Dankers and Feyen, 2009; Okazaki et al., 2012). Most studies focus on individual river basins or countries (e.g., te Linde et al., 2010; Veijalainen et al., 2010; Kay and Jones, 2012), and the use of different models and scenarios make it impossible to generalise the results.

The InterSectoral Impact Model Intercomparison Project (ISI-MIP; Warszawski et al., submitted) provides the opportunity to explore these uncertainties in projections of changes in flood hazard at a global scale. ISI-MIP offers a framework for comparing multiple climate impact models within and across different sectors, based on consistent climate and (where appropriate) socio-economic scenarios, providing a quantitative estimate of impacts and uncertainties.

Dankers et al. (submitted) analysed changes in flood hazard in the ISI-MIP ensemble using results from those models that provided simulations of daily river discharge at a global 0.5-degree grid. As an indicator of flood hazard they estimated the 30-year return level of river flow (Q30) at each grid cell for two 30-year periods (1971-2000 and 2070-2099). Under the RCP8.5 scenario of atmospheric greenhouse gas concentrations (see Moss et al., 2010) it was found that by the end of this century climate change does not result in a ubiquitous increase in flood hazard. Decreases in the magnitude of Q30 occurred particularly in areas where the hydrograph is dominated by the snowmelt flood peak in spring, although some high-latitude areas showed a consistent increase in Q30 magnitude, tentatively reflecting an increase in snow accumulation over winter. In most model experiments however an increase in flooding frequency was found in more than half of the global land grid points. At between 5 to 30% of the land grid points the current 30-year flood peak was simulated to occur more than once every five years in the future (Fig. 1). Although the large-scale patterns of change were remarkably consistent among impact models and even among the driving climate models, at local scale and for individual river basins there can be disagreement even on the sign of change. This indicates large modelling uncertainty which needs to be taken into account in local adaptation studies (Dankers et al., submitted).

In this paper we extend the analysis by Dankers et al. (submitted) by including results from the JULES model (Best et al., 2011; Clark et al., 2011) for the aggressive mitigation climate change scenario (RCP2.6). Comparing these results with RCP8.5 may give an indication of the climate change impacts that can be avoided by mitigation policies. We also performed additional experiments in which JULES was driven by uncorrected output from the HadGEM2-ES climate model, allowing us to explore if the projections of flood hazard are affected by the bias correction that was applied to the ISI-MIP climate scenarios (Hempel et al., 2013). Other studies (e.g., Rojas et al., 2011) have found that applying bias correction to the output from a regional climate model (RCM) can improve the simulation of observed flood characteristics. However, good model performance in the present day does not necessarily imply plausible projections into the future, and it has been argued that bias correction hides rather than reduces the uncertainty of the predictions (Ehret et al., 2012). An implicit assumption in bias correction is that biases in the climate simulations remain the same into the future, which is probably not very realistic. Bias correction may therefore add further uncertainty to climate impact projections (see e.g., Hagemann et al., 2011).

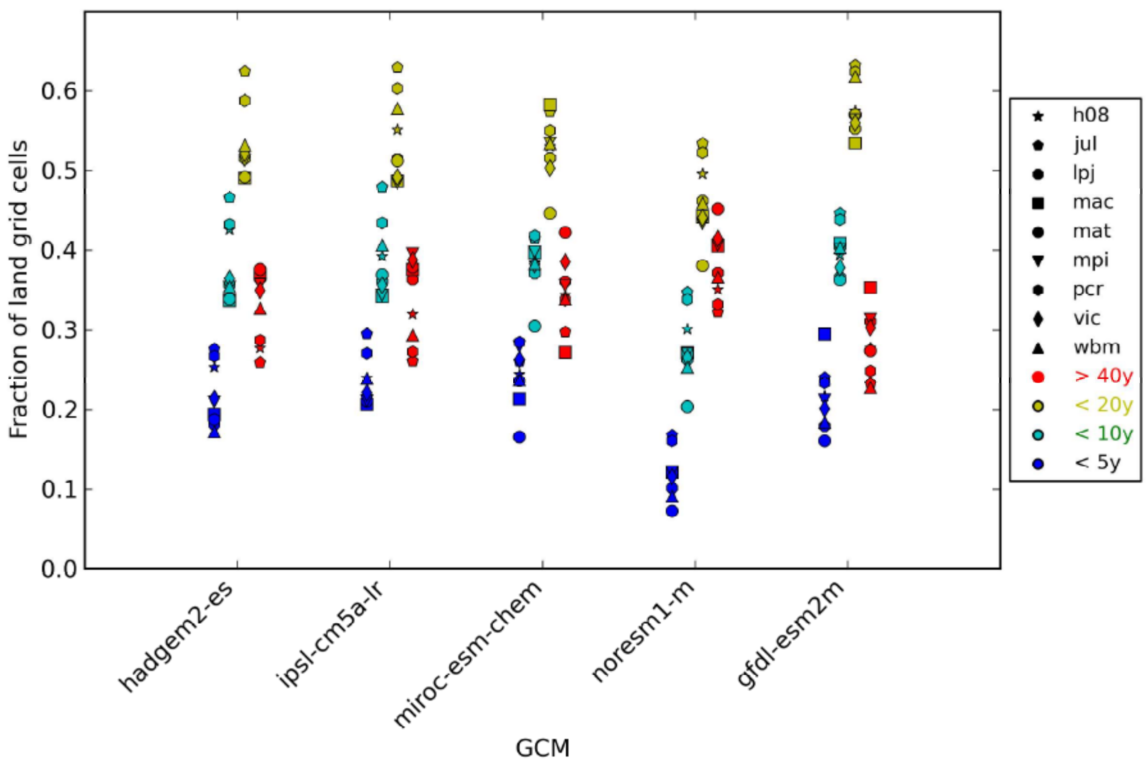

Fig. 1: Fraction of land grid points in the ISI-MIP simulations where the estimated future return period of the historical Q30 is more than 40y (red colours), less than 20y (light green), less than 10y (cyan) and less than 5y (blue), grouped by driving GCM (horizontal axis). Results from individual impact models (IMs) are indicated with different symbols. IMs were driven by bias-correctied climate variables from the GCMs under scenario RCP8.5. Note that the exact number of land points can be different for each GCM/IM combination. From Dankers et al. (submitted).

2 Analysis

2.1 The ISI-MIP setup

Within ISI-MIP Each impact model (IM) was driven by up to five Global Climate Models (GCMs) that were selected to represent the range of global mean temperature change and relative precipitation changes in the CMIP5 simulations (Taylor et al., 2012; see Warszawski et al. (submitted) for further details). Each GCM in turn was driven by up to four scenarios of future levels of atmospheric greenhouse gas concentrations (Representative Concentration Pathways (RCPs), see Moss et al., 2010). The output of each GCM was bias corrected to ensure statistical agreement with the observational data set of Weedon et al. (2011) over the period 1960-1999. The bias correction method that was used preserves the absolute trends in globally-averaged temperature and relative trends in land-averaged precipitation (Hempel et al., 2013).

In this paper we only discuss simulations from the land surface model JULES (Best et al., 2011; Clark et al., 2011) driven by the HadGEM2-ES earth system model using scenarios RCP2.6 and RCP8.5. HadGEM2-ES is the first priority GCM simulation in the ISI-MIP protocol. JULES was one of the models participating previously in the Water Model Intercomparison Project (WaterMIP), and more information on the model characteristics and hydrological performance can be found in Haddeland et al. (2011).

To assess the influence of the bias correction method applied in ISI-MIP on the projections of climate impacts, an additional set of simulations was performed in which JULES was driven directly by 3-hourly output from HadGEM2-ES, i.e. without any bias correction. These runs are based on the second ensemble member of the HadGEM2-ES CMIP5 simulations, as 3-hourly data for the first member (which was used in ISI-MIP) are unfortunately not available. The different initial conditions between these two members result in a different evolution of the weather through time, but at the global scale the impact on the climate signal is relatively small.

2.2 Analysis of flood hazards

Our analysis of changes in flood hazard is the same as in Dankers et al. (2009). For each experiment the timeseries of simulated daily river discharge at each land grid cell was smoothed to 5-daily running averages, and the annual maximum 5-daily flow was determined for both the historical and the future period. For each grid cell we thus have two distributions of 30 annual peak flows. To estimate the Q30 a Generalised Extreme Value distribution (GEV) (Coles, 2001; Katz et al., 2002) was fitted separately to these two sets of peak flows using a maximum likelihood approach. The goodness of fit was tested by calculating the Kolmogorov-Smirnov and Anderson-Darling statistics. Grid points with annual maxima close to zero $m^3 s^{-1}$ were excluded from the analysis as these generally resulted in poor fits. Finally, a likelihood ratio test (Coles, 2001) was performed to test wether the shape parameter of the GEV is significantly different from zero, or a Gumbel distribution should be used instead.

Note that the Q30 is only a moderately extreme discharge level: while the probability of exceedance (*Pe*) in any given year is 1/30, in any given 10-year period it amounts to almost a third (0.29). In flood risk management it is common to take higher flow levels (such as the 100-year return level) as a threshold for protection measures or planning regulations, but at longer return periods beyond the range of the data estimates of the corresponding extreme flow levels become increasingly uncertain.

Changes in Q30 may be expressed as a change in magnitude between the historical and future period, suggesting higher or lower flood levels. Alternatively the future return period (based on the future GEV) of the historical Q30 can be calculated, suggesting a change in probability and thus frequency. Although estimates of return levels are inherently uncertain, it is important to keep in mind that any changes in the Q30 are caused by changes in the underlying set of peak flows between the historical and future period that determine the shape of the GEV.

3 Results

Future changes in the recurrence of the historical Q30 in the simulations driven by bias-corrected and uncorrected HadGEM2-ES output are shown in Fig. 2. The large-scale pattern of regions with projected increases and decreases in flood frequency is, broadly speaking, similar between the two experiments, and also to the general pattern of change found in other IMs (Dankers et al., submitted) and in earlier studies (Hirabayashi et al., 2008; Okazaki et al., 2012). At regional scale, however, some important differences emerge, e.g. in eastern Eurasia and central South America. This means that, at the scale of individual river basins, bias correction adds to the uncertainty in flood hazard projections, in addition to the uncertainty arising from climate and impact modeling uncertainty discussed by Dankers et al. (submitted).

Fig. 3 shows the estimated future return periods in the RCP2.6 and RCP8.5 simulations, using bias-corrected climate model output. Under the low-end climate change scenario the changes are generally less extreme: in areas where the flood hazard is increasing (shorter return periods), this increase is generally smaller, and in areas where the flood hazard decreases (longer return periods), changes are mostly smaller as well.

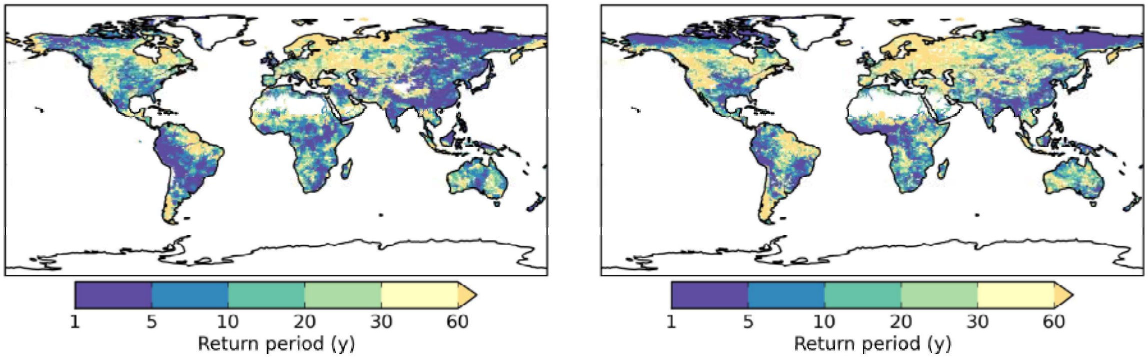

Fig.2: Estimated future (2070-2099) return period of the historical (1971-2000) Q30 in the JULES simulations driven by bias-corrected (left) and uncorrected (right) HadGEM2-ES simulations, under RCP8.5.

To summarise increases and decreases in the probability of flooding at a global scale, Dankers et al. (submitted) plotted the fraction of land grid cells where the future return period of the historical Q30 is expected to become longer or shorter (see Fig. 1). For the JULES simulations discussed in this paper, these fractions are given in Table 1. Differences between the two RCPs are especially noticeable in the more extreme changes, i.e. the fraction of land where the future return period is less than 5 y (implying that the current Q30 flow level will be exceeded every few years) is about 2.5 times larger in RCP8.5 than in RCP2.6. Differences between the bias-corrected and uncorrected runs are generally smaller.

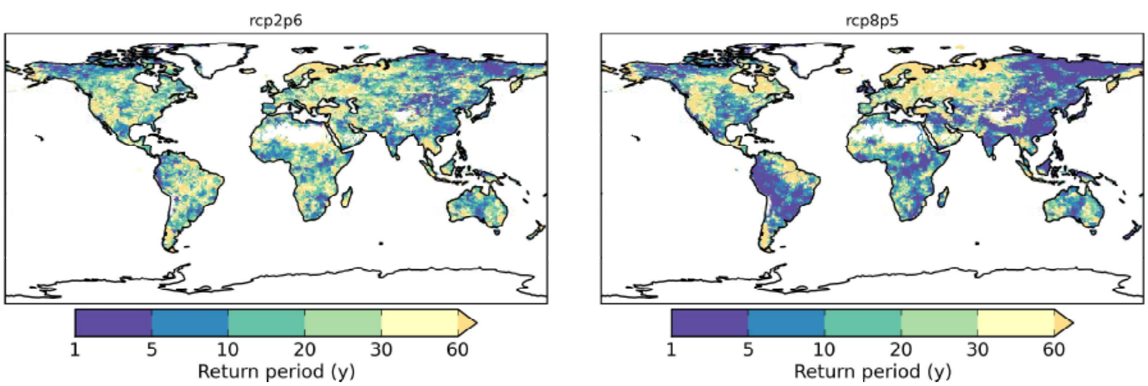

Fig. 3: Estimated future (2070-2099) return period of the historical (1971-2000) Q30 in the bias-corrected JULES HadGEM2-ES simulations, under RCP2.6 (left) and RCP8.5 (right).

Table 1: Fraction of land grid points where the estimated future return period of the historical Q30 is more than 40 years, or less than 20, 10 or 5 years.

	RCP2.6 (bias-corrected)	**RCP8.5** (bias-corrected)	**RCP8.5** (uncorrected)
> 40 y	0.26	0.26	0.30
< 20 y	0.56	0.62	0.57
< 10 y	0.32	0.47	0.41
< 5 y	0.11	0.28	0.24

4 Concluding remarks

The analysis presented here as well as in Dankers et al. (submitted) aims at exploring uncertainties in the potential impacts of climate change on flood hazard, and is not meant to provide specific guidance on adaptation to climate change in an individual river basin. The models used in ISI-MIP all have a global scope and may not provide an accurate description of the climatological and hydrological system at a given location. Vulnerability is also not taken into account in the current analysis (for examples of this see e.g., Hirabayashi and Kanae, 2009; te Linde et al., 2011; Feyen et al., 2012). Yet the results may have a clear implication for local adaptation: studies that are based on only one, or a limited set of model simulations, may underestimate the uncertainty in the climate change signal, and the corresponding change in flood hazard. This uncertainty has various causes, including climate and impact modelling uncertainty, and the additional JULES simulations driven by uncorrected HadGEM2-ES output suggest that at this scale bias correction may affect the projected changes in flood hazard as well.

It should be noted that large uncertainty even about the direction of change does not equate to no change. While it would be unwise to assume that flood hazard will remain stationary in a changing climate, it would equally be unwise to pretend these uncertainties do not exist. In those regions where even the sign of changes is uncertain, adaptation plans may therefore need to be flexible to changes in both directions (Mathison et al., 2012).

At the global scale, the results presented above suggest that climate mitigation may prevent some of the more extreme changes in flood hazard. Nevertheless, even under RCP2.6 an increase in flooding frequency is found in more than half of the global land points.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Uncertainties beyond ensembles and parameters – experiences of impact assessments using the HYPE model at various scales

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Abstract— Assessments of uncertainties when modelling climate change impact on hydrology have often been focused on either ensembles of climate forcing and impact models, or uncertainties in the parameters of the hydrological impact models. Less effort has been made to understand uncertainties arising at different hydrological model scales. This study compares results from the HYPE hydrological model in climate impact studies at national (Sweden), regional (Baltic Sea catchment) and continental scale (Europe), using appropriate input data for each scale and a multi-basin, transboundary approach. Climate change results for the overlapping domains of these models were compared for a single climate projection. For the 3 different model scales the same climate projection, bias-correction procedure, hydrological model code and setup approach were used. Bias in the simulated discharge for the reference period was shown to be of similar magnitude for each model scale but varied spatial distribution and direction. The predicted climate change impact on discharge varied in both magnitude and direction between the regional and continental scale models for the overlapping domain, but on the other hand, the climate change signal and magnitude varied remarkably little between the national and regional scale models for their overlapping domain. In this case, the cause was traced to the precipitation forcing data used for model calibration, validation and as a reference for bias-correction. Precipitation data from large-scale data sets introduces local and regional scale biases, which in turn are carried through to the bias-corrected climate projection and ultimately through the climate impact model. There is a need for sensitivity testing of bias-correction procedures to errors in precipitation fields do determine how such errors affect the precipitation climate change signal.

Index Terms — climate change projections , uncertainties, hydrological impact, modelling, scales

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1 Introduction

Global climate change is expected to have a strong impact on water resources on local, regional and global scales. As a result, the scientific community has been focusing on predicting the potential effects of climate change on the hydrological response. A common method to assess future climate change impacts on water resources involves climate variables (i.e. precipitation, temperature) from global climate models (GCMs) in combination with hydrological models. GCMs demonstrate significant skill at the continental and hemispheric spatial scales and incorporate a large proportion of the complexity of the global system; however they are inherently unable to represent local basin-scale features and dynamics (Fowler et al. 2007). To narrow the gap between GCMs ability and hydrological needs, regional climate models (RCMs) have been developed to generate high-resolution meteorological inputs. RCMs transfer the large-scale information from GCMs to scales, which are closer to the basin scale (25-50 km) but, RCM results still show large bias in the magnitude and distribution of precipitation and to a lesser extent, temperature. RCM outputs are therefore not considered to be directly useful for assessing hydrological impacts at the regional and/or local scale. For that reason, a multi-model ensemble of RCMs together with bias-correction methods is usually used to obtain a reliable impression of the climate change and provide uncertainty information (e.g. Sperna Weiland et al. 2010, Andreasson et al 2012). Results from impact studies are often subject to uncertainties which are propagated through the entire modelling chain and further interfere with each other. These could be categorized into: (1) climate models and their parameterization, (2) downscaling techniques, (3) bias correction methods, and (4) hydrological models and their parameterization. In this study, the influence of model scale and the associated differences in model set-up due to scale is investigated to see if this contributes to uncertainty in climate change impact modelling. We draw insights from our experience assessing climate change impacts at continental, regional and national scale (for Europe, the Baltic Sea catchment and Sweden, respectively) using the Hydrological predictions for the Environment (HYPE) model.

2 Data and Methods

To quantify how choice of input data at each model scale, and the parameterisation of the hydrological model in response to the chosen input data affects the predicted climate change signal, a hydrological model set up at 3 different scales and resolutions was used to make climate change impact predictions. The HYPE model (Lindström et al. 20101) was set up for all of Sweden: S-HYPE (Strömqvist et al. 2011), for the Baltic Sea basin: BALT-HYPE (Arheimer et al. 2012a) and for the European continent: E-HYPE (Donnelly et al. 2013). The model applications differ regarding inputs, resolution and domain (Table 1), but also in parameter values and performance as compared to observed time-series (in response to the varying input data). The reference periods for bias-correction also vary slightly due to availability of the reference data. The HYPE model code is the same in all the applications as well as the method for bias correction of forcing data from the climate models.

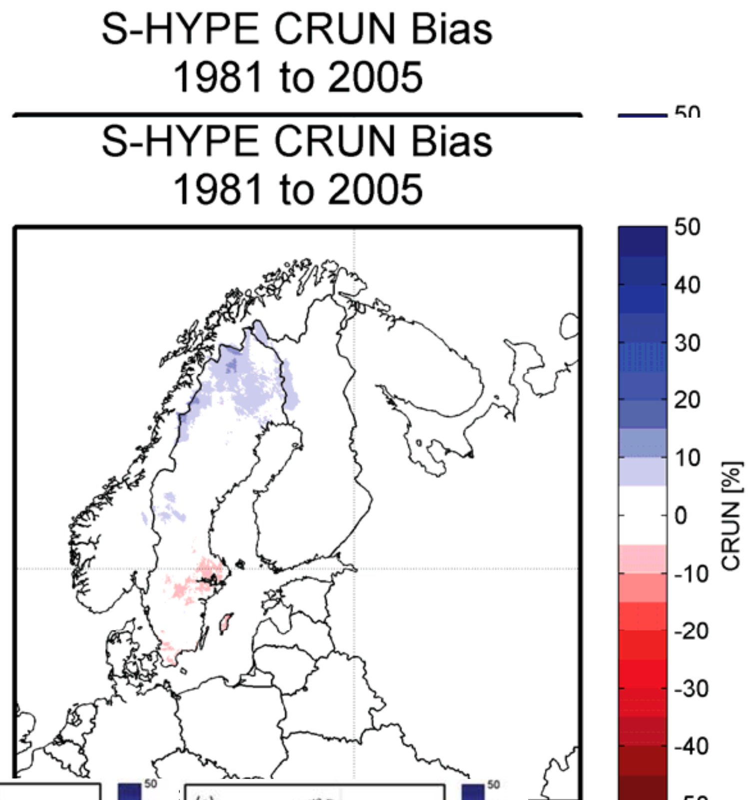
Table 1. Summary of model applications

Model	No subbasins	Median subbasin (km2)	Forcing	Forcing Resolution (km)	Ref Period for bias-correction
S-HYPE,	37786	7	PT-HBV (Johansson 2002)	4 km	1981 - 2010
Balt-HYPE	5128	325	ERAMESAN Jansson et al. (2007),	11 km	1981 - 2005
E-HYPE	35447	215	ERA-INTERIM with monthly bias correction against GPCC	80km (GPCC 55 km)	1981 - 2010

The A1B emissions scenario, simulated by the ECHAM5 GCM (start condition 3), dynamically downscaled by the Rossby Centre Model (RCA3, Kjellström et al. 2010) was bias-corrected to the 3 different reference forcing data sets using the Distribution Based Scaling methodology (DBS, Yang et al. 2011). The DBS method corrects the seasonal quantile distribution of precipitation and the annual cycle of the mean and the variance of temperature, conditional on the wet or dry state of precipitation. The bias-corrected data was used to force each of the 3 hydrological model applications. Long-term means of bias-corrected precipitation (*P*), temperature (*T*) as well as evapotranspiration (*E*), local runoff (*R*) and discharge (*Q*) were compared for the common domains of the 3 applications, i.e. Sweden and Baltic Sea catchment. Results from the respective hydrological models forced by the bias-corrected data were used for determining (a) how well the bias-corrected data reproduced the reference data for different periods and (b) how much the bias-corrected data sets at different scales differ from each other (noting how the reference data sets differ). Secondly, future changes in long-term mean *P*, *T*, *E*, *R* and *Q* were calculated as the percentage difference between a future period (2071-2100) and a current period (1971-2000). These changes were compared between model applications to determine how the projected change differs between the model applications.

3 Results

3.1 Ability of bias-correcti



Even though bias-correction a
period, not all aspects of the p
es remain. Bias is defined here
climate scenario and the same
was corrected. Dahné et al. (20
ing runoff and discharge, and
and surface runoff. Remaining
few small regions with slightly
0.5 degrees. Note that for S-H
than the bias-correction period
that temperature and precipita
some bias in the 3 model's ab
mostly within +/- 5 %, althoug
tend towards + 10 %, -10 % res
den is different than that seen
and large parts of the model do
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Apart from a few small regions

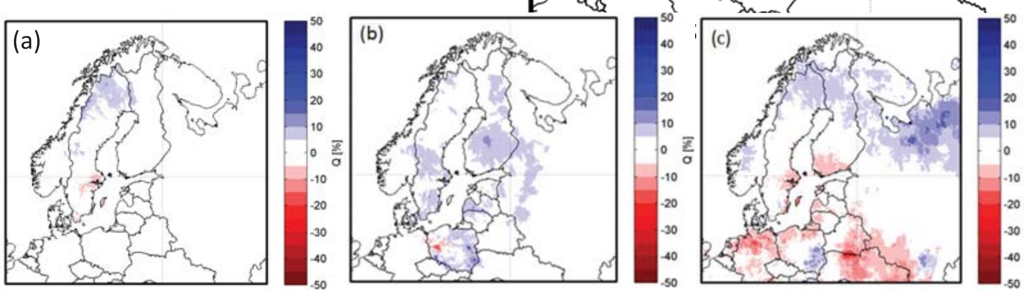

Fig. 1. Bias in mean discharge simulated with bias-corrected scenario data as compared to discharge simulated with reference data for (a) S-HYPE, (b) Balt-HYPE and (c) E-HYPE

3.2 Differences in projected impact

Fig. 2 shows the percent change in discharge predicted by each of the 3 models for the scenario tested. The percent change was calculated using the relative difference between the mean discharge for the period 2071 to 2100 as compared to the period 1971 to 2000. Despite the differences in model inputs, scale, parameterisation, performance and biases remaining after bias-correction, the climate change projected by the Balt-HYPE and S-HYPE models is remarkably similar over Sweden for the scenario tested with increases in discharge seen for the northern rivers, decreases in discharge for the southeastern rivers and insignificant changes for the rest of the country.

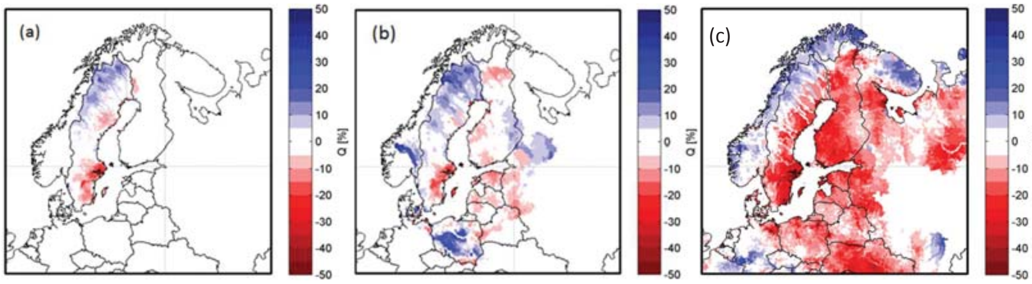

Fig. 2. Predicted relative discharge change for the E5A1B3_RCA3 (50km) scenario for (a) S-HYPE, (b) Balt-HYPE and (c) E-HYPE

On the other hand, the climate change projected by the E-HYPE model is somewhat different than both the S-HYPE and the Balt-HYPE model for the common domains, i.e. Sweden and Baltic Sea catchment. The increase in discharge to the northern Swedish rivers is the same, but decreases in discharge are seen for the entire Swedish eastern coast, Finland and Baltic States in the E-HYPE model. There are also differences in climate change direction with Balt-HYPE predicting discharge to increase in Poland and on the southern Finland/Russia border region and E-HYPE predicting decreases for these regions. In order to understand what causes these differences, we first checked how the climate change signal for the forcing data varied because of the different forcing data sets used for the bias-correction and model calibration/evaluation. Figs 3 and 4 show the predicted temperature and precipitation changes.

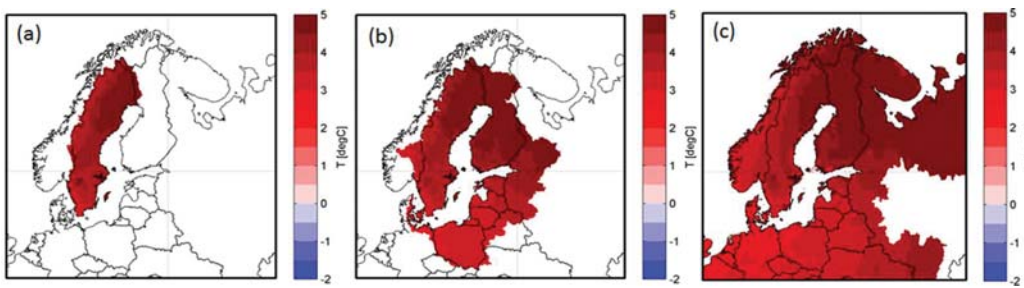

Fig 3. Predicted relative temperature change for the E5A1B3_RCA3 (50km) projection for (a) S-HYPE, (b) Balt-HYPE and (c) E-HYPE

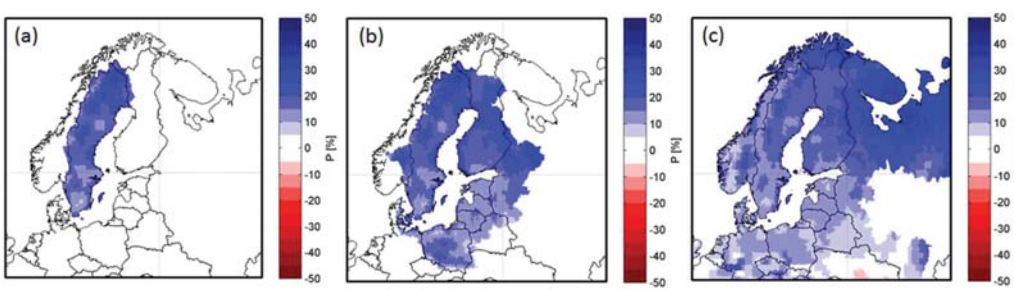

Fig 4. Predicted relative precipitation change for the E5A1B3_RCA3 (50km) projection for (a) S-HYPE, (b) Balt-HYPE and (c) E-HYPE

It is hard to discern any major differences in the change in temperature over the common model domain; however, for precipitation there are noticeable similarities and differences. As for the climate-change signal of discharge, the projected precipitation climate change signal is very similar over Sweden for the S-HYPE and Balt-HYPE models. The E-HYPE model predicts a smaller precipitation increase along the Swedish southern coast, in the northern Swedish highlands, in parts of western Russian, and in Poland. All of these regions coincide with regions for which projected change to discharge was different in the E-HYPE simulation and particularly where E-HYPE showed decreasing rather than stable or increasing precipitation as seen in the other applications (see Fig 2).

4 Discussion

The above analysis indicates that differences in bias-corrected precipitation caused differences in predicted hydrological climate change. The precipitation for all 3 model applications was corrected using the same methodology for the same climate projection: what differed was the reference data to which the bias-correction was made. Precipitation data came from both interpolated observations and reanalyses. Atmospheric reanalyses are commonly used to drive continental to global scale hydrological models due to the lack of observation data with sufficient resolution and temporal coverage (Weedon et al. 2012). At smaller scales, better data, usually interpolated observations is normally available. E-HYPE is driven using daily precipitation and temperature from the ERA-INTERIM reanalysis at 0.75 degrees (about 6800 km2, Dee et al. 2011) which has been corrected to monthly precipitation means from the GPCC database at 0.5 degrees (about 3000 km2, Rudolf et al. 2005). Balt-HYPE is driven by the ERAMESAN data set (Jansson et al. 2007), a 2-D mesoscale reanalysis data set of precipitation, wind and temperature that uses a reanalysis as a first guest for an optimal interpolation of observed meteorological parameters. S-HYPE is driven using the PT-HBV data set (Johansson 2002), a national 4km-resolution gridded data set based on interpolated daily precipitation and temperature from meteorological stations. Because the ERAMESAN data set was developed in Sweden the availability of observation data over Sweden for the optimal interpolation was good and the data set compares well with the PT-HBV data set. On the other hand, comparison of the S-HYPE and E-HYPE data sets for precipitation in gauged Swedish catchments showed that the E-HYPE precipitation is on average (and fairly consistently) 10 % less than PT-HBV. It is therefore thought that the differences in reference precipitation affected not only the bias-corrected precipitation, but also the change in precipitation in the bias-corrected data set.

Interestingly, the ability of the hydrological model to reproduce observed discharge did not affect the climate change signal for the S-HYPE and Balt-HYPE models. Performance differs considerably between all the model applications. Median NSE in the model versions studied is 0.74 and 0.41 for S-HYPE and Balt-HYPE, respectively. Mean absolute relative error (RE) is < 10 % and < 15 % for the respective models; however the mean and median bias calculated for all stations over these model domains is close to zero. Nevertheless, these two models gave very similar climate change signals. Model performance for the E-HYPE model is particularly poor over Scandinavia with a negative bias in simulated discharge (RE of approximately – 10 %) for nearly all stations north of 60 degrees due to the underestimation of precipitation in the E-HYPE forcing data set. On the other hand, model performance is reasonable for the southern part of the Baltic catchment with RE < 10 % at the few available gauging sites. In general NSE is poorer than for the S-HYPE and Balt-HYPE applications. Other factors that differed between all three model applications include subbasin delineation and linkage, scale, soil-type and landcover data, number of stations used in calibration, availability of lake rating curves as model input, the forcing data resolution and the bias remaining in the precipitation data set after bias-correction. All these factors strongly affect model performance, yet not necessarily predicted climate change, as seen in the national and regional scale comparison.

5 Conclusions

The results shown here indicate that model scale, calibration and input data don't necessarily affect climate change signal result, if the quality of the input data is sufficient. The exception is precipitation forcing, to which hydrological models are most sensitive, for which differences were seen when using a corrected large-scale reanalysis as reference data for bias-correction. There is a need for further analyses to determine to what extent different precipitation errors can affect climate change signal and why. It is therefore recommended that care be taken when using continental and global scale precipitation products to make climate change impacts studies. These products should be compared to regional and local precipitation data wherever available to determine the risk that climate change impact results may be affected.

6 Acknowledgements

We gratefully acknowledge financial support from the following research programs: ECOSUPPORT (Bonus), ECLISE (FP7), GEOLAND2 (FP7), CLEO (Swedish EPA)

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Evaluating the capacity to grasp extreme values of agro-climatic indices under changing climate conditions over Europe

G. Duveiller, A. Ceglar, O. Chukaliev and S. Niemeyer

Abstract—This study analyses the change of inter-annual variability of agro-climatic indices calculated for the major environmental zones in Europe from a baseline climate in 2000 to a projected climate in 2030. It leverages on a future daily weather dataset based on 2 constrasting realizations of scenario A1B by global circulation models (GCMs) dynamically downscaled with regional climate models (RCM) that have been bias-corrected. A special emphasis is given to the tails of the agro-climatic indices distributions, to how they relate to observed values in the present climate and to how they evolve in the near future.

Index Terms— agro-climatic indices, bias-corrected dynamically downscaled daily weather, changes in statistical distributions, uncertianty

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1 Introduction

Future climate change conditions are likely to be characterized by increased frequency of extreme weather events. This translates in making agriculture a riskier business, since more extreme agro-climatic events tend to have negative impacts on crop yields. In view of preparing strategies to increase crop resilience to climate variability, the present work proposes an analysis of agro-climatic indices calculated from present and future weather databases over the major environmental zones of Europe. While inspired by a previous similar study (Trnka et al. 2011), this exercise leverages on a new dataset of future daily weather that was especially tailored for crop growth applications in the near future (Donatelli et al. 2012). A special emphasis is given to the tails of the agro-climatic indices distributions, to how they relate to observed values and to how they evolve in the near future.

2 Data and Methods

2.1 Weather data

The future daily weather dataset used in this study is based on various realizations of scenario A1B by different global circulation models (GCMs) dynamically downscaled with regional climate models (RCM) within the ENSEMBLES project (Van der Linden & Mitchell 2009). The remaining bias present on both precipitation and temperature values was corrected by Dosio & Paruolo (2011) using an extension of the technique proposed by Piani et al. (2010). Bias-correction is of special importance since biased RCM simulations can lead to unrealistic simulations of impact models (e.g. Teutschbein & Seibert 2010; Ceglar & Kajfež-Bogataj 2012). Since the bias-correction was done only on a subset of weather variables (only rainfall and temperature) this dataset was further processed by Donatelli et al. (2012) to ensure that different weather variables of agronomic importance (such as global solar radiation) remained coherent amongst themselves, thus making them usable for crop simulations. This processing also included a resampling to a common 25 by 25 km grid and the use of the ClimGen weather generator (Stöckle et al. 2001) to increase the number of years within a given time window. The latter step was done to allow studying time horizons in the near-future (such as 2020 and 2030) by using 15 years of data (such as 2013-2027 and 2023-2037) to characterize the monthly climate and then generate 30 years of data with the same properties. In this way, time horizons such as 2020 and 2030 can be compared without using too many overlapping years.

This study focuses on two time horizons, 2000 and 2030 (i.e. each consist of 30 synthetic years representing respectively the periods of 1993-2007 and 2023-2037), simulated by two different GCM-RCM combinations. The first consist of the HadCM3 GCM coupled with the HadRM3 RCM, as processed by the UK Met Office (hereafter referred to as simply as HADLEY). The second consists of the ECHAM5 GCM coupled with HIRHAM5 RCM and processed by the Danish Meteorological Institute (hereafter ECHAM). These 2 climate projections represent the coldest (ECHAM) and warmest (HADLEY) out of those available from Dosio & Paruolo (2011) for the periods of interest. In addition, this study also considers observed weather from the MARS Crop Yield Forecasting System (MCYFS) database (Genovese 2004) for the period covering 1993 to 2007.

2.2 Agro-climatic indices

Agro-climatic indices were calculated using the ClimIndices software package (Confalonieri et al. 2010). Although more than 100 indices are systematically calculated (many of them are based on those used in (Barnett et al. 2006)), only 4 are presented here for the sake of brevity:

1. *Growing Season Start.* Defined as the fifth day in a row with an average daily temperature above or equal to a critical temperature, here defined as 5.6 °C. It is calculated from 1 January onwards. Note that this index is very generic and should not be taken literally, as crops are sown at different dates across Europe (and many before 1 January).
2. *Growing Season Length.* Defined as the number of days between the growing season start and the growing season end, which itself is defined as the fifth day in a row with an average daily

temperature of 5.6 °C or less.

3. *Last Air Frost Spring.* The last day in spring with a minimum temperature below 0 °C.
4. *Dry Spell.* The maximum number of consecutive dry days between April and September.

These indices have been chosen because they allow a quick assesement regarding adaptation strategies for agriculture, such as sowing crops earlier to benefit from a prolonged growing season but taking into account eventual changes in occurrence of the last frost (which can jeopardize the yield). Changes in the length of dry spells can also suggest where it is more critical to change crop varieties that will fare better under those conditions.

All indices are calculated for all available years in each time horizon and for each 25 by 25 km grid cell. The resulting statistical distributions per cell are then summarized by their 5^{th}, 25^{th}, 50^{th}, 75^{th} and 95^{th} percentiles.

2.3 Spatial agregation

The analysis is centred on European agricultural lands. Grid cells with less than 5% of surface covered by arable land (as defined by in MCYFS, see Genovese (2004)) are discarded (see Fig. 1a). The analysis is

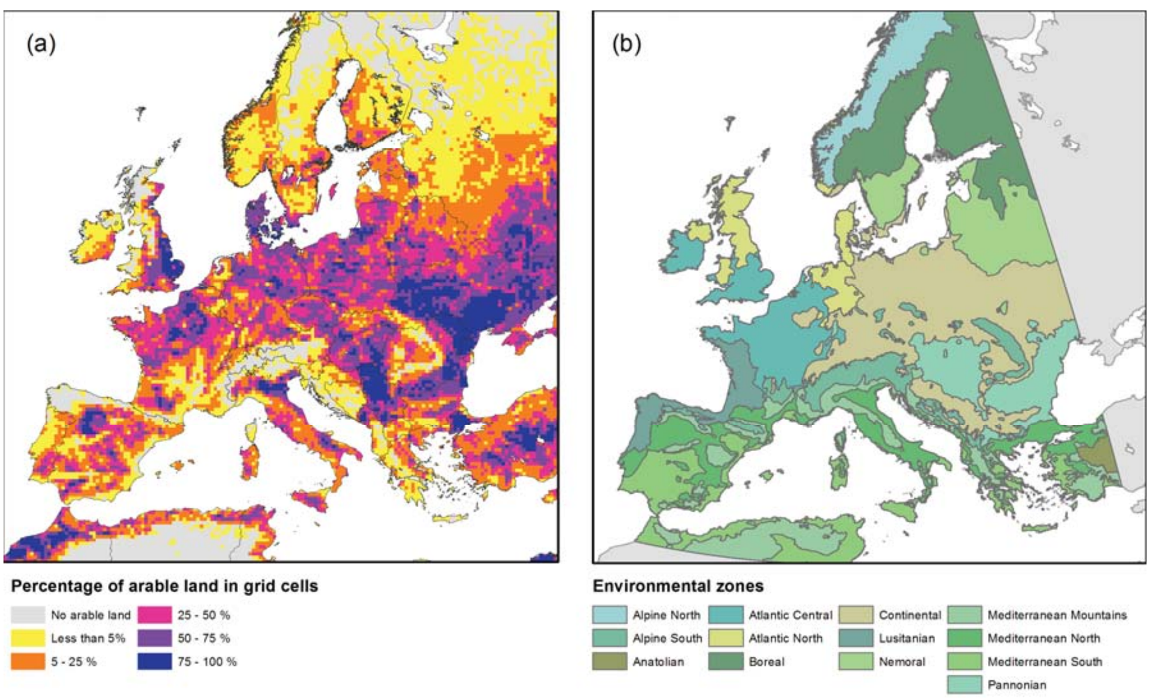

Figure 1 (a) Percentage of the 25 by 25 km grid cells covered by arable land according to the MARS Crop Yield Forecasting System (Genovese 2004). (b) Main environmental zones in Europe as proposed by Metzger et al. (2005) and Jongman et al (2006).

then stratified according to environmental zones (defined by Metzger et al. (2005) and Jongman et al. (2006) and illustrated in Fig. 1b). These are used to agregate percentiles of the selected agro-climatic indices for 6 of the main environmental zones in Europe: Atlantic Central (ATC), Continental (CON), Atlantic North (ATN), Mediterranean North (MDN), Mediterranean South (MDS) and Pannonian (PAN).

3 Results and Discussion

3.1 Assessment against observed data

The boxplots in Fig. 2 present a first comparison between the distributions from HADLEY and ECHAM projections and those from observations for the common 1993-2007 baseline period. This provides a first impression on whether the statistical distribution of the indices calculated from the modelled weather are in the same ranges as those calculated from observed data. This correspondence varies with respect to: what environmental zone is considered, which index is selected and even what GCM-RCM model run is used. For instance, the inter-annual distribution of dry spells over the baseline period are better represented by ECHAM than HADLEY over the Mediterranean South (MDN) while the inverse is observed for the Atlantic North (ATN). Despite the dynamical downscaling and the bias-correction, these figures show that there are still some considerable differences between models and observations in several areas.

3.2 Analysis of the distibution tails

A second analysis of the data emphasizes the changes in shape of the statistical distributions as characterized by its 5th and 95th percentile when passing from 2000 to 2030. By plotting the changes in these percentiles (Fig. 3), it is possible to show whether a shift in the distributions has occurred (when the arrows move parallel to the 1-to-1 line), whether there is an increase in variability (if the arrows indicate the direction perpendicular to 1-to-1 line), or a combination of both.

As expected, both climate projections seem to consistently portray an increase in the growing season length for all zones without any considerable increase in variability. This is partly caused by an earlier start of the season, for which the models provide coherent trajectories for Mediterranean (MDS and MDN) and the Atlantic Central (ATC) zones. For the other zones (CON, ATN and PAN), however, the HADLEY and ECHAM simulations are showing constrasting behaviours with ECHAM indicating a decrease in variability and HADLEY an increase, accompanied with a shift towards earlier values. For these same regions, changes in late frost dates are not apparent, warning that although sowing crops earlier might

Figure 2. Boxes representing the statistical distributions of 4 agro-climatic indices (from left to right: *Growing Season Start, Growing Season Length, Last Air Frost Spring* and *Dry Spell*) averaged for 6 environmental zones in Europe (from top to bottom: Atlantic Central, Atlantic North, Continental, Mediterranean North, Mediterranean South and Pannonian) covering the 1993-2007 range. In each case, the first box represents the distribution estimated by the HADLEY model, the second by ECHAM while the third is calculated from observed values obtained from MCYFS. The white box indicates the 5th to 95th percentile range, the coloured box the 25th to 75th percentile range and the central line the 50th percentile.

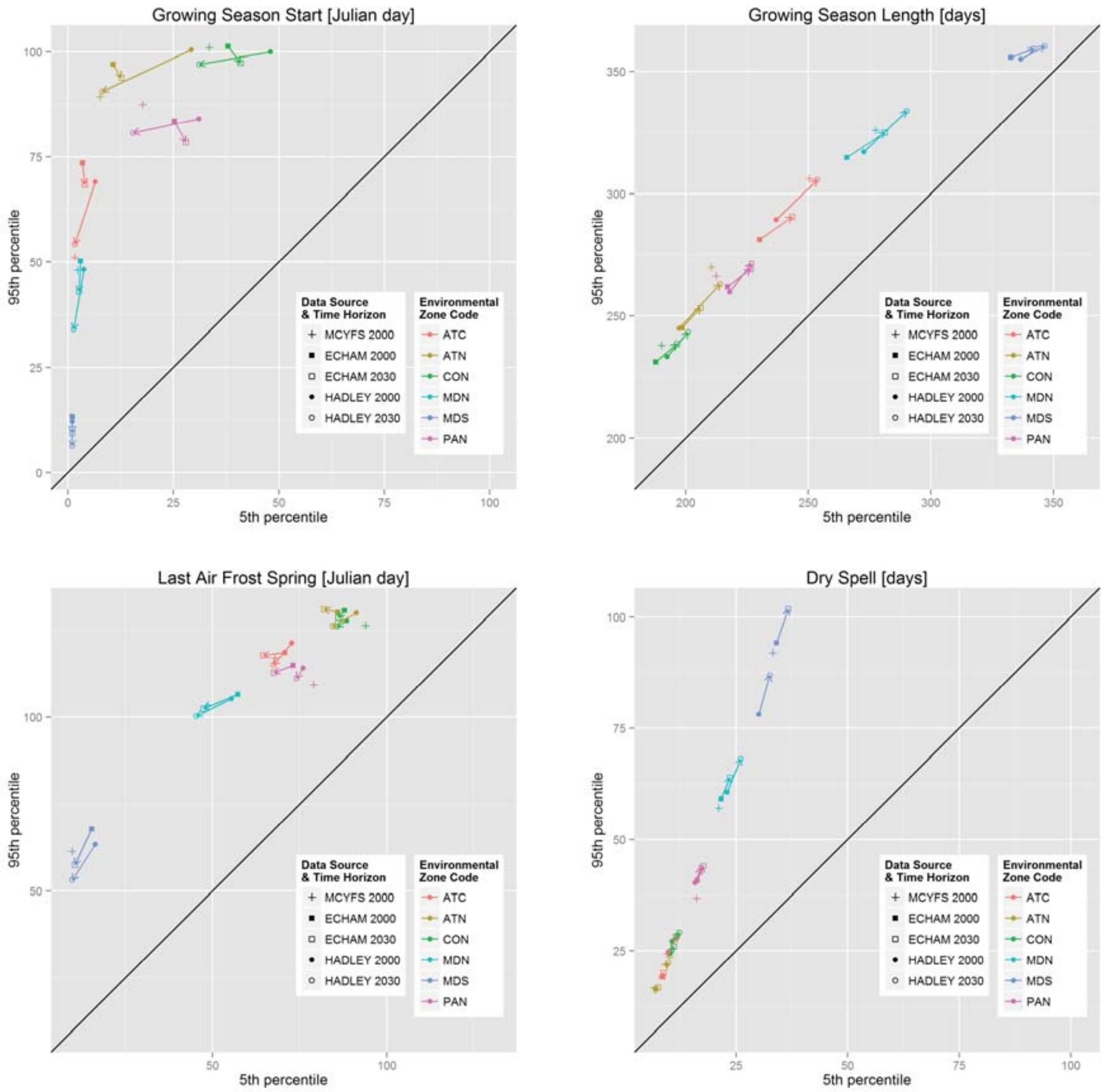

Figure 3. Scatterplots indicating how each model (HADLEY and ECHAM) project changes between the 2000 and 2030 time horizons to the 5th and 95th percentiles of the distributions of different agro-climatic indices aggregated by environmental zones. Additionally, the point representing the percentiles obtained from observations during the 2000 time horizon have been added for reference.

be beneficial to have a longer growth cycle, these may potentially be exposed to more frost damage. Regarding *Dry Spells*, a clear pattern of longer and more variable (from year-to-year) periods of consecutive dry days can be expected in the Mediterranean and Pannonian regions.

This analysis of the distribution tails also reveals that, in several cases, the 5th/95th percentiles of modelled data for the future can be closer to the 5th/95th percentiles of present observed data than the 5th/95th percentiles of modelled data for the present (Figure 3).

4 Conclusions and perspectives

This short paper is a small overview of the dataset prepared in the framework of this study, and a correspondinlgy short analysis of the information within. Results are still preliminary and require further attention. A first conclusion that stems from this analysis is that the statistical distributions of the four calculated agro-climatic indices presented here are not systematically coherent with the distributions of the same indices calculated on observed data. Even though the changes in these distributions generally seem coherent, in some cases the modelled data for the future is closer to the observed data in the present than the modelled data in the present. These results indicate that despite the efforts of improving the realism of the simulations with dynamical downscaling and bias-correction, there are still shortcomings in the weather data. Therefore, caution is necessary when deriving conclusions regarding climate change impacts on agriculture for the time scales considered.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

A multi-model ensemble for identifying future water stress hotspots

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Abstract— This study assesses the impact of climate and socio-economic changes on future freshwater resources with a special focus on water scarcity. Associated changes in water availability, water withdrawals and consumption are simulated using a multi-model ensemble, forced by statistical bias-corrected climate data from five Global Climate Models (GCMs) under three Representative Concentration Pathways (RCPs), and socio-economic input from the recently developed Shared Socio-Economic Pathways (SSPs). Water availability and demand projections are combined to identify future water stress hotspots, i.e. two indicators are calculated, one considering water withdrawals and the other including water consumption. Uncertainties in hydrological projections related to GCMs and scenarios are well known and have been studied in recent years. The establishment of a model intercomparison initiative in the water sector enabled the assessment of uncertainties related to global hydrological models (GHMs) with respect to water availability and irrigation. Our study goes beyond state-of-the-art by analyzing the uncertainty related to water withdrawals and consumption and its implication on the identification of hotspots. Preliminary GHM-ensemble results show reasonable agreement in projecting domestic and irrigation water withdrawals whilst there is a large discrepancy between the projections of industrial water withdrawals. An additional dimension of uncertainty needs to be considered if both exposure and sensitivity to climate change build the basis of an impact study.

Index Terms—ensemble modeling, indicator, uncertainty, water stress hotspots

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1 Introduction

Many river basins of the world are seriously affected by water scarcity, often caused by an imbalance between water availability and water demand. According to the FAO (2010), total freshwater abstraction today amounts to 3856 km^3 of which 70% is withdrawn by the agricultural sector, followed by the industry (19%) and domestic sectors (11%). Total water withdrawals increased threefold between 1950 and 2005 (Shiklomanov and Rodda 2003, Flörke et al. 2013) as a result of population growth and consumption change that have contributed to a rising demand for electricity, industrial and agricultural products, and thus for water. According to the newly developed “Shared Socio-Economic Pathways” (SSPs) global population is expected to increase to 7.2 or even 14 billion people by 2100 (O’Neill et al. 2012) and meeting the future demand for water will be a challenge, particularly in the context of avoiding further expansion of irrigated land.

Considering the impacts of climate change, socio-economic developments, further industrialization and urbanization, the competition for freshwater resources is likely to become a key concern for population, economy, and the environment. Water scarcity is both a natural and human-made phenomenon and defined as the condition where there are insufficient water resources to satisfy long-term average requirements. In other words, it refers to long-term water imbalances, combining low water availability with a level of water demand exceeding the supply capacity of the natural system (EC 2011). Changes in future water scarcity are mainly driven by changes in water withdrawals (Alcamo et al. 2007, Hanasaki et al. 2012), i.e. sensitivity to climate change outweighs exposure. Hanasaki et al. (2012) estimated that between 2.5 and 5.6 billion people will live under water stress by 2071 to 2100.

So far, the assessment of regional water-scarcity hotspots was mostly based on climate change impacts simulated by driving global hydrological models with climate projections from different Global Climate Models (GCMs) whereas less emphasise has been put on the water demand side.

The main objective of this study is to go one step further in identifying future water-scarce regions by using a multi-model ensemble of global hydrological and water demand projections for the 21st century as simulated within the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) with different water stress indices. Here, we analyse future global water resources under the latest generation of scenarios for global climate change studies (Moss et al. 2010). More specifically, we identify and compare future hotspot regions considering socio-economic scenarios of the lately developed SSPs (Kriegler et al. 2012) in combination with a set of climate scenarios generated under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5, Taylor et al. 2012).

Uncertainties resulting from the spread among climate scenarios and from global hydrological models (GHMs) have been assessed by Haddeland et al. (2011, 2013), Schewe et al. (2013), and Wada et al. (2013). This approach will address the main uncertainties related to both climate and socio-economic impacts on water scarcity and will provide more robust and consistent conclusions, which are important for adapting to these impacts as well as for future management of freshwater resources.

2 Methodology

We use a set of three state-of-the-art GHMs to quantify the impact of climate and socio-economic changes on global and regional freshwater scarcity, and the resulting uncertainties arising from the newly available CMIP5 climate projections obtained through the ISI-MIP initative. For our study we applied statistical bias-corrected daily climate model output as developed by Hempel et al. (2013). To explore the uncertainties related to climate change, we calculate water availablity, water withdrawals and consumption under three Representative Concentration Pathways (RCPs) from five GCMs and one SSP (SSP2), respectively. By balancing available freshwater resources and water abstracted or consumed for crop production, industrial and human needs we identify regions under water stress.

2.1 Modeling freshwater availability

In a first step, future freshwater availability affected solely by climate change is calculated ("natural conditions"). The three GHMs used in this study are: H08 (Hanasaki et al. 2008a, b), PCR-GLOBWB (van Beek et al. 2011, Wada et al. 2010, 2011), and WaterGAP (Döll et al. 2003, 2012, Flörke et al. 2013).

The aim of the hydrological modeling is to simulate the characteristic macro-scale behavior of the terrestrial water cycle in order to estimate water availability. Based on the daily time series of climatic projections, the GHMs calculate the water balance at a daily time step and a spatial resolution of 0.5 degree latitude and longitude (~50 km at the equator), respectively, taking into account physiographic characteristics such as soil type, vegetation, slope, etc. Runoff generated on the grid cells is routed to the catchment outlet on the basis of a global drainage direction map (DDM30, Döll and Lehner 2002), taking into account the extent and hydrological influence of lakes, reservoirs, dams, and wetlands.

2.2 Modeling water withdrawals and consumption

Next to water availability the three GHMs listed above calculate water withdrawals and consumption for the domestic, industrial and irrigation sectors. Irrigation water requirements are simulated on a grid cell level while domestic and industrial water uses are computed at the country scale and allocated to grid cells using demographic data.

Multi-model and multi-scenario ensemble projections of irrigation water requirements according to the ISI-MIP modeling protocol have been analysed by Wada et al. (2013). The models considered in that study simulate irrigation water requirements per unit crop area based on surface and soil water balance, by counterbalancing the difference between crop evapotranspiration and actual evapotranspiration (soil water availability) at a daily time step and correcting for conveyance and application losses. Future expansion of irrigated areas is not considered, and hence remains constant to the year 2000 (Portmann et al. 2010). Further, it must be noted that optimal crop growth is assumed, i.e. water supply is not limited.

Although the approaches to simulate domestic and industrial water use differ between the GHMs, in general, water withdrawals are calculated by multiplying sector-specific water use intensities by a sector-related socio-economic driving force (e.g. population, GDP, or energy-related input). In order to take into account improving water use efficiency, technological change rates per country are introduced. The H08 and PCR-GLOBWB models calculate water use for the total industry sector, whereas WaterGAP distinguishes between water used for cooling purposes in thermal power plants and water processed in manufacturing industries.

2.3 Identification of water stress hotspots

A set of impact indicators is derived from hydrological and water use projections, which were aggregated to river basins. We selected two water stress indicators, the first one based on water withdrawals and the second one depending on water consumption:

The water exploitation index (WEI) is defined as the total water withdrawals-to-availability ratio within a river basin. Generally speaking, the larger the volume of water withdrawn and the smaller water availability the higher the water stress. Increasing water stress results in stronger competition between society's users, as well as between society and ecosystem requirements. A river basin is assumed to be under low water stress if $WEI \leq 0.2$, under medium water stress if $0.2 < WEI \leq 0.4$, and under severe water stress if $WEI > 0.4$ (Vörösmarty et al. 2000, Alcamo et al. 2007).

Next to WEI, we address water stress related to water consumption, i.e. the share of water withdrawals that is not returned to the surface waters, with the consumption-to-availability ratio CTA. According to Hoekstra et al. (2012) a river basin is considered to be under severe water stress if $CTA > 0.2$. This impact indicator predominates in regions where agriculture is a major water user as nearly 90% of the irrigation water withdrawals is consumed (Shiklomanov and Rodda 2003), i.e. lost by evaporation during supply or evapotranspiration from plants. Both indicators, WEI and CTA, are computed on an annual and monthly basis.

3 Results

At this stage of the study we can only provide preliminary results and most of the analysis is still work in progress. Regarding water withdrawals, first results were generated for the "middle of the road" scenario SSP2 under RCP6.0 conditions, i.e. comparable to a business-as-usual case. However, the analysis to identify future water scarcity hotspots has started and results will be presented at the conference.

Fig. 1 presents the future projections of global domestic, industrial, and irrigation water withdrawals as calculated by the three GHMs. The figure indicates that the GHM-ensemble results clustered around a very narrow range for domestic and irrigation water withdrawals. Depending on the GHM, domestic water withdrawals vary between 758 km^3 and 976 km^3, whereas water abstractions for irrigation purposes (median of 5 GCM driven model runs) range from 3636 km^3 to 3900 km^3. Further it can also be noted that the variation between the model outcomes is largest in terms of industrial water withdrawals, which differ between 800 km^3 and 4000 km^3 globally in 2100. Due to this discrepancy total water withdrawals are expected to amount between 5370 and 8890 km³ by the end of the century. In fact, the industrial sector may become the most important water use sector in the future, and hence replace the agricultural sector.

The huge differences in future industrial water withdrawals as calculated by the GHMs are a result of applying different model functions and driving forces in order to estimate the same metric. Key socio-economic input (e.g. population, GDP per capita, electricity production) has been harmonized between the different GHMs. Furthermore, the same assumption of technological improvements was used, i.e. technological change rates of 0.7% per year for developed countries and 0.3% per year for least developed countries (GDP per capita < 1500 USD). Account should be taken of the fact that data records on industrial water withdrawals and consumption are rare compared to the other sectors, in particular related to the manufacturing sector. Although all models showed their ability to back-calculate historical water withdrawals based on a function of current water intensities and socio-economic drivers, some of the socio-economic driving forces are expected to change in an unprecedented scale.

It is apparent from Fig. 1 that the uncertainty related to the methods used by the different GHMs can be high, here especially in case of industrial water withdrawals. The same can be assumed for the calculation of sectoral water consumption where the usage of consumption factors will be an additional element of uncertainty. However, Haddeland et al. (2011) and Schewe et al. (2013) showed in their studies that GHM uncertainty is higher than the uncertainty related to GCMs and socio-economic input. For our further analysis, i.e. to identify future water stress hotspots, it will be of importance not only to quantify the uncertainty but also to present and explain the discrepancy between model results in a transparent fashion.

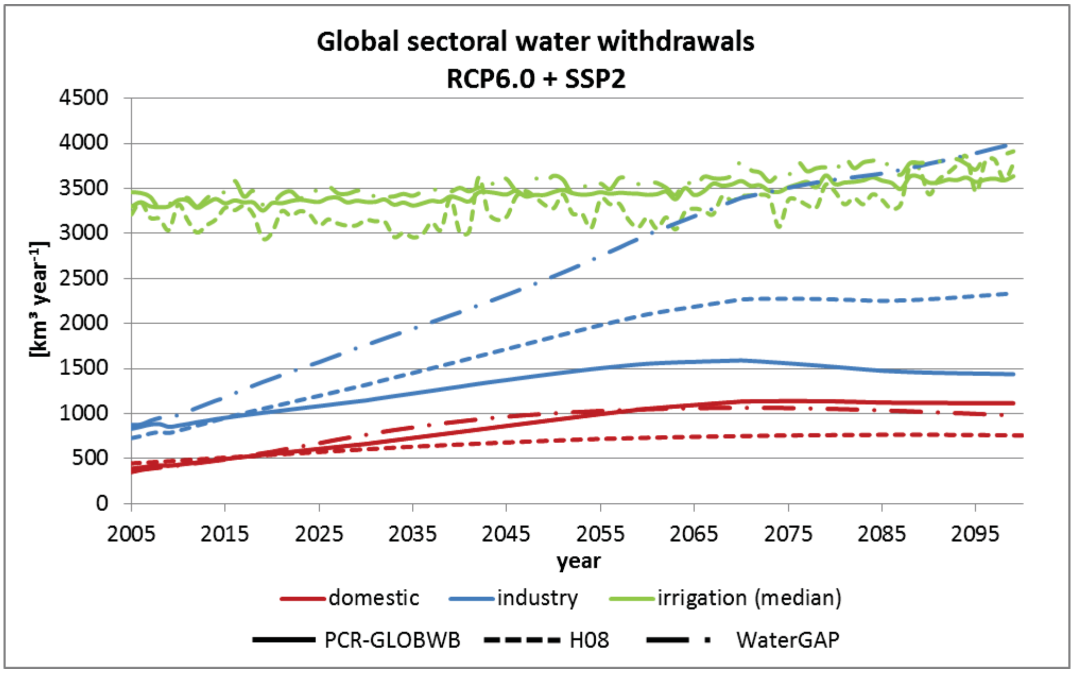

Fig. 1 Global sectoral water withdrawals under RCP6.0 as calculate by the model ensemble for the 21st century.

4 Conclusions

Our preliminary results confirm that GHM uncertainty is not only related to water availability but also to water withdrawals. Whilst the results of future domestic and irrigation water withdrawals of the GHM ensemble are in a close range, projecting industrial water withdrawals is subject to considerable uncertainties. Although the GHM input was harmonized the methodological realizations differ within the model ensemble.

Overall, an additional dimension of uncertainty needs to be considered if both exposure and sensitivity to climate change build the basis of an impact study. The estimation of future water withdrawals (and consumption) is a function of climate change as well as socio-economic developments, and changes in electricity production and technological improvements. In order to identify future hotspots of water stress both the supply and demand sides are of importance but also susceptible to uncertainties.

Further analysis of water stress measures, the identification of robust results, and the quantification of uncertainty will contribute to improving the assessment of impact studies. Nevertheless, these studies build the basis for adaptation or mitigation strategies, i.e. technological innovations or transformations will help either to decrease the intensity of radiative forcing in order to reduce the effects of global warming or to reduce or even prevent unnecessary water abstractions in water scarce regions.

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Improved consideration of uncertainties in a comprehensive assessment of climate change impacts in Europe

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Abstract— In November 2012 the European Environment Agency (EEA) published its third indicator-based report on climate change, impacts and vulnerability in Europe. This report aimed among others at improving the assessment and reporting of uncertainties in observed and projected climate change and its impacts. EEA decided not to copy the IPCC approach for using calibrated uncertainty language, due among others to differences in the purpose and process between IPCC and EEA reports. Instead, authors were requested to consider the following aspects when writing their assessment and in particular when formulating key messages: choosing the appropriate type of statement, choosing the appropriate level of precision, considering all relevant sources of uncertainty, and reporting explicitly on the lack of information where appropriate. The treatment of uncertainties in the report was described in a dedicated section in the introduction. This paper presents the experiences with improving the consideration and reporting of uncertainties in the 2012 EEA climate impacts report.

Index Terms—climate impacts, European Environment Agency, indicators, uncertainty.

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1 Introduction

The European Environment Agency (EEA) is mandated by its founding regulation[1] *"to provide the Community and the Member States with the objective information necessary for framing and implementing sound and effective environmental policies"* and *"to publish […] indicator reports focusing upon specific issues"*. One topic where EEA activities have increased in recent years is climate change impacts and adaptation. The increased information demand is driven, among others, by the commitment in the European Commission's 2009 White Paper *"Adapting to climate change: Towards a European framework for action"*[2] to develop a comprehensive EU Adaptation Strategy by 2013[3]. Furthermore, 16 EEA member countries have developed National Adaptation Strategies and/or National Adaptation Action Plans in recent years, and many others are currently doing so.[4]

In response to the policy demands, EEA has so far published three indicator-based reports dealing with climate change (EEA 2004; EEA 2008; EEA 2012). The main target group of the reports are European and national policy-makers but they also serve academic scientists, non-governmental organisations, the press and the public at large. Within 3 months of its publication, the 2012 report already had around 100 000 Google hits and more than 500 media citations.

* European Environment Agency (EEA)
[1] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31990R1210:EN:HTML, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:126:0013:0022:EN:PDF
[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2009:0147:FIN:EN:PDF
[3] http://ec.europa.eu/clima/events/0069/index_en.htm
[4] http://climate-adapt.eea.europa.eu/countries

2 EEA reports vs. IPCC reports

All environmental information managed by EEA is subject to some uncertainties, and EEA is working actively with its member countries to improve the consistency and accuracy of data reported from countries to EEA. The assessment and communication of uncertainty related to climate impacts faces particular challenges:

1. EEA indicators on climate impacts generally do not rely on data reporting from countries. Instead, data stems from international organizations, European research projects, research networks and individual institutions.
2. EEA indicators on climate change are primarily used to inform adaptation policies, which in turn are largely driven by anticipated changes in climate. Hence the importance of future projections is much more important for EEA indicators on climate impacts than for most other EEA indicators.

EEA has paid considerable attention to uncertainties in climate impact indicators already in its first and second indicator-based reports. The importance of this topic increased further in the preparation of the third indicator-based report for two main reasons:

1. The substantially increased activities around climate change adaptation at the European and national level resulted in higher demands on the underlying knowledge base, including relevant EEA indicators.
2. The discovery of an erroneous statement about the melting of Himalayan glaciers in a chapter of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change in December 2009 (dubbed "Glaciergate") resulted in strong public and political criticism of the IPCC. In response, the UN Secretary-General and the IPCC Chair asked the InterAcademy Council (IAC) in March 2010 to carry out an independent review of IPCC processes and procedures.[5]

The IPCC has considerable experience in assessing and communicating uncertainties in its assessment reports. Over a period of 10 years, the IPCC has developed and refined a 'calibrated language' to express the confidence in and/or likelihood of specific findings, which is applied in most key messages of IPCC reports (Moss & Schneider 2000; IPCC 2005; Mastrandrea et al. 2010). This author had been involved in the preparation of the IPCC AR4 as an author, review editor, expert reviewer and government representative in IPCC plenary meetings. The increased efforts to describe the accuracy and robustness of the data underlying indicators in the 2012 EEA report was facilitated by his close familiarity with relevant IPCC practices.

EEA reports share some similarities with IPCC assessment, including a mandatory review by EEA member countries. However, there are also some important differences:

1. IPCC assessment reports aim to assess all information available in the relevant (academic) literature whereas the EEA climate impact reports focus on the presentation of selected indicators.
2. The writing team of a chapter in an IPCC report typically consists of 20 or more authors

[5] https://www.ipcc.ch/pdf/IAC_report/iac_letter.pdf, https://www.ipcc.ch/organization/organization_review.shtml#.UTnrPCJZxqE

supported by at least two review editors. For example, the writing team of the chapter on Europe in the Working Group II contribution to the IPCC AR4 consisted of 3 convening lead authors, 7 lead authors, 12 contributing authors and 2 review editors. In contrast, most chapters of the EEA climate impacts report are written by only one or two authors supported by a small number of contributors.

3. IPCC reports receive very strong attention from the media world-wide, including from countries where climate change is a very contentious issue. Their publication is regularly covered in the main evening news. The EEA climate impacts reports also receive considerable attention in the media (e.g. the 2012 report was cited more than 500 times in newspapers and websites), but this is still much less than for an IPCC report. Furthermore, EEA reports have not (yet) faced such a hostile reception by parts of its target audience as the IPCC reports.

Copying the IPCC approach for assessing and communicating uncertainty appeared neither feasible nor necessary for the EEA climate impacts report. Most importantly, the small number of experts involved in each indicator assessment prohibits quantitative expert assessments of confidence and uncertainty. Additionally, key messages would have become rather cumbersome and difficult to interpret for the target audience, without providing readers with substantial relevant information. It is important to emphasize that this decision does not in any way imply a criticism of the IPCC approach. It simply reflects the different needs and capacities between EEA and IPCC.

3 Consideration of uncertainty in the 2012 EEA climate impacts report

In the 2012 climate impacts report, uncertainty was addressed by the following elements, which were applied in particular in its key messages:

1. Dedicated uncertainty section
2. Careful choice of the type of statement
3. Careful choice of the appropriate level of precision
4. Explicit information on the pedigree of information and uncertainty
5. Explicit reporting of knowledge gaps
6. Central editing of uncertainty language
7. Extended expert review

These elements are further explained below.

Dedicated uncertainty section

A dedicated uncertainty section was included in the report that outlines the relevant key sources of uncertainty and explains how they are addressed and communicated in the report.

Appropriate choice of type of statement

Most key messages related to indicators can be categorized into a limited number of “types” of statements. The following types of statements are distinguished in key messages related to climate and impact indicators in the EEA report (based on IPCC 2007, Table SPM.2):

1. Observation of a climate variable or a climate-sensitive ‘impact’ variable
2. Observation of a statistically significant (change in) trend of a climate or impact variable
3. Attribution of a change in a climate or impact variable to a particular cause
4. Projection of a climate or impact variable into the future

Different types of statements are subject to different sources of uncertainty. As a general rule, the (sources of) uncertainty increases from observations to attributions and projections and from climate indicators to climate impact indicators. For example, observations of a climate or climate impact variable can be made for short time series whereas statements about statistically significant trends require availability of longer time series and the consideration of natural interannual variability. Authors were advised to formulate key messages so that it is clear what type of statement they make, and to avoid the combination of different types of statements in a single message.

Careful choice of the appropriate level of precision

Statements in key messages can be made at different levels of precision (or quantification), which are ordered here from least to most precise (based on IPCC 2005):

1. Existence of effect (but the direction is ambiguous or unpredictable)
2. Direction (of change or trend)
3. Order of magnitude
4. Range or confidence interval
5. Single value (implying confidence in all significant digits)

Authors were advised to formulate key messages at the highest level of precision justified by the underlying data, and to separate statements with different levels of precision (e.g. related to observations vs. projections) in order to clearly indicate the precision of each individual statement.

Explicit information on the pedigree of information and uncertainty

Authors were advised to state explicitly whether and how key sources of uncertainty have been considered in the underlying dataset, and what this implies for the confidence that can be put in a specific data set or conclusion (where relevant and feasible). For example, a message on future climate change would indicate which emission scenarios and how many climate models are considered in this projection.

Explicit reporting of knowledge gaps

Authors were advised to report explicitly on the availability of data related to past trends as well as future projections. Explicit statements on knowledge gaps can inform future efforts for data collection and research. Additionally, they ensure the reader that a lack of reporting on an issued does not reflect a lack of consideration.

Central editing of uncertainty language

Some authors of the 2012 report had previously contributed to IPCC assessments and were prepared to pay particular attention to uncertainty assessment and communication whereas others felt less comfortable assessing the merits and robustness of research results reported in the academic literature that they were not directly involved in. As a result, the degree to which the recommendations above were followed differed substantially across chapters. In the end, central editing by EEA lead authors was needed to improve the consistency of uncertainty reporting across the report.

Extended expert review

All EEA reports are reviewed by experts from so-called National Focal Points and thematic National Reference Centres from all EEA member countries. These experts are generally employed by government institutions, such as national Environmental Protection Agencies. For this report, the review was extended to an advisory group of about 20 thematic experts that had supported the report production from the beginning and to about 20 further scientific experts from academic institutions that were not involved as authors.

4 Discussion and conclusions

The clear communication of the state of knowledge on a particular subject, including associated uncertainties, is relevant in all work areas of the EEA. EEA reports and indicators addressing climate change and its impacts face particular challenges due to the large importance of future projections for informing present adaptation planning. For more than a decade, the IPCC has been guiding its authors on the consistent assessment and reporting of relevant uncertainties. While the efforts of the IPCC have been inspiring for the EEA, application of the IPCC uncertainty guidance to the EEA report was not feasible, largely due to the small number of authors working on a particular topic.

Instead of applying a calibrated uncertainty language, EEA efforts focussed on clarity about the type of statements (e.g. observation of a trend vs. attribution to a particular cause), careful choice of the level of quantification, and explicitit discussion of key uncertainties and of knowledge gaps. The efforts at improved consideration of uncertainty in the 2012 EEA climate impacts report have also inspired a wider discussion on uncertainty communication in EEA assessment reports.

Feedback from academic readers on the uncertainty reporting in the 2012 EEA report has generally been very positive. EEA has only received limited feedback from policy makers on this specific topic. However, key uncertainties relevant for climate change adaptation are clearly referred in the EU

Strategy on adaptation to climate change[6] adopted in April 2013 as well as in national adaptation strategies. Hence, we feel confident to conclude that European and national decision-makers have accepted that adaptation planning involves decision-making under uncertainty, and that they do appreciate efforts by EEA (and others) to communicate the scope and source of these uncertainties as clearly as possible.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Systematic quantification of climate change impacts modelling uncertainty

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Abstract—ISI-MIP has made important advances in climate change impacts modeling by using multiple climate models and impacts models together with socio-economic and emissions scenarios to quantify uncertainties in projections of the impacts of climate change. This is in recognition of the fact that different models will simulate different outputs, even when forced with identical input data. However, two links of the chain of uncertainties in climate change impacts modelling are still missing. These are 1) quantification of uncertainty from the application of *different versions* of the *same* climate model, and 2) quantification of uncertainty from application of *different versions* of the *same* impacts model. This paper facilitates discussion around this topic by explaining why these uncertainties need to be quantified. It also demonstrates how these uncertainties may be quantified by using examples from climate model experiments and one of the impacts models included in the water sector of ISI-MIP. Three recommendations for addressing this gap in knowledge are suggested.

Index Terms—climate change impacts modelling, perturbed parameter ensemble, uncertainty

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1 Introduction

The aim of this paper is to raise awareness of, and trigger discussion of, an important element of climate change impacts science that is still largely missing from the literature; the systematic quantification of inherent uncertainties that arise from the application of *different versions* of the same climate and impacts models. For example, how large might be the range in simulations if multiple, yet plausible, versions of the same climate model and/or impacts model are used? Specifically, this paper focuses on one of the questions included in the second fundamental challenge that the conference seeks to address ("How certain are we?"); "*What are the main sources of uncertainty along the chain from climate change and socio-economic drivers to impact projections?*"

2 Quantification of uncertainties thus far

It is well known that impacts models developed by different institutions will perform slightly differently from each other even when they are forced with consistent input data (Gosling et al., 2011, Haddeland et al., 2011, Thompson et al., 2013). This is because each impacts model will apply different, but equally plausible, paramaterisations of the environment that they are attempting to model. The same holds for climate models developed at different institutions (Meehl et al., 2007). Application of different climate models and impacts models gives rise to uncertainties and these have been well quantified in ISI-MIP, where, for instance, in the water sector impacts assessment, 5 different climate models were used with 11 different impacts models (Schewe et al., submitted). This has been an important advance from other assessments that have typically applied multiple climate model simulations to only a single impacts model (Arnell et al., 2013, Gosling et al., 2010). So far, ISI-MIP has quantified these two sources of uncertainty along with socio-economic and emissions uncertainty. These represent important sources of uncertainty in the overall chain of impacts modelling uncertainty that is illustrated in boxes 1, 3, 4 and 6 in Fig 1.

However, the quantification of two sources of uncertainty is still largely missing from the impacts modelling literature; 1) uncertainty from the application of different versions of the same climate model, and 2) uncertainty from application of different versions of the same impacts model. The following two sections explain why these two uncertainties are important.

3 Different versions of the same climate model

The implementation of different paramaterisations within climate models, and indeed in any model, gives rise to uncertainties in the model simulations. Within the climate modelling community, two main strategies exist for quantifying this uncertainty. One approach involves collecting climate model results from several different models (Meehl et al., 2007) to produce an ensemble of projections for comparison. This is sometimes referred to as an "ensemble of opportunity" (Fig. 1) and the uncertainty is attributed to different institutions applying different but plausible paramaterisations in their models. A second approach generates a "perturbed parameter ensemble" (PPE; Fig. 1) that introduces perturbations to the physical parameterisation schemes of a single climate model, leading to many plausible versions of the same underlying model (Murphy et al., 2004).

Each approach has its own advantages and disadvantages. Ensembles of opportunity tend to be more readily available because individual institutions will have run their models for major international exercises such as the IPCC AR5. However, such ensembles may not span the true range of parameter values or schemes that are considered plausible and/or may miss some out. PPEs facilitate a more systematic consideration of parameter space but they can be demanding and expensive in terms of computational and resource requirements.

Fig. 2 shows simulations for the 2080s of daily maximum temperature from a single climate model grid cell located over London, UK, for a single climate model (HadCM3) under three emissions scenarios (B2, A1B, A2), compared with simulations under a single emissions scenario (A1B) but with a PPE for the same climate model. All 17 ensemble members of the PPE are equally plausible representations of future climate. The range in both the variability and mean temperature across the PPE is greater than the range across three emissions scenarios when employing a single version of the climate model. The differences are typically greater for other variables such as precipitation.

It has been found that the range of uncertainty across simulations from a PPE is comparable to that across an ensemble of opportunity (Collins et al., 2006) but the absolute values of the upper and lower limits of these ranges may be different. To this end, application of a PPE is not a substitute for applying an ensemble of opportunity. Rather, if resources allow, combined ensembles made up of a number of PPEs made with a number of individual climate models should be sought (Collins et al., 2006). The quantification of uncertainty in impacts projections from PPEs is in its infancy (Gosling et al., 2012, Fung et al., 2011) and it deserves further attention.

4 Different versions of the same impact model

Mac-PDM.09 is one of the global hydrological models included in ISI-MIP. The standard model setup described by Gosling and Arnell (2011) has been used in ISI-MIP. However, just as parameterisations in individual climate models are a source of uncertainty, so they are also in individual impacts models like Mac-PDM.09. This is why multiple impacts models present different impacts even when they are forced with consistent forcing climate data (Gosling et al., 2011, Haddeland et al., 2011, Thompson et al., 2013). ISI-MIP has addressed this to some extent by using multiple impacts models from various institutions; essentially an ensemble of opportunity of impacts models (Fig. 1).

However, there remains an opportunity to quantify impacts model uncertainty more systematically by applying different plausible versions of the same impacts model. This could be achieved in a very similar approach to that adopted by the climate modelling community, discussed previously; i.e. by conducting a PPE comprised of several versions of a global-scale impacts model.

Fig. 3 shows the effects of changing simultaneously three paramaterisations in Mac-PDM.09, within plausible bounds, by comparing a “baseline” simulation with a “perturbed” simulation. The forcing data was identical for each simulation (1961-1990). Differences in average annual runoff of up to ±40% are observed between the two simulations. This is appreciable, especially considering that the results are from plausible versions of a *single* impacts model. Additional work would repeat this but with more parameter perturbations and under climate change scenarios. The range across simulations could then be compared to the ISI-MIP impacts model ensemble of opportunity.

While impacts models can be calibrated to help select appropriate parameter values, when climate change scenarios are applied, the models are operating outside of their calibration range. To this end, modelers are encouraged to explore the sensitivity of their models under climate change scenarios to alternative and plausible parameter setups.

5 Conclusions and recommendations

The climate modelling community have been quantifying uncertainties in individual climate models (e.g. HadCM3) for around a decade (Murphy et al., 2004) but this approach has not yet transcended to the impacts modelling community. This means that two links in the chain of uncertainties in climate change impacts modelling are missing. The following three recommendations for further research are suggested to address this.

1. **Application of a climate model PPE to one global-scale impacts model**. This would facilitate quantification of climate model uncertainty more systematically than has been achieved before and would address box 2 in Fig. 1. The results could be compared with impacts associated with a climate model ensemble of opportunity such as that already applied in ISI-MIP.
2. **Application of a single climate change scenario to an impacts model PPE**. This would facilitate quantification of impacts model uncertainty more systematically than has been achieved before and address box 5 in Fig. 1. The results could be compared with impacts associated with an impacts model ensemble of opportunity such as that already undertaken in ISI-MIP.
3. A combination of 1) and 2), where **a climate model PPE is applied to an impacts model PPE**. This would require greater resources but it would complete the missing links in the chain of uncertainties displayed in Fig. 1.

In all three cases above, careful thought will need to be given as to whether every combination of model parameter values within the PPE is plausible. This is related to the issue of equifinality in hydrological modelling (Beven, 1993). It could be addressed by considering the uncertainty in the model simulations of observed climate for any number of test catchments across the globe and weighting them by their relative likelihood or level of acceptability (Beven and Freer, 2001). There are various methods for doing this, e.g. Generalised Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992).

6 Figures and Tables

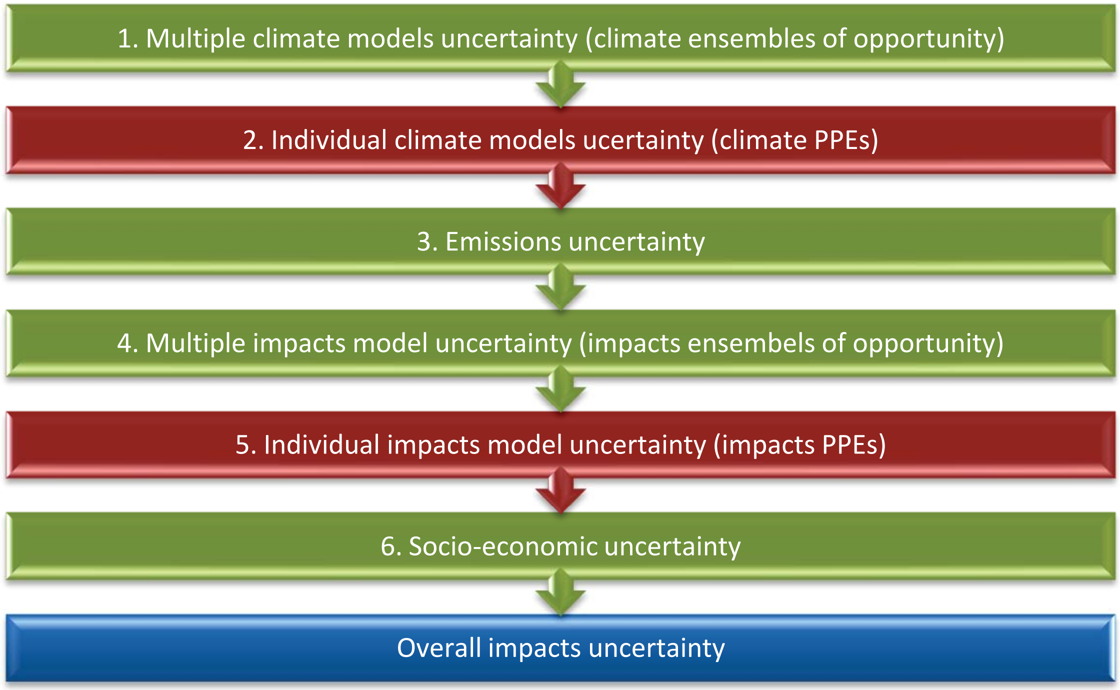

Fig. 1. The chain of uncertainties in climate change impacts modelling that lead to overall impacts uncertainty (blue bar). The green bars denote uncertainties considered in ISI-MIP so far. Red bars denote uncertainties that remain to be quantified. PPE denotes "Perturbed Parameter Ensemble".

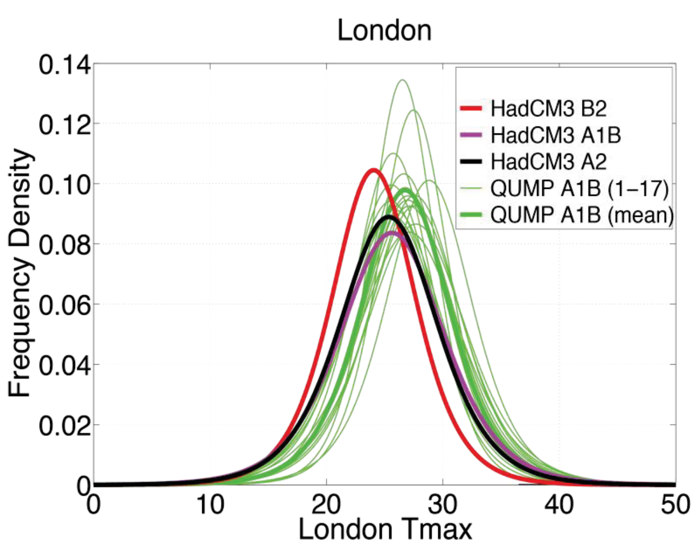

Fig. 2. PDFs of simulated daily maximum temperature for the period 2070–2099 under three emissions scenarios (SRES B2, A1B, A2) with a single climate model (HadCM3) compared with 17 simulations under A1B with a PPE (QUMP) and the QUMP ensemble mean. Adapted from Gosling et al. (2012).

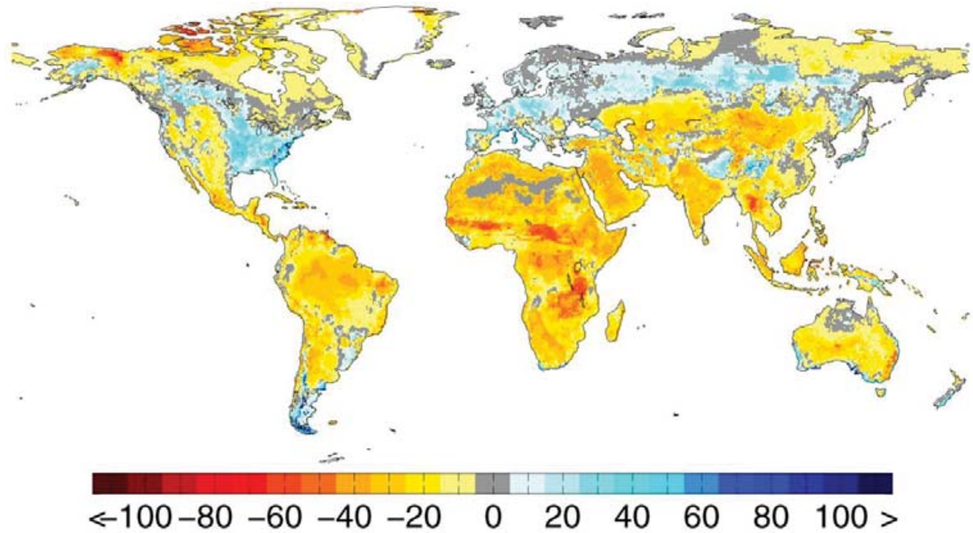

Fig. 3. Difference in average annual runoff (%) between the standard Mac-PDM.09 hydrological model parameter setup (Gosling and Arnell, 2011) and a perturbed version of the model where parameter values and/or parameter schemes are changed as follows; beta soil moisture variability parameter (changed from 0.5 to 0.3), field capacity parameter (1.0 to 1.2) and method of PE calculation (Penman-Monteith to Priestley-Taylor). Adapted from Gosling and Arnell (2011).

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Will the Global Warming Alleviate Cold-related Mortality?

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Abstract— Introduction: In temperate countries, mortality rates are generally lowest in the warmer summer months. This average seasonal pattern reflects the net effect of seasonally varying exposures, via complex mechanisms. Heatwaves and cold events can cause transient departure from the seasonal pattern (temperature-related excess mortality). However, the mechanisms of "heat-related" and "cold-related" excess mortality may differ. Global climate change is projected to cause increases in average temperatures, but the net effect of these trends on mortality is not clear. In this study, we investigated whether or not global warming will alleviate "cold-related" excess mortality using monthly data from several countries.

Methods: We investigated the relation between monthly average temperature and monthly average relative mortality risk for 47 prefectures of Japan, 6 cities of Korea, 3 cities of Taiwan and 20 large cities of US.

Results: Mortality rates were generally highest during winter, moderate during spring and fall and lowest in summer. This pattern was basically seen across cities and countries. There was little evidence that warmer areas had lower mortality during spring, summer and fall. There was some evidence that colder areas in Korea and Japan had lower mortality level in winter.

Discussion: This study suggests that month-specific relative risk is similar across cities in wide range of climate zones. Hence, it may not be appropriate to apply a V-shaped relation between temperature and mortality to long term climate projections. The effect of global climate change on "cold related excess mortality" may be much smaller than previously expected.

Index Terms— Climate, cold-related mortality, month-specific analysis , multi-country analysis,

———————————————————————

1 Introduction

In temperate countries, mortality rates are generally lowest in the warmer summer months. This average seasonal pattern reflects the net effect of seasonally varying exposures, via complex mechanisms. Heat-waves and cold events can cause transient departure from the seasonal pattern (temperature-related excess mortality). However, the mechanisms of "heat-related" and "cold-related" excess mortality may differ. For example, if we control for year trend only, the relation between daily maximum temperature and mortality appears V-shaped, but if we control for season in addition to year trend, then the colder part of the V-shape disappeared (Honda & Ono 2009)(Kinney et al. 2012) also raised concern about naive use of temperature-mortality relation for evaluating cold effect. In this regard, we should evaluate the net impact of global climate change based on different evaluation method for cold-related and heat-related health effect.

In this paper, we offer some critical findings for discussion that contradict the previous belief that the global warming will alleviate "cold-related" excess mortality, and that may alter our policy how we avoid heat- and cold-related mortality.

2 Data and Methods

All the mortality and meteorology data were obtained from respective governmental agencies in Janna, Korea, and Taiwan. For US, we obtained NMMAPS data in 2010, when the data were available through internet.

We first observed the relation between monthly average daily maximum temperature and monthly average of "detrended relative mortality risk," which we will explain below. Unit of analysis is area, i.e., prefecture for Japan, city for Korea, Taiwan and US. All 47 prefectures were included for Japanese analyses, and 6 cities (Seoul, Incheon, Deajeon, Daegu, Busan and Gwangju) for Korea, 3 cities for Taiwan (Taipei, Taichung and Kaohsiung) and 20 largest NMMAPS cities (Los Angeles, New York, Chicago, Dallas/Fort Worth, Houston, Phoenix, Santa Ana/Anaheim, San Diego, Miami, Detroit, Seattle, San Bernardino, San Jose, Minneapolis/St. Paul, Riverside, Philadelphia, Atlanta, Oakland, Denver and Cleveland) for US were selected for the analyses.

The method we obtained the “detrended relative mortality risk” is as follows: (1) For each year, we collected the days with daily maximum temperature level between 75 percentile value and 85 percentile value; (2) we computed the average number of daily deaths for these collected days; (3) setting the computed average for the year as reference, we computed the year’s relative mortality; (4) we iterated the process for all the observation period. This procedure appears complicated, but the number of deaths on days with daily maximum temperature level between 75 percentile value and 85 percentile value is the lowest during the year (Honda et al. 2007) and is usually not affected by influenza epidemics, which occur during winter and the size of which varies from year to year.

3 Results and Discussion

3.1 Temperature-mortality difference by area

Figure 1 shows the relation between average of daily maximum temperature and relative mortality in Japan, Korea, Taiwan and US. The numbers in the figure represent the month; “1” stands for January for example.

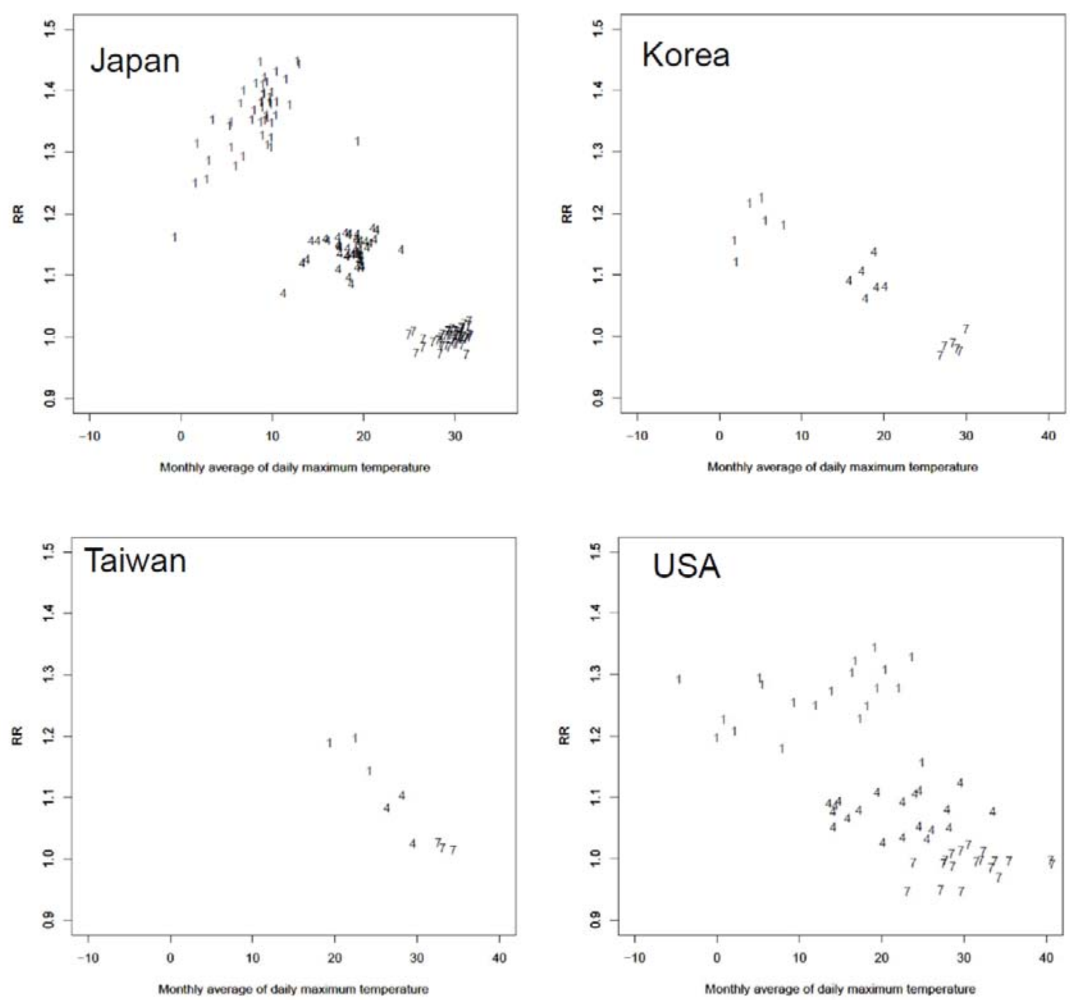

Figure 1. Relation between monthly average of daily maximum temperature and relative mortality. (Numbers in the graph represent month of year.)

3.1.1 Winter pattern

Taiwan has only 3 cities and hard to determine the trend, but the colder areas have lower mortality than warmer areas in Japan and Korea. This implies that colder areas adapted better to colder climate than warmer areas. If this applies to the future, warmer winter due to global warming will not alleviate winter mortality. In the US, there was no clear tendency, but at least negative correlation was not shown, and we cannot expect alleviation of winter mortality either.

3.1.2 Spring (and autumn) pattern

All the countries and territory showed the mortality level in April (represented by "4") between that for winter and summer. Three Taiwan cities and some of the US cities are very warm, with spring average daily maximum temperature close to 30 degrees C and still the mortality level is higher than summer. Although not shown here, autumn months also showed similar pattern to spring months.

It is counterintuitive that the mortality level in comfortable seasons is higher than that in hot season. However, Figure 1 shows that hot weather is good for survival. This poses us serious question: Do we want to warm up our rooms in spring or autumn up to 30 degrees C to avoid excess mortality due to "higher than optimal temperature"?

3.1.3 Summer pattern

Figure 1 does not consistently show that heat is harmful. However, unlike cold effect, heat effect is acute, i.e., the same day high temperature yields excess mortality and the carry-over effect lasts only a couple of days. Due to this acuteness, the heat effect was not captured in Figure 1. Based on this observation, it is not recommended to evaluate the heat effect using monthly analysis. On the other hand, daily mortality analyses of cold effect using distributed lag non-linear model by Armstrong (Ben Armstrong 2006) showed that the effect was not very acute and has a long lag (carry-over effect), usually a couple of weeks (Gasparrini et al. 2010)(Sugimoto et al. 2012). This warrants weekly or monthly analysis for cold effect evaluation. Because some readers may want to see the difference between monthly analysis and weekly analysis, we prepared Figure 2 for comparison. This is a Japanese example, and US had similar pattern (figure not shown).

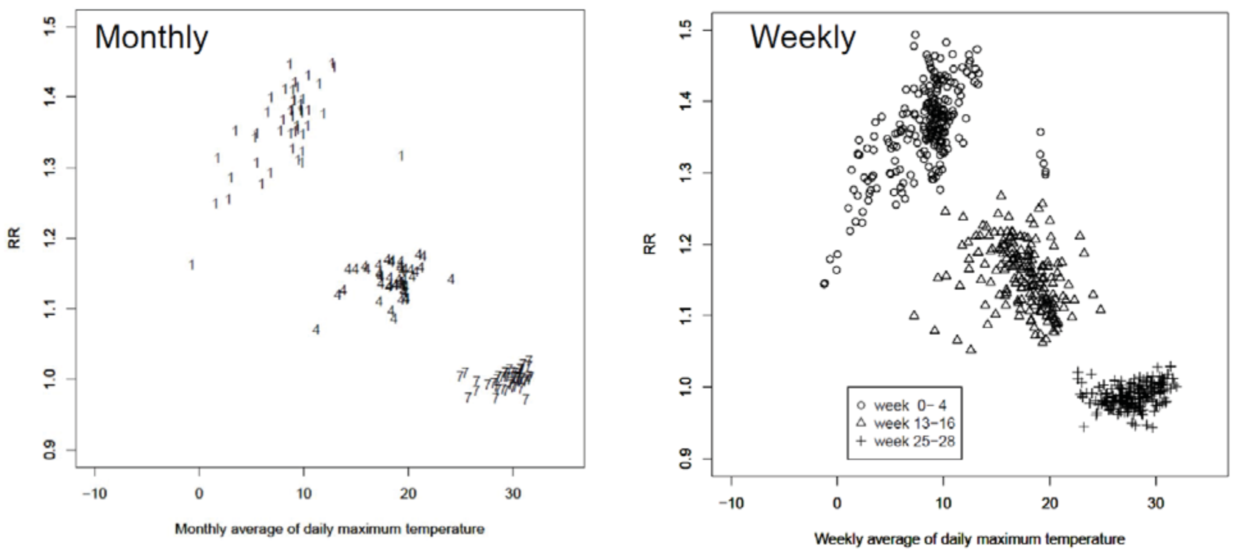

Figure 2. Comparison between monthly analysis and weekly analysis in Japan. (Numbers in the graph represent month of year.)

3.2 Temperature-mortality relation by year

Figure 3 showed the relation between monthly average daily maximum temperature and relative mortality by year in 4 representative prefectures from north to south. There is no indication that colder winters had higher mortality, except for Okinawa's winter. Although not shown here, US, Korea and Taiwan did not show that colder winter had higher mortality, and this Okinawa's pattern can be due to chance. In this figure, we did not control for influenza epidemic, but the years with larger influenza epidemic did not necessarily showed higher mortality level (presented at 2012 meeting of International Society for Environmental Epidemiology), and it is unlikely the pattern shown here is due to influenza..

4 Conclusions

It is unlikely that global warming will alleviate the winter excess mortality. Even in spring and autumn, the excess mortality was observed. Whether or not we should take actions for this excess mortality is debatable.

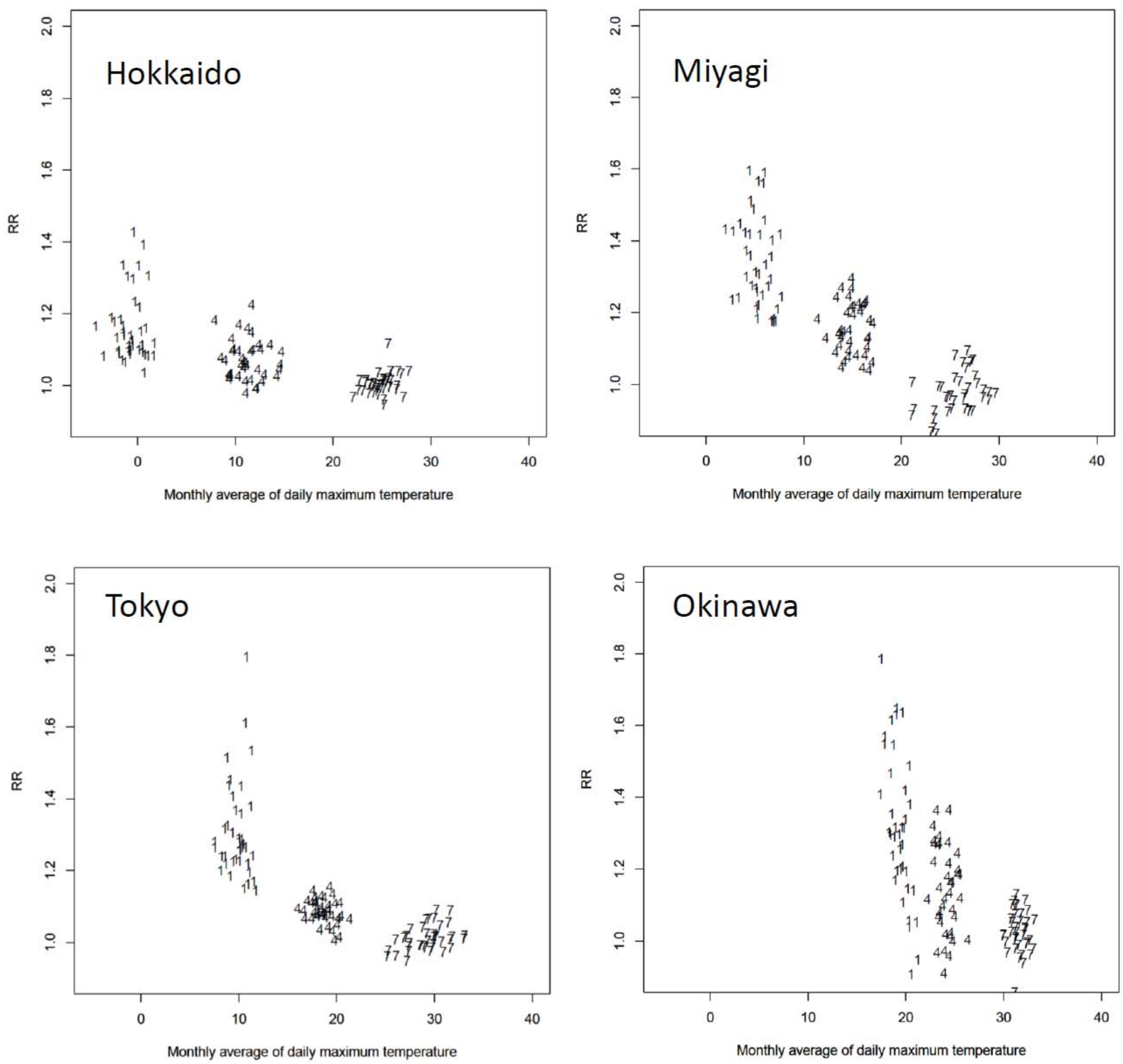

Figure 3. Relation between monthly average of daily maximum temperature and mortality by year. (Numbers in the graph represent month of year.)

(1)

5 Acknowledgements

This study was funded by Environment Research and Technology Development Fund S-8 and S-10 from Ministry of the Environment, Japan and the Global Research Laboratory (K21004000001-10AO500-00710) through the National Research Foundation funded by the Ministry of Education, Science and Technology, Korea.

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Climate change impact on hydrological extreme events in Germany: a modelling study using an ensemble of climate scenarios

Shaochun Huang, Valentina Krysanova and Fred F. Hattermann

Abstract—This study aimed to evaluate the performance of the ensemble of climate scenarios for flood and drought projections, and to detect the robust changes in floods and droughts under a warmer climate in five large river basins in Germany. The results show that most German rivers may experience more extreme 50-year floods and more frequent occurrence of current 50-year droughts agreed by 60-70% of simulations. Changes with a high agreement include an increasing trend of floods in the Elbe basin and more frequent extreme droughts in the Rhine basin from 2060 to 2100. The use of the whole ensemble of available scenarios is necessary because the use of a few best performing RCM outputs in the reference period does not guarantee a low uncertainty of the future projections.

Index Terms— SWIM, uncertainty, ENSEMBLES project, flood, drought, Germany

1 Introduction

A changing climate ultimately links to changes in the hydrological cycle, and changes in hydrological extremes may be more significant than changes in hydrological mean conditions under a warmer climate (Katz and Brown, 1992; IPCC, 1996). Located in Central Europe, Germany is experiencing increasing trends in flood and drought conditions (Petrow and Menz, 2009; Stahl et al. 2010, Hattermann et al. 2012), which have a great potential to threat the human society and the environment. To better plan water management adaptation strategies, more information is necessary on the potential changes in flood and drought conditions.

However, extreme event projections particularly for floods are associated with large uncertainties (Huang et al. 2012a). The large uncertainty is partly due to differences in GCM and RCM structures, emission scenarios, hydrological models and model parameters (Kay et al. 2009), and partly due to the natural variability of rare events.

In order to account for different uncertainty sources for climate, we applied an ensemble of climate scenarios from the European ENSEMBLES project (ENSEMBLES, 2009) to drive the hydrological model. These ensemble scenarios make it possible to investigate the potential changes in floods and droughts in Germany under climate change based on our previous studies (Huang et al. 2012a and b). In addition, they are helpful for analysing the uncertainties due to different GCM and RCM structures.

The main objectives of this study were (a) to evaluate the performance of the ensemble climate scenarios for flood and drought impact assessment in Germany, and (b) to identify the robust changes in flood and drought conditions in the five large river basins in Germany under climate change.

2 Study area, data and methods

The study area includes the five large river basins in Germany (the upper Danube, Elbe, Ems, Rhine and Weser) and their parts in the neighboring countries such as the Czech Republic, Austria, Switzerland, Luxemburg and France. 30 selected gauge stations were used for assessing the flood and drought conditions at the main rivers and their large tributaries. More detailed information about these basins can be found in Huang et al. (2012a and b).

The eco-hydrological model SWIM (Soil and Water Integrated Model) was used to simulate daily discharges for the five river basins. It is a process-based, semi-distributed eco-hydrological model developed based on two previously developed models: SWAT (Soil and Water Assessment Tool: Arnold et al. 1993) and MATSALU (Krysanova et al. 1989). A full description of the basic version of SWIM can be found in Krysanova et al. (1998).

To setup the SWIM model, four spatial maps are required: a digital elevation model (DEM), a soil map, a land use map and a sub-basin map. Observed climate (daily temperature, precipitation, global radiation and relative humidity) and hydrological data were used to calibrate and validate the SWIM model in the historical period.

In total, there are 16 RCM scenarios used in this study, including 13 simulations from the ENSEMBLES project (ENSEMBLES, 2009) and 3 simulations from the CCLM (Rockel et al. 2008) and REMO (Jacob, 2001) models developed in Germany. The detailed information on these simulations is listed in Table 1. All the simulated outputs before and after 2000 were considered as hindcasts and scenarios, correspondingly. No bias correction was applied on these RCMs outputs because there are still large doubts on the bias correction procedures, especially for extreme events.

The 50-year floods and droughts were estimated by fitting the peak discharges above threshold and the deficit volumes using the Generalized Pareto Distribution (GPD) (Coles, 2001) for all 30 gauges for the reference period 1961-2000 and two scenario periods (2021-2060 and 2061-2100). The changes in the 50-year flood discharge (or deficit volume) in percents and the frequency of today's 50-year droughts in the future were used to analyse the climate impacts on hydrological extremes.

Table 1: regional climate model data used in this study. (notice: there are two realizations from CCLM; modified from Table. 1 in Huang et al. in review)

Acronym	GCM	RCM	Data period	Emssion scenarios	Nr. Of Realization	Resolution (km)
C4IRCA3	HadCM3Q16	RCA3	1951-2099	A1B	1	25
DMI-Arpege	Arpege	HIRHAM	1951-2099	A1B	1	25
DMI-ECHAM5	ECHAM5-r3	HIRHAM	1951-2099	A1B	1	25
ETHZ	HadCM3Q0	CLM	1951-2099	A1B	1	25
ICTP	ECHAM5-r3	RegCM	1951-2100	A1B	1	25
KNMI	ECHAM5-r3	RACMO	1951-2100	A1B	1	25
METO	HadCM3Q0	HadRM3Q0	1951-2099	A1B	1	25
METO-Q3	HadCM3Q3	HadRM3Q3	1951-2100	A1B	1	25
METO-Q16	HadCM3Q16	HadCM3Q16	1951-2099	A1B	1	25
MPI	ECHAM5-r3	REMO	1951-2100	A1B	1	25
SMHIRCA-BCM	BCM	RCA3	1961-2099	A1B	1	25
SMHIRCA-ECH	ECHAM5-r3	RCA3	1951-2100	A1B	1	25
SMHIRCA-HAD	HadCM3Q3	RCA3	1951-2099	A1B	1	25
REMO	ECHAM5-r2	REMO	1951-2100	A1B	1	10
CCLM	ECHAM5-r2	CCLM	1960-2100	A1B	2	22

3 Results

3.1 Simulations for the reference period (1961-2000)

SWIM has already been calibrated and validated in terms of daily river discharge, floods and low flows using observed climate data for the five river basins in Germany (see in Huang et al. 2012a and b). In both the calibration (1981-1990) and validation (1961-1980) periods, more than 90% of the 30 gauges have the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) larger than 0.7 and the percent bias within ±5%.

However, when the RCM hindcast data were used instead of the observed climate data, the differences between the simulated and observed mean discharges for the five last gauges are significant, ranging from -30% to +120% and indicating a substantial discrepancy among the ensemble of hindcast data and observed climate (Fig. 1a). In more than 60% cases, the simulated annual mean discharge is higher than the observed one mainly due to the precipitation bias of the RCM outputs.

There is a large uncertainty in simulations using RCMs to project extreme drought events compared to the seasonal average conditions (Fig. 1b). The medium deviation is ranging from -15% to 50% for the five gauges, but with a large spread: from -80% to +200%. It should be noted that neither water management nor land use change impact in these rivers was considered in this study, and they may be attributable to large deviations between the simulated and observed droughts as well.

The simulated 50-year floods have a better agreement with the observations (Fig. 1c), especially for the rivers Rhine and Elbe. The medium deviation is from -22% to 0%, and the total range of deviations is within ±40% for all the rivers.

Based on Fig. 1b and c, we selected the best fitting five RCM hindcast simulations for each river and for floods and droughts separately. The best fitting five RCM hindcast simulations provide the smallest deviations in 50-year droughts and floods. As a result, there is no one single RCM hindcast, which would be good for all the rivers or for certain extreme event. This result highlights the importance of using an ensemble of RCM data because a single RCM output is insufficient to provide a reliable climate hindcast for such a large study area and for both hydrological extremes.

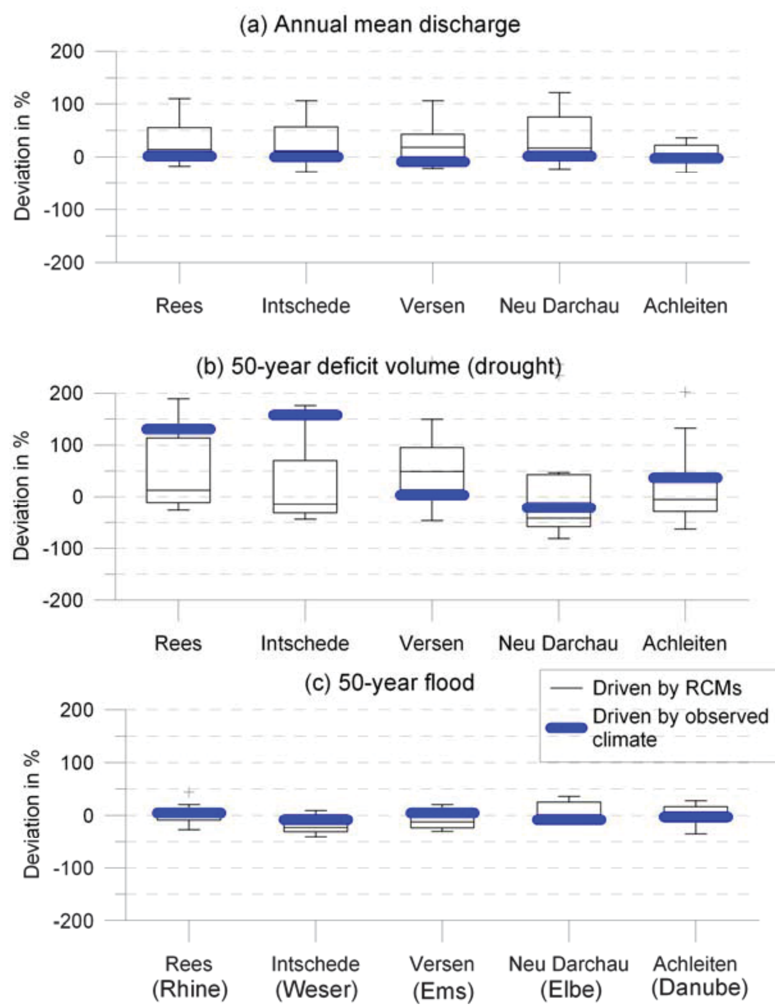

Figure 2: differences between the observed and simulated annual mean discharge, 50-year deficit vol-

ume (droughts) and floods driven by RCM data for the reference period. (modified from Fig. 4 in Huang et al. in review)

3.2 Projections in the scenario periods (2021-2060 and 2061-2100)

At first, the changes in the 50-year flood discharge and deficit volume under all RCM scenarios were compared with the ones driven by the "best fitting" five models. The projected changes driven by all scenarios are from -100% to 800% for droughts and from -20% to 90% for floods. The "best fitting" five scenarios, which are assumed to generate more reliable projections due to their better performance in the reference period, could not help to substantially reduce this large uncertainty. The changes under the five "best fitting" scenarios can still cover more than 75% of the total range of the changes using all ensemble data. This indicates that the large uncertainty in the projection of extreme events is not attributable to the bias of the RCM outputs, but mainly due to the RCM concepts and their parameterizations, as well as GCM boundary conditions driving RCMs. Hence, the results using the ensemble of all scenarios are presented in the following assessment for the 30 gauges.

Due to the large uncertainty from different RCM outputs, only the median changes in 50-year floods and the median return period for current 50-year droughts in 2061-2100, which are agreed by >= 80% (13 simulations) and 60% (10 simulations) of all results, are shown in Fig. 2.

As agreed by >= 60% simulations, more than 20 gauges show an increase in 50-year flood discharge. If only the results with the high certainty (agreed by >= 80% simulations) are considered, only the upper Elbe and the Inn river flowing from the southern alpine regions have an increasing trend of extreme flood discharge.

The current 50-year droughts may occur more frequently in the Rhine, Danube and some sub-regions in the Weser, Elbe and Ems basins, as agreed by >= 60% simualtions. A trend to less frequent droughts was found for the Inn River and some northern sub-regions in Germany. More frequent droughts with a high certainty are found along the Rhine River and its tributary Moselle. The robust projections with less frequent droughts can only be found in the Inn River in the period 2021 – 2060 (not shown here).

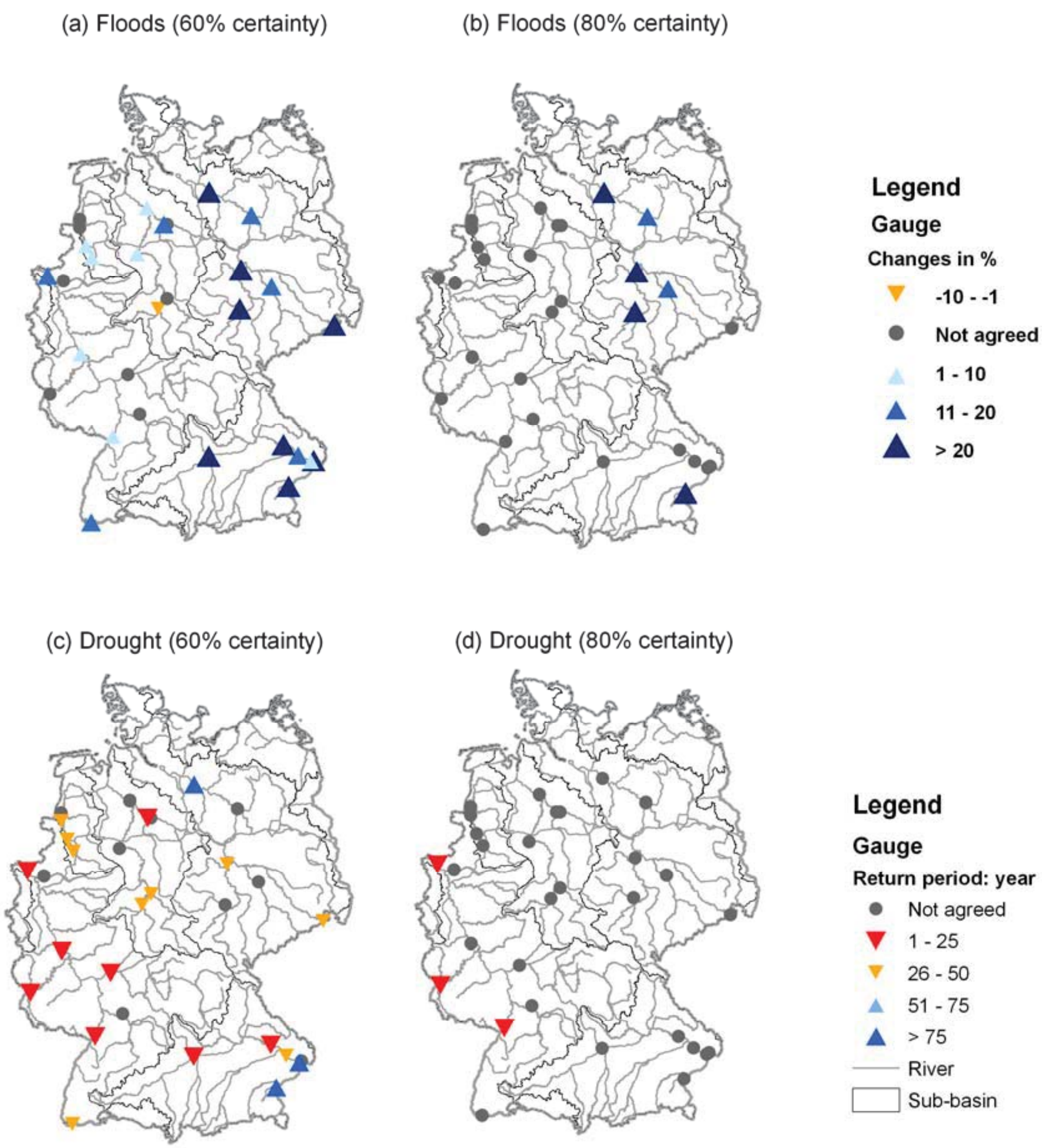

Figure 3: changes in 50-year floods (median values under all scenarios, unit: %) with the change directions agreed by ≥ 60% projections (a), and ≥ 80% projections (b) in 2061-2100. The same for the return period for 50-year droughts (median values under all scenarios, unit: year) (c and d). (modified from the Fig. 6-7 in Huang et al. in review)

4 Conclusions

This study projected the flood and drought conditions in the five large river basins in Germany using an ensemble of 16 RCM scenarios. As there is a large uncertainty caused by different RCM outputs, 60-70%

of simulations suggests that most German rivers may experience extremer 50-year floods and more frequent occurrence of extreme droughts. Robust signals agreed by 80-100% of projections can only be found in the Elbe basin with an increasing trend of floods and in the Rhine basin with more frequent extreme droughts from 2061 to 2100.

The use of all ensemble scenarios is necessary because the best performing RCM outputs for the reference period do not guarantee a reduced uncertainty of the future projections. The uncertainty sources in this study include the differences between GCMs, RCMs, and between the realizations generated from one GCM. More uncertainty sources should be included in the following studies, such as more emission scenarios, different hydrological models and their parameters. The inter-comparison across the projections accounting for the uncertainty sources mentioned above can help understanding the weights of different uncertainty sources in the climate impact studies and detecting robust trend signals.

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Flood risk assessment – how certain are we?

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Abstract - Flood risk assessment is a pre-requisite to flood risk management, required by the Floods Directive of the European Union. However, even evaluation of flood risk changes in past-to-present is problematic. No ubiquitous, general, and significant changes in observed flood flows can be detected. Flood risk projections for the future are far more uncertain. A climatic track is likely but there is also a strong natural variability and, at times, non-climatic factors dominate. Clearly, climate models cannot reliably reconstruct past precipitation and massive bias reduction is necessary that does not build confidence. Projections are not only scenario-specific, but also largely model-specific.Robust projections are sought across models and scenarios, but often in vain. Hence, the question "adapt to what?" comes about. For the time being, precautionary principle is of use. Even if science cannot deliver a crisp number, safety margin approach lends itself well and adaptation is driven by the willingness to be on the safe side. There is hope in reducing uncertainty by advancing rigorous attribution, via model-based interpretation of past extreme flood events.

Index terms - flood risk, change detection and attribution, projections, adaptation

1 Notion of flood risk and design flood

One increasingly deals with floods using flood risk as a decision parameter. The notion of flood risk plays a central role in the European Commission's Floods Directive 2007/60/EC (CEC 2007) that interprets flood risk as a combination of the probability of a flood event and of the potential adverse consequences for human health, environment, cultural heritage and economic activity.

Flood defenses are typically designed to withstand an N-year flood, i.e. a flood discharge whose probability of exceedance in any one year is 1/N, where N may differ between countries and land-use classes within the range from 10 to 1,000 years and more. In most countries the principal design standard for river dikes is a 100-year flood.

Evaluation of flood risk changes is problematic, even in past-to-present. In a stationary situation, 100 years of records would enable robust estimation of a 20-year flood. However, the situation is not stationary and often we have only 20 years of data and the task is to determine a 100-year flood. The flood records are non-uniform and non-homogeneous, with gaps and inaccuracies, e.g. due to missing flood peak information (destroyed gauges), uncertain stage-discharge relation, etc. Long time series of good observation records are badly needed, but are not common, inter alia due to financial stringencies (shrinking observation networks) and lack of willingness to share the data (especially for international rivers).

2 Change detection in observation records

Despite considerable investments into flood defenses, floods continue to be an acute problem, causing high material damage worldwide and considerable death toll. Globally, direct material losses from floods have reached the level of tens of billions of US$ per annum and the number of fatalities reached thousands. The highest numbers of flood victims have been recorded in densely populated, large developing countries in Asia, where the population is especially vulnerable.

The IPCC SREX (Field *et al.* 2012) assessed that there is *high confidence*, based on *high agreement* and *medium evidence*, that economic losses from weather- and climate-related events have increasing trend. The global number of reported hydrological events (floods and landslides) associated with major losses has considerably increased in the last three decades (Fig. 1) at a rate greater than the number of reported geophysical events (Kundzewicz *et al.* 2013b). This difference in the rate underpins that vulnerability and exposure may not develop in a similar manner over time (Bouwer 2011). However, there is a caveat that reporting on hydro-meteorological disasters has improved significantly due to denser satellite network, internet and international media, whereas earthquakes were recorded globally from terrestrial stations. These improvements have introduced a bias in information access through time which needs to be addressed in trend analysis (Peduzzi *et al*. 2012). However, a portion of this difference may be related to changes in weather patterns and rainfall characteristics. There are indications that exposed population and assets have increased more rapidly than overall population or economic growth (Bouwer 2011). However, aggregate global trends can be irrelevant in a specific location.

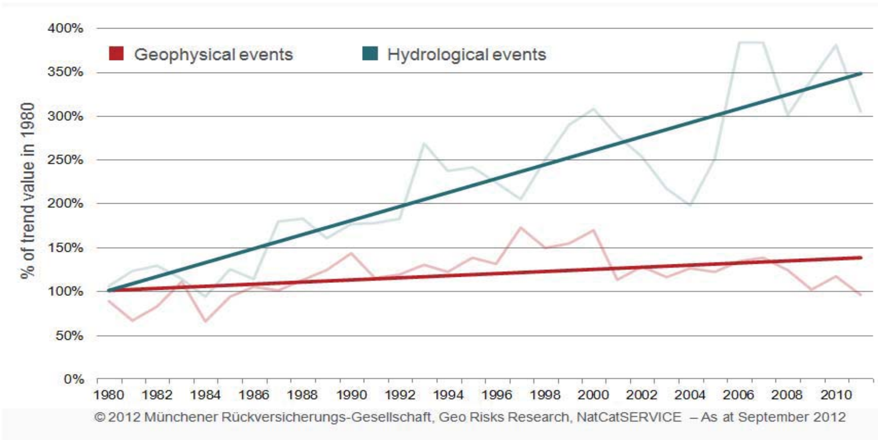

Fig. 1 Changes in global number of large geophysical and hydrological events. Source: Munich Re.

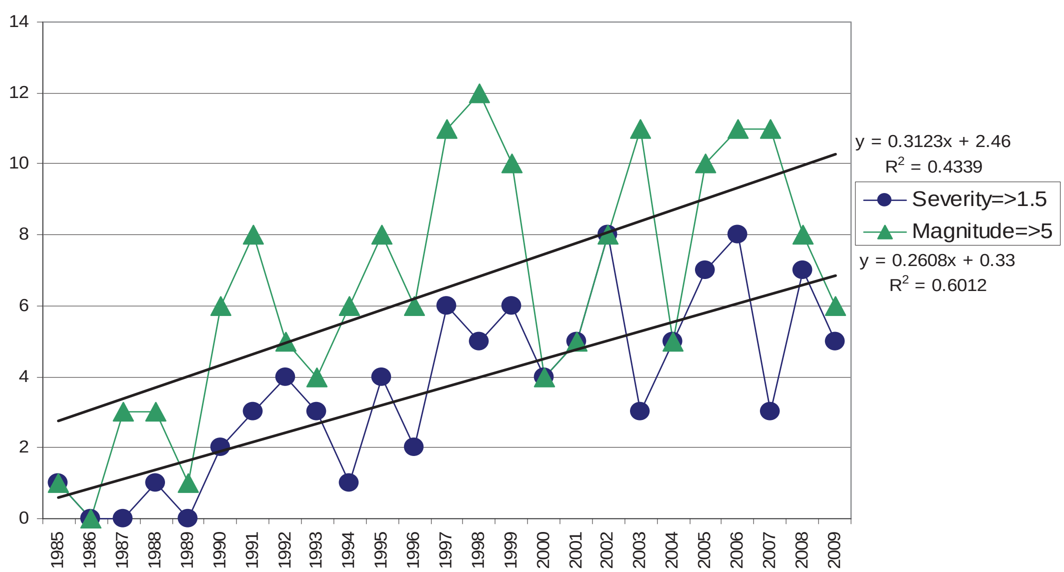

Fig. 2 Numbers of large floods in Europe in 1985-2009, based on Flood Observatory records. Source: Kundzewicz *et al.* (2013a).

Availability of 25 years of records in the Flood Observatory archive (web site: http://floodobservatory.colorado.edu).allows us to analyze changes in the time series of counts of large floods in Europe. One can note the temporal changes of numbers of floods above fixed thresholds of severity or magnitude (Kundzewicz *et al.*, 2013a). Figure 2 demonstrates that for both definitions of large floods used in Kundzewicz *et al.* (2013a), there are increasing trends in numbers of large flood events during the 25-year period, 1985- 2009. However, considerable variability is superimposed on the overall tendency. For instance, in flood-rich years 1997 and 1998, the number of large floods (with magnitude ≥ 5) in Europe was equal to 11 and 12, respectively, while in a flood-poor year, such as 2000, it went down to 4. Nevertheless, caution is needed that the series is not entirely homogeneous – less information was possibly available in the early days of the data base.

The physics of rain-caused river flooding suggests the following rule: If [temperature is rising] and [rainfall intensity increases with warming] then [flood discharge is on the rise]. The first two elements of the rule – temperature rise and increasing trends in heavy rains (Trenberth *et al.,* 2007) have been observed, respectively, in all and some regions. However, no clear and ubiquitous trend in flood flows has been observed. Some increases and some decreases in intense flood flows have been detected, but many of these changes are not statistically significant.

As most of the climate warming is very likely due to anthropogenic influence, one could expect the existence of a link between increasing atmospheric greenhouse gas concentrations and increasing flood proxies (e.g. maximum river flow). However, Hirsch & Ryberg (2012) conducted an observation-based study with use of 200 long-term streamgauge flow series in the coterminous United States, in which they did not find significant evidence for flood magnitudes increasing with atmospheric concentration of carbon dioxide in any of the four regions defined. One region, the southwest, showed a statistically significant negative relationship between atmospheric concentration of carbon dioxide and flood magnitudes. In contrast, Pall *et al*. (2011) have demonstrated, in a model-based study, that increasing global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence in the UK in 2000.

There is little doubt that a multi-factor situation, weakness of the change signal and a strong natural variability render the detection and attribution problems very difficult. Nevertheless, it is clear that where increase in flood risk has occurred, it has been largely caused by direct anthropogenic influences. Climate trends can be found in some areas, but not uniformly, even within a single country like Germany, as shown by Hattermann *et al.* (2012).

Flood risk has typically increased as a consequence of the increase in exposure to floods and damage potential as a result of social and economic advances. Hence, it is of utmost priority to manage land development and to enforce flood zoning.

River flow is an integrated result of multiple natural factors, such as precipitation, catchment storage and evaporation, as well as watershed management practices and river engineering that alters the river conveyance system over time. This complicates the problem of detecting a climate change signature in river flow data. Hence, particular care is needed in selecting data and sites for use in studying climate impact on floods. In order to assess climatically-forced hydrological changes, data should be taken, to the extent possible, from pristine drainage basins that are minimally affected by human activities such as deforestation, urbanization, river engineering, or reservoir construction. However, in some countries, where anthropogenic influences are strong everywhere, it may be very difficult to select pristine basins. Data should be of high quality and extend over a long period, preferably at least 50 years (Kundzewicz & Robson, 2004). The currency of records is important, and should preferably extend to the present. Ideally, there should be no missing values and gaps in data because they are complicating factors; a dilemma arises whether or not to fill them, and if so, how. Inevitably, available flood records are of different lengths.

Flood risk and vulnerability tend to increase over many areas, due to a range of climatic and non-climatic impacts whose relative importance is site-specific. Deforestation, urbanization, and reduction of wetlands diminish the available water storage capacity and increase the runoff coefficient, leading to growth in the flow amplitude and reduction of the time-to-peak of a flood triggered by 'typical' intense precipitation (e.g. design precipitation). Human encroachment into unsafe areas has increased the potential for damage. Societies become more exposed, developing flood-prone areas (maladaptation).

3 Projections for the future

Flood risk projections for the future are very uncertain. A climatic track is likely but there is also a strong natural variability and non-climatic factors (e.g. land-use change, change in water storage volume, exposure, vulnerability) may dominate. Clearly, climate models are not ready for prime time. They cannot reliably reconstruct past precipitation and massive bias reduction is necessary that does not build confidence in projections that are not only scenario-specific, by definition, but also largely model-specific. Weaknesses of GCMs with respect to representing precipitation are well visible at a range of spatial scales. In the global scale, GCMs do not even preserve mass in the water balance (cf. Liepert and Previdi, 2012). According to Stephens et al.

(2010), the state of precipitation in global models is dreary, as there is little skill in precipitation in individual grid cell – models produce more frequent and less intense precipitation.

As the world population grows, more people and property will be at risk from floods. The toll of death and destruction can be expected to rise, especially in the developing world where vulnerability is generally much higher than in the industrialized countries.

Changes in river flows due to climate change depend primarily on changes in the volume and timing of precipitation and, crucially, whether precipitation falls as snow or rain. A robust finding is that warming would lead to changes in the seasonality of river flows where much winter precipitation currently falls as snow, with spring flows decreasing because of the reduced or earlier snowmelt, and winter flows increasing, with likely consequences to flood risk. In regions with little or no snowfall, changes in runoff are much more dependent on changes in rainfall than on changes in temperature, and studies often project an increase in the seasonality

of flows, with higher flows in the peak flow season (Meehl et al. 2007). Due to the region-dependent uncertainty of precipitation projections, projected direction of change of long-term average annual runoff can be inconsistent across different climate models.

Flooding is a complex phenomenon and several generating mechanisms can be involved, such as intense and/or long-lasting precipitation, snowmelt, dike or dam break, ice jam/landslide, outburst of glacial lake. Climate-driven changes in future flood frequency are projected to be complex, depending on the generating mechanism, e.g., increasing flood magnitudes where floods result of heavy rainfall on the rise and decreasing magnitudes where floods are generated by spring snowmelt under less abundant snow cover. However, global warming may not necessarily reduce snowmelt flooding everywhere, as an increase in winter precipitation is expected, and snow cover may actually increase in areas where the temperature is still below 0^{o}C. In some areas, where snowmelt is the principal flood-generating mechanism, the time of greatest flood risk would shift from spring to winter. Winter (rain-caused) flood hazard is likely to rise for many catchments under many scenarios.

Several researchers, e.g. Lehner et al. (2006), Hirabayashi et al. (2008), and Dankers and Feyen (2008) developed quantitative projections of flood hazard in Europe based on climatic and hydrological models. What used to be a 100-year flood in the control period becomes either more frequent or less frequent in the future time horizon of concern (Fig. 3) and this is of importance for design and operation of large water infrastructure (e.g. dikes, dams and spillways). Climate change is likely to cause an increase of the risk of riverine flooding across much of Europe, as a 100-year flood may become more commonplace, occurring every 50 years, or even more frequently. Hence, in order to maintain the same standard of protection against a 100-year flood, a need for a costly overhauling comes about.

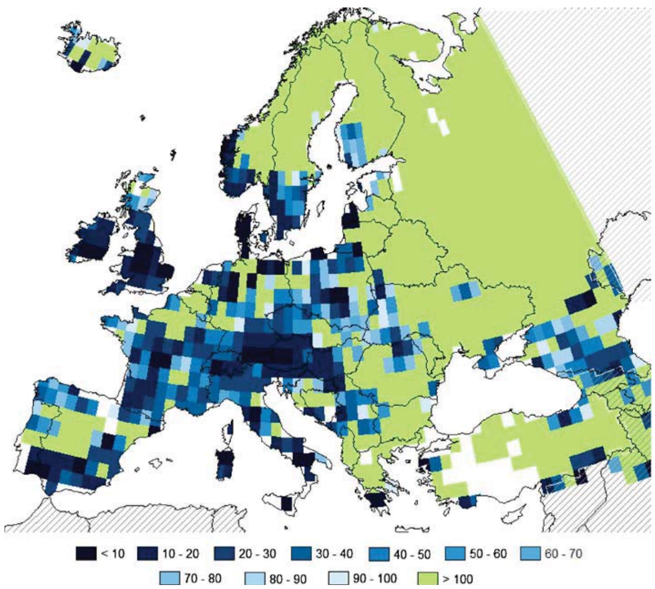

Fig. 3 Recurrence interval (return period) of today's 100-year flood (i.e. flood with exceedence interval of 100 years during the period 1961–1990) at the end of the 21st century (2071–2100), in case of scenario SRES A1B. Source: Kundzewicz *et al.* (2010), using results from Hirabayashi *et al.* (2008).

4 Stationarity is dead, but… - adaptation dilemma

If the flood hazard is changing, we will have to adapt flood frequency methods used in hydrological and hydraulic design to the non-stationary situation (cf. Milly *et al*., 2008). However, since projections for the future are not robust across models and scenarios, a question "adapt to what?" comes about. Due to large uncertainty of climate projections, there is no scientifically-sound procedure for redefining design floods (e.g. 100-year flood) under strong non-stationarity of the changing climate and land use, and appraisal of all uncertainties involved. For the time being, precautionary principle is of use. Even if science cannot deliver a crisp number, safety margin approach lends itself well and adaptation is driven by the willingness to be on the safe side. Design floods are adjusted using a "climate change factor", which can be greater than 1 in areas with likely increase of flood hazard and less than 1 (i.e. a "new" N-year flood is higher than an "old" N-year flood) in areas with likely decrease of flood hazard. In the former case, strengthening and heightening of dikes would be needed in order to maintain the protection level. In the latter case, a fine dike, dimensioned after the old design flood and adequately maintained, would offer over-protection, without any need for strengthening and heightening effort. Due to uncertainty, flood risk reduction strategies should be reviewed on a regular basis, in the light of new data and information, and—if necessary—updated.

In parts of Germany (e.g. in the State of Bavaria), flood design values have been increased by a safety margin, based on projections corresponding to climate change impact scenarios. In the UK, Defra's precautionary allowance (DEFRA, 2006) accounts for expected increases in the peak rainfall intensity (up to 20% by 2085 and 30% by 2115) and in peak river flows (up to 10% by 2025 and 20% by 2085), based on early impact assessments. Measures to cope with the increase in the design discharge for the Rhine in the Netherlands from 15 000 to 16 000 m^3/s must be implemented by 2015.

5 Prospects and priorities for the future

There is a prospect to reduce uncertainty by advancing rigorous attribution, via interpretation of past extreme flood events (such as in Pall et al. 2011). It is crucial to continue seeking a significant change in flood records. Nevertheless, model-supported studies projecting such changes before they become reality in the flood record is useful (Raff et al. 2009).

In order to reduce future flood damage, flood risk reduction measures should start early, because development and implementation of plans and associated political decision processes take a long time. Hence, there is a trade-off between, on the one hand, waiting for detection of a significant signal in flood records, determining its cause and reducing uncertainty in projections and, on the other hand, missing the opportunity for adequate adaptation.

Detection of climate change in river flow at global or regional (let alone catchment) scales is inherently difficult, because of the low signal-to-noise ratio (Wilby et al., 2008). The relatively weak climate change signal is superimposed on a large natural, inter-annual variability of rainfall and river flow (under a confounding effect of land-use change). Hence, Wilby et al. (2008) speculate that statistically robust trends are unlikely to be found for several decades more. They state that for flood risk assessment, "treatment of uncertainty is still very much in its infancy".

Hence, the response to the question posed in the title „how certain are we?” is as follows: we are not certain at all and this uncertainty is unlikely to disappear soon.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Making adaptation decisions: the far end of the uncertainty cascade

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Abstract

The now convincing evidence that climate is changing brings about additional sources of uncertainty for adaptation decision-makers across scales (i.e. local to international) and capacities (e.g. policy-makers, practitioners). Uncertainty is associated with limitations on the knowledge of a relevant system. The scientific enterprise thrives on uncertainty and on the quest for knowledge. But for adaptation, as for most all high-stake, potentially transformative and financially sensitive decisions, there is a clear need for a robust evidence-base ('a figure to put on the decision') placing adaptation decisions at the far end of a complex cascade of uncertainties. Taking model-based decision support as example, uncertainty can spur from the choice of socio-economic scenarios (e.g. SRES), climate models (e.g. HadCM), biophysical impacts models (e.g. SWAT), integrated assessment models (e.g. IMAGE), vulnerability assessments (e.g. DIVA), to end up in the decision-making process itself. Climate impact and more recently adaptation research communities have focused their efforts in improving the utility of their results by reducing uncertainties in conceptual and modelling frameworks. But little attention has been given to understanding if these efforts have been successful in supporting the sort of complex decisions they aim at ('are adaptation decisions being made?'). Recent literature, mostly related to high-end climate change scenarios has called the attention to some key gaps. Firstly, the need of innovative strategies and end-user involvement in the development of uncertainty-management methods; and secondly, the need to frame these within a broader sorting of decision types systematizing them into support frameworks. This paper reports on work carried out in the CIRCLE-2 Joint Initiative on Climate Uncertainties leading to the publication of a 'lessons learned' guide to uncertainty, and stimulated from real case-studies where dealing with uncertainties in adaptation decision-making processes was successfully accounted for (or identified but failed).

Keywords: Adaptation, Climate Change, Decision-making, Uncertainties

1 Introduction

Decisions associated with planning and managing the environment are severely affected by uncertainty (Dessai & Hulme 2007) bringing about complexity for both scientists and decision-makers (Hanger et al. 2012). However, in many circumstances decisions must be made before robust evidence-base is available or before uncertainties can be reduced (Walker et al., 2003; van der Sluijs et al., 2008).

Walker et al. 2003 defined uncertainty as "any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system". Thus, uncertainty is also a natural product of the scientific process where typically questions arise as to what information can be considered valid and reliable (van der Sluijs et al. 2008; Lemos & Rood 2010). Even though progress has been made in quantifying and characterising the uncertainty relevant for climate adaptation planning not much progress has been made in reducing it (Mearns 2010).

For quite some time the scientific community has been debating whether the focus should be in reducing uncertainty or whether it should be to embrace and deal with uncertainties in decision making processes (Mearns 2011). Several scientists advocated the need to reduce uncertainties in climate models and projections since these are being increasingly procured by decision-makers and seem essential in assessing the impacts of climate change and the development of adaptation strategies (Gagnon-Lebrun & Agrawala, 2006; Füssel, 2007; Shukla et al. 2009; Hawkins & Sutton 2010). However, prospects of fully reducing uncertainties are very limited and the potential for climate science to achieve these reductions will only be through contributions associated with internal variability and model uncertainty, and not the uncertainty associated with future emissions of greenhouse gases (Hawkins & Sutton 2010), since these are mostly policy dependent. In any case, the argument that decision-makers are increasingly demanding such information is contested by Tribbia & Moser (2008) and Hanger et al. (2012) which demonstrated that decision-makers do not feel that there is a need for more information, but rather for better access to and easiness of use of the existing data. On the other hand, more and/or better information may not be as significant to decision-makers as has been thought and efforts should focus on integrating available information in the decision-making process (Tribbia & Moser 2008).

In fact, Lemos & Rood (2010), argue that "there is an uncertainty fallacy, that is, a belief that the systematic reduction of uncertainty in climate projections is required in order for the projections to be used by decision makers" and others state that effective and successful adaptation planning and strategies can be developed and implemented without being significantly limited by the uncertainties present, e.g., in climate predictions (Lempert et al. 2004; Hulme & Dessai 2008; Dessai et al. 2009; Lempert & Groves 2010; Walker et al. 2003; Smith et al. 2011).

Furthermore, there are other barriers to decision-making besides uncertainty (Moser & Ekstrom 2010; Tompkins et al. 2010; Eisenack & Stecker 2011; Smith et al. 2011; Pidgeon & Fischhoff 2011; Runhaar et al. 2012) and decision-makers should examine "the performance of their adaptation strategies/policies/activities over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political and cultural factors" (Dessai et al. 2009).

This paper addresses a primarily the Conference question 'How certain are we?' and aims to present the work of the CIRCLE-2 Joint Initiative on Climate Uncertainties, leading to the publication of a science-practice oriented book on how climate uncertainties have been dealt with and accounted for (or failed to) in real-life adaptation decisions. The Initiative was set up in 2011 under the umbrella of the FP7 CIRCLE-2 ERA-Net (www.circle-era.eu). It aims at the development of a network of researchers and practitioners involved in dealing and communicating climate change related uncertainties in support of adaptation decision-making processes. This article will report on one of the chapters of that book and on the supporting case-study analytical work.

2 Methods

Work carried out involved four steps, of which the first three were implemented during 2012 and the final one will be finalised by mid-2013: (i) a world-wide call for practical case-study examples of science-supported adaptation decision-making process and how these dealt with climate-related uncertainties; (ii) a review and selection of examples; (iii) a set of individual interviews with researchers and decision-makers involved in the selected cases; and (iv) the review, critical analysis and publication of the empirical data obtained in the previous steps.

The first step consisted on a widely disseminated call for case-studies using a pre-defined template. In it, interested applicants were introduced to the initiative, objectives and selection process and asked to describe their case in terms of general information (origin, scale, sectors, type of organisations involved) and more specifically on what kind of climate information was used, which methods to deal with the cascade of uncertainties were applied, what were the expected outcomes from the decision-making process, and generally what went well, what not and what kind of lessons could be extracted to support similar decision needs.

The second step was to select a set of representative cases. The selection was conducted by a group of experts, all of them members of the CIRCLE-2 Joint Initiative. Previous agreement defined that the final selection had to include cases that could tentatively help to reply to the question '*have better informed adaptation decisions been taken because uncertainties were conscientiously addressed?*' Other criterions for selection included the need that each case was related to a real adaptation decision process, the degree of involvement of stakeholders and decision-makers in the research process, and diversity in scope (geographical, sectorial and scale). E-mail contacts with authors of the submitted case-studies were conducted during this step in order to clarify doubts and specific questions about the work described in their responses.

Step three involved individual phone interviews with the authors (mostly researchers) and the decision-makers (policy or practitioners in most cases) of all the selected cases. The interviews were conducted by the initiative experts with the assistance of a professional science storywriter. These interviews had two objectives: (i) to clarify specific doubts left open by the template and subsequent contacts and (ii) to further investigate the researchers' and decision-makers' perspectives on how the adaptation decisions were (or not) affected by the inclusion, in the decision support, of methods to deal with (and/or communicate) uncertainties.

Finally, step four is still underway and consists in the application of a qualitative Common Frame of Reference (i.e. common definitions, understandings, disagreements and recommendations) to the analysis of selected cases and the extraction of key lessons to support complex adaptation decision-making processes. For each of the cases, this reference framework looks into: (a) the adaptation decision-making objectives[1] (Kwakkel et al. 2011); (b) the research approach to the decision-making support (i.e. development and use of model or non-model based evidence) (Dessai et al. 2009); (c) the direction of the approach regarding Climate Change Impacts, Vulnerability and Adaptation (CCIVA) assessments (i.e. predictive top-down or robustness/resilience bottom-up) (Dessai & van Der Sluijs 2007); (d) the uncertainty level addressed (i.e. statistical; scenario; recognised ignorance) (Walker et al. 2003); and finally (e) the decision-making outcome (i.e. the decision made in relation to the original objectives of the decision-maker). This paper reports only on points (a) through (d) leaving out the analysis of the decisions made in each case-study.

3 Results and discussion

Responses to the survey in step one yielded a total of 27 validated replies from 15 different countries. Despite some bias towards Water Management, Infrastructure and Disaster Risk Reduction (DRR) projects, there was a diverse sectoral distribution of cases covering a wide range of decision-making processes. Only 6 cases (22%) reported a single-sector focus, while 21 reported a multi-sector approach and of those 2 reported efforts on all of the sectors (in some cases other sectors not described in the template were reported). Submitted cases presented a clear geographical bias towards Europe (almost 90% of cases), developed countries (more than 95% of cases) and sub-national scales (over 95% of cases).

[1] This Common Frame of Reference distinguishes between 3 types of objectives for an adaptation decision: (a) Normative or Regulatory, associated with governance actions that aim to establish a standard or norm; (b) Strategic or Process-oriented, associated with the identification of long-term or overall aims and the necessary setting up of actions and means to achieve them; and (c) Operative or Action-oriented, related to the practical actions and steps required to do something, typically to achieve an aim.

All of the organisations responsible for the adaptation decisions were public, stated owned or a mix of public-private institutions. No completely private case replied to the survey. Table 1 presents the total number of cases submitted, as well as their geographical, sectoral, scale and type of organisation distribution. Highlighted cases in table 1 represent those selected for further analysis in step two.

Table 1 - Total number of received case-studies according to their geographical, sectoral, scale and type of organisation distribution.

Case ID	Origin	Sector										Scale				Type of organisation			
		Water Management	Agriculture & Forestry	Biodiversity	Coastal areas	Marine & Fisheries	Health	Infrastructure	Financial	Disaster Risk Reduction	Other(s) - as submitted	International	National	Regional	Local	Private	Public	State owned	Non-profit org.
001.1	Austria							●					●				●		
001.2	Austria		●											●				●	
002.1	Canada	●						●					●					●	
003.1	Greece	●	●		●	●	●		●				●				●		
004.1	Netherlands										Multi-sector focused on spatial planning			●	●		●		
004.2	Netherlands	●					●						●				●		
005.1	Portugal	●						●						●				●	
005.2	Portugal	●						●	●	●			●						●
005.3	Portugal				●			●	●	●					●		●		
006.1	Spain	●								●			●				●		
006.2	Spain	●	●											●			●		
007.1	Sweden	●								●	Dam safety		●			●	●		
007.2	Sweden		●										●			●	●		
008.1	United Kingdom	●		●	●						Ecosystem services and land use planning		●				●		
008.2	United Kingdom	●	●	●	●	●	●	●	●	●	Tourism		●				●		
008.3	United Kingdom	●													●		●		
008.4	United Kingdom	●		●			●	●	●	●	Policy			●		●	●		
009.1	Hungary	●						●					●				●		
010.1	Ireland							●		●			●				●		
011.1	Germany	●	●	●	●			●	●						●	●	●		
011.2	Germany							●							●		●		
011.3	Germany	●	●	●			●				Regional planning			●			●		
012.1	France			●				●		●					●		●		
013.1	Kiribati										Climate Change displacement	●					●		
014.1	Finland	●	●	●	●	●	●	●	●	●	Energy supply, Culture and Insurance				●		●		
014.2	Finland	●						●		●	Urban planning			●		●	●		
015.1	New Zealand							●		●					●		●		
Total		**17**	**8**	**7**	**6**	**3**	**6**	**15**	**8**	**12**	**9**	**1**	**12**	**7**	**8**	**5**	**23**	**3**	**1**

From the 27 submitted case-studies, 12 were selected for analysis. Table 2 depicts how the authors of those cases described: (i) the methods used to deal with uncertainty (after Dessai & van der Sluijs 2007); (ii) attempts made to change the decision-maker's initial perspectives on uncertainty, and if so what methodologies were used; and (iii) if decisions (and which) were taken based on the information provided by science.

Nine out of the 12 selected cases reported the use of Expert Elicitation (EE) and Stakeholder Involvement (SI) as methods applied to deal and communicate uncertainties. In fact, these 9 cases applied both methods in conjunction and there was no single case reporting the use of just one of these 2 methods. Only 3 cases did not report the use of such methodologies. Yet, in these cases the use of meetings, workshops and interviews as a mean to change decision-makers perspectives about uncertainty was reported.

Eight of the selected case-studies reported the use of Sensitivity Analysis (SENS) and 6 the use of Scenario Analysis (SA) as methodological approaches to uncertainty. Probabilistic multi-model ensemble (PMME) methods were only reported by 4 of the cases and all remaining methods were described either by 1 or 2 case-studies.

All reported examples applied at least 2 methods and except for 2 cases that reported only the use of EE and SI, all others used 3 or more methods to inform adaptation decisions. The interviews conducted in step 2 with both researchers and decision-makers clarified that this is often related to the fact that each project is usually dealing with multiple adaptation-decisions, sometimes at different scales and areas.

Regarding actual decisions in each of the case-studies, only 2 reported that no decisions were made (yet) while 1 reported that the decision(s) had been delayed. Although it is not the focus of this paper, table 2 briefly presents some of the types of adaptation decisions that were made and that could be traced back to - or analysed in light of - the uncertainty management or communication methodologies that were applied to the decision-making support process.

Another interesting feature of this empirical information is the fact that all cases reported that the science advice conscientiously used some type methodology to change the decision-makers perspectives about what uncertainty means, and how it may (or may not) affect their decisions. Nevertheless, caution must be placed in the analysis since the survey process (e.g. the template for reporting examples) may have biased the type of respondents towards researchers that already conscientiously apply this sort of approaches in their research designs.

Table 2 - Selected case-studies for analysis including reported: (a) description of the methods used to deal with uncertainty; (b) usage of methods to change decision-maker's perspective on uncertainty; and (c) decisions taken (or not).

Case ID	Methods used to deal with uncertainty													Methods used to change perspectives on uncertainty	Decisions taken?
	SA	EE	SENS	MC	PMME	BM	NUSAP	FZ/IP	SI	QA/QC	EPP	WC/SS	Other(s)		
001.1		●	●			●			●					Meetings and workshops	Improve railway track drainage. Include climate change into company's long-term strategy. Invest in a monitoring system.
002.1	●	●	●		●				●					Meetings	Use multiple-scenarios in current analysis of climate change impacts on the company's infrastructures and pursue further in-depth research.
004.1	●	●	●						●		●			Workshops	No.
004.2		●							●					Workshops and questionnaires	No.
005.1	●	●							●					Meetings and workshops	Establish cooperation protocols with external stakeholders. Withhold investments in nanofiltration systems. Delay investment decision on protection measures against forest fires.
008.2	●	●	●			●	●		●	●	●			Workshops and questionnaires	Officially use evidence in national and local support of adaptation decision-making (policy and planning).
008.3				●	●									Meetings and workshops	Recommend and provide guidance on the use of probabilistic climate change information in water resources plans.
009.1		●	●		●			●	●					Meetings	Invest in new flash flood monitoring systems. Install new treatment plant. Shut down small groundwater abstractions and concentrate in larger water sources. Develop a regional water pipeline.
010.1			●									●		Meetings	Move from deterministic to robust approaches on the design of structural flood defences.
011.2	●	●	●					●	●			●	Causal and Fuzzy cognitive mapping	Workshops	Decision was delayed.
012.1		●							●					Meetings and public consultation	Use a 'low regret' approach by restoring sand dunes as flood defences instead of dykes and relocating road landward.
015.1	●		●		●									Interviews and workshops	Include evidence in the review of flood risk management plan.
Total	**6**	**9**	**8**	**1**	**4**	**2**	**1**	**2**	**9**	**1**	**2**	**2**	**1**		

Abbreviations: SA - Scenario analysis ('surprise-free'); EE - Expert elicitation; SENS - Sensitivity analysis; MC - Monte Carlo; PMME - Probabilistic multi model ensemble; BM - Bayesian methods; NUSAP - NUSAP / Pedigree analysis; FZ/IP - Fuzzy sets / Imprecise probabilities; SI - Stakeholder involvement; QA/QC - Quality assurance / Quality checklists; EPP - Extended peer review (review by stakeholders); WC/SS - Wild cards / Surprise scenarios.

Together with the individual interviews, the application of a Common Frame of Reference to the selected case studies provides an initial approach to the understanding of how uncertainty was dealt with and communicated in each of the cases. This means reflecting upon how the adaptation decision-making needs (or questions) were methodically addressed by research and, in turn, what were the outcomes in terms of actual decisions made (or not). Table 3 presents some of the preliminary results of the systematic application of the Common Frame of Reference to the analysis of each of the selected case studies. It presents the nature of each case's decision-making objectives and the approaches followed by researchers to support those decisions (i.e. modelling; direction of the causal chain of evidence; and levels of uncertainty addressed). This analysis is currently being undertaken in step 4 of the previously described methodology.

Table 3 - Analysis of the selected case-studies using the Common Frame of Reference, including: (a) the nature of the decision-making objectives; and (b) the type of approaches used by research.

Case Study ID	a. Decision-making objective(s)			b. Research approach to:						
				Decision-making support		CCIVA assessment & decision-making strategy		Uncertainty level		
	Normative or Regulatory	Strategic or Process-oriented	Operative or Action-oriented	Model based (quantitative)	Non-model based (qualitative)	Top-down & predictive oriented	Bottom-up & robustness / resilience oriented	Statistical	Scenario	Recognised ignorance
001.1		●	●		●	●		●		
002.1		●		●		●		●		
004.1		●		●	●	●			●	
004.2	●				●		●		●	
005.1		●	●	●	●	●	●		●	
008.2	●			●	●	●		●	●	
008.3	●		●	●		●		●		
009.1		●		●	●	●	●		●	
010.1		●		●			●		●	●
011.2		●			●		●		●	●
012.1	●				●		●			●
015.1		●		●	●	●	●		●	

Regarding the objectives of the analysed practical decision-making processes there is a bias in favour of strategic or process-changing oriented examples (8 out of 12) against normative (4 out of 12) and operative decisions (3 out of 12). Despite the existence of several cases addressing multiple decisions, only 3 cases (from Austria, Portugal and the UK) appear to deal with decisions of different fundamental nature. While the first deals with operative and strategic decisions, the later with regulatory and operative decision processes. The relatively small number of analysed cases raises the question whether it is possible to capture a significant range of types of decision-making objectives or if there are 'other' types that may have been left out. Since there was no pre-judgement of cases, that is, there was no limitation to the submission of cases according to their type of decision objectives there is still room for further investigation using all the submitted cases, including those that were not selected for analysis through this common framework.

In terms of the research approach to the decision-making support results are somewhat balanced with the analysis showing that 4 cases used only modelled evidence, 4 used only non-model information and 5 used both approaches. In the latter ones, the fact that often multi-sector and multi-scale decision-processes are acknowledged indicates that projects are also using multiple and diverse approaches to inform decisions.

When it comes to the direction of the CCIVA assessment chain followed by the selected cases, there are 5 examples that used a marked top-down and optimization focused approach, while 4 applied a fully robustness-based bottom-up approach. Only 3 cases appear to have made used of both approaches, although it is not easy to grasp if simultaneously or in different phases of the project.

Regarding the uncertainty level addressed in the support to decision-makers, no single case demonstrably dealt with all 3 levels (from statistical to recognised ignorance, following Walker et al. 2003). Only 1 case (French) dealt exclusively with this higher level of uncertainty, while 3 cases only with statistical uncertainty. Eight cases out of the 12 dealt with or communicated uncertainties along the scenario level although 3 of them did it in combination with other levels (1 with statistical and 2 with recognised ignorance).

4 Conclusions

It has been argued that further research is required to develop methods that evaluate planned and unplanned adaptations and to locate adaptations in the landscape of decision-making and risk (Tompkins et al. 2010). Recent literature, mostly related to high-end climate change scenarios (i.e. above 4ºC), has called the attention to some key gaps and requirements of this analysis. It has been suggested that rather than being unable to make decisions under uncertainty, what has been missing is the deployment of innovative decision-making frameworks to deal with uncertainties prompted by climate adaptation assessments (Hallegatte 2009; Smith et al. 2011). The application of a Common Frame of Reference in the analysis of different types of adaptation decision objectives and of the research approaches used to inform them provides a further step in the understanding of how to design and apply such novel decision-making frameworks (e.g. the role of different information needs vs. different decisions approaches).

Although the empirical analysis described in this article is not sufficient to draw generalised frameworks for all types of adaptation decisions (site- and culture-specificity still prevails), this preliminary work makes a move towards key adaptation research and decision-making needs. By systematically collecting, selecting and analysing concrete examples where science was called upon to support real adaptation decision-making processes, and did so using uncertainty management and communication approaches, we move a step closer in the understanding of two relevant questions. Firstly, how is science dealing with (and communicating) uncertainty in light of what the adaptation decision objectives and needs are. And secondly, what have been the outcomes of such approaches in terms of concrete decisions that were made (or not) and how did the use of such methodologies improve the support to those decision processes ('are better informed adaptation decisions being made?'). The systematization presented here requires further development and enrichment but the gradual emerging of case-studies where concrete adaptation decisions are made provides a required stepping-stone towards clear guiding frameworks to both decision-makers and researchers.

5 Acknowledgements

The work presented in this paper was supported by the CIRCLE-2 Joint Initiative on Climate Uncertainties and its network members. The initiative is financially supported by the Calouste Gulbenkian Foundation - Portugal and by the institutions where network members are affiliated. The authors wish to thank all the authors and decision-makers involved in the submission and review of case-studies.

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Impact of climate change on ozone related mortality in Europe

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Abstract—Ozone is a highly oxidative pollutant formed from precursors in the presence of sunlight, associated with respiratory morbidity. All else being equal, concentrations of ground-level ozone are expected to increase due to climate change; however, the projections of changes might differ depending on used data.

Ozone-related health impacts under a changing climate were projected using emission scenarios, models and epidemiological data. European ozone concentrations were modelled with MATCH-RCA3 (50x50 km) with two anthropogenic precurson databases EMEP and RCP4.5. Projections from two climate models, ECHAM4 and HadCM3, were applied, under greenhouse gas emission scenarios A2 and A1B respectively. We applied a European-wide exposure-response function to gridded population data and country-specific baseline mortality.

Comparing the current situation (1990–2009) with the baseline period (1961–1990), the largest increase in ozone-associated mortality due to climate change (4–5%) have occurred in Belgium, Ireland, Netherlands and UK. Comparing the baseline period and the future periods (2021–2050 and 2041–2060), much larger increase in ozone-related mortality is projected for Belgium, France, Spain and Portugal with the impact being stronger using the climate projection from ECHAM4 (A2). However, in Nordic and Baltic countries the same magnitude of decrease is projected.

The HadCM3 global model projected somewhat higher ozone concentrations for the baseline compared to using ECHAM4 in many countries. ECHAM4 gave generally larger health impacts for 2021–2050.

The current study suggested that projected effects of climate change on ozone concentrations could differentially influence mortality across Europe and the results depend the most on the chosen global climate model and the greenhouse gas emission scenario.

Index Terms—climate change, health, ozone, global climate model, greenhouse gas emission.

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1 Introduction

Ozone is one of the most important air pollutants formed in photochemical reactions, with concentrations affected by weather and chemical precursors as nitrogen oxides (NOX), volatile organic compounds (VOCs), carbon monoxide (CO) and methane (CH4). Climate change (CC) can affect ozone concentrations through a number of processes, including chemical production, dilution and deposition of ozone that are regulated by temperature, cloud cover, humidity, wind and precipitation (Andersson and Engardt 2010, Andersson et al. 2007, US EPA 2009). Even there is high confidence in projected changing temperatures (IPCC 2007) that would increase ozone levels, changes in other meteorological parameters, such as precipitation and cloud cover are more uncertain. The uncertainty is also large in how natural vegetation will respond to climate change: CC may lead to higher biogenic VOC emissions (Steiner et al. 2005) and warmer temperatures may lead to increasing soil microbial activity that may cause an increase in NOX emissions (Pfeiffer and Kaplan 2010). CC and increasing temperature could also affect the risk of wildfires and increase the emissions of CO (Westerling et al. 2006). Moreover, methane emissions promote tropospheric ozone formation and global climate change (West et al. 2006). The sensitivity of ground-level ozone to climate change is particularly high in urban areas, reflecting the concentration of precursors for ozone formation. The frequency of stagnation episodes is projected to increase over northern mid-latitude continents and the ventilation is projected to decrease in Europe, eastern North America and East Asia (Jacob and Winner 2009).

Epidemiological studies have shown a broad range of effects of ground-level ozone on health, leading to excess daily mortality and morbidity. Significant negative health effects have been demonstrated for different causes, mainly for respiratory (e.g. Bell et al. 2005, Gryparis et al. 2004, Ito et al. 2005, Levy et al. 2005) and (to a lesser extent) cardiovascular diseases (e.g. Anderson et al. 2004, Chuang et al. 2007, Zanobetti and Schwartz 2011).

The current study assesses the impacts of climate change on ozone-related mortality in Europe over number of time periods than often used. Further, it illustrates the impact of applied precursor emission database, greenhouse gas emission scenarios and global climate models on projected health impacts and discusses the uncertainties.

2 Material and methods

European ozone concentrations were modelled at a grid size of 50x50 km using the chemistry-transport model MATCH (Andersson et al. 2007, Robertson et al. 1999). Species at the lateral and top boundaries of MATCH were kept at levels representative for year 2000. MATCH simulates biogenic emissions of isoprene based on hourly temperature and solar radiation and anthropogenic precursor emissions (NOX, SOX, CO VOC, NH3) were retrieved from two data bases: EMEP (http://www.ceip.at) and RCP4.5 (www.iiasa.ac.at/web-apps/tnt/RcpDb/). MATCH uses meteorology produced by the regional climate model RCA3 (Kjellström et al. 2005, Samuelsson et al. 2011). Projections from two global climate models, ECHAM4 and HadCM3 under greenhouse gas emission scenarios A2 and A1B, respectively. With ECHAM4 (A2) two periods were compared: the baseline period as 1961–1990 and future as 2021–2050. With HadCM3 (A1B) two additional periods with different precurss emission (EMEP and RCP4.5) were included: the current situation as 1990–2009 and further future as 2041–2060.

Often the cut-off value of 70 µgm-3 ($SOMO_{35}$) is used in risk assessments, as a statistically significant increase in mortality risk estimates has been observed at daily ozone concentrations above 50–70 μgm^{-3} (Amann et al. 2008, Bell et al. 2006a). As a sensitivity analysis we also used cut-off values of $SOMO_{50}$ and $SOMO_{25}$. To see the seasonal impacts, the $SOMO_{35}$ values and its expected health impacts were calculated separately for summer and winter.

The data the crude non-standardized all-cause mortality (2000–2005) was obtained from WHO European Health for All Database (http://data.euro.who.int/hfadbThe gridded population data for Europe in 2000 were taken from the HYDE theme within the Netherlands Environmental Assessment Agency (Goldewijk et al. 2010).

For the calculation of mortality cases (ΔY) in absolute and relative numbers the following equation was used:

$$\Delta Y = (Y_O \times pop) \times (e^{\beta \times X} - 1),$$

where *Y0* is the baseline mortality rate; *pop* the number of exposed persons; *β* the exposure-response function (relative risk) and *X* the estimated excess exposure.

The WHO meta-analysis all-cause mortality relative risk (RR) 1.003 per 10 μgm^{-3} increase in the maximum daily 8-hour average ozone concentration (95% CI 1.001–1.004) was used as the exposure-response coefficient (ERC) (Anderson et al. 2004).

3 Results

Changing ozone concentrations will affect mortality; however differently in different regions (Table 1). When the current situation (1990–2009) is compared with the baseline period (1961–1990) using the ozone estimates based on MATCH-EMEP-RCA3-HadCM3, the largest climate change driven relative increase in ozone related mortality is modelled to have occurred in Ireland, UK , the Netherlands and Belgium (Table 1); an increase up to 5% is estimated. A decrease is estimated for the northernmost countries, with largest decrease, by 5%, in Finland. In absolute numbers, the model suggests 647 more deaths per year in Europe being the largest in Italy with 100 cases.

If we compare the baseline period (1961–1990) with the future (2021–2050), the difference is even more dramatic for several countries (Table 1). The increase in ozone related cases is projected to be largest in

Belgium, France, Spain and Portugal (10–14%). However, in most Nordic and Baltic countries, there is a projected decrease in ozone-related mortality of the same magnitude. The change is stronger if we compare the further future (2041–2060) with the baseline period (1961–1990) as simulated using HadCM3 (A1B). The projected impacts are larger using the ECHAM4 (A2) projection, up to 34% increase in Belgium, due to a stronger reduction in summer precipitation in this region and corresponding reductions in cloudiness and soil moisture leading to higher ozone concentrations.

Comparing the current period (1990–2009) with the baseline (1961–1990) and the further future (2041–2060) with baseline (1961–1990) using the HadCM3 (A1B) projection suggests that the majority of the impacts in the highest risk areas will happen in the future and only a smaller part has already occurred. However, we have to keep in mind that there is variability on decadal scale in the models, hence change over time periods differing by one or a few decades simulated by climate models are not necessarily comparable to reality.

There are regional differences in the climate change projections (1961–1990 vs 2021–2050), depending on which global climate model (ECHAM4 or HadCM3) and CO_2 emission scenario (A2 or A1B) were used as input to RCA3. For most countries, MATCH-RCA3-ECHAM4 (under the A2 scenario) produced larger increases; however, for some countries (e.g. Greece, Bulgaria), the increase is of the same magnitude in the MATCH-RCA3-HadCM3 scenario (under the A1B scenario). Due to differences in the model realisations of the current climate, there are also differences in $SOMO_{35}$ values in the base-line period (1961–1990). For some countries, e.g. Belgium, Netherlands and UK, the MATCH-RCA3-HadCM3 scenario results in more than 25% higher concentrations; whereas for Southern European countries e.g. Spain and Portugal, the $SOMO_{35}$ values were more than 10% lower compared to MATCH-RCA3-ECHAM4.

Table 1. Projected annual counts of premature mortality due to ozone >$SOMO_{35}$ in the EU27 countries, Norway and Switzerland. Estimates build on modelled ground-level ozone concentrations based on two different anthropogenic precursor emission databases (EMEP and RCP4.5) and chemistry-transport calculations using regional climate downscaling (with RCA3) of two different global climate models (ECHAM4 and HadCM3) with two CO_2 emission scenarios (A2 and A1B) in different time periods

	MATCH-EMEP-RCA3-ECHAM4 (A2)		MATCH-EMEP-RCA3-HadCM3 (A1B)				MATCH-RCP4.5-RCA3-HadCM3 (A1B)		
	1961–1990	2021–2050	1961–1990	1990–2009	2021–2050	2041–2060	1990–2009	2021–2050	2041–2060
Austria	485	522	533	539	559	558	521	529	524
Belgium	381	512	529	551	602	626	592	630	645

Bulgaria	720	744	672	693	716	722	785	805	809
Cyprus	54	54	51	51	52	52	46	46	47
Czech	600	650	664	678	704	704	687	703	700
Denmark	238	255	290	291	295	292	288	285	279
Estonia	55	51	61	60	58	54	58	56	52
Finland	123	113	145	138	132	126	123	116	111
France	2659	3320	3123	3178	3488	3594	3473	3721	3783
Germany	2167	2562	2675	2723	2903	2945	2304	2422	2441
Greece	1007	1052	956	984	1020	1045	872	888	902
Hungary	791	853	802	830	874	866	902	934	918
Ireland	62	72	79	83	78	75	81	75	71
Italy	5737	6491	6003	6103	6553	6630	5865	6197	6229
Latvia	100	94	108	108	106	98	108	104	96
Lithuania	123	113	129	130	127	119	136	132	123
Luxembourg	19	24	24	24	26	27	23	24	25
Malta	35	37	38	38	39	40	35	38	38
Netherlands	496	640	696	729	776	791	842	875	885
Norway	121	115	150	148	137	132	186	170	165
Poland	1771	1825	1939	1990	2028	1957	2018	2028	1947
Portugal	819	972	726	744	823	848	703	769	787
Romania	1481	1500	1397	1435	1486	1473	1654	1701	1680
Slovakia	302	315	312	317	328	325	340	347	342
Slovenia	127	138	132	134	139	139	130	131	133
Spain	3236	3730	2887	2975	3324	3425	2494	2762	2828
Sweden	303	295	360	355	347	337	334	316	303
Switzerland	412	456	485	488	502	507	459	463	464
UK	1489	1954	2045	2143	2191	2215	2194	2216	2219
Total	25915	29458	28012	28658	30414	30723	28251	29484	29545

4 Discussion

Factor affecting absolute results most is the SOMO value. In health impact assessments (e.g. Anderson et al. 2008, De Marco 2009, Watkiss et al. 2005) often used cut-off value (35 ppb(v)) is below the WHO air quality guideline for ozone of maximum daily 8-hour average 100 μgm^{-3} (WHO 2006) and the EU air quality directive 2008/50/EC of maximum daily 8-hour average 120 μgm^{-3}, not to be exceeded on more than 25 days per calendar year (EC 2008). As epidemiological studies have shown associations also at lower concentrations (e.g. Amann et al. 2008, Bell et al. 2006), the total number of cases attributed to ozone is likely underestimated in all scenarios. Using $SOMO_{25}$ values as a cut-off would approximately double the number of attributed cases, but decrease the projected relative increase (Table 2). However, using the higher cut-off of $SOMO_{50}$ would significantly decrease the number of cases, but increase the relative changes (Table 2), since the largest increase appeared among high ozone days (maximum daily 8-hour average more than 100 μgm^{-3}). Most of the projected increase in $SOMO_{35}$ is during summer, April–September (Table 2).

Table 2. Total annual counts of premature mortality in Europe and projected change (%) in future due to ozone exposure change using different seasons and cut-off values

	MATCH-EMEP-RCA3-ECHAM4 (A2)		**MATCH-EMEP-RCA3-HadCM3 (A1B)**			
	1961–1990 (number of cases)	**2021–2050 vs 1961–1990 (%)**	**1961–1990 (number of cases)**	**1990–2009 vs 1961–1990 (%)**	**2021–2050 vs 1961–1990 (%)**	**2041–2060 vs 1961–1990 (%)**
$SOMO_{35}$ annual	25,915	13.7	28,012	2.3	8.6	9.7
$SOMO_{35}$ winter	4,550	9.1	4,553	-3.2	0.6	-0.9
$SOMO_{35}$ summer	21,342	14.6	23,434	3.4	10.1	11.7
$SOMO_{25}$	47,389	8.2	49,558	0.9	4.6	5.1
$SOMO_{50}$	7,108	35.3	8,289	7.4	23.8	27.8

We focused on the impacts of climate change-related alterations in ground-level ozone concentrations, holding other factors constant. Our results show that climate change could impact health in the future through higher ozone concentrations in several countries. Nevertheless, in some countries (e.g. Northern Europe) reduction of ozone induced mortality is expected in the future due to climate change. Many processes contribute to the decrease in tropospheric ozone including increasing chemical destruction due to more water vapour, decreasing natural isoprene emissions, increased dry deposition and changing pollution transport patterns (Andersson and Engardt 2010).

Several methodological issues may also have affected the results. For the time periods studied, the choice of greenhouse gas emission scenario is not crucially important because the differences in emissions between the scenarios are small before 2050. A more important factor is the global climate model used. The downscaling of the two different global climate models gave somewhat different results in different regions of Europe. In most countries, using the HadCM3 global model resulted in higher ground-level ozone baseline values (1961–1990) compared to ECHAM4. This indicates that in assessing local effects, the choice of global model is important. Also, the climatic variables (such as temperature, humidity, etc.) could affect mortality rates and thus the impacts of ozone. The choice of anthropogenic precursor emissions also affected the total numbers in different periods, but it did not affect largely the trends in different areas.

These projections can be used in combination with projections of changes in emissions under different proposed regulations to understand the magnitude and extent of impacts under a higher temperature future. It could help the ministries of health and public health organizations to begin planning how to improve current programmes to ensure that vulnerable populations are protected from projected increases in ground-level ozone concentrations in a changing climate.

5 Conclusions

The projected effects of climate change on ground-level ozone concentrations could differentially influence mortality across Europe. There would be an increase in ozone-related mortality in Southern and Central Europe and a slight decrease in Northern Europe. Compared to the baseline period (1961–1990), few climate-related ozone impacts appeared in the last two decades (1990–2009), with more projected in the future (2021–2050 and 2041–2060). The HadCM3 global model projected somewhat higher ozone concentrations for the baseline compared to using ECHAM4 in many countries. ECHAM4 gave generally larger health impacts for 2021–2050. The selection of anthropogenic precursor database affected the absolute values (higher in Eastern and Northern, lower in Southern and Western Europe); however, it did not change the trends.

6 Acknowledgements

The work was supported by the EU-funded Climate-Trap project (contract EAHC 20081108)) and by the Swedish Environmental Protection Agency through the research programme CLEO – Climate Change and Environmental Objectives. We would also like to acknowledge Estonia's Ministry of Education for providing resources to H. Orru with the grant SF0180060s09.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Autumn school '"Dealing with uncertainties in research for climate adaptation"

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Abstract— Climate adaptation research inevitably involves uncertainty issues - whether you build a model, use climate scenarios, or evaluate policy processes. Uncertainties propagate from one field of research (e.g. socio-economic scenarios) to the other (e.g. climate scenarios). It is therefore essential to look over the borders of ones own discipline and find out which uncertainties exist in ones input data and how results are used by others.

The Dutch research program Knowledge for Climate (KfC) noticed a need for exchange of information about dealing with uncertainties among the different disciplines in the program. Therefore the three day Autumn School Dealing with Uncertainties was organized in October 2012, which brought together 38 researchers in climate adaptation (PhDs/postdocs) ranging from governance, decision management, climate impacts and climate physics.

Aims of the Autumn School are 1) Active learning about uncertainties and dealing with uncertainties in research and decision making, 2) Obtaining insight in different approaches for communication about and visualization of uncertainties, 3) Constructing of common frame of reference (CFR) for dealing with uncertainties and communication about uncertainties to help researchers in climate adaptation to improve interaction between disciplines.

The mornings consisted of lectures about aspects of uncertainty and climate change. In the afternoon students worked with the information given in the morning, in case sessions and a serious game. The days were closed by a discussion. The lectures and discussions contributed to the "Common Frame of Reference", containing common definitions, do's and don'ts in dealing with uncertainties and communicating etc. Relevant literature is collected in a Digital Reader.

Index Terms— integrate climate and impact information, stakeholder consultations, dealing with uncertainties

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1 Background and aim

Climate adaptation research inevitably involves uncertainty issues - whether you build a model, use climate scenarios, or evaluate policy processes. Dealing with these uncertainties demands a lot of knowledge about types of uncertainties, methods for assessment, for determining the relevance and the propagation of uncertainties. Communication skills are needed to find out the actual information needs of the user and to tell the message fit to the user. Uncertainties propagate from one field of research (e.g. socio-economic scenarios) to the other (e.g. climate scenarios). It is therefore essential to look over the borders of ones own discipline and find out which uncertainties exist in input data and how results are used by others.

The Dutch research program Knowledge for Climate (KfC) noticed a need for exchange of information about dealing with uncertainties among the different disciplines in the program. Therefore the three day Autumn School Dealing with Uncertainties was organized in October 2012 which brought together 38 researchers in climate adaptation (PhDs/postdocs) ranging from governance, decision management, climate impacts and climate physics.

The central theme of the Autumn School was dealing with and communicating about uncertainties, in climate- and socioeconomic scenarios, in impact models and in the decision making process. More specifically the aims were 1) active learning about uncertainties and dealing with uncertainties in research and decision making, 2) obtaining insight in different approaches for communication about and visualization of uncertainties, 3) constructing of common frame of reference (CFR) for dealing with uncertainties and communication about uncertainties to help researchers in climate adaptation to improve interaction between disciplines.

2 Organisation and set-up

The Autumn School was organised by KNMI in partnership with the other consortia of the KfC Research Programme. KNMI is consortium leader of KfC Theme 6 “High Quality Climate Projections”, but the aim of the Autumn School was to search for common ground between the different research themes (and outside of the KfC Programme) on the subject of uncertainties.

The mornings of the three day Autumn school consisted of lectures about aspects of uncertainty and climate change 1) terminology and types of uncertainty, 2) methods for dealing with uncertainties and 3) communiation about uncertainties. In the afternoon participants worked with the information given in the morning in case sessions and a serious game. The days were closed by a discussion. The lectures and discussions contributed to the “Common Frame of Reference”, which will be treated in more detail below.

All documentation, lectures, summaries of discussions, the Common Frame of Reference, etc. are made available through a website: http://www.knmi.nl/climatescenarios/autumnschool2012/.

3 Common Frame of Reference

The lectures and discussions contributed to the development of a Common Frame of Reference (CFR) for dealing with uncertainties. The CFR is meant to help researchers in climate adaptation to work together and communicate together on climate change (better interaction between disciplines). It is also meant to help researchers to explain to others (e.g. decision makers) why and when we agree and when and why we disagree, and on what exactly. The common frame contains the following:

1. common definitions;
2. common understanding and aspects on which we disagree;
3. documents that are considered important by all participants;
4. do's and don'ts in dealing with uncertainties and communicating about uncertainties;
5. recommendations.

3.1 Common definitions and typology

Participants used various descriptions of the term uncertainty, however all agreed that it can be defined as any departure from complete deterministic knowledge of the relevant system (based on Walker et al., 2003). Uncertainty is not simply a lack of knowledge, because an increase in knowledge might lead to an increase of knowledge about things we don’t know, and thus increase uncertainty.

Useful typologies of uncertainties (Dessai & van der Sluijs, 2007) are based on distinctions between:

1. levels (indicate how difficult it is to describe uncertainty);
2. sources
    a. (natural) variability;
    b. lack of (system) understanding, inherent complexity
    c. varying perceptions, preferences (ambiguity)
3. locations (for model-based analysis).

For policy makers the levels also could be of most value as these indicate how difficult it is to describe uncertainty. The source and location might be less relevant for them. In scientific literature typologies for varying perceptions (also called ambiguity) is not given a lot of attention yet (Brugnach et al., 2011).

3.2 Common understanding

3.2.1 Why take uncertainties into account

The main reasons why the participants considered it important to take uncertainties into account are:

1. scientists' goal is to improve humanity's understanding of the World. That can only be accomplished when they communicate those factors that could make their findings limited or uncertain;
2. communicating uncertainty enhances credibility, in particular when that uncertainty diminishes the apparent importance of our work;
3. in many cases, decision-makers can achieve superior outcomes when they take uncertainties into account;
4. communicating the limitations and uncertainties inherent in sceintific findings helps other scientists to formulate important research questions.

3.2.2 Usefulness of a common typology

A common typology of uncertainties was rendered useful for the following reasons:

1. it could improve communication between people, both those engaged in research as in decision-making, if we all use the same typology, because we can be more specific;
2. useful to know where uncertainty comes from;
3. the typology could give directions on how to deal with it: Useful to know whether it is an uncertainty that can be expressed in a probabilistic way;
4. you can refer to it in a paper (you can easily point out which uncertainties you have and which you have not addressed).

Most participants agreed that a common typology will improve communication among disciplines, although we should probably use a few common typologies, as the usefulness of the typology differs per discipline and type of user. A common typology especially is useful for professional users. For the general public stories of uncertainties that illustrate the different types of uncertainties and which have a human element, might be more effective in that case.

3.2.3 Communication

From the discussions it was concluded that policy makers and scientists both have a task in communication about science: 1) scientists in trying to understand policy makers (e.g. their information needs and how they use information) and explaining in a clear way their research and 2) policy makers in making clear what is relevant to them and trying to understand scientists.

Communication between scientists and decision makers requires a lot of effort (from both the scientists and decision makers) due to the differences in language, knowledge, framing, scales on which they operate usually (practical versus conceptual, short versus long term, local versus international) and lack of familiarity with each other's working environment.

Although everyone wants scientific results to be used by decision makers, there was no agreement among the participants on how far scientists should go in communication. It ranges from limited efforts (too much simplification touches upon integrity of researcher), up to much effort (societal responsibility). Emphasizing or de-emphasizing uncertainties can also be used strategically (by both scientists and policy makers). Results of scientific work should be communicated to decision makers and also the uncertainties included. However, not everyone has the skills (and willingness) to invest much time in communication. In general, it was felt that there is a need for specifically trained "boundary workers" to organize the interface.

3.2.4 Documents considered important and do's and don'ts

As part of the discussions at the end of each day, several do's and don'ts were formulated and a list of useful information was compiled. These can all be found on the web site. A few examples of the do's and don'ts are:

1. adjust the communication to the target audience. Sometimes it may be better to talk about risks or margins than about uncertainties;
2. persist to make sure the question of the target audience is clear. Be aware of the question behind the question;
3. don't take over the chair of the policymaker: scientists should deliver the scientific information, policy makers should make the decision;
4. don't only focus on uncertainties (model/perceptions), but also highlight what is certain. Only focussing on uncertainties could paralyze decision makers.

4 Recommendations

Based on the Autumn school and discussions afterwards when writing the CFR, the following recommendations regarding dealing with uncertainties were presented:

1. there is a need for a useful typology for social sciences including decision-making: it would be good to have a typology of ambiguity;
2. more guidance is needed in finding the right method to deal with uncertainties: there is a large number of combinations of types of uncertainties, methods to deal with them analytically, and (policy) strategies to follow in light of them. It would be useful to have some ranking, or a list with advantages and disadvantages of each method and a sort of matching of uncertainty situations, policy attitudes, and policy strategies in order to determine which method to use when. A description of pitfalls, strengths en limitations of a selection of analysis methods (error propagation, Monte Carlo analysis, sensitivity analysis, etc.) is given by van der Sluijs et al. (2004);
3. more information needed on methods how to deal with uncertainties related to human actions (ambiguity, framing, perception, risk aversion) (de Boer et al., 2010);
4. the participants of the Autumn school also expressed the need for a platform to discuss methods and exchange experiences in dealing and communication with uncertainties is needed. It is not clear yet which form of such a community is most effective.

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Acknowledgements

The authors would like to thank the Knowledge for Climate programme for funding, as well as all the lecturers who contributed to the Autumn school for their fruitful collaboration.

How to assess climate change impacts on farmers' crop yields?

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Abstract— Farmers' yields are affected by multiple environmental and socio-economic factors. Crop simulation models that are thoroughly calibrated and evaluated for local conditions and fed with data from climate change projections are principally well-suited to estimate the impacts of climate change on potential yields, assuming optimal management. Important question is, however, what will happen to the yields on farmers fields in the future and to the gap between actual and potential yields. This will require linking crop model-based impact projections with socio-economic analysis.

In Finland, farmer's crop yields have been steadily increasing after World War II, mainly due to improvements in agro-management driven by technological development and genetic improvements with higher-yielding new cultivars. During past few decades, however, the yield gap has increased as farmers put less emphasis on high crop yields but apply cost-reducing management. This is mainly due to discouraging input and output prices and subsidy systems. Comprehensive yield series (1971 to present) from Finnish experimental and farmers' fields provide the basis to analyse yield trends, yield-influencing factors and develop modelling tools for improved prediction of future actual yields under climate change.

Crop simulation model WOFOST was used to simulate historical (1971-2008) and future (2011-2040, 2041-2070) potential yields of spring barley, in two regions representing different agro-ecological zones in Finland. The development of historical yield gaps was analysed and linked to the information on socio-economic developments. This is to contribute to the discussion on uncertainties related to climate change impact projections taking into account both environmental and socio-economic drivers.

In conclusion, more integrated efforts are needed to develop modelling tools taking into account both, environmental and socio-economic effects on farmer's behavior and future yields. Most measures to narrow current yield gaps also have a high potential to maintain or increase crop yield levels under future climatic conditions.

Index Terms— crop production, simulation modelling, yield gap, spring barley

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1 Introduction

Farmers' yields are affected by multiple environmental and socio-economic factors and by progress in plant breeding. In Finland, farmer's crop yields have been steadily increasing after World War II, mainly due to improvements in agro-management driven by technological development, genetic improvements with higher-yielding new cultivars and higher use of material inputs by farmers. During past few decades, however, the yield gap has increased as farmers put relatively less emphasis on high crop yields but apply cost reducing sub-optimum management. This is due to discouraging input and output prices, subsidy systems together with environmental restrictions and stagnated land ownership. For example, the increasing land tenure insecurity has been linked to the decreased soil pH and phosphorus status of Finnish agricultural soils on leased land (Myyrä et al., 2005).

Crop simulation models that are thoroughly calibrated and evaluated for local conditions and fed with data from climate change projections are principally well-suited to estimate the climate change impacts on potential yields assuming optimal management (Evans and Fischer, 1999, Rötter et al., 2011b). Important question is, however, what will happen to the yields on farmers fields in the future and to the gap between actual and potential yields. This will require linking crop model-based impact projections with socio-economic analysis. For example, Reidsma et al. (2009) noted that the actual climate change impacts are largely dependent on farm characteristics, e.g. farm size and input use intensity.

The aim of this paper is to discuss how effectively development of impacts of climate change on crop yields over time can be projected using simulation models. We approached this question by using simulation model to estimate the potential yields and analysis of comprehensive observed yield series to study the actual farmer's yields and the yield gap between them. The development of historical yield gaps was analysed and linked to the information on socio-economic developments. This is to contribute to the discussion on uncertainties related to climate change impact projections taking into account both environmental and socio-economic drivers, i.e. the effects of adaptation and different management levels.

2 Material and methods

2.1 Model simulations

Crop simulation model WOFOST (Boogaard et al., 1998) was used to simulate historical (1971-2008) and future (2011- 2040 and 2041-2070) water-limited yields (assuming otherwise optimal management) of spring barley (*Hordeum vulgare L.*), in two study sites, Jokioinen and Ruukki, representing different cultivation areas (Häme and Oulu) and agro-ecological zones in Finland (Fig. 1). WOFOST has been previously calibrated for spring barley cultivation in Finland (Rötter et al., 2011a). For the historical simulations we used a set of cultivars representing modern and historical early, medium and late maturing cultivars. For future projections, cultivars used were late maturing Annabell and medium maturing Kustaa for Jokioinen and Ruukki, respectively. Simulations were done assuming clay soil at both sites.

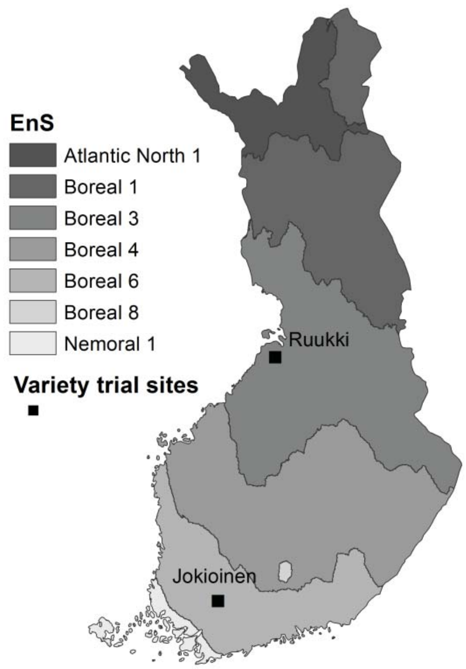

Figure 1. Location of two study sites with names of the experimental stations and environmental stratification (EnS) according to Metzger et al. (2005).

Future weather data were generated for the combinations of two General Circulation Models (GCM), i.e. IPSL-CM4 and CSIRO-MK 3.5 with two alternative SRES emission pathways, A2 (high) and B1 (low) (Nakicenovic et al., 2000). The climate change projections for time slices 2011-2040 and 2041–2070 were done for combinations IPSL-CM4 A2 and CSIRO-MK 3.5 B1, and simulated changes were calculated relative to baseline 1971-2000. These were then down-scaled to the study sites using the delta change method (Räisänen and Räty, 2012) as applied in Rötter et al. (2013). These two climate scenarios selected from CMIP3 Multi Model dataset (Meehl et al., 2007) project quite contrasting future climates for Finnish conditions (Rötter et al., 2013).

The increase in atmospheric CO_2 was taken into account by adjusting the crop parameters following Rötter et al. (2011a) to represent shifts in crop characteristics for higher levels of atmospheric CO_2 concentrations. We assumed the increase rates between 2 and 4 ppmv per year based on estimates by Anderson and Bows (2008) and took the approximates for the midpoint levels for the periods. As compared to the midpoint (1985) of reference period concentration (350 ppmv), the concentration assumed for 2011-2040 was 435 ppmv and for 2041-2070 525 ppmv.

Autonomous adaptation was assumed with sowings following the increasing spring temperatures.

2.2 Empirical data

The cultivar-specific information applied in simulations were created based on analysis of barley data from Finnish official variety trials (Kangas et al., 2010) for the period 1970-2010. The simulated yields were compared with the barley yields of farmers reported for the regions were the study sites were located. This data were taken from the EVIRA data base (EVIRA, 2012) and it covered years 1988-2008.

3 Results

Simulated water-limited yields for the period 1970-2008 had high inter-annual variability and the cultivars showed different yield levels (grey lines in Fig. 2). Average simulated yield weighted with the cultivar use of farmers of the surrounding areas were 5480 kg (dry matter) ha^{-1} for Jokioinen and 4880 kg (dry matter) ha^{-1} for Ruukki for the period 1988-2008. The mean yields of at farmer's fields during the same period were for Häme region 3220 and for Oulu region 2780 kg ha^{-1} indicating large yield gap between the potential and actual yields. During the same period the mean yields reported for these experimental sites were 4650 kg ha^{-1} for Jokioinen and 4350 kg ha^{-1} for Ruukki (data not shown). The gap between the farmers' yields and potential yields has been slightly increasing during the observed period.

Overall, there is a slightly decreasing trend in simulated barley yields over the coming decades (Fig.2). The two selected climate scenarios show decreases to different extent even though the CO_2 fertilization effect partly compensated the marked yield decline resulting from changed climate variables.

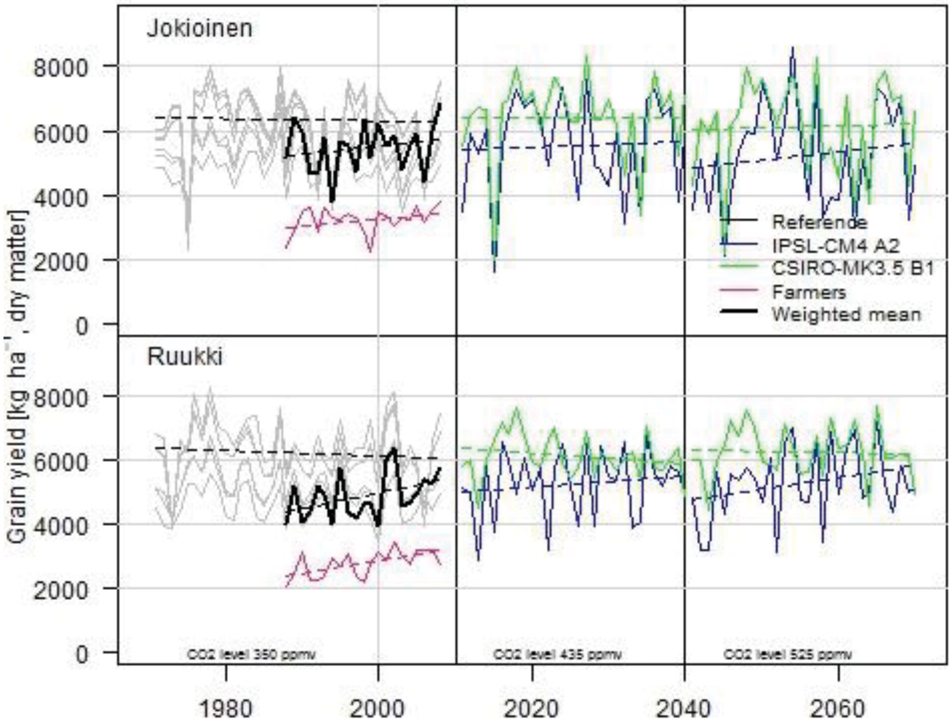

Figure 2. Simulated water-limited annual yields of spring barley for the Jokioinen and Ruukki study sites for historical weather 1970 – 2008 and projections for periods 2011-2040 and 2041-2070 (solid lines) with trends calculated for each period (dashed line) and mean regional yields of the farmers at surrounding rural centre areas (pink solid line) with trend (pink dashed line). Grey lines show the simulated yields for different cultivar types and dashed black like the trend for the cultivar type used in future projections. Bold solid black line shows simulated average yields weighted according to cultivar use by farmers and dashed bold black line the trend of the weighted means.

4 Discussion

Finland is one of the few European countries that experiences relatively high yield gaps that are widening over time as shown for barley in this study, but elsewhere also for other cereals (Boogaard et al., 2013, Peltonen-Sainio et al., 2009). Main reasons for this are the decreased use of inputs, mainly fertilizers and liming, by farmers, as a reaction to decreased real prices of cereals during the last decades. Also agricultural policies, decoupling agricultural support from production decisions, as well as explicit limits and restrictions for nutrient use (N,P) in agri-environmental programmes have discouraged farmers from aiming to high yields and utilising sufficient fertiliser, pesticide and other inputs for yield improvements.

The farm level incentives as well as production possibilities are likely to change in future. Impacts of more frequent and severe extreme weather events may play an increasing role (Field et al., 2012, Olesen et al., 2011). Under future climates, whether yield gaps widen or narrow will be closely related to the way socio-economic, agricultural and environmental policies develop and how they allow expected technological progress to be implemented in actual management practices by farmers (Claessens et al., 2012). This clearly calls for developing new integrative assessment approaches and tools that concentrate on farm level, where the final decisions on agricultural production and resource management are taken. For Finland such integrated modelling framework has been outlined (Lehtonen et al., 2010). A key issue in such integrative studies is how to consistently link farm level productivity improving measures, such as improved pesticide use and fertilisation practices, to yield improvements. It is important from farmers' point of view to evaluate under which prices it pays off to aim for high yields by using variable inputs, and even invest in soil improvements which only pay off in the longer run. In short, such integrative work should be able to compare increased marginal costs to the marginal benefits of yield improvements, which may even facilitate further gains in overall re-organisation of farm production. Risks of both action and inaction yield improvements in changing conditions are also important to be evaluated.

Van Ittersum et al. (2012) recently proposed a protocol for yield gap assessment and argued that crop simulation modelling is the most reliable way to estimate the potential yields. We followed that protocol and projected the future water-limited barley yields with WOFOST in a fairly conservative manner. Those projections, albeit being based on a couple of scenarios and climate model projections only, show future trends in barley yields as driven by climate effects, i.e. weather and CO_2 concentrations. For simplicity we only used average CO_2 levels for future periods, but in more detailed analysis annual CO_2 levels could be applied. Our results for the historical period show the importance of the genetic improvement of cultivars for the yield trends. Simulation models can, in principle, also take into account foreseeable changes in crop properties, i.e. the genetic development (e.g. Rötter et al., 2011a) and their effects on potential yields. The properties of the future cultivars remain, however, a source of uncertainty for the simulation results. Modellers should strive for active collaboration with breeders for future projections.

The capacity of the crop models to simulate the yields under sub-optimal management to estimate the actual yields is less certain. That is because of many yield-limiting factors, such as pests and diseases, are excluded from the models. For that reason, establishment of current yield gap factors and assumptions about their future development is needed to estimate farmer's yields under climate change as needed by trade models (e.g. Nelson et al., 2010).

In conclusion, more integrated efforts are needed to develop modelling tools taking into account both, environmental and socio-economic effects on farmer's behaviour and future yields. Most measures to narrow current yield gaps also have a high potential to maintain or increase crop yield levels under future climatic conditions. There is a large potential for sustainable intensification of crop production by closing yield gaps e.g. with enhanced water and nutrient management (Mueller et al., 2012). Whether such intensification can be realized will largely depend on socio-economic factors.

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How the hydrologic adjustment may affect assessing climate change impacts on water?

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Abstract—The response of land surface evapotranspiration (ET) to climatic changes has been primarily indexed by near-surface air temperature changes in hydrologic models to evaluate climate change impacts on water. However, climate models directly compute the surface energy balance and do not use the empirical temperature-based relations for estimation of potential ET. Temperature may not be seen as force of potential ET rather it is a result of surface energy balance that is affected by many atmospheric variables. In this study, we use different sets of climatic variables from the climate model to drive a hydrologic model. The climatic variables are obtained from the bias-corrected climatic variables generated for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP). We investigate the difference of the model estimated changes in surface fluxes when different sets of climatic variables from the climate models are used. When considering the effects of changes in temperature among other climatic variables (surface radiation, air pressure, and specific humidity) in the Variable Infiltration Capacity (VIC) hydrologic model, we show that the estimated changes in ET and runoff could be quite different from those estimated from a short set of climatic variables (precipitation, temperature, and wind speed only). The change in surface shortwave radiation (SW) with VIC adjustment could be more negative than that without adjustment. Consequently, VIC adjustment may lead to underestimation of ET increase and thus underestimate future drought and water scarcity in a warming world. The different hydrologic adjustment methods could differ from each other even in the sign of bias. Therefore, we highlight the potential influence of hydrologic adjustment in assessing climate change impacts on water.

Index Terms—climate change impacts, evapotranspiration, hydrologic adjustment, surface radiation.

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1 Introduction

Understanding the impacts of climate change on water cycle is essential for climate change adaptation. The general circulation models (GCMs) can project the responses of the climate system to climate change, and consequent changes in the water cycle. The hydrologic responses to climate change implied by the climate models for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change were assessed in many studies (Milly et al. 2005; Nohara et al. 2006; Tang and Lettenmaier 2012). In these studies, the runoff produced by the GCMs was used. The assessment using the GCM produced runoff would suffer from the coarse resolution and the imperfect representation of surface hydrologic processes in the climate models.

Many hydrologic modeling studies have used hydrologic model driven by downscaled climatic variables to produce runoff projections under a future climate (Crosbie et al. 2011; Teng et al. 2012). In these studies, the modeled future and historical runoff were compared to estimate the hydrologic responses to climate change. In many cases, the hydrologic models use precipitation and air temperature as the primary climatic inputs (Maurer et al. 2002; Tang et al. 2006). And the computation of potential ET, which is a conceptual variable used for ET calculation in the hydrologic models, is mainly indexed to air temperature. However, the validation of the empirical temperature-based relations for potential ET has been less investigated. Milly and Dunne (2011) showed that the relative changes in runoff with hydrologic adjustment could be much less positive than the estimates from the climate models and they attributed the decrease in hydrologic model-simulated runoff to the amplification of the climate model-implied increase in potential ET.

In this study, we use different sets of climatic variables from 5 GCMs to drive a hydrologic model which includes an energy balance approach to express the surface radiation fluxes based on air temperature. We investigate the difference of the model estimated changes in surface fluxes when different sets of climatic variables from the climate models are used.

2 Method

The Variable Infiltration Capacity (VIC) hydrologic model is used (Liang et al. 1994). The VIC model can be forced with precipitation, air temperature, wind speed, vapor pressure, incoming longwave and shortwave radiations, and air pressure, meanwhile, it includes an optional module to relate the meteorological variables (other than precipitation, temperatures and wind) and radiations to precipitation, daily temperature, and temperature range (Kimball et al. 1997; Thornton and Running 1999). As only precipitation and temperature are routinely measured at meteorological stations, the empirical relations are commonly used in the hydrologic models (Maurer et al. 2002). This approach is a reasonable compromise between available measurements and required meteorological forcings for the hydrologic models.

The bias-corrected climate data from 5 GCMs (HadGEM2-ES, GFDL-ESM2M, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M) of Representative Concentration Pathways (RCP) 8.5 outputs produced by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) are used (Hempel et al. 2013). The data are made available at 0.5°×0.5° spatial resolution and daily time step. The bias-corrected climate data are used to drive the VIC model. The mean annual VIC estimates in the historical period (1971-2000) and the

RCP 8.5 future climate scenario (2070-2099) are used for analyses. We used two sets of climatic variables to drive the VIC model. One short set contains precipitation, air temperature and wind speed. The long set includes all the available ISI-MIP forcings (precipitation, air temperature, wind speed, surface radiations, air pressure, and specific humidity). When the short set is used, the optional module in the VIC model is used to derive the meteorological variables (other than precipitation, temperature, and wind) and radiation variables. The VIC estimates with the short set (VIC derived) data are compared with those with the long set (ISI-MIP data).

3 Results

Fig. 1 shows the difference between the VIC derived surface shortwave radiation (SW) and the ISI-MIP data in the period of 1971-2099. There are substantial differences in the middle and high latitudes between the VIC derived SW and the ISI-MIP data. Specifically, at the northern high latitudes, the VIC derived shortwave radiation is about 30% higher than the ISI-MIP data. However, at the southern middle latitudes, the VIC derived shortwave radiation is about 10% lower than the ISI-MIP data. The other peaks of the difference occur around the equator where the VIC derived shortwave radiation is about 20% higher than the ISI-MIP data. The difference is generally small at the southern low latitudes. These show the large systemic bias between the VIC derived SW and the ISI-MIP data.

Fig. 2 compares the changes in SW between the future period (2070-2099) and the historical period (1971-2000) implied by the VIC derived and ISI-MIP data. The VIC derived data show large decrease in SW over major land areas whereas the ISI-MIP data show that the SW change would be small. The VIC derived SW change is (about 10 W m^{-2}) smaller than that of ISI-MIP in the low and northern middle latitudes. Since ET is closely related to SW, the difference of changes in SW might affect the hydrologic model-estimated changes in ET and runoff.

Figs. 3 and 4 show the changes in ET and runoff between the future and historical periods estimated from the VIC derived and ISI-MIP data. Both VIC runs show that ET would increase in the future over most land area except for the current dry areas. However, the VIC run with the ISI-MIP data shows larger relative increase than the run with the VIC derived data (Fig. 3). It indicates that the VIC derived data may lead to underestimation of ET increase in a warming world. The underestimation is large (~10%) at the northern middle to high latitudes. The underestimation of ET change may also affect the runoff change. The VIC run with the VIC derived data shows more positive runoff change than the run with the ISI-MIP data (Fig. 4). It indicates the use of short set climatic variable could induce less negative runoff change and therefore underestimate future drought and water scarcity. Our finding is opposite to that of Milly and Dunne (2011) which showed the runoff changes with hydrologic adjustment were less positive than those from climate model. It suggests that the hydrologic adjustments could differ from each other even in the sign of systematic bias.

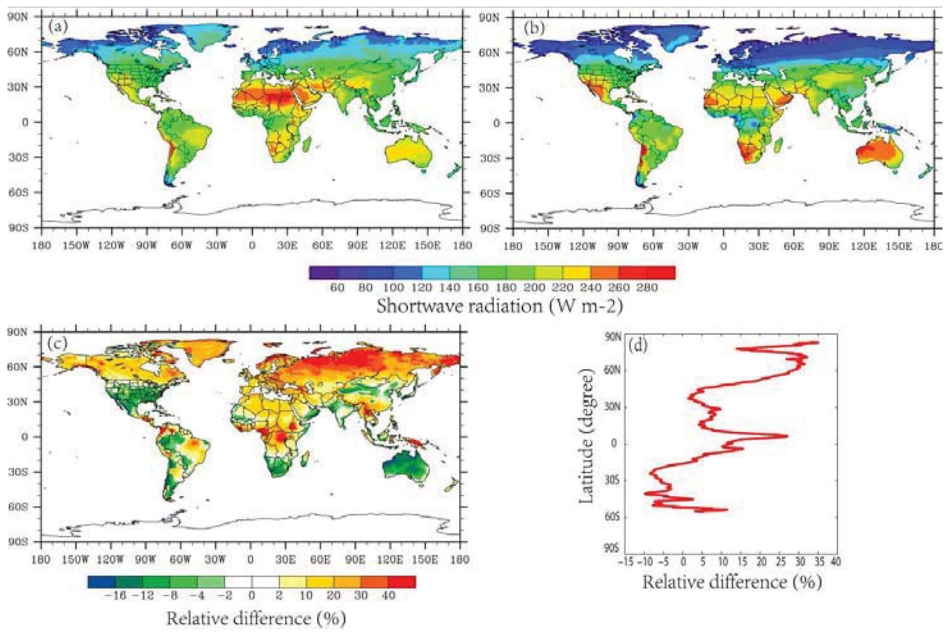

Fig. 1. The muti-model ensemble mean SW derived by VIC (a), and from ISI-MIP (b), relative difference between the VIC derived SW and the bias-corrected SW in the period of 1971-2099 (c) and the latitudinal profile of the difference (d).

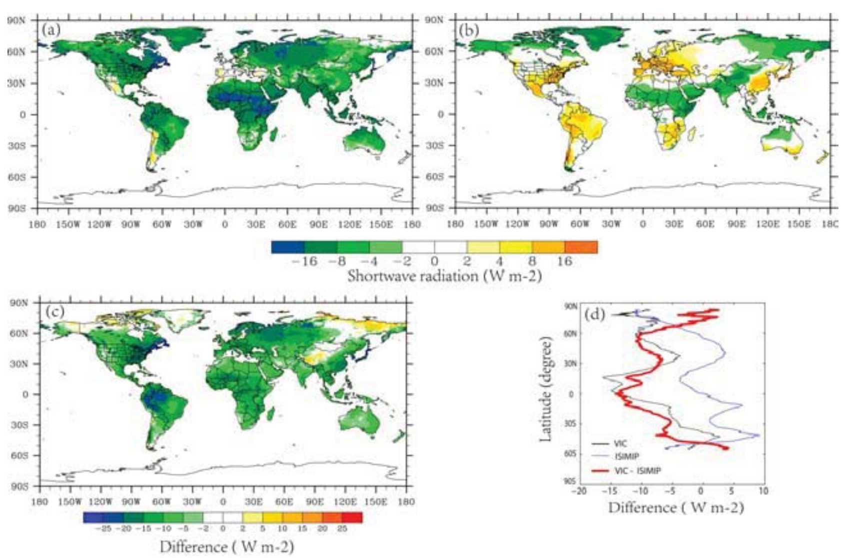

Fig. 2. The muti-model ensemble mean changes in SW between the future period (2070-2099) and the historical period (1971-2000) implied by the VIC derived (a) and ISI-MIP data (b), difference between the changes implied by the VIC derived and ISI-MIP data (panel a minus panel b) (c) and the latitudinal profile of the changes and difference (d).

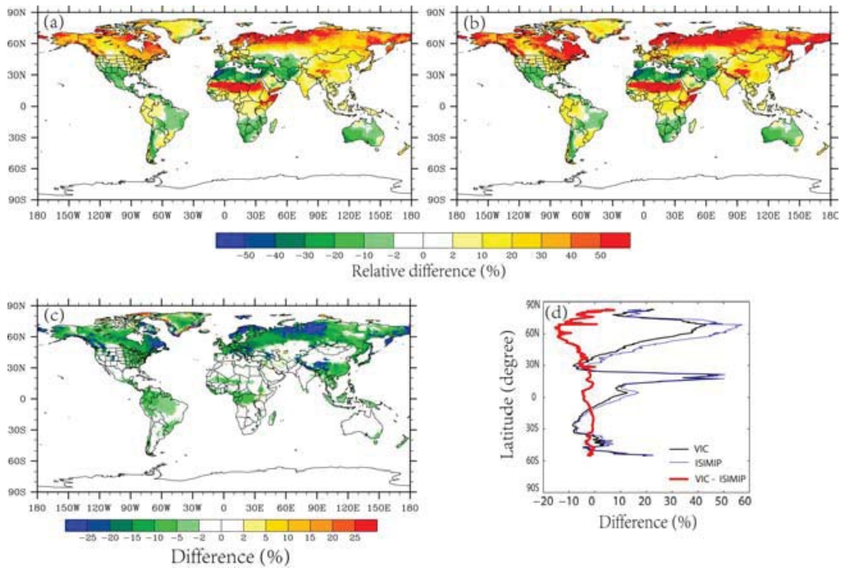

Fig. 3. The muti-model ensemble mean relative changes in surface ET between the future period (2070-2099) and the historical period (1971-2000) estimated from the VIC derived (a) and ISI-MIP data (b), difference between the changes (panel a minus panel b) (c) and the latitudinal profile of the changes and difference (d).

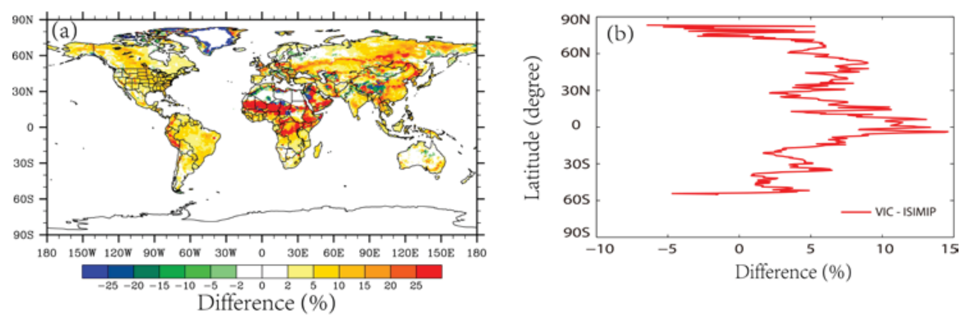

Fig. 4. The difference between the muti-model ensemble mean relative changes in runoff between the future period (2070-2099) and the historical period (1971-2000) estimated from the VIC derived and ISI-MIP data (a) and the latitudinal profile of the difference (b).

4 Conclusion and Discussion

Our results show that the change in SW inferred from the VIC model may largely differ from that implied by climate models in a changing climate. The SW change with VIC adjustment could be more negative than the change without adjustment. Consequently, VIC adjustment may lead to underestimation of ET increase and thus underestimate future drought and water scarcity in a warming world. The different hydrologic adjustment methods could differ from each other even in the sign of bias. Our results suggest that the empirical temperature-based relation might derive different climatic information from the climate model projection. The use of the hydrologic adjustment must choose the set of climatic variables that can carry the main climatic change information in the climate model projections.

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Topic 3:

Can we integrate our existing knowledge across sectors?

How useful are regional climate projections for hydrological impact assessment?

Axel Bronstert [1,2]

Abstract - Regional climate projections are frequently being used to drive meso-scale hydrological models in order to assess hydrological impacts of the anticipated future climate conditions. However, less emphasis is given to the question what meteorological variables, what degree of certainty and what spatial and temporal resolution are needed to enable hydrological impact assessments with a scientifically sound basis for water management or hydro risk assessment. A hydrological oriented approach is introduced to evaluate the usability of climate change projections for hydro impacts, and examples are presented, demonstrating capabilities and limits of current CC impact assessments in hydrological sciences.

Index Terms – regional climate change projections, hydrological impacts, extreme events.

1 Introduction

There is a rather large variety of methods available to derive regional climate projections (RCP). However, the resulting projections are only rarely scrutinized for their potential applicability in impact assessment of different scientific fields. Regarding hydrological impacts, the frequent careless use of RCP has significantly undermined the confidence in such studies (Blöschl & Montanari, 2010). Therefore, a scheme has been developed for evaluating regional climate projections referring their suitability for hydrological impact studies. The procedure focuses on the sensitivity of different meteorological drivers on the governing hydrological processes and accounts for different hydrological catchment status. In this paper, the method is briefly summarized and some application examples are given. The discussion elaborates the reliability of current climate change impact assessments for hydrological sciences.

2 How to evaluate the suitability of climate change projections for hydrological impact studies

2.1 Specific requirements for hydrological impact studies

2.1.1 Essential meteorological variables

Hydrological impact analysis can have different focal points, such as the rate of certain hydrological fluxes (e.g. evapotranspiration, groundwater recharge, snowmelt, surface runoff), the description of water resources state (e.g. water stored in the soil, groundwater level, snow pack, lake level, average catchment water yield), or their combination. Depending on the actual focus, different meteorological conditions have to be provided and are of varying relevance. For example, for an assessment concerning impacts on runoff generation processes (e.g. infiltration excess or saturation-excess induced overland flow) the provision of precipitation information is essential. If runoff due to snowmelt is discussed, temperature and (with a little less degree of importance) radiation information also needs to be provided. Without question, precipitation and air temperature are the most important variables for such analyses. However, other meteorological variables can be of additional relevance, such as net radiation, air humidity, and wind velocity for plant transpiration and soil evaporation.

2.1.2 Scale issues

Depending on the process under consideration, different typical space and time scales are relevant for an appropriate description of that process. Questions relating to climate change impacts on water resources management need to be analyzed at the “management scale”, which is usually a mid-size or large river catchment or a spatial unit for water allocation and distribution. Such spatial domains usually embrace areas of several 1,000km² to several 10,000km², in exceptional cases even in the order of 100,000km². Besides water management, this scale also addresses most vulnerability issues of the sectors dependent on water resources, such as agriculture, energy production or municipal water supply.

The time scale of decades to century is the most relevant for water management and adaptation, that’s why climate projections should provide information for a similar time span. However, for some “quick” hydrological processes it is of equal importance to provide the data in the appropriate temporal resolution. If, for example, the process of infiltration excess is addressed, the appropriate time step is smaller than days – i.e. hours or even less – because this process is primarily controlled by the rainfall intensity, which varies in such relatively short time increments.

2.1.3 Variability

Besides the relevance of different hydrological processes and scale issues, the appropriate representation of the variability of meteorological variables in time and space is the third essential. This means that an adequate consideration of the variability in time and space is required. Some hydrological processes may show a rather high variability in space and time (such as infiltration excess overland flow), while others (such as groundwater table dynamics) might be more homogeneous, and this has to be reflected by the climate change projections.

2.2 A systematic evaluation scheme

A scheme for evaluation of climate projections for hydrological impact analysis, as shown in Fig 1, has been designed along the requirements outlined above. It contains two main evaluation steps:

1. "Climatic Adequateness": This step examines the predictive power of the given climate projection by checking its ability to

- represent current climate conditions ("credibility"). This involves the review of the scenario regarding its ability to reproduce mean values, spatial and temporal variability, and extreme conditions of the observed climate variables under study,
- constitute a physically sound realisation of a possible future climate ("plausibility"). This involves the review of the scenario concerning its ability to
    i. represent the main regional climate features, e.g. orographic features, luff-lee or land-sea effects, ("regional climate representativity")
    ii. use available large-scale information about future climate conditions, normally provided by GCMs ("prognostic capacity"),
    iii. avoid introducing too much uncertainty, e.g. related to GCM-results ("reliability").

2. "Hydrological Usefulness": This second step examines the usefulness of the information gained in the first step for hydrological impact analysis:
    - First, the climatic information given by the scenarios is reviewed concerning their appropriateness for quantifying different relevant hydrological processes.
    - Second, the obtained information quality about the hydrological processes is reviewed conc. their relevance and appropriateness to assess the hydrological status of a region. This step distinguishes between mean water balance, long-term dynamics, event scale (time scale of a rainfall-runoff event, i.e. hours to several days) and extreme conditions.

The evaluation results of the climate predictability (step I) and the hydrological usefulness (step II) are finally combined to yield an integrated hydrological evaluation, as summarized in Fig. 1. The full procedure and its mathematical background are described in Bronstert et al., (2007).

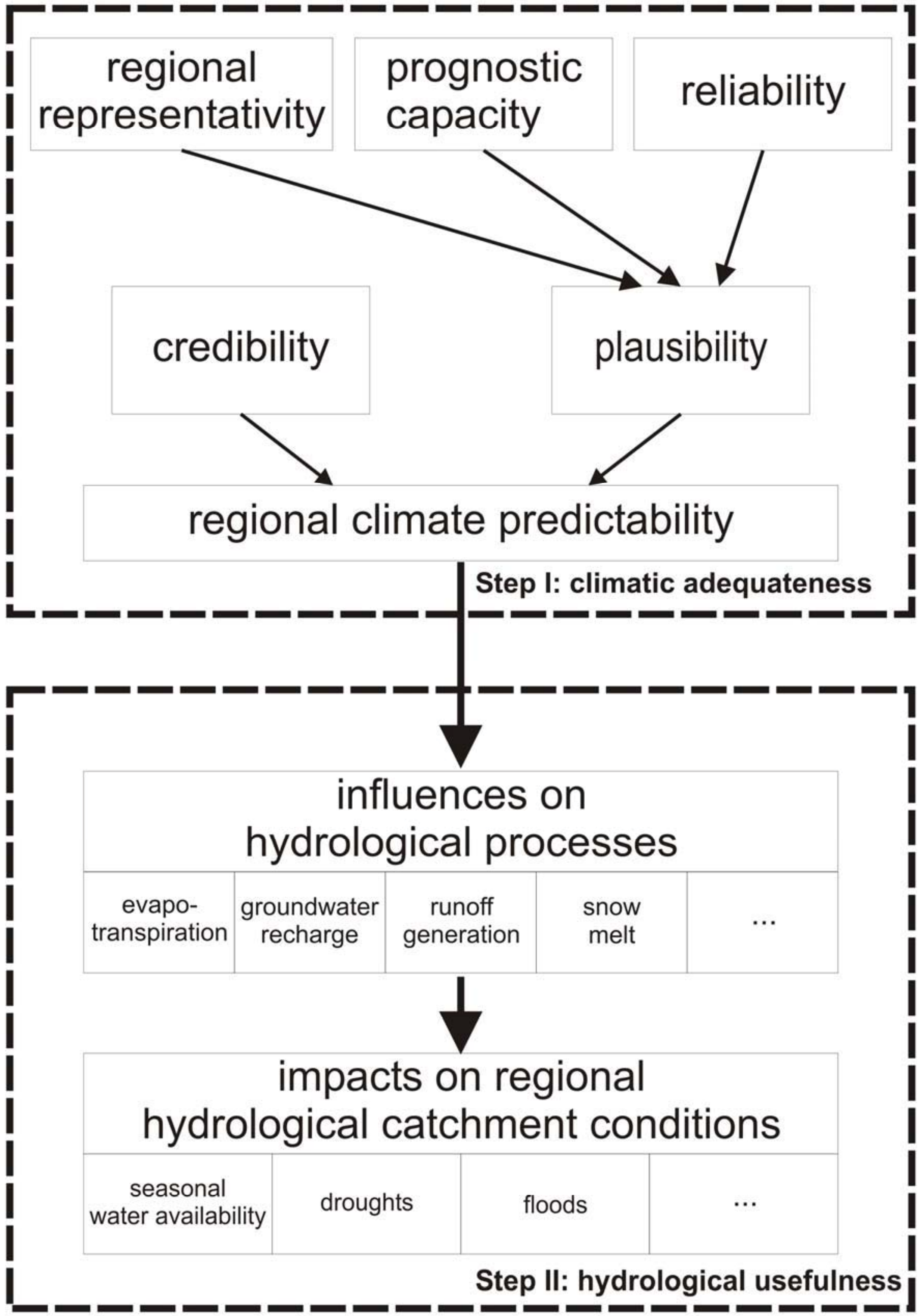

Fig. 1: Summary of the evaluation scheme of climate projections for hydrological impact analysis

3 An application for South Germany

The full application procedure has been applied to three different methods for regional climate change projections, taking South Germany as an example region. The projections obtained by three downscaling methods, and direct GCM results (GCM-grids without any further processing) are compared. All downscaling methods have been applied for South Germany, which comprises the Federal States of Bavaria and Baden-Württemberg, covering a total area of 106,000 km², see Fig. 2.

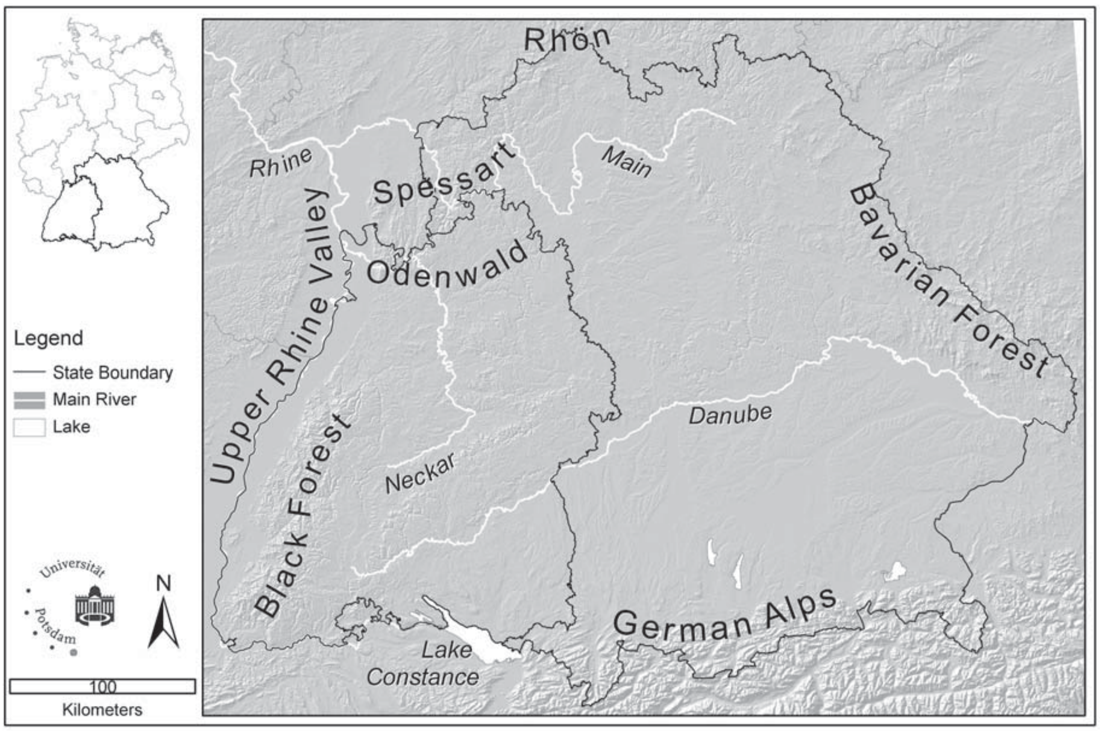

Fig. 2: Application region: the German federal states of Baden-Württemberg (left) and Bavaria (right). Shown are also the locations of different landscapes and the main rivers.

All methods used the results from the GCM ECHAM4 (see Roeckner *et al*., 1999) with the global emission scenario B2 (IPCC, 2001) as common information source for the future climate conditions. The time period for verification of the methods with observed climate has been fixed as 1971–2000, the chosen common scenario period is 2021–2050. A description of these three downscaling methods (named "REMO", "WettReg". "STAR") is available in the literature, e.g. Jacob & Podzun (1997), Enke *et al*. (2005a, 2005b), Werner & Gerstengarbe (1997).

4.1 Results of the evaluation procedure

The different regional climate projections have been evaluated as outlined above. To evaluate the capability of representing current and future climate the following features were analysed:

- Spatial variability of seasonal and annual values of T and P (variogram analysis);
- Annual and seasonal temperature (both spatially averaged and distributed values);
- Annual and seasonal precipitation values (both spatially averaged and distributed values);
- Temporal variations in temperature dynamics at selected stations;
- Temporal variations in precipitation dynamics at selected stations.

Tab. 1 summarises the evaluation results referring credibility of current climate and those of plausibility of future conditions. Ii is expressed in qualitative terms (rated) by assigning a value [0,3], where 0 is the "lowest" and 3 is the "best" grade, e.g. 0 stands for *not usable*, 1 for *low usability*, 2 for *moderately usable* and 3 for *good usable.* The numbers shown in Tab. 1 are derived by combining the evaluation results for all single criteria, see Bronstert et al., (2007) for details.

<table>
<tr><th></th><th></th><th>X_i</th><th>STAR</th><th>WettReg</th><th>REMO</th><th>GCM</th></tr>
<tr><td colspan="2" rowspan="2">average conditions</td><td>$\overline{P}$</td><td>1.7</td><td>2.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td>$\overline{T}$</td><td>2.3</td><td>2.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td rowspan="4">variability</td><td rowspan="2">time</td><td>$V_t(P)$</td><td>1.3</td><td>1.7</td><td>2.0</td><td>1.0</td></tr>
<tr><td>$V_t(T)$</td><td>2.3</td><td>2.0</td><td>2.0</td><td>1.7</td></tr>
<tr><td rowspan="2">space</td><td>$V_s(P)$</td><td>n/a</td><td>1.3</td><td>1.0</td><td>0.3</td></tr>
<tr><td>$V_s(T)$</td><td>n/a</td><td>2.0</td><td>1.0</td><td>1.0</td></tr>
<tr><td rowspan="4">extreme variability</td><td rowspan="2">time</td><td>$Vx_t(P)$</td><td>1.0</td><td>1.0</td><td>1.0</td><td>0.0</td></tr>
<tr><td>$Vx_t(T)$</td><td>2.0</td><td>1.3</td><td>1.0</td><td>1.0</td></tr>
<tr><td rowspan="2">space</td><td>$Vx_s(P)$</td><td>n/a</td><td>1.0</td><td>1.0</td><td>0.0</td></tr>
<tr><td>$Vx_s(T)$</td><td>n/a</td><td>1.0</td><td>1.0</td><td>1.0</td></tr>
</table>

Tab. 1: Evaluation of the *regional climate predictability* (0 is the "worst" and 3 is the "best" grade).

In the second main step, the hydrological usefulness of the projections has been scrutinized for different hydrological processes and conditions, see Tab. 2 for a summary of this step.

	STAR	***WettReg***	***REMO***	***GCM***
hydrological processes				
mean seasonal catchment runoff	1.6	1.5	1.2	1.0
evapotranspiration	1.6	1.6	1.4	1.0
soil moisture dynamics and groundwater recharge	1.3	1.5	1.2	0.9
snow melt	1.3	1.3	1.2	0.9
hydrological conditions (regional status)				
moderate flooding conditions	1.0	1.3	1.2	0.6
extreme flooding conditions	0.5	1.0	1.2	0.3
low flow conditions	1.1	1.3	1.4	0.6

Tab. 2: Summary of the final *hydrological evaluations* (0 is the "worst" and 3 is the "best" grade, e.g., assigned with the following meaning: 0 = "fail", 1 = "modest", 2 = satisfactory, 3 = "good").

The results show that the hydrological evaluation of climate change projections yields rather different levels of adequateness, depending on the hydrological processes under study. A rather general conclusion is that impacts induced by processes governed by temperature conditions (e.g. evaporation, snow melt) can be assessed more reliably than the ones governed by precipitation features (e.g. runoff generation, floods). It became very clear that regional climate change scenarios derived from appropriate downscaling methods improves their suitability compared with direct use of GCM results. This means that direct use of GCM results for regional hydrological impact analysis cannot be recommended. However, even all the regional climate change scenario methods investigated are of rather limited value for extreme hydrological conditions.

4 Discussion

A stringent procedure has been developed to investigate the usability of CC projections for hydrological impact assessments. The author is confident that this principle procedure could be adapted for applications to other disciplines, such as ecology, or urban studies.

For the specific case study presented here, one could see that the analysed downscaling scenario techniques are of little value if hydrological extreme conditions are under question. This is – on the one hand – a rather uncomfortable if not undesirable conclusion, because many important issues of water management are linked to hydrological extremes and the assessment of water management options in a changed climate is of very high importance. On the other hand, this conclusion is not really surprising since the largest uncertainties in hydrology and hydrological modelling are always related to extreme (very rare) conditions, be it in the context of climate change or others.

The shown evaluation results in different levels of adequacy, depending on the hydrological process under study. In general, projections of hydrological conditions governed by temperature conditions (e.g. evaporation, snowmelt) are ‘more useful’ than the projections governed by precipitation characteristics (e.g. runoff generation, floods). All regional climate change scenario methods investigated are of rather limited value for extreme hydrological conditions. It becomes apparent that regional climate projections should only be used for hydrological impact analysis if the spatial-temporal dynamics of the governing hydrological processes can be represented.

5 Outlook

Studying hydrological impacts on climate change require careful consideration of the capabilities and limits of the modelling chain required in such studies. On the one hand, the tools to derive the regional climate projections have a limited validity only, but the validity makes them usable for some typical impacts related to warming (and less to precipitation differences). Such studies have been presented, e.g. by Hattermann et al (2007) for the evaporation over Germany and by Tecklenburg et al. (2012) for snow and ice melt conditions in high mountain areas of the Eastern Alps. Hydrological extremes, in particular floods are – by their nature – subject of high variability in time and space and of high measurement and modelling uncertainty, as demonstrated by Huang et al (2013). That is why using the standard-type available regional CC projections as driving meteorological fields for the impact assessment referring hydrological extremes can be not much more than a sensitivity study and is of rather limited value for management decisions.

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Impacts World 2013, International Conference on Climate Change Effects,
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Comparing projections of future changes in runoff from hydrological and ecosystem models in ISI-MIP for the "aggressive mitigation" scenario RCP2.6, compared with the high-end scenario RCP8.5

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Abstract— Runoff projections from ISI-MIP (Inter-sectoral Impact Model Intercomparison Project) simulations forced by HadGEM2-ES bias corrected climate data for the Representative Concentration Pathways 2.6 and 8.5 have been analysed. Differences between runoff projections from models in the hydrological and ecosystems sectors were assessed for RCP2.6, as has been done previously for RCP8.5, to investigate whether these depend on future scenario. The ecosystem models tended to predict larger increases and smaller decreases in runoff than the hydrological models for RCP2.6, as was also found for RCP8.5, however this was less clear for the aggressive mitigation scenario. It was also found that the differences in spatial patterns between runoff projections with CO_2 varying and kept constant at 2000 concentrations were similar for the two future scenarios RCP2.6 and RCP8.5. Another difference found between the two scenarios was that for the same amount of increase in precipitation, there was less increase in runoff from RCP2.6 than had been found for RCP8.5 previously, suggesting that differences between the scenarios affected the influence of evapotranspiration. Overall, there is notable variation between impacts models even when forced with common climate data, for both low- and high-end scenarios.

Index Terms—ISI-MIP, multiple impact models, runoff

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1 Introduction

At the global scale, projections of future freshwater availability may be provided by different modelling approaches, potentially producing different results, even with common forcing data. For example, global hydrological models (GHMs), and land surface models (LSMs) showed considerable differences in simulating the present-day water balance (Haddeland et al., 2011), suggesting that impact model differences are a major source of uncertainty, and that both multiple climate models and multiple impact models need to be considered for impacts assessments.

The Inter-sectoral Impact Model Intercomparison Project (ISI-MIP) is a community-driven modelling effort to provide cross-sectoral global impact assessments (Warszawski et al., 2013) based on common climate and socio-economic scenarios using multiple impact models. Runoff projections were provided by both hydrological and ecosystem sector models.

Vegetation dynamics may alter the future runoff response by altering the energy and water fluxes. For example, models with vegetation change may enhance the advancement of the spring snowmelt peak seen in some basins (e.g. Falloon et al., 2006) more than models without, by surface warming from projected high latitude forest expansion (Falloon et al., 2012). On the other hand, projected Amazon forest cover loss reduces evaporation, with less marked seasonal differences (Falloon et al., 2012), so the impact on runoff may also be more even seasonally. However, these changes will not feedback to the climate in the stand-alone models.

Inter-model differences in runoff may arise from the inclusion of specific processes such as elevated CO_2 impacts on transpiration (Gedney et al., 2006; Betts et al., 2007). For instance, Hadelland et al. (2011), found large differences in response between the GHMs studied including CO_2 impacts on vegetation and those not including them (Hagemann et al., 2012).

Previously, we found notable differences between hydrological and ecosystems models' projections of regionally averaged runoff with the RCP 8.5 scenario. Hydrological models tended to give larger decreases and smaller increases in runoff than ecosystems models between 1981-2010 and 2070-2099 (Davie et al., 2013). There was variation regionally and temporally, with most regions showing model agreement on the direction of change. Western Africa, however, had low consensus with generally opposite directions of change projected by hydrological and ecosystems models. Looking into processes that may contribute to these differences, sensitivity experiments were investigated. The impact of varying CO_2 on runoff projections was inconsistent across the ecosystems sector models, probably due to differing strengths of processes whereby CO_2 enhances and reduces evapotranspiration between the models. Based only on sensitivity runs for the ecosystem model JULES, the effects of vegetation distribution on runoff change varied regionally, and were much smaller than projected changes over time. However, differences between runs with varying and constant CO_2 were of similar magnitude to the change over time in some regions.

A limitation of the previous study was that it was based on a high-end future emissions scenario (RCP 8.5) and model differences may vary between scenarios. Therefore, this paper aims to assess differences between impact models based on the future scenario RCP2.6, spatially and through regional and global averages, and to consider how this compares with RCP8.5.

2 Methodology

We have analysed available monthly runoff data from a range of impacts model runs from ISI-MIP (Warszawski et al., 2013), covering the ecosystems and hydrology sectors (Table 1), forced by bias-corrected HadGEM2-ES climate data (Hempel et al., 2013). We considered two future scenarios, RCP2.6 and RCP8.5, for all available models. The data was generally on a 0.5º x 0.5 º grid, but a 1.25 º x 1.875 º grid for JULES and JeDi.

Table 1 - Impact models used and their references

Model Name	References
Hydrological models	
DBH	Tang et al. (2006, 2007)
VIC	Liang et al. (1994)
WBM	Vörösmarty et al. (1998)
MacPDM.09	Arnell (1999); Gosling et al. (2010)
MPI-HM	Hagemann and Gates (2003); Stack and Hagemann (2012)
WaterGAP	Alcamo et al. (2003); Döll et al. (2003, 2012); Flörke et al. (2013)
H08	Hanasaki et al. (2008a,b)
Ecosystem models	

LPJmL	Bondeau et al. (2007); Rost et al. (2008)
JULES	Clark et al. (2011); Best et al. (2011)
VISIT	Ito and Inatomi (2011)
JeDi	Pavlick et al. (2012)

We assessed the projected changes in runoff for RCP2.6 (rather than RCP8.5 as in Davie et al., 2013), by comparing 30-year historical (1981-2010) and future (2070-2099) regional averages over land Giorgi regions (Giorgi and Bi, 2005; Ruosteenoja, 2003) and average annual cycles over 10 year periods, 1981-1990 and 2081-2090.

The main simulations analysed in this study were ISI-MIP "minimal settings" simulations (Warszawski et al., 2013). A subset of ecosystems models carried out sensitivity experiments including varying CO_2 (as specified for the RCP scenario) or constant CO_2 (kept at the concentration of the year 2000) and dynamic or static vegetation distributions, which were used to investigate the importance of individual processes.

Scatter plots of regionally averaged precipitation change against regionally averaged runoff change for RCP2.6 were created with the minimal setting model runs, to compare ecosystem and hydrological model responses to precipitation change in different Giorgi regions, and with the sensitivity runs from the ecosystem model JULES, to investigate the effects of varying CO_2 or constant CO_2 and dynamic or static vegetation distribution. Plots of historical and future annual cycles of runoff and the change in annual cycles for four Giorgi regions (Amazonia, Western Africa, Southern Asia and Alaska and Western Canada) were also created for the minimal settings runs. These are equivalent to plots in Davie et al. (2013) for RCP8.5, so findings for the two scenarios may be compared directly. Maps of the relative difference in future average runoff between varying and constant CO_2 runs were made for both scenarios using each ecosystem model's simulations to look at whether there were different effects in the two types of experiment. Time series of 9-year running mean global average runoff were plotted for the ecosystem models runs with varying CO_2 and constant CO_2 under both RCP2.6 and RCP8.5 to compare the effect of CO_2 varying or being kept constant for different scenarios and individual models.

3 Results and Discussion

Figure 1 shows that the ecosystem models generally seem to have greater increases and smaller decreases in runoff between 1981-1990 and 2081-2090 than the hydrological models for RCP2.6, as was also found for RCP8.5 (Davie et al., 2013). However, for some regions this is not the case, as is seen in Figure 1h for Alaska and Western Canada; this may be related to differences in timing and projected advancement of the spring snowmelt peak. The patterns found are similar to those found for RCP8.5 in Davie et al. (2013), however the magnitudes of change over the year vary between the scenarios.

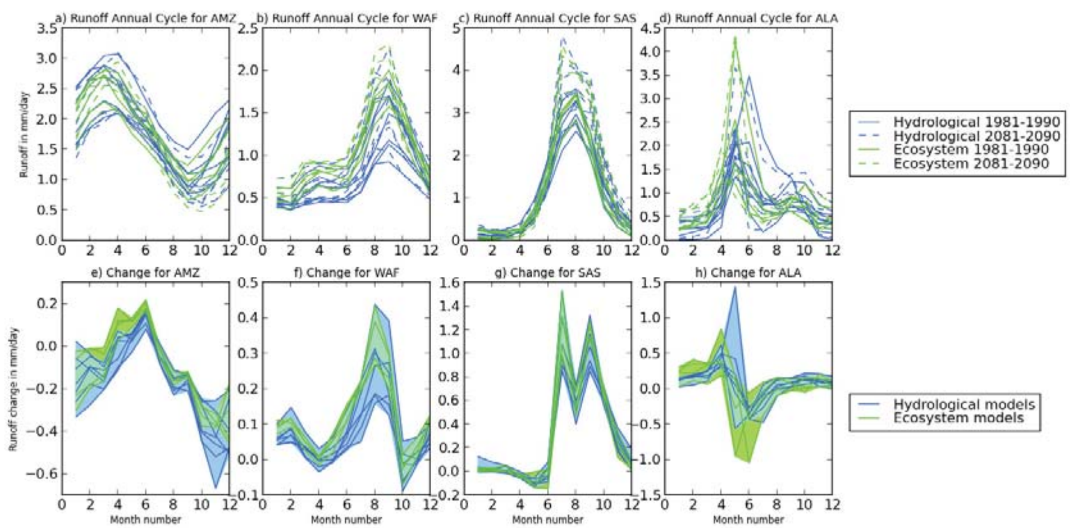

Figure 1 – (a-d) Historical , 1981-1990 (solid lines) and future, 2081-2090 (dashed lines) average annual cycles of runoff from ecosystem (green) and hydrological (blue) models. (e-h) Future minus historical runoff average annual cycle. Shading shows the range covered by the model types, with green showing the range of ecosystem models' projections and blue showing the range of hydrological models' projections when forced with HadGEM2-ES RCP2.6 climate.

For RCP2.6, there seems to be less difference between the hydrological and ecosystems models in runoff change projections than there was seen for RCP8.5 (Davie et al., 2013), with both model types predicting a similar range of change. This may be due to smaller changes in CO_2 concentration causing less effect on vegetation and therefore affecting the runoff response less in the ecosystems models, giving more similar projections to the hydrological models. Looking at the distribution of points around the 1:1 lines in Fig. 2, they appear mostly below the line for RCP2.6. However, in a previous study (Davie et al., 2013), it was found that for RCP8.5, points were more evenly spread about the line. This suggests that for the same amount of increase in precipitation, typically less increase in runoff is projected for RCP2.6 than for RCP8.5.

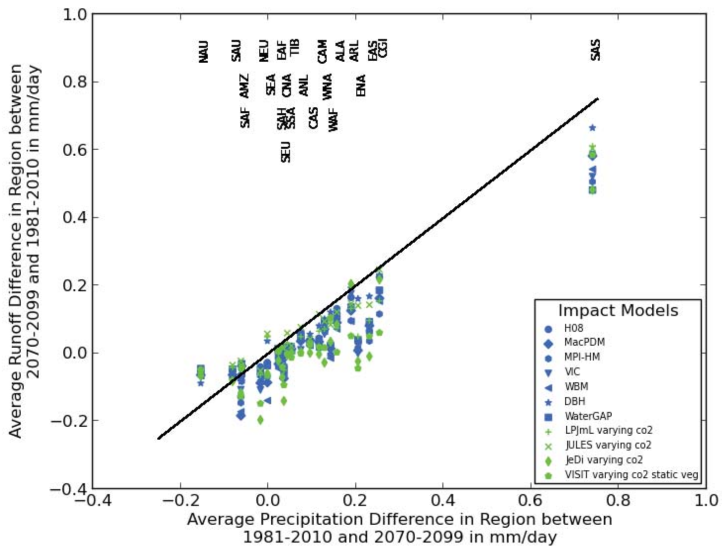

Figure 2 - Scatter plot of projected precipitation change versus projected runoff change under the HadGEM2-ES RCP2.6 scenario between 1981-2010 and 2070-2099 averages for land Giorgi regions. Black points – hydrological models, blue points – ecosystems models.

In Fig. 3, JULES shows some contrast between varying and constant CO_2 for RCP2.6, but these were smaller magnitude differences than were seen in Davie et al. (2013) for RCP8.5. The effect of a dynamic vegetation distribution differs regionally as would be expected due to heterogeneity in the vegetation changes projected, with some regions projected to have increased runoff if it is allowed to vary rather than remain static and some decreased. Annual evaporation is generally higher in forested catchments compared to non-forested catchments (Zhang et al., 2001); similarly evaporation may generally be greater under shrub vegetation compared to grasses (depending on the composition). Therefore, all other factors being equal, a change in vegetation type from tree to shrub, or grass would generally be expected to increase runoff, and vice versa.

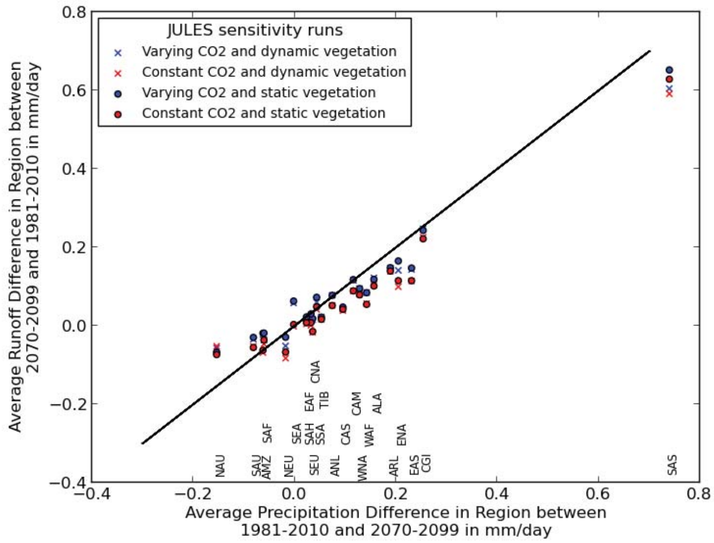

Figure 3 - Scatter plot of projected precipitation change against projected runoff change for land Giorgi regions from JULES sensitivity runs for HadGEM2-ES RCP2.6

The effect that varying CO_2, rather than keeping CO_2 constant, has on projections of runoff for RCP 2.6 is inconsistent in direction between models (Figs. 4 and 5), which was also found for RCP8.5 (Davie et al., 2013). This inconsistency is probably due to differing treatment of CO_2 in the impact models. Increased CO_2 is considered to cause both increases and decreases in evapotranspiration which will then affect runoff. CO_2 fertilisation of photosynthesis may increase plant productivity and leaf area index, increasing possible canopy evaporation (Betts et al., 2007; Alo and Wang, 2008), which would decrease runoff. CO_2 may reduce stomatal conductance at the leaf-level, inhibiting evapotranspiration and increasing runoff (Gedney et al., 2006; Betts et al., 2007; Cao et al., 2010). The relative size of these two opposing effects may vary (Alkama et al., 2010), particularly regionally and seasonally. For each ecosystem model, Fig. 4 shows that the relative difference in runoff between runs with CO_2 varying or constant for each ecosystem model remains broadly similar spatially for the two scenarios, as suggested by Tang and Lettenmaier (2012), while both Fig.4 and Fig. 5 show larger magnitude differences between varying and constant CO_2 model runs' global average runoff projections for RCP8.5 than for RCP2.6.

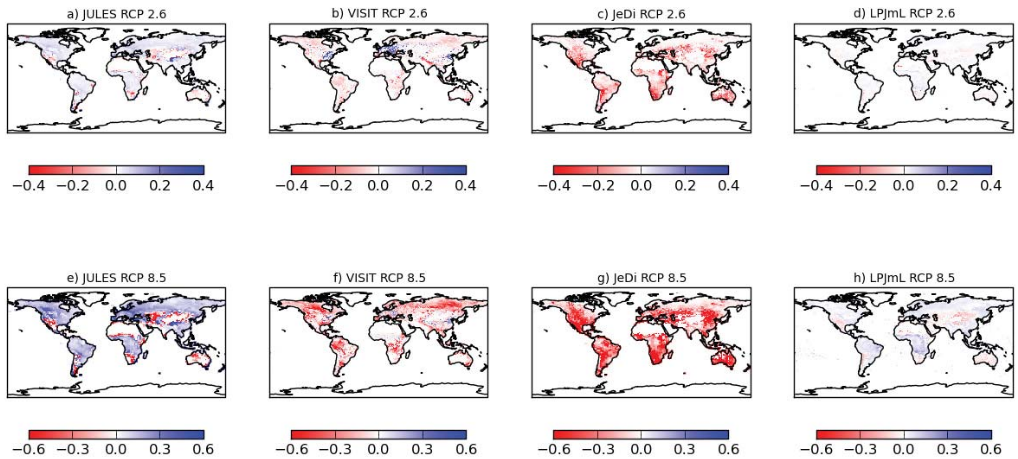

Figure 4a-h - Spatial patterns of relative difference between runoff from varying and constant CO2 runs for RCP 2.6 (a-d) and RCP 8.5 (e-h) future scenarios ((varying CO2 mean runoff minus constant CO2 mean runoff)/varying CO2 mean runoff)

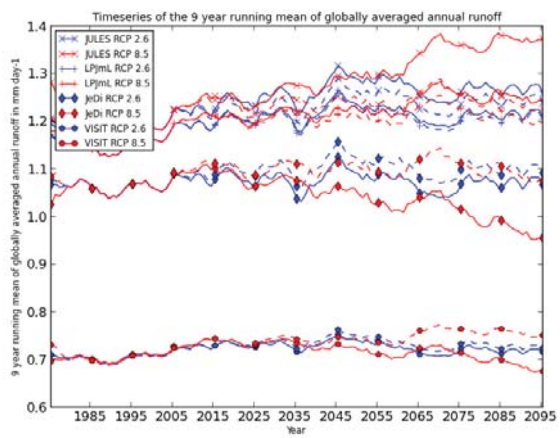

Figure 5 - Time series of 9-year running mean global average runoff in mm/day (solid lines for model runs with varying CO2 and dashed lines for model runs with constant CO2)

4 Conclusions

Ecosystems and hydrological models give differing runoff projections using the RCP2.6 scenario, with the ecosystem models tending to project larger increases and smaller decreases than the hydrological models. However, these regional averages over land Giorgi regions seem to show less difference between the model categories than for RCP8.5. There is inconsistency between the ecosystem models as to the direction of change on runoff change that CO_2 varying will have compared to remaining constant, although spatial patterns of the relative influence of CO_2 for each scenario are similar when each ecosystem model is looked at separately. In general, from the impact models considered, RCP2.6 projects less increased regionally averaged runoff for the same regionally averaged precipitation change than RCP8.5. This suggests that factors other than precipitation differences between RCP scenarios are important in affecting the runoff projections, which could include temperature and CO_2 concentration affecting evapotranspiration and soil moisture, and therefore runoff. Therefore, there appear to be differences between runoff projections from ecosystem and hydrological models for RCP2.6, which is in common with previous results for RCP8.5; however these seem to be of a smaller magnitude for RCP2.6.

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Constraints to Climate Change Adaptation and Food Security in West Africa: the Case of Nigeria, Sierra Leone and Liberia

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Abstract

The study ascertained constraints to Climate Change adaptation and food security in Nigeria, Sierra Leone and Liberia. Data for the study were collected randomly from a total of 1,424 respondents using both qualitative and quantitative techniques and analyzed using percentage, and mean score. The results showed that respondents in Nigeria sourced useful information on Climate Change and food security issues through radio, while respondents from Sierra Leone got useful information on Climate Change and food security from government researchers and Ministries of Agriculture staff. With regards to available public extension activities on Climate Change and food security, few (26.2%) respondents in Nigeria noted that there were available public extension activities on Climate Change and food security. In Sierra Leone and Liberia only 2.2% and 14.3% of respondents affirmed that there were public extension activities on Climate Change and food security issues. Major factors that constrain farmers' ability to adapt to the changing climate in the three countries include poor/low extension services, poor access to information relevant to adaptation, absence of government policy among others. The study concludes that since similar problems are encountered by respondents across the three countries in the effort to adapt to the changes brought by variations in the climate, there is need for the governments to work collaboratively with key stakeholders so as to ensure the future of their citizens.

Key words: Adaptation, Climate Change, Constraints, West Africa

1.0 Introduction

Climatic variability and change are major threats to food security in many regions of the developing world (Archer, 2003), which are largely dependent on rain-fed and labour intensive agricultural production because of the limited amount and uneven distribution of rainfall. Climate Change variability impact on food security, health and disaster management forms a complex labyrinth of network that has strong correlation with socio-economic growth and development. For instance, it has long been acknowledged that the health status of the population of any place or country influences development as poor individual health can lower work capacity and productivity; this impact can severely restrict the growth of economies (Philips and Verhasselt, 1994). In aggregate, this increases expenditure and lowers work capacity of poorer communities, which further complicates local economic growth (Morlai, Mansaray and Vandy, 2010).

In many African countries, food security at both the national and household level is a dismal. Africa has the highest prevalence of undernourishment. In 2004, whereas 14% of the global population was undernourished, 27.4% of the population in Africa as a whole was undernourished (Babatunde, Omotesho and Shotolan, 2007). In some countries, the rate of undernourishment is above 40% while it exceeds 50% in those countries experiencing or emerging from armed conflict (Todd, 2004). In West African sub-region, Liberia and Sierra Leone are among those with the highest rate of undernourishment in the continent with 1.4 and 2.3 million undernourished people respectively in 2002 (Babatunde *et. al.,*2007). In Nigeria, the most populous country in Africa, the majority of households are food insecure, especially the rural farming households.

These perceived situations are brought to by constraints experienced due to the changing climate. The constraint being experienced not only limits income generation capacity of farmers but also predispose them to food insecurity as their production rarely meets their consumption needs. Considering the constraints farmers experience in adapting to the effects of Climate Change variability in the West African sub region, this research was set out to provide answers to the following questions: what are the available sources of information on Climate Change variability issues? Are there available extension activities on Climate Change variability and food security issues in these countries? What is the food security situation in the West African sub region? More importantly, what are the constraints experienced by farmers in adapting to the effects of Climate Change variability in the region?

The study specifically sought to achieve the following objectives:

i. ascertain quality sources of information on Climate Change variability adaptation;
ii. identify available extension activities on Climate Change variability and food security issues;
iii. ascertain perceived food security situation in the region; and
iv. ascertain constraints to Climate Change variability adaptation in the region.

2.0 Methodology

Data for the study were collected from a total of 1,424 respondents using both qualitative and quantitative techniques in three West African countries. Respondents for this study were selected through multistage sampling technique. In the first stage, thirteen states were selected from the seven agro-ecological zones in Nigeria; in Sierra Leone, six districts were selected from the four agro-climatic regions, while seven counties were selected from the four agro-climatic regions, in Liberia.

In the second stage, using the delineation by the different states' Agricultural Development Programmes (ADPs), in Nigeria, two agricultural zones were randomly selected from each state giving a total of 26 agricultural zones in Nigeria. From each of the selected zones, 25 farming households were randomly selected for interview. This gave a total of 650 framing households from Nigeria. In Sierra Leone, a sample size of 70 farming households were randomly selected from each of the six districts giving a total of 420 households; while in Liberia 60 farming households were randomly selected from each of the counties surveyed, giving a total of 420 farming households.

In all, a total of 1,490 farming households were interviewed through a combination of strategies that took cognizance of social components of indigenous knowledge and practices. However, 1,424 (624 from Nigeria); (400 from Sierra Leone) and (400 from Liberia) completely filled copies of interview schedule were used for analysis.

To ascertain useful sources of information on Climate Change and food security issues, respondents were asked to indicate useful sources through which they receive information on a 5 point Likert – type scale. To identify available extension activities on Climate Change and food security, respondents' were provided with a list of options on extension activities and were asked to tick available extension activities. To elicit information on food security issues as they affect the respondents, they were asked to show the frequency at which they had difficulties in meeting food needs of their households and the number of times they fed in a day by ticking the correct options as provided.

To ascertain problems encountered by the farmers in adapting to the effects of Climate Change, respondents indicated the extent to which variables like lack of information, low awareness level, low institutional capacity etc., acted as constraints to Climate Change adaptation. A three point Likert –type scaled 3 to 1 was used to ascertain the level of seriousness of the different constraints listed. Data gathered were summarized using percentage, mean score and standard deviation.

3.0 Results and Discussion

3.1 Useful sources of information on Climate Change, food security issues and innovations

The mean score on useful sources of information by respondents from Nigeria showed that they perceived information sourced from other farmers (M =3.08) and radio (M=3.02) as useful. In Sierra Leone, respondents reported that they sourced useful information from Ministries of Agriculture (M =4.02), government researchers (M =3.38), radio (3.44) and television (M =3.06). However, respondents from Liberia did not indicate any of these sources as useful sources of information on Climate Change and food security issues. The standard deviations of the mean scores in most cases were all greater than or equal to 1.0, showing that the respondents' individual scores in respect to useful sources of information on Climate Change vary much from the mean, hence indicating high level of variation in their responses.

It is evident that many farmers' regarded the mass media as useful sources of information on Climate Change. This could be due to the presence of interactions aided by phone-in programmes during live broadcast as observed in Nigeria. Therefore, it can be inferred that efforts should be geared towards using the mass media in promoting information on Climate Change and food security issues across the West African sub region.

Table 1: Useful sources of information on Climate Change and food security issues

Sources of information	Nigeria		Sierra Leone		Liberia	
	Mean	SD	Mean	SD	Mean	SD
Radio	3.02*	0.95	3.44*	1.31	2.66	1.28
Television	2.74	1.10	3.06*	1.12	1.49	1.05
Other Farmers	3.08*	1.17	2.84	0.92	2.10	1.13
Meetings / seminars / trade fairs	2.98	1.34	2.76	1.30	1.83	1.14
Extension Officers	2.44	1.45	2.64	0.81	1.68	0.92
Government Researchers	2.43	1.39	3.38*	1.77	1.50	0.81
Input suppliers e.g. seed, fertilizer companies	2.71	1.34	1.00	0.00	1.40	0.58
University	2.74	1.52	1.00	0.00	1.59	0.83
Internet	2.44	1.43	1.00	0.00	1.36	0.81
Ministries of Agriculture	2.63	1.42	4.20*	1.88	1.70	0.92
Ministries of Environment	2.45	1.47	1.00	0.00	1.78	0.93

*Mean ≥ 3.0

3.2 Available extension activities on Climate Change and food security issues

Fig. 1 shows that 22.6% of the respondents in Nigeria reported the availability of extension activities on Climate Change variability through the use of demonstration/training. About 25% of the respondents asserted that there were advisory services on how to manage the farm in order to reduce the effect of Climate Change variability in Nigeria; while 26.2% of them reported that there were awareness creation events on the effects/consequences of Climate Change variability by extension agencies.

In Sierra Leone and Liberia, only 2.2% and 14.3% of the respondents respectively noted that there were extension activities with regard to visiting sites that were undergoing changes due to variations in climate. About 3% and 7% of the respondents from Sierra Leone and Liberia reported that there were awareness creation events on the effects of Climate Change variability through extension activities. The results, generally, revealed low activities of extension agencies with regard to issues of Climate Change variability and food security in the three countries. However, there seem to be more extension activities on these issues in Nigeria than in Sierra Leone and Liberia. This makes it imperative that extension service delivery rework ways of information dissemination by using modern means to get across to their clientele.

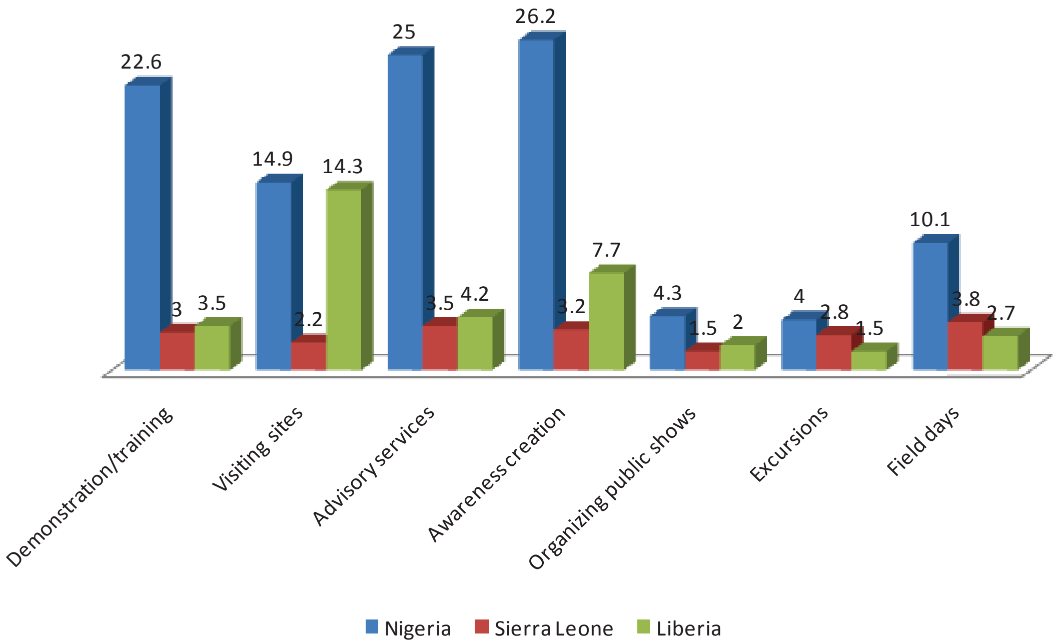

Fig. 1: Respondents' reported extension activities on Climate Change and food security issues in the three countries

3.3 Respondents' perception of household food security issues

3.3.1 Problems of satisfying household food needs

Fig. 2 shows that, about 20% of households in Nigeria perceived seldom problems in satisfying family food needs; in Sierra Leone and Liberia respectively, 20% and 27% of the rural households noted that they perceived problems seldomly in meeting family food needs. Also, 32.3%, 34.5% and 28% of respondents in Nigeria, Sierra Leone and Liberia respectively, noted that they sometimes have difficulties in satisfying family food needs. About 13% of households in Nigeria, 16.2% in Sierra Leone and 18.1% in Liberia noted that they often had problems satisfying their household food needs. As evident from Fig. 2, 29% of households in Sierra Leone noted that they always had problems in meeting household food needs, whereas only 7.2% and 1.9% of households in Nigeria and Liberia respectively noted they always had problems satisfying household food needs. It can be inferred from the above findings, that rural households across the three countries still have difficulties in meeting their food needs. FAO (2000) earlier reported that food insecurity is among developmental problems facing developing countries like Nigeria.

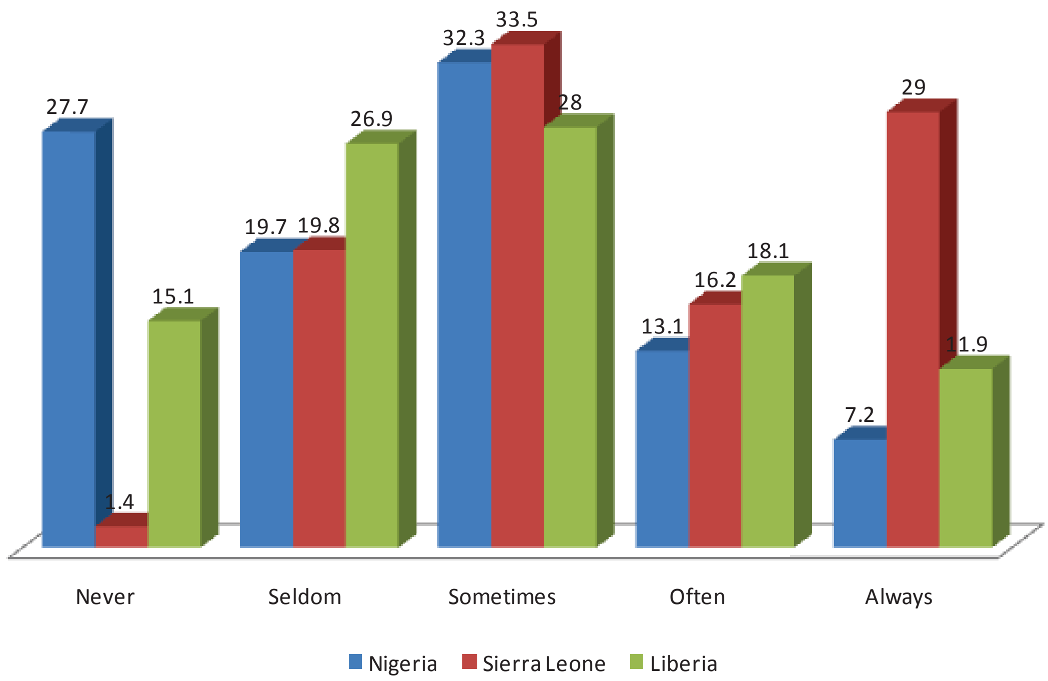

Fig. 2: Percentage distribution of rural households by their perceived abilities to satisfy family food needs in Nigeria, Sierra Leone and Liberia

3.3.2 Number of times household feed in a day

Fig. 3, shows that majority (75.8%) of the respondents in Nigeria fed at least three times per day, in Sierra Leone more of the rural households (67.2%) noted that they fed twice per day; while respondents in Liberia noted that they fed once (40.0%) and twice (50.6%) per day. This shows that on the average, the rural respondents in the three countries were not feeding adequately on daily basis; indicating that they were feeding majorly for survival. This finding is also in line with the work of Idachaba (2004) who noted that many households and individuals in Nigeria merely ate for survival. The situation in Liberia could be attributed to the just ended war, which had a devastating effect on all sector of their economy, particularly, agriculture.

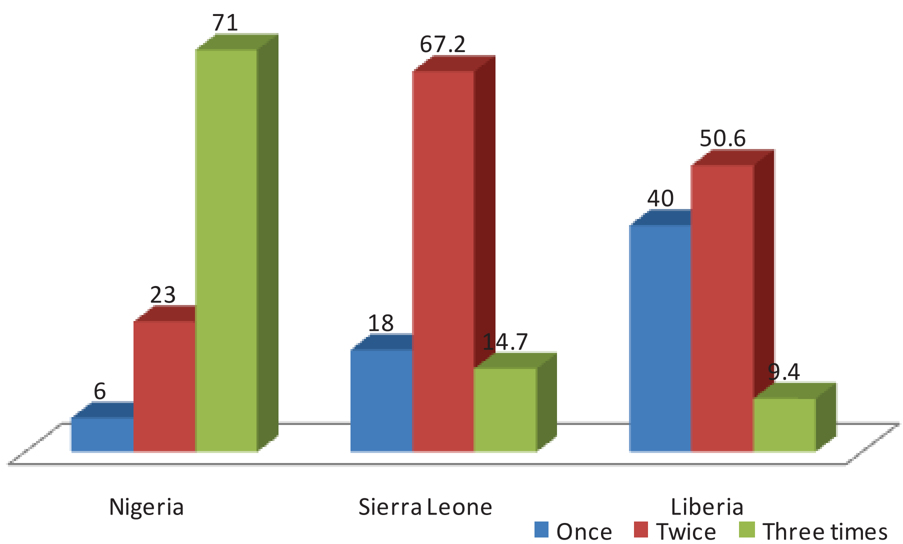

Fig. 3: Distribution of rural households by number of times eaten per day

3.4 Respondents' perception of current household food situations

From Fig. 4, it is evident that 21.4% respondents from Nigeria, 24.5% Sierra Leone and 25.9% Liberia perceived the current household food situations as a little worse than what it was previously. About 28% of respondents from Nigeria noted that the situation has remained the same, while 31.8% of rural households from Sierra Leone and 18.5% from Liberia noted also that the situation has not changed. Only 23.5% of rural households from Nigeria perceived their current food situation to have been improved a little. Respondents from Sierra Leone and Liberia (33.8% and 21.2%) respectively, noted that there has also been a little improvement on their current food situation over time. This means that on an average note, there have not been major changes in their current food situations. In order to beef up food security issues and self sufficiency in terms of food production in these countries, there is need to invest more in agricultural production so that the teeming populations food needs can be met appropriately.

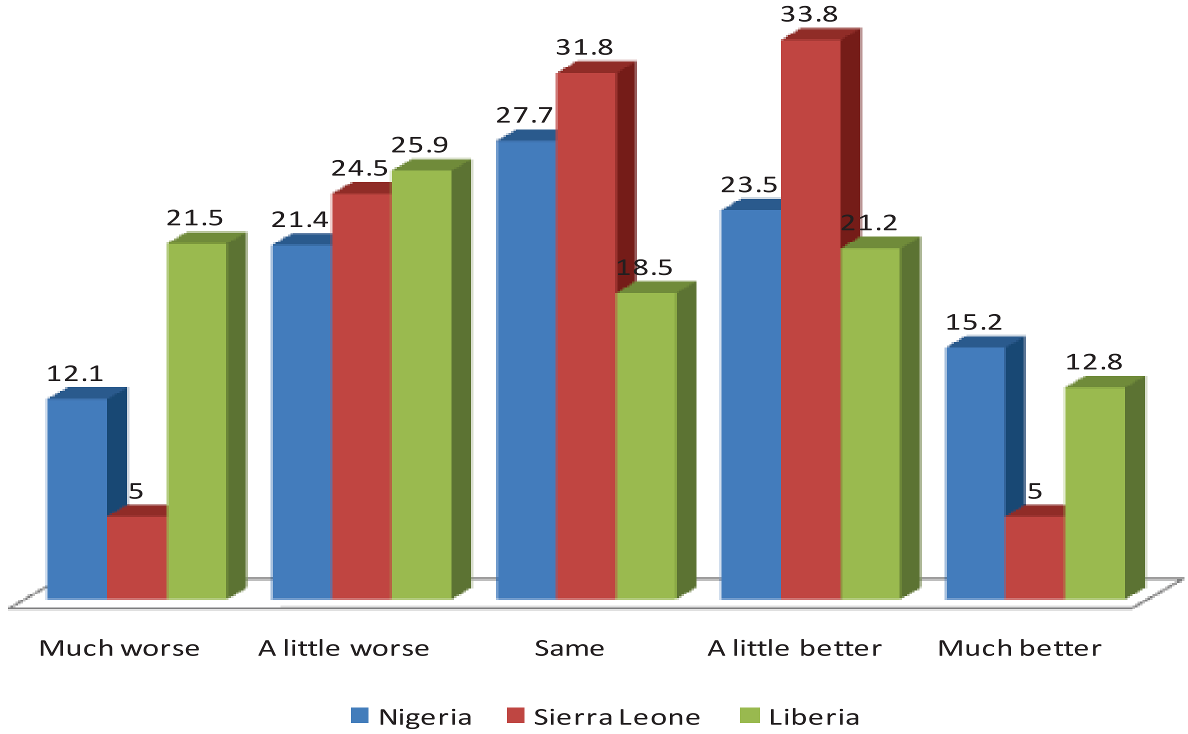

Fig. 4: Distribution of respondents by perceived current household food situation in Nigeria, Sierra Leone and Liberia

3.5 Problems encountered by farmers in adapting to the effects of Climate Change variability

Entries in Table 2 show that the three countries under study encountered similar problems in their efforts to adapt to the negative effects of climate change variability. The constraints experienced in Nigeria, Sierra Leone and Liberia respectively included: poor access to information relevant to adaptation (M = 2.60, 2.88 and 2.77), lack of financial resources (M = 2.50, 2.87 and 2.62), poor/low extension services (M = 2.48, 2.78 and 2.58) and lack of access to weather forecasts (M = 2.04, 2.67 and 2.51). On the issue of financial constraints, Adger *et al* (2007) reported that adaptation to Climate Change variability at local, individual and community levels could be constrained by lack of adequate financial resources. Another study in Nigeria (Egbule, 2010), noted that irregularities of extension activities/services was perceived as a constraint to Climate Change adaptation. The problems imposed by information lack and poor extension services in the three countries point to the fact that there could be limited extension activities on Climate Change adaptation in the three countries. There is need therefore to have an enduring system through which information can be disseminated, as information exists currently at the global levels on measures of adapting to the changing climate.

Other problems encountered in the three countries respectively, were: high cost of improved crop varieties (M =2.42, 2.77 and 2.08), absence of governments policy on Climate Change (M =2.35, 2.66 and 2.35), non availability of credit facilities (M =2.49, 2.30 and 2.38), limited knowledge on adaptation measures (M =2.28, 2.64 and 2.52) and poor response to crises related to Climate Change by the governments agencies and interest groups (M =2.36, 2.52 and 2.26). Findings on absence of governments policies corroborates the work of Ngigi (2009) who affirmed that lack of government policies on adaptation has remained a serious limitation to effective Climate Change adaptation in developing countries and this has limited the availability of infrastructure needed to enhance adaptation.

Further problems included: non availability of processing facilities (M =2.17, 2.03 and 2.00), inadequate knowledge on how to cope adequately (M =2.21, 2.50 and 2.22) and high cost of farm labour (M =2.38, 2.17 and 2.04). The standard deviations of the mean scores were all less than 1.0. This shows that all the respondents' individual scores in respect of problems encountered in adapting to the effects of Climate Change variability did not vary much from the mean. These findings reveal some level of disconnect among the major stakeholders across the three countries under study. The findings also show that the respondents have very limited knowledge on effective adaptation measures to combat the negative challenges of Climate Change variability. This means that more efforts should be channeled by the governments to put in place appropriate policies on Climate Change. Again, research should build up more adaptation measures so that farmers can be exposed to a variety of options on adaptation as best suits their environment.

Table 2: Mean scores on problems encountered by farmers in adapting to the effects of Climate Change

Problems encountered in adapting to the effects of Climate Change	Nigeria		Sierra Leone		Liberia	
	Mean	SD	Mean	SD	Mean	SD
Poor access to information source relevant to adaptation	2.60*	0.60	2.88*	0.36	2.77*	0.45
Type of land tenure system practiced in my area	2.00*	0.67	1.75	0.79	1.42	0.68
Ineffectiveness of indigenous strategies	1.98	0.76	2.52*	0.74	1.38	0.59
Lack of financial resources	2.50*	0.54	2.87*	0.37	2.62*	0.54
Poor/low extension services	2.48*	0.66	2.78*	0.48	2.58*	0.51
Lack of access to weather forecasts	2.04*	0.76	2.67*	0.57	2.51*	0.56
Limited access to improved crop varieties	2.24*	0.65	1.87	0.83	2.18*	0.74
Lack of access to improved livestock breeds	2.23*	0.79	2.23*	0.80	1.99	0.87
High cost of improved crop varieties	2.42*	0.58	2.77	0.47	2.08*	0.72
Non-availability of storage facilities	2.01*	0.74	1.97	0.85	1.93	0.85
Absence of government policy on adaptation	2.35*	0.62	2.66*	0.59	2.35*	0.58
Non-availability of credit facilities	2.49*	0.62	2.30*	0.78	2.38*	0.68
Limited knowledge on adaptation measures	2.28*	0.68	2.64*	0.67	2.52*	0.56
Poor response to crises related to Climate Change by the governments agencies and interest groups	2.36*	0.66	2.52*	0.72	2.26*	0.75
Risk of adaptation	1.95	0.71	2.49*	0.77	2.09*	0.57
High cost of fertilizers and other inputs	2.41*	0.58	2.75*	0.49	1.72	0.79
High cost of irrigation facilities	2.43*	0.65	2.73*	0.55	1.71	0.87
Non-availability of farm inputs	2.00*	0.76	1.95	0.85	1.80	0.62
Non-availability of processing facilities	2.17*	0.71	2.03*	0.86	2.00*	0.82
Inadequate knowledge of how to cope	2.21*	0.67	2.50*	0.72	2.22*	0.68
Non-availability of farm labour	2.01*	0.74	1.56	0.66	1.63	0.61
High cost of farm labour	2.38*	0.60	2.17*	0.74	2.04*	0.53

* Mean ≥ 2.0

4.0 Recommendations

The study concludes that there is need for relevant ministries (Agriculture, Environment, and Information) to embark on vigorous information dissemination on causes, effects and adaptation to Climate Change variability. This will expose to farmers the need to rework their farming practices along current research efforts in favour of Climate Change adaptation. Also, information on Climate Change variability and adaptation should be made accessible to farmers using various means. This will ensure better understanding, as farmers will have different alternatives to learn from. There is need to improve access to extension services for disseminating relevant information that can aid in avoiding the constraints experienced by farmers in adapting to the effects of Climate Change variability.

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ACKNOWLEDGMENTS

This report was produced as part of the implementation of the ATPS Phase Vl Strategic Plan, 2008-2012 funded ATPS Donors including the Ministerie van Buitenlandse Zaken (DGIS) the Netherlands, and the Rockefeller Foundation, amongst others. The authors hereby thank the ATPS for the financial and technical support during the implementation of the program.

Pollen forecasting, climate change & public health

Bernd Eggen, Sotiris Vardoulakis, Debbie Hemming, Yolanda Clewlow

Abstract— Pollen and fungal spores exacerbate allergic (e.g. hay fever) and respiratory (e.g. asthma) conditions, affecting hundreds of millions of people worldwide. Climate change is likely to alter the distribution and timing of these health impacts, possibly increasing the public health burden. A number of national weather services offer pollen forecasts, which are commonly derived from pollen measurements and dispersion models. In the UK, the Met Office manages the only UK-wide pollen measurement network. Automated pollen measurements are expensive and manual measurements (e.g. with Burkard traps) time consuming, and pollen counts alone may not give an accurate indication of health risks for sufferers, as many compounding factors including pollen potency can vary widely. New approaches are emerging to address these technical and scientific challenges, and to improve the modelling of pollen/spore development and dispersion as well as their integration into numerical weather and climate models. These improvements would fill important gaps in current understanding and improve the utility of pollen forecasts for public health practitioners, particularly allergy experts.

Index Terms—allergies, bioaerosols, climate, dispersion, human health, pollen

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1 Introduction

Pollen and fungal spores (collectively referred to as 'aeroallergens') exacerbate allergic (e.g. hay fever = allergic rhinitis) and respiratory (e.g. asthma) conditions, affecting hundreds of millions of people worldwide (Bousquet et al., 2008). In the UK, approximately 20% of the population suffer from hay fever - around 95% of hay fever sufferers are allergic to grass pollen and 25% to tree pollen. There are approximately 150 species of grass in the UK, 12 of which are important with respect to atmospheric pollen load (Emberlin et al., 1999).

The dynamics of pollen production and dispersal involve complex processes that are challenging to model and forecast. These processes are influenced by multiple environmental factors including meteorology over time-scales of hours to years, plant biology, atmospheric dispersion conditions and anthropomorphic effects such as land-use. Furthermore, the impacts of pollen on human health and societies involve further complex interactions relating human exposure, physiological susceptibility and societal dynamics. Gaps in current knowledge of these complex systems mean forecasts of the impacts of pollen on human health are, at best, rudimentary with considerable uncertainties.

Climate change is likely to alter the timing of the pollen season (e.g. for hazel, alder and birch)and distribution of certain plant species, such as ambrosia (Vardoulakis and Heaviside, 2012) which may influence the public health burden associated with hay fever (i.e. allergic rhinitis) and asthma. Longer and earlier pollen seasons have been observed, e.g. in the US since 1995 a significant increase has been noted in the length of the ragweed pollen season by as much as 27 days at latitudes above 44°N (Ziska et al., 2011), in southern Germany the grass pollen season (May-August) started approx 20 days earlier in 2010 compared with 1988 and ended approx 4 days later, lengthening the time sufferers were affected by nearly 1 month; a similar trend has been observed in the UK over the last decade (Kennedy and Smith, 2012). The Health Effects of Climate Change in the UK report (Vardoulakis and Heaviside, 2012) also states that:
- Climate change may result in earlier seasonal appearance of respiratory symptoms and longer duration of exposure to aeroallergens.
- The effects of climate change on plant distribution through range shifts and invasions can expose the population to pollen from more plants with different flowering seasons.
- Variations in the potency of allergen carriers (e.g. the amount of allergen per pollen grain) might make it difficult

to correlate symptoms and effectiveness of treatment with pollen or fungal spore counts. The problem of variations in potency might be overcome by monitoring atmospheric concentrations of allergens instead of pollen grains or fungal spore counts.

2 Pollen Measurements and Forecasts

A number of national weather services offer pollen forecasts, which are commonly derived from pollen measurements, basic models of plant pollen phenology, and dispersion models, such as the NAME (Numerical Atmospheric-dispersion Modelling Environment) model from the UK Met Office (Jones et al., 2007). Typically the dispersion models are Lagrangian particle models which calculate dispersion by tracking model particles through the atmosphere. These particles move with the resolved wind described by the meteorology, which varies in space and time. Recently, basic pollen development and emission modules, which predict the onset and duration of flowering, as well as emitted pollen concentrations as a function of meteorological variables (temperature, humidity, precipitation, and wind speed), have been integrated with numerical weather and particle dispersion models (e.g. Sofiev et al., 2013, Helbig et al., 2004). This has enabled pollen forecasts to be provided in association with weather (NWP: Numerical Weather Prediction), or atmospheric chemistry (CTM: Chemical Transport) models. Such pollen forecasts are not yet available for regional (nor global) climate models.

At the continental and national scale, a number of national weather services and academic institutes produce pollen forecasts which are commonly derived from pollen measurements, plant vegetation models, atmospheric dispersion models, and expert judgement. In Europe, many national pollen monitoring networks contribute their pollen count data to the European Aeroallergen Network (EAN) Pollen database (see https://ean.polleninfo.eu/Ean/). The EAN is part of the World Allergy Organisation's World Pollen Network (see http://www.worldallergy.org/pollen) which collates links to data, information and guidance resources focussed on pollen allergies worldwide.

In the UK, the Met Office manages the only pollen monitoring network, and in collaboration with the National Pollen and Aerobiological Unit at the University of Worcester and PollenUK, produces UK-wide pollen forecasts for up to five days ahead (see: http://www.metoffice.gov.uk/health/public/pollen-forecast). These forecasts are designed to help support allergy and hay fever sufferers through the most difficult time of the year.

As with the majority of European pollen monitoring sites, the UK network uses the Burkard Seven-Day Recording Volumetric Spore Trap (Fig. 1) (Hirst, 1952) to collect pollen from the air on an adhesive coated transparent plastic tape. Each day's tape stretch is transferred to a slide and placed under a microscope for counting, providing a measure of grains per cubic metre per 24 hours. Up to twelve different pollen types are counted (normally only 3-4 pollen types, of significance to allergy, are present in the air at any time period due to different flowering seasons of plant species). Counts are performed daily during the grass season and weekly during the tree and weed seasons.

Fig. 1: A Burkard 7-day recording volumetric spore trap

The majority of current methods for monitoring pollen, such as using the Burkard trap, are very time consuming, relying on manual counts of pollen and spore grains under a microscope. To try to improve this, various systems for automated pollen measurements (e.g. with Hund pollen monitoring system BAA500) have recently been developed and/or are currently under development. However, so far these have proved prohibitively expensive for widespread use in existing pollen monitoring networks. Some new developments of hand-held pollen counting devices should reach operational status soon.

UK pollen forecasts are provided as part of the public weather service, they give an estimate of the likelihood that the count for the ensemble of monitored species, will be within certain concentration levels. The forecasted levels (low, moderate, high, or very high) are derived using observed pollen counts, meteorological information, expert judgement from allergy specialists and local and seasonal information relevant to the typical pollen calendar (Fig. 2) for plant species that are considered a possible allergenic risk (see section 3, below). For example, for grass pollen, the number of grains per cubic metre of air corresponding to each level are: low 0-39; moderate 30-49; high 50-149; and very high > 150. As well as providing an information service on pollen allergy risk for the general public, national health experts and suppliers of allergy medicine use the pollen forecast to help understand and plan for increases in demand for allergy medication and treatment.

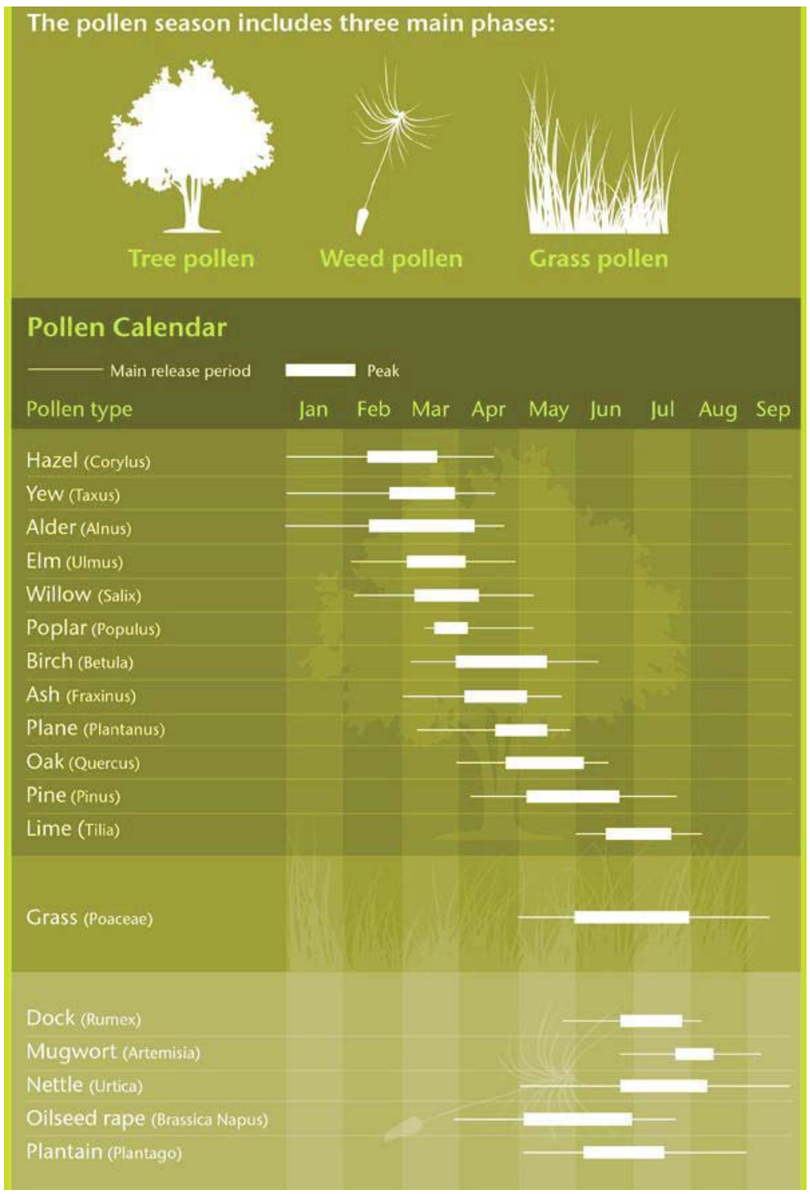

Fig 2: The UK pollen calendar (Source: Met Office)

In Europe, a recent project entitled 'Evaluating and Forecasting of Atmospheric Concentrations of Allergenic Pollen in Europe' has made significant advances in forecasting European pollen distribution. Led by the Finnish Meteorological Institute (FMI), it produced an integrated modelling system for simulating and forecasting in time the pollen emissions and transport on a European scale (Siljamo et al., 2007).

Despite recent advances in pollen forecasting, there is a need for improved pollen models that include more detailed mechanistic understanding of the pollen development processes. Furthermore, to understand and forecast the distribution of pollen of key species at weather and climate timescales, these improved models need to be integrated (e.g. as with the FMI pollen forecast with pollen emission modules (Sofiev et al., 2013)) into NWP models, and extended to climate projection models. Through such improvements, operational pollen distribution models could provide greater accuracy and longer lead times in short- and medium-time pollen forecasting and better projections for future years and decades under climate change scenarios.

3 Human Health and Pollen

When pollen are inhaled by individuals with a sensitised immune system, the allergen triggers the production of the antibody immunoglobulin E (IgE), which binds to mast cells containing histamine. The release of inflammatory mediators such as histamine can cause sneezing, itchy and watery eyes, swelling and inflammation of the nasal passages, and an increase in mucus production. Sufferers can also become more sensitised as the season progresses such that they may react in a similar way to a low pollen count at the end of the pollen season as they did to a high count at the beginning of the pollen season. Some plant species which are known to trigger allergic reactions are displayed in Fig. 2 (normally only 3-4 pollen types, of significance to allergy, are present in the air at any time period due to different flowering seasons of plant species).

The European pollen diary is a long-term study that will significantly aid research into pollen and hay fever (see: https://www.pollendiary.com/Phd/) – this is an important Europe-wide study, where hay fever sufferers are recording their symptoms online through the European Aeroallergen Network (EAN) Patient's Hayfever Diary. Symptoms are documented and can be compared with concentrations of pollen in the air, to help identify which pollen individuals are allergic to, look back at pollen levels from previous seasons and read the latest pollen news.

Pollen counts alone are unlikely to give an accurate indication of health risks for allergy or asthma sufferers, as pollen potency can vary widely. Hay fever sufferers can become sensitised by other, less allergenic, pollen species in advance of the main pollen season, which may increase the severity of the allergic reaction. Exposure to air pollution may also increase airway responsiveness to aeroallergens (D'Amato et al., 2002).

The pollen forecast and pollen calendar (which shows when different types of plant pollen that cause allergic reactions are present in the environment) also involve expert judgement on, and provide information about, the specific allergenic pollen types in the area of interest. Pharmaceutical organisations often use these forecasts not only by displaying it on their website but also to predict demand and supply of medication, such as histamine antagonists (commonly known as antihistamines), which alleviate some of the hay fever symptoms.

Understanding the potential increase in the health burden in relation to allergy will help health organisations and clinicians to plan for the future. There are already significant costs to the economy relating to allergic rhinitis in loss of productivity and days off work. Understanding how this financial burden may increase in the future is another area of potential interest.

4 Summary of Key Science and Technology Gaps

To help fill major gaps in understanding in this area new scientific evidence and technologies are emerging, including: 1) **Automated pollen monitoring** – manual pollen counting is a labour-intensive process which limits the number of monitoring sites, therefore the development of automatic pollen monitoring equipment will facilitate consistent monitoring and expansion of existing observation networks. 2) **Detailed land-use datasets** - pollen forecasting relies on knowledge of pollen release from specific species in conjunction with pollen measurements at a regional level; explicit use of detailed land-use datasets together with numerical dispersion model simulations would provide more spatially resolved pollen species forecasts. 3) **Integrated modelling of pollen production** - weather and climate forecasting models have land surface schemes that include algorithms for modelling vegetation responses, i.e. photosynthesis and respiration; by improving these schemes to include pollen responses, forecasts of pollen production could be fully integrated with weather/climate forecasts. 4) **Integration of pollen forecasting models with human health modelling** - linking pollen forecasts with understanding and modelling of the health impacts of pollen would provide an end-to-end forecasting system to support the management and understanding of pollen-related health conditions.

Through improvements in scientific understanding and technology, such as those described above, the end-to-end robustness of pollen forecasts, from monitoring of pollen development and its dispersion to human health implications, should be improved. This will lead to advancements in pollen forecasting and managing the related health impacts of pollen changes, both on operational timescales from days to seasons, and also on longer-term multi-decadal timescales of relevance for large-scale climate and land-use changes.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

What do we know about climate change and its impacts – conclusions from a comprehensive European-wide assessment

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Abstract — In November 2012 the European Environment Agency (EEA) published its third indicator-based report on climate change, impacts and vulnerability in Europe. This report presents more than 40 quantitative indicators on observed and projected climate change and its impacts, most of them with European-wide coverage. These indicators are also a major source of information for the European Climate Adaptation Platform (Climate-ADAPT). However, some important impact domains are not covered because information is not readily available at the European level, impacts are hard to quantify or to measure, and/or because the influence of climate change is hard to disentangle from socio-economic, technical, cultural and political developments. This paper summarizes the availability of consistent information on observed and projected climate change and its impacts across climate-sensitive sectors and systems in Europe and identifies major knowledge gaps. The paper argues that the improvement of indicators and assessments is not simply a question of increasing monitoring and data collection, but also a task of deepening the theoretical and practical understanding of underlying processes.

Index Terms — assessment, climate change impact, Europe, indicators, vulnerability.

1 Introduction

The European Environment Agency (EEA) is an agency of the European Union (EU) with the task of providing relevant, objective and up-to-date information on the environment to public decision-makers in Europe. So far the EEA has published three reports specifically devoted to climate change (EEA 2004; EEA 2008; EEA 2012a). These reports rely heavily on indicators, which EEA defines as *“a measure, generally quantitative, that can be used to illustrate and communicate complex environmental phenomena simply, including trends and progress over time – and thus helps provide insight into the state of the environment”* (EEA 2005). The EEA maintains an indicator management system (IMS) that presents indicators in a structured way on the EEA website. The selection of indicators to be included in the IMS is based on a review process, which applies eight selection criteria from four groups: relevance, method and process, coverage, and user friendliness (EEA 2012b).

The climate change reports provide numerous indicators on different aspects of climate change. Owing to the complexity of climate change and the inertia of the climate system, most indicators comprise quantitative data about observed changes and projections of future changes, together with information

[a] European Environment Agency (EEA)
[b] European Topic Centre for Climate Impacts, Vulnerability and Adaptation (ETC/CCA); Finnish Environment Institute (SYKE)

on key uncertainties.

The EEA climate change reports have attracted significant public attention, with tens of thousands of hits in internet search engines (Table 1). The number of Google hits of the 2012 report is remarkable in comparison with the previous reports, considering that the report had been available on the internet for just over three months at the time of the search. While this increase in Google hits is likely to be partly explained by the growth of the internet, it also shows that there is a strong demand for accessible information on climate change. In comparison, the reports are not very widely cited in the academic literature (Table 1). A detailed analysis of how the indicator reports are used in practice is beyond the scope of this paper. However, a rapid scan of the websites citing the reports suggests a great diversity, including government reports, popular journals and news items.

Table 1. References to the 2004, 2008 and 2012 EEA climate impacts reports on the internet (search 6 March 2013).

Search term	Google hits	Google scholar hits[1]
"Impacts of Europe's changing climate: An indicator-based assessment"	67 800	97
"Impacts of Europe's changing climate - 2008 indicator-based assessment"	41 300	117
"Climate change, impacts and vulnerability in Europe 2012"	96 900	6

All EEA indicators included in the 2012 climate change report are available online on the EEA website[2] and on the European Climate Adaptation Platform, Climate-ADAPT[3]. Climate-ADAPT is a web portal hosted jointly by the European Commission and the EEA that intends to support governmental organisations in developing adaptation strategies and plans. It includes among others an Adaptation Support Tool, country-specific information on national climate impact assessments and adaptation strategies, and a large database of adaptation case studies. Key impact maps for Europe are visualised in a map viewer that includes additional maps (e.g. from ClimWatAdapt, ESPON Climate and JRC-IES) compared to the more limited number of maps in the report. Climate impact researchers are invited to provide further impact maps, provided these are relevant for Europe and have undergone peer review. EEA will review and decide which maps to include, in close consultation with the researchers.

[1] Note that Google scholar reports a total of 275 citations for „Impacts of Europe's changing climate", which is more than the sum of citations of the 2004 and 2008 reports. This difference suggests that some of the 275 citations did not include the full title of the 2004 and 2008 reports.
[2] http://www.eea.europa.eu/promoproducts/indicators
[3] http://climate-adapt.eea.europa.eu/

2 Contents of the report

The EEA report on climate change, impacts and vulnerability (2012 CC IV report) (EEA 2012a) was published in November 2012 with contributions from JRC, ECDC, WHO, a large number of research institutes and government agencies (including from three European Topic Centres contracted by the EEA) and individual scientists. The 2012 CC IV report is an updated and extended version of the 2008 report (EEA 2008), which itself was an update and extension of the 2004 report (EEA 2004).

The main objectives of the 2012 CC IV report were to:

- present past and projected climate change and impacts through indicators;
- identify sectors and regions most at risk;
- highlight the need for adaptation actions;
- identify main sources of uncertainty; and
- demonstrate how monitoring and scenario development can improve the knowledge base.

The 2012 CC IV report presents a range of indicators and supporting information that highlight past and projected climate change and related impacts in Europe. The report also brings together information to assess the vulnerability of society, human health and ecosystems in Europe and to identify those regions in Europe most at risk from climate change. As uncertainty is a key factor in climate change projections, the report discusses the principal sources of uncertainty for the indicators and notes how monitoring and scenario development can improve our understanding of climate change, its impacts and related vulnerabilities.

The 2012 CC IV report paints a broad picture of climate change and impacts (Fig. 1). It starts with changes in the climate system and their effects on environmental systems. Both of these have impacts on socio-economic systems and sectors, including human health. Vulnerability to climate change in the context of socio-economic changes is explored by presenting key results from relevant European research projects, but these are not included in the EEA IMS. The basic idea underlying the reports has remained unchanged from 2004 to 2012. The 2004 report was based on 22 indicators, divided into eight different categories. In 2008 the number of indicators had increased to about 40 indicators, and in 2012 approximately the same number of indicators was used. All reports have covered roughly the same issues and topics (see Fig. 1). The expansion of the indicators from 2004 to 2008 was achieved by adding additional indicators for nearly all sectors, but in particular by adding 6 new indicators on agriculture and forestry and 9 new indicators on impacts in economic sectors and health.

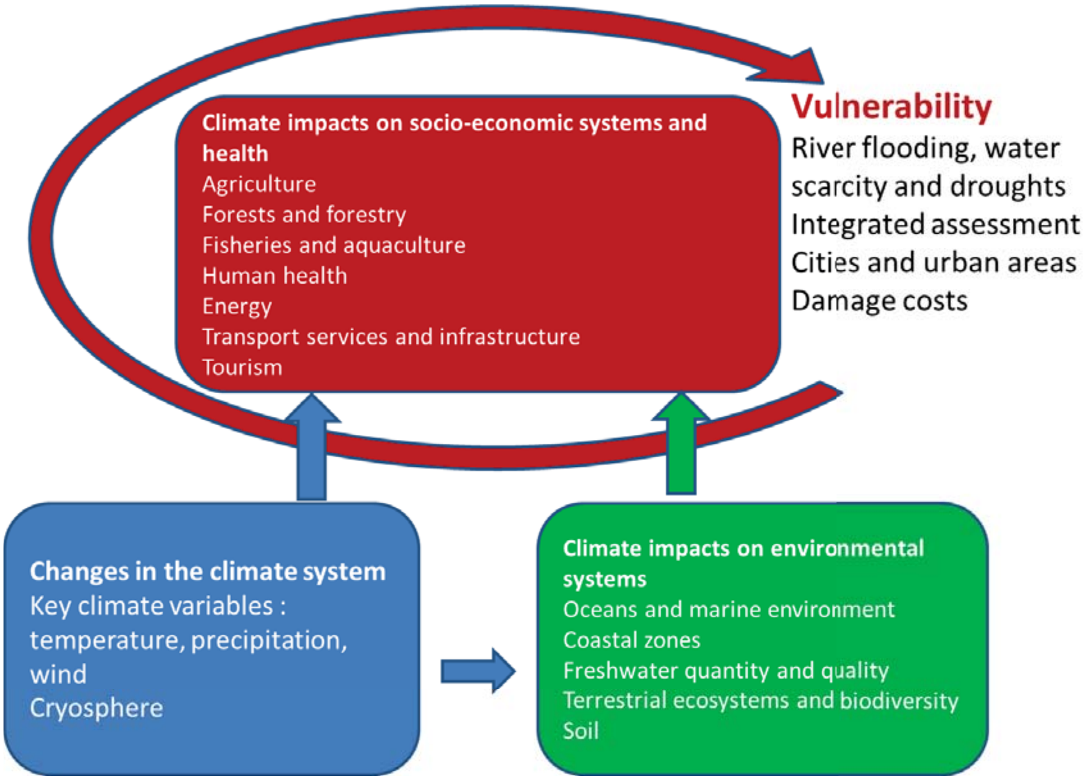

Fig. 1. Basic structure of the 2012 CC IV report. EEA indicators cover the following main groups: changes in the climate system, climate impacts on environmental systems, and climate impacts on socio-economic systems and health.

The main change in the reports over time is a growing emphasis on societal impacts, vulnerabilities and adaptation. For example, the issue of resource efficiency was hardly mentioned in the 2004 report and recognised but not elaborated in the 2008 report. In the 2012 report, however, several aspects of resource use effiency are highlighted. The growing importance of societal aspects can also be seen in the decision to produce a separate assessment report on adaptation. In the 2004 and 2008 reports, adaptation was dealt with in one short chapter only. This time, EEA decided to expand the treatment of adaptation into a full report (EEA 2013) which is scheduled for publication in parallel with the launch of the EU Adaptation Strategy (on 29 April 2013).

3 Indicator selection and coverage

Ideally environmental indicators provide quantitative measures that illustrate and communicate complex environmental phenomena simply, including trends and progress over time. The EEA indicator review process (see Section 1) aimed at ensuring that the EEA indicators in the IMS are policy-relevant, methodologically valid and user-friendly.

The selection of indicators for the 2012 CC IV report started with the indicator set of the 2008 report and suggestions by thematic experts for potential new indicators. All existing and suggested indicators were then evaluated according to 13 criteria from 5 groups (Hildén & Marx 2013). These criteria are similar to the criteria used in the EEA-wide indicator review mentioned above, which started after the review of indicators for the CC IV report. However, there are also some differences that stem from the differences in policy purpose and data collection between the CC IV indicators and most other EEA indicators. In particular, the emphasis of CC IV indicators on supporting policy planning rather than reviewing policy effectiveness results in a stronger focus on future projections and on spatially explicit reporting (rather than nationally aggregated information) than for most other EEA indicators. Somewhat different evaluation criteria were applied to past trends and future projections. Guiding questions were developed to help experts to consistently assess potential indicators. Different aspects of uncertainty, which are particularly relevant in the context of climate change, were also emphasized although uncertainties are difficult to convey in simple indicators.

The 2012 CC IV report covers 16 systems, sectors or topics with large differences in the availability and the quality of the underlying data (Table 2). The longest data series and the most elaborate projections are generally found for climatic variables and some indicators related to ecosystems. For many other topics, the historical data series are short and the projections indicative at best, underlining the importance of a proper treatment of uncertainty. Table 2 shows that the indicators of climate impacts on socio-economic systems and health suffer from the greatest uncertainties. In this area there are problems related to data availability, adequate modelling, and attribution. The difficulties may not lie primarily in the lack of data as such, but the in the lack of data that is assembled in standard form over large geographical areas and that can be linked to climate change.

Several climate-sensitive impact domains are either not covered at all or only through narratives without formal indicators. Climate impacts on industry and manufacturing, insurance, infrastructure (except for transport infrastructure), livestock production and cultural heritage are not covered due to the lack of available information. Climate impacts on personal well-being, aesthetic changes and other immaterial impacts are not systematically covered because they are hard to quantify or meaningful indicators are not available. Finally, information on changes in migration of people within and to the EU is not included because of a lack of evidence of the relevance of climate change.

Table 2. Overview of the material presented in the 2012 CC IV report: availability of data on past trends and projections, and main gaps. The colour scheme refers to Fig. 1: changes in the climate system (blue), climate impacts on environmental system (green) and climate impacts on socio-economic systems and health (red).

Topic and indicators	Availability: past trends	Availability: projections	Main gaps
Key climate variables: Global and European mean temperature; temperature extremes; mean precipitation; precipitation extremes; storms	Five indicators based on actual observations (also reconstructions and reanalysis); available time series from several decades to >100 years.	Projections for all indicators based on different models and scenarios.	**Past trends:** Only long-term trend provided, little discussion of decadal variation **Projections:** Little discussion of co-variation in climate variables.
Cryosphere: Snow cover, Greenland ice sheet; glaciers; permafrost; Arctic and Baltic Sea ice; lake and river ice	Six indicators based on actual observations with time series ranging from a little more than a decade to >100 years.	Projections for most of the indicators based on individual studies.	**Past trends:** Short data series for permafrost; lake and river ice data only available for a few sites. **Projections:** Only indicative and uncertain projections for most indicators
Oceans and marine environment: Ocean acidification; ocean heat content; sea surface temperature; phenology of marine species; distribution of marine species	Five indicators based on observations with time series of a few to several decades, but often restricted to limited sea areas. Ocean acidification indicator based on proxy data from Hawaii.	Generally qualitative projections or individual studies	**Past trends:** Somewhat fragmentary information on trends; data is sparse for acidification and long term changes of species distribution and phenology. **Projections:** In most cases highly uncertain projections
Coastal zones: Global and European sea-level rise (SLR); storm surges	Two indicators based on observations. SLR observations up to >100 years depending on data set. Storm surges based on individual studies of events rather than comprehensive time series.	SLR based on a range of quantitative projections. Highly uncertain projections for storm surges.	**Past trends:** Lack of comprehensive data on storm surges. **Projections:** Significant uncertainty for SLR and very high uncertainty for storm surges.
Freshwater quantity and quality: Mean river flow; river floods; river flow droughts; water temperature of rivers and lakes; lake and river ice	Five indicators based on observations of several decades. Except for mean river flows and floods, and to some extent droughts, data are based on singular local data series rather than comprehensive coverage of large regions or the whole of Europe. For individual locations time series extend >100 years. In addition a narrative on freshwater ecosystem and water quality.	Model-based quantitative projections for river flow, floods and droughts. Projection based on inferences from air temperature for water temperature, and single study for ice. Narrative on freshwater ecosystems and water quality	**Past trends:** Lack of empirical and regional analyses/modelling of changes in freshwaters and freshwater ecosystems; thin spatial coverage and poorly harmonized data. **Projections:** Lack of regional projections on scales relevant to decision making
Terrestrial ecosystems and biodiversity: Plant and fungi phenology; animal phenology; distribution of plant species; distribution and abundance of animal species; species interactions.	Five indicators. Phenology and distribution patterns based on two to several decades of observations of selected species groups and habitats. Narrative description of species interactions based on review of individual studies.	Phenology projections based on inferences from climate projections. Model-based projections for selected species distributions. Narrative description of potential changes in species distribution.	**Past trends:** Partly fragmented view of changes due to non-standardized data and limited availability. **Projections:** High uncertainty, lack of alternative models and ensemble studies. Lack of data on species interactions (including alien species).
Soil: Soil organic carbon; soil erosion; soil moisture	Three indicators based on snapshot observations of variables. No comprehensive trend data, except a proxy for wind erosion over several decades. Narrative on biomass production and recurrent negative precipitation anomalies ("droughts") as proxy for soil degradation.	Qualitative projections based on a conceptual model of relevant processes	**Past trends:** No comprehensive compilation of soil data. **Projections:** Highly uncertain projections, lack of relevant modelling.

Topic and indicators	Availability: past trends	Availability: projections	Main gaps
Agriculture: Growing season for agricultural crops; agrophenology; water-limited crop productivity; water requirement for irrigation	Four indicators based on two to several decades of observations of actual variables or relevant determinants.	Model-based projections for growing season, agrophenology, and water-limited crop productivity.	**Past trends:** Partly fragmented and non-standardised data; filtering of climate signal from observed data. **Projections:** Missing information on uncertainty related to modelling impacts of climate change on crop yield considering effects of possible adaptation options; lack of projections of the possible role of extreme events and pests.
Forests and forestry: Forest growth; forest fires	Two indicators based on two decades of observation for 17 EU countries on forest growth and three decades of forest fire observations.	Model projection of tree species composition using several scenarios; projection of fire danger under one scenario.	**Past trends:** Lack of harmonised and comparable data on forests across countries. Difficulties in filtering climate signal from data. **Projections:** Lack of separation of the impacts of climate change on forests and forestry in combination with other factors.
Fisheries and aquaculture	General narrative with information on temperature response of fish stocks in the north-eastern Atlantic	General narrative on possible consequences	**Past trends:** Disentagling and filtering climate effects from other changes. **Projections:** Lack of data on the impacts of climate change on fisheries and aquaculture in combination with other factors.
Human health: Floods and health (addressing both coastal and river floods); extreme temperatures and health; air pollution by ozone and health; vector-borne diseases.	Four indicators that include several data series with coverage of one to two decades. For several vector borne diseases periodic snapshots rather than full data series. Narrative on water- and food-borne diseases	Narrative based on climate projections and review of individual studies.	**Past trends:** Fragmentary data, incomplete and short data series, difficulties in attribution. **Projections:** Lack of process-verification and scenario modelling
Energy: Heating degree days	Three decades of observations. Narrative description of electricity demand and production.	Narrative based on climate projections and review of studies on electricity demand	**Past trends:** Limited data, current indicator provides only one aspect of the relationship between climate change and energy. **Projections:** Limited picture of energy use and production in a changing climate.
Transport services and infrastructure	Narrative on impacts focussing on inland water transport and impacts of changes in extreme weather events. No data series or actual indicator	Narrative based on reviews	**Past trends:** Lack of data compilation to detect changes. **Projections:** Lack of systematic work on projections and scenario modelling
Tourism	No indicator, Narrative on general tourism and winter sport tourism.	Projections for general tourism using the tourism climatic index as a proxy	**Past trends:** Lack of data to examine change, filtering of climate effect **Projections:** Lack of understanding of preferences and reactions to climate change
Damage costs: Direct losses from weather disasters	One indicator on damages due to natural disasters in EEA member countries	Narrative projection, supplemented with quantifications based on model studies of the research project ClimateCost	**Past trends:** Difficulties in attribution. Projections: Not possible to cover all cost categories, cross-sectoral cost estimates are lacking

4 Discussion

The 2012 IV report demonstrates that there are great differences in the availability of data underlying climate and impact indicators (Table 2). The best information is available on climate variables (temperature, precipitation and some aspects of the cryosphere), for which long historical data series as well as projections are available. Indicators on climate change impacts on environmental systems include some well-researched areas where impacts of climate change have already been observed and where attribution studies have been made. However, data availability for some environmental systems (e.g., soil) is rather limited. Time series on climate impacts on socio-economic systems and health are generally limited, and the attribution of observed changes to changes in climate has proven to be difficult.

EEA indicators on climate change and impacts are primarily intended to inform the development of adaptation policies that address future climate risks. Quantitative projections of future developments exist for most (but not all) climate variables and for some impact indicators, although uncertainties are often large. The greatest "white spots" relate to future climate impacts on socio-economic systems and health where projections are often based on statistical modelling or on qualitative narratives inferred from projections of climate variables. Obviously, adaptation planning would benefit from deeper knowledge about societal impacts under different policies.

It is easy to demand more data and monitoring using harmonized methods in order to fill the gaps. Progress might be achievable to some degree by making greater use of available statistical data. For example, the ESPON Climate project combined spatially explicit data on the distribution of climate-sensitive infrastructure and other assets with one climate projection to obtain indications of vulnerability at the NUTS-3 level (Greiving et al. 2011). There is, however, a need for more process-oriented studies that set climate change in a wider context of societal change and that can identify the climatic component in observed and projected changes. For example, studies have shown that the increasing trend in economic damages caused by natural hazards is driven primarily by socio-economic factors and not by climatic events (Visser et al. 2012; Barredo 2010). Carefully designed analyses are therefore needed for a correct interpretation of indicators because a simple compilation of observed data or a presentation of projections can easily lead to flawed conclusions.

Further improvement of indicators and indicator-based assessments requires a reflection on the primary use of the information. If the aim is to monitor and understand the sensitivity of environmental systems to large-scale changes, detailed data from a few geographically limited systems may provide valuable information. If the the aim is to inform the development of European adaptation policies, there is a greater need to embrace the diversity of conditions throughout Europe. For such indicators, comprehensive geographical coverage is important, and the related assessment must include a narrative reflection on the diversity, uncertainties and caveats in the information provided.

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Climate Change impacts on Tabasco, Mexico

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Abstract—Tabasco is located on the southern coast area of the Gulf of Mexico. It has lost important natural areas and ecosystems due to different natural and human effects. It is vulnerable to important threats related to climate change. The climate is warm and humid with abundant rains in summer, and is one of the wettest areas with important wetlands. Oil exploitation, cattle breeding and agriculture are the main economic activities and responsible for an important lost of natural landscapes resulting in a lack of resources and alternatives for local poverty communities of the area. The objective of this research was to study impacts related to global warming effects (floods, drought and sea level increase) and increased due to some natural processes. A landscape map was configured to identify impacts. Historical reviews of the land use, as well as natural phenomenons like sea shore variation were performed to evaluate their effects on the different ecosystems. A historical review of the hydrology, and land use, was done to have a base line for the study. Results show that the area is situated in a vast plateau with occasional floods. Intrusions of salt water during the dry season allow mangroves in this region to grow up to 30 km inland however the strong effect of salinization of soils is affecting different production activities. Road infrastructure without planning, urban growth and oil exploitation infrastructure has caused important impacts especially on the hydrodynamic and coastal areas reducing sedimentation process. Local fisheries, deforestation for agricultural purposes and cattle grazing, and industrial pollution are currently the major threats. The data regarding sea shore erosion show a loss that goes from centimeters to meters in some parts of the coast. Sea level increase sceneries show an important future alteration to wetlands of this area.

Index Terms—Climate change, coast erosion, floods, vulnerability.

1 Introduction

The geographical location of the State of Tabasco, its proximity to the sea shore and its physiographical and geomorphologic features, are part of the reasons for seasonal floods, among other impacts. These floods have different duration, extension, and magnitude depending on the climatic events. However, due to climate change, these patterns are changing and their effects are expected to increase (Hernandez-Santana, *et al*, 2008). An example of these potential impacts is the increase of the intensity of extreme precipitation events resulting in flood events of extraordinary magnitude, endangering besides people and infrastructure the development capabilities.

Climate is the landscape component that defines the ecological conditions of each region and therefore the socio-economic activities (Chiappy, et al, 2001). However, man has used natural resources, on an indiscriminate and incompatible way, resulting in modifications ranging from light to irreversible. Changes on climate brought about by heating increases impacts on nature, leading to damages with higher costs especially on vulnerable areas (IPCC, 2007), such as the State of Tabasco. Research to determine the regime of precipitation among others (Tejeda, 2007), will allow the local government to be able to take decisions and generate development strategies taking into consideration risk zones.

Tabasco in the coast of the Gulf of Mexico is suffering important lost of ecosystems due to different natural and human effects.

Because of its climate and biologic characteristics, the most important Mesoamerican wetlands present a high diversity of species. Tabasco has also undergone drastic disaster events during the last decades. Mexican authorities estimate that this is a very vulnerable area to climate change impacts. Salt water intrusions during the dry season allow mangroves in this region to grow up to 30 kilometers inland however a strong effect of salinization on soils are affecting agricultural uses. The moist forests have been gradually eliminated over the years due to their importance as a source of food and timber for local villagers. Local fisheries, deforestation for agricultural purposes and cattle grazing, and industrial pollution are currently the major threats.

The last flooding events, are an important reference in the analysis for adaptation strategies, disasters occurred in 1999, 2007, 2008, 2009, 2010 and 2011 are not specially related to this global shift, where important extensions suffered flooding of a magnitude and duration without precedent, but are a reference of the potential impacts expected to increase in magnitude with global warming scenaries.

It is important to take into consideration modifications caused by human interventions, altering their habitats of species population and their distribution or balance. This alteration increases the possibility that climate events impacts increase their magnitude and extension by the reduction among other things, of the vegetation cover, changes in the composition of species, or changes that facilitate opportunistic and invasive species. In addition, deforestation, allows a higher sediment transportation leading to river bed siltation, which reduces their ability to transport large volumes of water, contributing to the possibility of generating more frequent floods.

Therefore, solutions for understanding a system as complex as this, are required for high quality, active and systematic research. A strategy to facilitate the sharing of experiences among researchers in interdisciplinary and inter-agency manner was developed to increase the possibilities in finding efficient alternatives, promoting direct contacts between different academic communities and optimizing human and material resources that provide support to the plans and programs required to apply the rule. The National Institute of Ecology, the local government and the local research institutions started a research with the support of other national and international research institutions focusing on the construction of a strategy to confront future impacts that have been made up from vulnerability maps.

2 Methodology

To evaluate risk of having natural and anthropogenic impacts, a research was carried out to identify potential kinds of hazards (floods due to hidrometeorological, climate change, sea erosion) as well as the natural characteristics of the area that could represent a vulnerability condition, taking into account: 1) recorded data of hazards in the area related to rainfall, floods, drought, tropical storms or hurricanes; 2) land changes in the territory, 3) vulnerable areas to sea erosion and sea level rise and 4) salinitation.

A review was done based on historical literature from the National Historical Archive related to hazards that originated important impacts in the region. The information was recorded on a cartographic data base. Meteorological data such as temperature and precipitation from different sources were recorded for statistical, graphic and cartographic analysis. A vulnerability map was configured based on altitude, sea erosion, hydrology, drainage, soil, precipitation, land change, natural vegetation and infrastructure as well as information related to measures taken into account to avoid future floods and infrastructure implemented resulting from the analysis of each event.

3 Results

A total of 61 different events were identified, from 26 different information sources. Temperature data was plotted to identify the areas with the highest temperatures and where dry times are causing problems to the population and different productive sectors. This shows that four municipalities will be seriously affected by drought with a potential temperature increase up to 5 degrees with maximums of 51 Celsius.

Having lost most of its tropical forests, the State is currently presenting drastic modifications on its natural systems, with effects on the hydrological system and a loss of natural resources available for development strategies .These losses will not only result in a decline of the quality of the habitat, but in the loss of environmental services that regulate the dynamics, functionality and processes of ecosystems, which will favor impacts expected by climate change.

Trends showed an increase in extraordinary events and a redistribution of the precipitation throughout the year with more potential major flood events. Since Tabasco has a complex network of hydrological surface, a review of the natural or anthropogenic changes in the structure of this hydrodynamic net was mapped to understand potential to increase or prevent floods and relate them to infrastructure constructed and results showed an increase in the magnitude of floods.

A comparative analysis between the coast lines of 1972, 1984 and 1995 and 2004 (Hernández *et al,* 2007), identified major changes resulting from erosion and determined their vulnerability to the increase of the sea level. Cosst monitoring data (Ortiz and Gama *in* Botello, *et al*., 2010), identified areas with major losses of up to six meters per year.

Six coast sectors are suffering strong coast lost due to coast erosion. Road construction had caused important impacts on the hydrodynamic of the coast. Sea level data show an increase of up to 4 mm a year with the possibility of entering inland up to 50 km, although the main threat for species would be the modification on salt content of water bodies close to the coast with low altitudes (fig. 1).

Figure 1. Measures taken to find loss of sea shore per year (Ortiz, et al, 2010).

Intrusions of salt water during the dry season allow the mangroves to grow up to 30 km inland. However the strong effects of salinization on soil are affecting them. Soils are deep, very acidic, and rich in organic matter. The climate is warm-humid with abundant rains in summer, and this mangrove region is one of the wettest in the area with 1,600 mm annually. Natural effects like salinization due to sea shore variation are seriously endangering natural ecosystems in this area.

4 Conclusions

The state is located on a highly vulnerable area to extraordinary rainfall events related to tropical storms from the Atlantic and Pacific oceans during the summer as well as the influence from cold fronts on winter. Human environmental impacts such as deforestation, unplanned urban growth and river fragmentation had increased the magnitude, extension and duration of these impacts specially the floods that are endangering people, especially those that live in vulnerable areas. The analysis of precipitation data had allowed the identifivation of the risk to more intense events associated to anthropic factors and those related to global warming to construct a “State Action Plan for Climate Change” that not only includes data regarding vulnerability of the area but also proposes adaptation alternatives.

Although alternative of adaptations can be implemented regarding floods, the potential scenarios constructed related to sea level increase and coast erosion are showing a need to find alternatives areas for people leaving there as the impact expected not only will result on the salinization of lagoons and marshes which will affect the distribution of many species but will radically change the sea shore with important losses of territory.

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Adapting agriculture to reduce nutrient loads to the Baltic Sea under future climate and socio-economic conditions – a modelling study in the Reda catchment, Poland.

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Abstract— Eutrophication of the Baltic Sea driven predominantly by overloading with nutrients from the Baltic Sea catchment is a major and well recognised environmental problem. Poland is the main country contributing nitrogen (24%) and phosphorus (37%) input to the Baltic Sea and agricultural non-point sources are reported to have the highest share in observed nutrient loads. Little is known about the effects of projected climate and socio-economic changes up to 2050s on nutrient loads discharged to the Baltic Sea by Polish rivers and about the efficiency of agricultural best management practices (BMPs) under future conditions. This paper attempts to fill this gap by using a scenario-modelling framework applied in the small, predominantly agricultural Reda catchment situated in northern Poland. The SWAT model is applied to assess the current state of the system, and to quantify effects of future changes under multiple scenarios. The model was calibrated and validated against daily river flows and bi-monthly measurements of sediment and nitrate nitrogen load. The model performance was assessed as good for river flow simulation and satisfactory for sediment and N-NO_3 load simulation. The future scenarios consisted of changes in climate, population and urban land cover use. On top of these changes, two agricultural scenarios were developed: one assuming spontaneous development of agriculture and the second one its rapid intensification following the Danish model. The climate change projections assumed catchment-averaged mean annual temperature and precipitation increase equalled 1.3 ^{o}C and 10%, respectively. Urban sprawl driven by population increase (by 37% in 2011-2050) was implemented in SWAT by changing low quality agricultural land into low density residential land cover classes. Adaptation measures tested in the model were selected with stakeholder participation and concerned reduced fertilization, catch crops and buffer zones. The results of this study demonstrate that both climate change and the level of intensity of agriculture have a pronounce effect on N-NO_3 loads from a small-scale Polish river basin to the sea in 2050s. Even though some of the tested measures do possess a visible efficiency in reduction of N-NO_3 losses, none of them is able to balance out the negative effects caused mainly by the major shift in agriculture and the second most important factor, climate change.

Index Terms— adaptation measures, Baltic Sea, nutrient load, SWAT

1 Introduction

Aquatic eutrophication, being an effect of excessive loads of biogenic substances transported by rivers to the sea waters, has become the primary environmental issue of the Baltic Sea (Glasby and Szefer 1998). It is nowadays widely accepted that preventing sea water quality from further deterioration requires actions stimulated by polices beyond national level e.g. the Baltic Sea Action Plan (BSAP; Helcom 2007).

The Polish share in generated nutrient load still remains the largest among the Baltic states (Kowalkowski et al. 2012). Three major driving forces that are supposed to have influence on future nutrient loads are: projected climate change, development of agriculture (non-point pollution sources) and point source emissions. The long-term future of nutrient loads generated by Polish rivers is unknown, yet it is possible to estimate it using state-of-the art hydrological models. Current research focuses on mathematical modelling of nutrient load to the Baltic Sea at variety of spatial scales and using different tools, i.e. the Balt-HYPE model of the entire Baltic Sea Basin (Arheimer et al. 2012), the MONERIS model of the large Polish river basins Vistula and Odra (Kowalkowski et al. 2012), as well as the SWAT model applied in small or medium catchments in Poland (Piniewski 2012; Ostojski 2012), and in Sweden (Ekstrand et al. 2010). While large-scale studies allow having a broad overview on projected changes, small-scale studies can usually profit from the availability of better quality input data for modelling. This study is carried out in the Reda catchment situated in the northern Poland (Fig. 1), draining an area of 482 km^2 to the Puck Lagoon (inner Puck Bay), a very shallow coastal water body (mean depth 3,1 m) of 103 km^2 area, particularly sensitive to eutrophication due to limited water exchange with the outer part of the Puck Bay (Krzymiński et al 2005; Bogdanowicz et al. 2007). It attempts to bring together state-of-the-art modelling with scenario development in order to: (1) Quantify nutrient loads under future climate and land use in 2050; (2) Estimate the effect of agricultural adaptation measures aimed at nutrient load reduction under future scenarios. The focus in this study is mainly on modelling nitrate nitrogen ($N\text{-}NO_3$) loads.

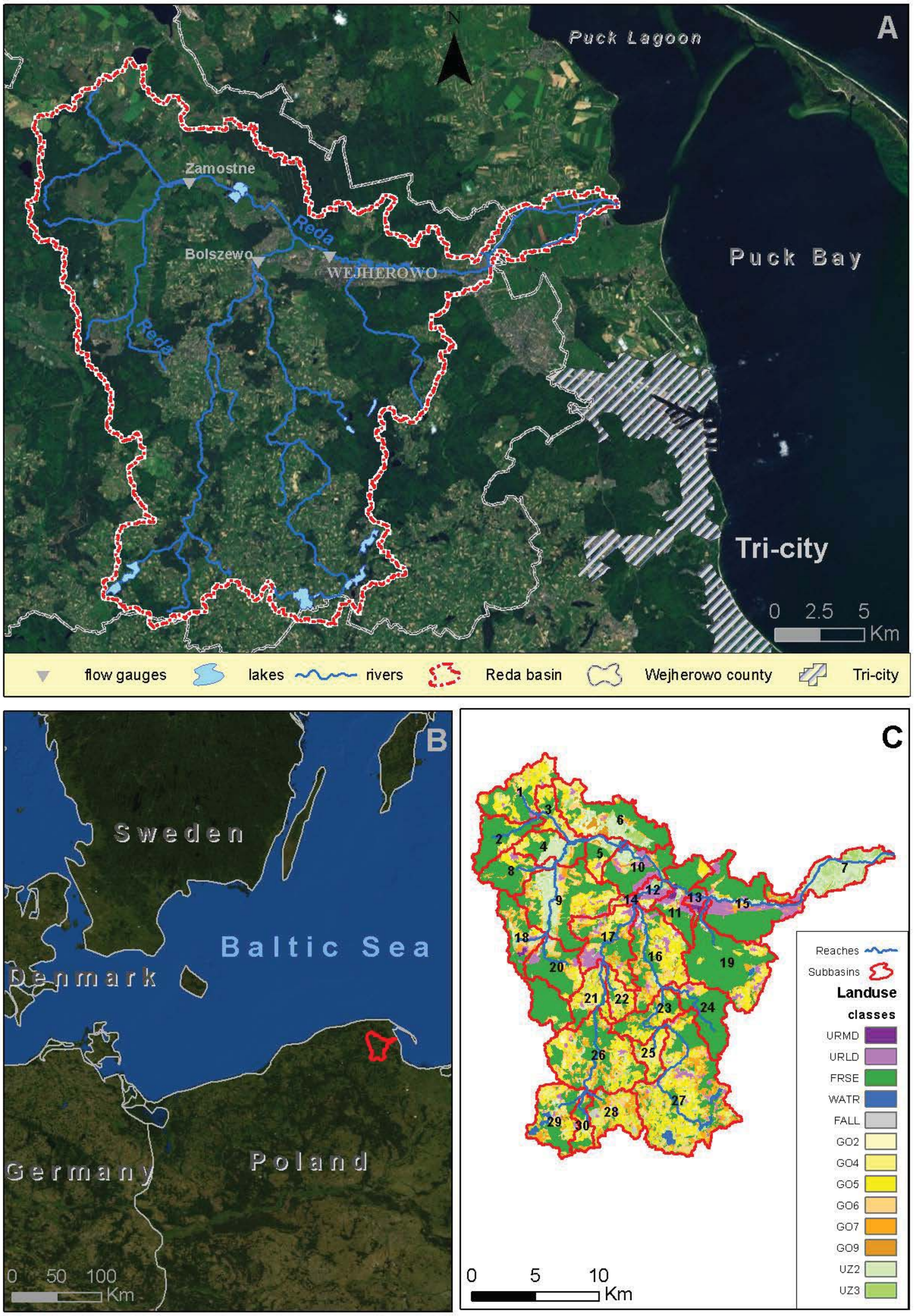

Figure 1. The Reda catchment (A), its location in the Baltic region (B) and its land cover map (C).

2 Materials and Methods

2.1 Study area

The river Reda is situated in the northern Poland, close to the Tri-city (Gdańsk, Gdynia and Sopot), the largest urban area on the Polish seaside. Agricultural land occupying 51.2% of catchment area is the predominating land cover class, while forests are second largest class occupying 41.6%. The percentage of farms larger than 10 ha was estimated at only 28%. Mean farm size in Poland is a few times smaller than in western countries from the same climatic zone: Germany, Denmark and the Netherlands (Bański 2010). Among crops cultivated on arable land, spring cereals dominate on better quality soils in the north west part of the basin, while extensive farming of winter cereals and potatoes dominates on poor quality soils in the south part of the basin. The majority of grasslands are cultivated as permanent meadows and pastures. Pig raising is more frequent than cattle raising and the mean livestock density was estimated at 0.56 LSU/ha.

2.2 Modelling tool

SWAT is a public domain, river basin scale model developed to quantify the impact of land management practices in large, complex river basins (Arnold et al. 1998). SWAT2009 model version (Neitsch et al. 2011) was used in this study. SWAT is a physically-based, semi-distributed, continuous time model that operates on a daily time step and simulates the movement of water, sediment and nutrients, on a catchment scale. The smallest unit of discretisation is a unique combination of land use, soil and slope overlay, referred to as a “hydrological response unit” (HRU). Runoff is predicted separately for each HRU, and then aggregated to the sub-basin level and routed through the stream network to the main outlet, in order to obtain the total runoff for the river basin.

2.3 Model setup

The study area was divided into 30 sub-basins. Mean basin elevation was equal to 107 m.a.s.l. SWAT input land cover map was created using Corine Land Cover 2006 layer. Fig. 1 illustrates all land cover types in the Reda catchment. Soil input map was created based on soil types, subtypes and soil layer texture map available from the Institute of Soil Science and Plant Cultivation in Puławy. The total number of 18 unique soil classes was used. The dominant soil class are highly permeable sands (usually Cambisols) occupying 51% of basin area. 36% is occupied by different soil types with texture of loamy sands or sandy loams. Intersection of land use map, soil map and slope classes map enabled creation of 465

HRUs, whose mean area yields 104 ha. Daily climate data (five stations with precipitation records, four stations with temperature, humidity and wind speed records and one station with solar radiation records) were acquired from the Institute of Meteorology and Water Management, Marine Branch in Gdynia (IMGW-PIB) for the time period of 1991-2010.

Since the focus of this study is on the impact of agriculture on water quality, special attention in SWAT setup was devoted to definition of agricultural management practices. Required data and expert information were acquired from Pomeranian Agricultural Advisory Board in Gdańsk (PODR) and Central Statistical Office (GUS). All the analyzed data were collected for four communes from Wejherowo county: Gniewino, Luzino, Szemud and Wejherowo. Seven major crops grown on arable land were defined in the model setup: winter cereals (rye), spring cereals (oats and spring wheat), potatoes, field peas, red clover and spring canola. For each crop a separate cropping system was defined in SWAT through scheduled management practices option. Cereals and potatoes, cultivated in a traditional, extensive manner rather than in an intensive manner, constituted nearly 90% of total arable land area. Mean mineral fertilizer usage in 1998-2006 yielded 40 kg N/ha and 11 kg P/ha. Organic fertilizers used by farmers in the Reda catchment include solid manure and slurry that are spread predominantly at grassland and potato fields.

2.4 Model calibration

SWAT was calibrated and validated against daily discharge data and against bimonthly suspended sediment, N-NO_3 loads at Wejherowo gauging station. The calibration period was 1998-2002, whereas the validation period was 2003-2006. SUFI-2 automatic calibration tool from SWAT-CUP software (Abbaspour et al. 2007) was applied. The Nash-Sutcliffe Efficiency, NSE (Moriasi et al. 2007) was set as an objective function. The values of goodness-of-fit measures at Wejherowo gauging station indicate good model performance for discharge and N-NO_3 in both calibration and validation periods (Table 1). However, for sediment load the results for validation period are remarkably worse than the results for calibration period. A 20-year-long simulation run was executed (1991-2010, with three years of warm-up period) with the calibrated model. This simulation run served as reference (baseline) scenario in further analyses. Mean annual discharge at catchment outlet yielded 4.5 m^3/s, and mean annual loads of suspended sediment, and N-NO_3 to the Puck Lagoon in the baseline scenario yielded 2.24 and 168 tons per year, respectively.

Table 1. Calibration and validation goodness-of-fit measures at Wejherowo gauging station.

	Calibration period			Validation period		
Variable	NSE	R^2	PBIAS [%]	NSE	R^2	PBIAS [%]
Discharge	0.75	0.79	-8	0.61	0.78	-18
Sediment load	0.55	0.58	10	0.22	0.23	-12
$N\text{-}NO_3$ load	0.62	0.62	-4	0.64	0.83	3

2.5 Future scenario assumptions

In this study the period centred around 2050 was selected as the time horizon of future scenarios. Two major driving forces of future catchment change are climate and land use. Point source emissions are currently not, and are not supposed to be a problem in the Reda catchment. While climate change projections for the Reda catchment were downscaled from a climate model, assumptions for land use change scenarios were established by expert judgment using stakeholder input as an additional source of information.

The climate projections by ECHAM5 GCM driven by SRES A1B emission scenario and coupled with RCA3 RCM were acquired from the Swedish Meteorological and Hydrological Institute, SMHI (Samuelsson et al. 2011). The delta change approach was applied to represent the future climate in SWAT (Fowler et al. 2007). Fig. 2 illustrates basin-averaged downscaled projections of monthly precipitation and temperature for 2050s versus current situation.

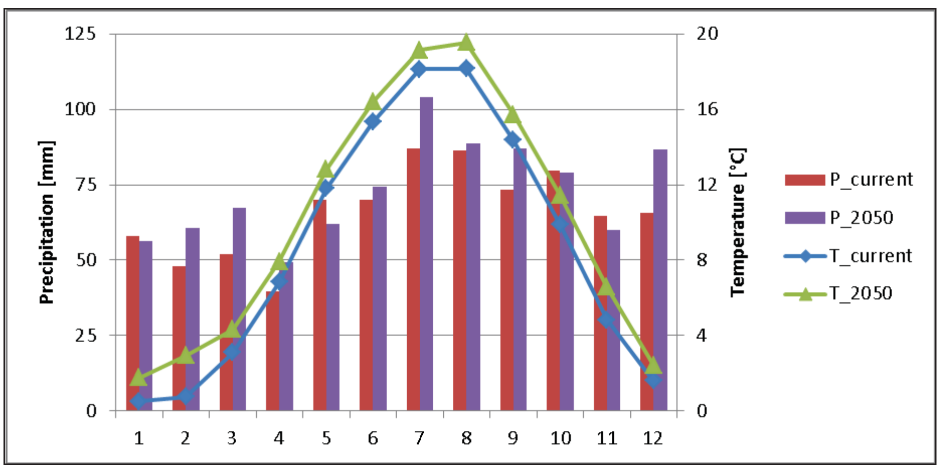

Figure 2. Basin-averaged downscaled projections of monthly precipitation and temperature for 2050s versus current situation.

While climate change in the Reda catchment is driven mainly by global-scale factors, land use change is related to factors acting on various scales: climate, population growth, future national and EU policies (in such domains as agriculture and spatial planning), local and global food demand, etc. Projections of urban land cover change due to population growth (or decline) are probably the least uncertain ones. The study area has experienced a rapid urban sprawl in recent years: According to data from Central Statistical Office (GUS[1]) mean annual population growth in 1995-2011 yielded 3% in rural areas and 0.3% in urban. This trend is supposed to continue in the foreseeable future: expected mean annual population growth in 2011-2035 yields 0.85% in urban areas and 1.27% in rural areas (GUS 2012). These figures were extrapolated until 2050 and transformed into urban land cover growth in SWAT. HRUs occupying 909 ha that used to have fallow land or low quality agricultural land were turned into low-density residential land cover.

There is much more uncertainty related to the future of agriculture than to the future of urban sprawl in the Reda catchment. Therefore, on top of urban land cover change, two agricultural scenarios for this area were developed: one assuming spontaneous development of agriculture and the second one its rapid intensification (Tab. 2). The first scenario assumes adaptation of production to rising temperatures and takes into account some of the recently observed trends (e.g. biogas plants using corn silage as substrate), however, both crop structure, animal production and fertilizer usage remain only slightly altered compared to the reference state. In contrast, the second scenario assumes that Poland (and Reda catchment in particular) will experience a major shift (driven mainly by export of products to EU market) in agriculture, that will resemble intensive agriculture of some of the neighbouring Western countries, e.g. Denmark, Germany or Sweden. In order to create a coherent and plausible scenario, from practical reasons one country – Denmark – was selected as a good model to which Poland will ultimately converge. Both scenarios form a range of possible change that Polish agriculture is likely to undergo in the future: a shift into Danish-type intensive agriculture in the Reda catchment is the upper limit of possible changes, whereas a business-as-usual scenario is their lower limit.

[1] http://www.stat.gov.pl/bdlen/app/strona.html?p_name=indeks, subgroup "Population by domicile/residence and sex" (last accessed 3/28/2013).

Table 2. Comparison of two developed agricultural scenarios for the Reda catchment in 2050s.

Scenario feature	Business-As-Usual	Major Shift in Agriculture
Type	Traditional (extensive), oriented on own farm needs (driven by local socio-economic conditions and EU policies)	Intensive, export-oriented (driven by global food demand)
Crop structure (% of agricultural land; SWAT crop names used)	Tall fescue (grassland) 25.1%, Oats 21.4%, Rye 19.6%, Spring wheat 13.5%, Potatoes 8.9%, Red clover 5.9%, Corn silage 2.3%, Field peas 2.1%, Spring canola 1.1%	Spring wheat 26.7%, Spring barley 22.0%, Tall fescue (grassland) 15.2%, Red clover 11.7%, Corn silage 10.9%, Spring canola 6.0%, Potatoes 2.9%, Field peas 2.1%, Rye 1.9%, Oats 0.5%
Livestock density	0.56 LSU/ha	1.43 LSU/ha
Fodder source	Locally produced fodder	Imported fodder
Fertilizer types and rates on agricultural land	Mineral fertilizer (N 71%, P 87%), Organic fertilizer (N 29%, P 13%) Average rate 32 kg N/ha, 12 kg P/ha	Mineral fertilizer (N 25%, P 15%), Organic fertilizer (N 75%, P 85%) Average rate 102 kg N/ha, 53 kg P/ha
Timing of practices	Shift triggered by warmer climate	Shift triggered by warmer climate
Expected yields	Similar to current ones	Much higher than current ones
Expected water pollution	Similar to current state	Much higher than current state

Six unique combinations (including the baseline scenario) of model experiments were carried out (Table 3). For each of these experiments three indicators are calculated: (1) percent change in mean annual discharge; (2) percent change in mean annual $N\text{-}NO_3$ load to the Puck Lagoon; (3) percent change in mean annual $N\text{-}NO_3$ leaching past the bottom of soil profile to shallow groundwater aquifer. The latter indicator is basin-averaged and thus represents all HRUs, not only agricultural ones.

Table 3. Experimental design for running scenario simulations.

Driving forces		Climate: Current	Climate: 2050 (ECHAM5-RCA3-SRESA1B)
Land use	Current	1. Baseline	4. CC-2050
Land use	2050 (Business-As-Usual)	2. BAU-2050	**5. BAU-CC-2050**
Land use	2050 (Major Shift in Agriculture)	3. MSA-2050	**6. MSA-CC-2050**

2.6 Adaptation measures

The starting point for selection of adaptation measures was the list of prioritized measures elaborated within the BalticCOMPASS project[2]. The final selection of measures, made with stakeholder advice, was a trade-off forced by model limitations (not all interesting measures can be represented in SWAT). Finally, three measures were selected as valued by stakeholders and possible for modelling:

1. Vegetative cover in autumn and winter (VC).
2. Avoiding fertilisation to risk areas (RA).
3. Buffer zones along water areas and erosion sensitive field areas (BZ).

Ad. 1 In order to implement this measure, modifications in scheduled management practices were made in the model structure. Red clover was used as catch-crop after spring cereals and corn silage, whereas rye was used as catch-crop after potatoes.

Ad. 2 To reduce nutrient losses, special “risk area” HRUs were identified in which the schedule of management practices was changed. These were: (1) HRUs with slopes above 10%; (2) HRUs with defined tile drainage operation; (3) HRUs with heavy soils. Fertilisation rates in selected HRUs were reduced by 50%.

Ad. 3 In SWAT buffer zones are represented by the vegetative filter strip (VFS) sub-model (Neitsch et al. 2011) that uses different empirical reduction rate equations. VFS were defined in all arable land HRUs with their default parameter values.

Adaptation measures were run both as single measures and as combined measures. Since they refer to the future period, they were run on top of two combined future scenarios: BAU-CC-2050 and MSA-CC-2050 (cf. Table 3). Measure efficiency under future conditions was calculated as follows: For a variable X,

[2] http://www.balticcompass.org/_blog/Project_Reports/post/Prioritized_measures_by_Work_Package_3_/ (last accessed 3/28/2013)

ΔX yielded:

$$\Delta X = \frac{X_{adaptation} - X_{scenario}}{X_{scenario}} \cdot 100\%. \quad (1)$$

3 Results

3.1 Nutrient loads in future scenarios

The results presented in Table 4 show that under the Business-As-Usual (BAU) without consideration of climate change nutrient loads and leaching remain on the similar level as currently. In contrast, large changes are expected under the Major Shift in Agriculture (MSA) scenario. Under future climate, N-NO_3 loads are expected to rise by 18.8% and this rise is related to increased runoff under wetter climate (cf. Fig. 2). However, the effect of intensified agriculture is clearly larger than the effect of climate change. The results are amplified, when combined effects of climate and land use change are analysed: for example under MSA-CC-2050 N-NO_3 loads are expected to rise by 60.1%.

Table 4. Percent changes in selected parameters (discharge, N-NO_3 loads and N-NO_3 leaching to groundwater) for analysed scenarios in 2050 with respect to current (baseline) scenario (results for combined climate-land use change scenarios are marked in bold).

Driving forces		Climate					
		Current			2050 (ECHAM5-RCA3-SRESA1B)		
		Discharge	N-NO_3 load	N-NO_3 leaching	Discharge	N-NO_3 load	N-NO_3 leaching
Land use	Current				21.8	18.8	12.0
	2050 BAU[3]	1.6	0.8	2.8	**23.7**	**19.7**	**14.0**
	2050 MSA	1.2	39.2	83.5	**23.6**	**60.1**	**85.9**

Direct comparison of BAU-CC-2050 with MSA-CC-2050 shows that under the latter nitrate water pollution is expected to grow significantly as the result of agricultural intensification. On the other hand, simulated yields and harvest of main crops are expected to be higher by 31% and 49% in MSA compared to BAU, respectively. Corn silage yield is expected to grow by 51%.

3.2 Efficiency of adaptation measures in future scenarios

In order to estimate efficiency of nutrient reduction measures in future conditions (cf. Eq. 1), selected

[3] BAU – Business-As-Usual; MSA – Major Shift in Agriculture

measures were implemented into the model on top of two combined scenarios: BAU-CC-2050 and MSA-CC-2050. Table 5 shows calculated efficiencies in reduction of mean $N\text{-}NO_3$ leaching and mean $N\text{-}NO_3$ load at the catchment outlet for the most efficient single measure (*Vegetative cover in winter and spring*) and for the most efficient combined measure (all three measures altogether). The results show that:

- Calculated efficiencies are higher for groundwater leaching indicator than for river load indicator
- Higher efficiencies can be expected under MSA-CC-2050 scenario than under BAU-CC-2050 scenario
- Application of all three measures at a time is only a little more efficient that application of one single most efficient measure (VC).

Table 5. Simulated efficiencies (%) of selected adaptation measures under future scenarios.

Measure	VC		VC+RA+BZ[4]	
Scenario	$N\text{-}NO_3$ load	$N\text{-}NO_3$ leaching	$N\text{-}NO_3$ load	$N\text{-}NO_3$ leaching
BAU-CC-2050	3.8	13.0	5.1	13.5
MSA-CC-2050	6.3	14.6	11.4	16.7

Application of the most efficient combination of measures under BAU-CC-2050 will lead to $N\text{-}NO_3$ loads higher by 14%, and under MSA-CC-2050 higher by 41% than at present. This shows that projected rising intensity of agriculture and climate change are first and second most important factors affecting $N\text{-}NO_3$ loads. Estimated efficiency of adaptation measures is clearly too low to balance out these negative effects. Meier et al. (2012), who applied a statistical runoff model forced with a GCM-ensemble in the whole Baltic Sea Basin, also concluded that the climate effect was in their study larger than the effect of nutrient load reductions: even in the most optimistic scenario following the BSAP, reduction targets would not be achieved.

4 Conclusion

The results of this study demonstrate that both climate change and the level of intensity of agriculture have a pronounce effect on nitrate nitrogen loads from a small-scale Polish river basin to the sea in 2050s. In contrast, under the Business-As-Usual scenario, in which the major driving force is urban sprawl, simulated changes are negligible compared to current situation. Using vegetative cover in winter

[4] VC - *Vegetative cover in autumn and winter*, RA - *Avoiding fertilisation to risk areas*, BZ - *Buffer zones along water areas and erosion sensitive field areas*

and spring (i.e. catch-crops) would be the most efficient way to partly remediate negative effects of climate change and major shift in agriculture. However, even the most efficient combination of different measures would not mitigate these negative effects. On the other hand, major shift in Polish agriculture, following the Danish model, would bring significantly higher crop yields, at a major cost for water quality. Both climate and land use change until 2050 are very uncertain and scenarios used in this study are not comprehensive of all possible futures, hence future work should also focus on better understanding, reducing and quantifying this uncertainty.

5 Acknowledgements

This study was partly funded by the Baltic Compass project (part-financed by the European Union, within the European Regional Development Fund and European Neighbourhood and Partnership Instrument). The authors would like to acknowledge Halina Burakowska and Włodzimierz Krzymiński from the Institute of Meteorology and Water Management in Gdynia, Waldemar Mioduszewski from the Institute of Technology and Life Sciences in Falenty, Katarzyna Kotewicz and Katarzyna Jasińska from the Pomeranian Agricultural Advisory Board in Gdańsk, Sirkka Tattari from the Finnish Environment Institute, Henrik Eckersten from the Swedish University of Agricultural Sciences and Christen Duus Børgesen from the Aarhus University.

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Forecasting Civil Conflict under Different Climate Change Scenarios

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Abstract— Climate change is anticipated to increase societal vulnerability through a wide range of physical impacts that could adversely affect human health, economic development and resource availability. While it is unlikely that climate will have a direct effect on conflict, plausible causal mechanisms may link climate change to conflict through intermediate variables, such as economic growth. Here, we present an approach to produce forecasts of the onset and duration of civil (intrastate) conflict that are consistent with climate change scenarios. Our framework consists of the following elements: 1) statistical models based on existing data that capture how the physical impacts of climate change may affect conflict through indirect and structural variables with known risks for conflict; 2) scenarios for both socio-economic and climate change variables that are internally consistent and span the range of expected projections from present to 2100; and 3) a simulation approach that allow us to generate probabilistic forecasts of conflict at different resolutions and model emergent system behavior by incorporating variables that are endogenous to conflict. This work aims to improve the understanding of links between climate change and civil conflict as well as produce forecasts of future conflict burdens that are consistent with widely used climate change scenarios.

Index Terms— civil conflict, climate change scenarios, probabilistic forecasts

1 Motivation

Over the past decades, the world has observed a decline in armed conflict (Themnér and Wallensteen, 2012). The decrease in conflict has been ascribed to a number of factors, including economic growth, improvements in governance, demographic shifts such as lower fertility rates, and advances on human development indicators such as infant mortality and health. Despite the overall decline, some regions of the world still observe higher than average levels of civil (intrastate) conflict due to restricted economic growth, ethnic divisions and other risk factors, including resource and environmental stressors. The physical impacts of climate change are likely to interact with these underlying risk factors in ways that are poorly understood (IPCC AR4 SYR, 2007; Salehyan, 2008; Gleditsch, 2012). Rigorous and quantitative efforts to assess how these impacts may influence civil conflict, however, are relatively limited. To fill this gap, we first need to refine our understanding of the mechanisms by which the physical climate impacts may affect the onset and duration of conflict. Additionally, in the absence of mitigation, the physical effects of climate change are projected to intensify with unknown implications for civil conflict.

Thus, developing a framework to project what these mechanisms imply for future conflict burdens can provide relevant information to decision-makers about the need and effectiveness of potential interventions (Malone, 2012; National Academy of Science, 2012).

2 Research Objectives

In this paper, we outline the development of an integrated modeling framework designed to generate estimates of the likely onset, duration and termination of future civil (intrastate) conflicts under a range of socio-economic and climate change scenarios from the present to 2100. This framework consists of the following elements: 1) statistical models that aim to capture how the physical impacts of climate change will influence the onset and duration of conflict through indirect and structural variables which present known risks; 2) scenarios for both socio-economic and climate change variables that are internally consistent and span the range of expected projections; and, 3) a simulation approach that allows us to generate probabilistic forecasts at different resolutions as well as model emergent system behavior by incorporating variables that are endogenous to the conflict.

3 Developing an Integrated Modeling Framework for Climate and Conflict

3.1 Statistical Modeling of Conflict and Climate Change

The first step is to generate underlying statistical models of the onset and duration of conflict in a given country or region. The narratives of any given conflict are always complex; however, there is strong evidence supporting the significance of specific exogenous predictors on conflict. Our model takes the form of a relationship between conflict and primary socio-economic drivers (e.g. structural variables such as GDP and demographics) as well as conflict history and neighboring country conflict history. The predictors include population size, socio-economic development, demographic composition, education levels, oil dependence, ethnic cleavages, political and institutional features (e.g. weakened states) and characteristics of neighboring countries (e.g. Fearon and Laitin, 2003). The dependent variable is the incidence of conflict, i.e. whether conflict was present in the country and location in a given year. Conflicts, recent conflict history and neighboring conflicts are treated as endogenous and are coded from the UCDP/PRIO Armed Conflict Dataset (Themnér and Wallensteen, 2012). This datasets defines conflict as “a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths" (Gleditsch et al, 2002). The statistical model includes lagged dependent variables and interactions with predictors to allow predictors to have different effects on the risk of onset and duration of conflict. The model also includes information on the conflict state at earlier points in time. The use of incidence of conflict as well as a model for how conflict recurs sets our approach apart from other recent efforts. We make extensive use of out-of-sample evaluation to decide on issues of model specification such as functional forms or whether an explanatory variable should be included in our model.

We then add the climate interactions to the existing model of civil conflict onset and duration by focusing on the mechanisms through which the physical impacts anticipated from climate change will interact with the structural variables identified above. We conceptualize the association between climate and conflict as a two-step process where the physical impacts of climate change will interact with other known conflict predictors, thereby changing the underlying propensity for conflict. Our initial screening suggests five possible pathways from climate to conflict: 1) changes in economic growth; 2) changes in agricultural output through water availability; 3) changes in key human health indicators, namely infant mortality; 4) changes in migration patterns, and 5) changes in political legitimacy and institutional capacity (Buhaug et al., 2010; National Academy of Science, 2012). Thus, the physical impacts of climate change will not result in elevated conflict risks in all countries. This will depend on the country specific and contextual factors captured in the structural predictors. We will begin by developing these relationships with climate variables with strong historical records, namely temperature and precipitation. Recognizing that there are challenges in developing historical datasets, we hope to extend the number of climate variables to include, for example, water availability and natural disasters. Through this effort, we will continue to refine the list of climate variables and causal mechanisms, focusing on mechanisms where changes in climatic variables interact with known conflict predictors.

3.2 Scenarios for Socio-economic and Climate Change Variables

Recognizing that climate change is a long-term process, our approach requires scenarios that cover the present to 2100. We will start with the representative concentration pathways (RCPs) (Meinshausen et al., 2011). These pathways are based on end of century radiative forcing (RF) metrics and are designed to span the range of emissions scenarios in the literature. The RCPs supplant the previous scenarios documented in the Special Report on Emissions (SRES). Five shared socio-economic-ecological pathways (SSPs) are being developed to complement the RCPs (Moss et al., 2010). The SSPs make assumptions about the state of the global and regional society and ecosystems through 2100. These scenarios include storylines, quantitative estimates of key drivers, including future population, income, and urbanization. The general notion is that, in theory, any SSP can be combined with any RCP.

We will adapt and extend the information in these scenarios to the resolution needed for the statistical conflict model. This will provide consistency across the climate change impacts and socio-economic drivers as well as compatibility with other analyses in the impact assessment community. Corresponding to the statistical relationships that we outline in Section 3.1, we will start by producing forecasts of the best-resolved physical variables, such as temperature and precipitation, before extending our efforts to short-term shocks and natural disasters. We will also extend the SSPs as needed to incorporate the variables required for conflict forecasting. These scenarios and climate impacts will be analyzed in the Global Change Assessment Model (GCAM) run by the Joint Global Change Research Institute (JGCRI).

3.3 Simulation to Generate Probabilistic Forecasts of Civil Conflict

To model the future propensity for conflict, a novel simulation approach is required as some predictors are endogenous to conflict. In this approach, first, the statistical model and the distribution of the exogenous forecasted scenario variables are defined. Based on this distribution and the conflict history, the model estimates the risk of conflict in the first year of simulation and then randomly draws conflict outcomes based on these estimates. The procedure then updates the conflict history as well as any other variable responding to conflict, recalculates the risk of conflict for the next year, draws simulated outcomes, and repeats this process for the entire time period. This procedure is then repeated to even out the impact of individual random draws. To account for the uncertainty in our statistical estimates, this is repeated multiple times for individual realizations of coefficients based on the coefficient estimates and the estimated variance-covariance matrix. We start with the baseline conflict prediction model recently published by Hegre (Hegre et al., 2013). Presently, this model predicts changes in global and regional incidences of armed conflict for the 2010 – 2050 period. In the first iteration of the model, most drivers were treated as exogenous. We will modify this model to incorporate the new predictors and climate change mechanisms as well as their endogeneity.

4 Conclusions

The main product of the work is an integrated model for forecasting how civil conflict will evolve under climate change scenarios. While some of the claims linking climate change and civil conflict may appear alarmist, there is recognition in the security community that the evidence that links climate change to conflict is likely credible, if poorly resolved (National Academy of Science, 2012). There is also growing recognition that the associations between climate and conflict will be indirect and conditional. Our work will contribute directly to addressing this gap in the academic literature by conducting empirical work on climate change and civil conflict. In addition to improving the understanding of the underlying mechanisms, our forecasting effort will enhance decision-making for mitigating potential conflicts by providing critical information that can be used to take actions, allocate resources and identify opportunities for intervention. Finally, these efforts are also designed to produce estimates of conflict burdens that are consistent with widely used climate change scenarios.

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Generalized system services and structural vulnerability assessment as the foundation to systematically address climate change impacts

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Abstract— Climate change is expected to have severe impacts on various economic sectors due to both extreme events and gradual changes. In both cases, the sectoral climate impacts should be evaluated in terms of the services the sector provides (e.g. food production, energy supply). The system services description provided here consist of a description of the physical quantity being delivered (e.g. energy delivered, food produced) and of socio-economic criteria (e.g. prices, carbon emissions, land use), which both can be affected by climate change. For a vulnerability assessment, these system services and tolerable limits for all physical and socio-economic criteria are to be defined involving relevant stakeholder groups. This allows systematically addressing sectoral consequences of climate change and helps identifying related adaptation measures. In the future, this approach may also be applied to assess the dependencies between ecosystem services and socio-economic system services. These dependencies could be used to link biophysical impact studies with a quantification of impacts on human systems.

Index Terms— climate adaptation, energy systems, system services, resilience, vulnerability assessment

1 Introduction

The research project "nordwest2050 – Prospects for Climate-Adapted Innovation Processes in the Metropolitan Region Bremen-Oldenburg in Northwestern Germany" is one out of seven pilot projects on regional climate change adaptation funded by the research program "Creating Climate Change-Ready Regions" (KLIMZUG) of the German Federal Ministry of Education and Research. Besides the region as a whole, the project focuses on three business clusters: Energy supply, Food & Agriculture, Harbors & Logistics. The ongoing research process comprises five steps theory development, vulnerability aassessment, innovation potential analysis, innovation paths selection and implementation, roadmap generation. The main goal of the two analytical steps (vulnerability assessment and innovation potential analysis) was to identify the region's risks and opportunities in view of climate change with a focus on the three business clusters mentioned above. We will here report only on methodological aspects of the vulnerability assessment.

Since climate adaptation is embedded in complex sectoral development processes, it seems wise to harmonize sectoral climate vulnerability assessments with the analysis of structural weaknesses (or structural vulnerabilities). Even more so since climate change is by far not the only challenge for most of

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the economic sectors. This extension of the classical approach to climate vulnerability assessment is in line with the finding by Smit and Wandel (2006) that “successful climate change adaptation and vulnerability reduction is rarely undertaken with respect to climate change alone, and vulnerability reduction appears to be most effective if undertaken in combination with other strategies and plans at various levels.” However, most, if not all, of the climate vulnerability assessment studies focus on climate change impacts and do not systematically address the existing weaknesses of the system. By including this second layer of assessment one can achieve to improvements: a) get a clearer picture of the scale of the climate adaption needs in comparison to other threats to the system and b) find synergies between climate change adaptation and general improvements to system resilience.

Our methodological approach was also shaped by another defining characteristic of climate adaptation: the long time-horizons and the inherent uncertainties of the climate projections (especially on the regional scale) and their impacts. We thus decided very early in the project to focus our theoretical and methodological framework around the concept of ecosystem resilience (Holling 1973, 1986, 1996, Lovins and Lovins 1982). Ecosystems seem to have developed both, specific answers to specific events and threats, as well as structural provisions for unexpected or new challenges. While the resilience concept can be used to inspire adaptive solutions, it also carries the core of our assessment methodology: ecosystem services. With resilience being defined as the capacity to maintain system services in the face of external stress and internal failures, the focus of our vulnerability assessment became services, not structures. In this respect, our approach differs from a conventional vulnerability assessment in the sense, that the guiding question is “which system service is affected” and “can the syswtem adapt to maintain the service”. This has implications for assessing potential impacts, as well as for assessing adaptive capacity. Following this approach, adapative capacity lies also in the fact that the system has the potential to change its structure, as opossed to fortifying it.

In order to apply the methodlogical concept, we used technological models to estimate the quantitative potential impacts of regional climate change on regional energy infrastructure components, and we carried out a more qualitative analysis of potential impacts of regional and global climate change on the different parts of the regional energy system and its national and global supply chains. The findings from both approaches were then discussed with regional utility companies and stakeholders from politics, science and society, in order to assess the risks they perceive and their adaptive capacity. Due to space constraints, neither the quantitative nor the qualitative findings are presented here in detail. Some of them can be found in Gößling-Reisemann et al. (2013a), Wachsmuth et al. (2012) and in the full project report soon to be available on the project's website (www.nordwest2050.de).

2 Methodology

2.1 Vulnerability definition

Based on the distinction between external perturbations and internal stressors or weaknesses (see Introduction), we have differentiated the vulnerability assessment into two complementary parts (Gleich et al. 2010b). The *event based vulnerability assessment* (EVA) focuses on the external perturbations, the system's exposure to these perturbations and its adaptive capacity in view of these perturbations. The *structural vulnerability assessment* (SVA) focuses on potential internal weaknesses (but independent of any external perturbations) and on the adaptive capacity. This form of vulnerability assessment looks for components that could fail under stress and analyses how this failure would propagate through the system. Both forms of the vulnerability assessment are thus referring to perturbations or failures: externally driven in the EVA and internally driven in the SVA.

In agreement with a large part of the relevant literature (cf. Deutsche Bundesregierung 2008; Ekins et al. 2003; Isoard et al. 2008; European Commission 2009; Kropp et al. 2009; Stock 2005), we determine vulnerability in the EVA context as a function of exposure E, sensitivity S and adaptive capacity AC[1]: $V_E = f(E,S,AC)$. In the SVA context, we deviate from the current literature and vulnerability is then determined as a function of sensitivity and adaptive capacity alone: $V_S = f(S,AC)$, see Fig. 1.

[1] „In all formulations, the key parameters of vulnerability are the stress to which a system is exposed, its sensitivity, and its adaptive capacity" (Adger 2006, p. 269). A more detailed definition und operationalization of the climate change related EVA is given by Schuchardt et al. (2011).

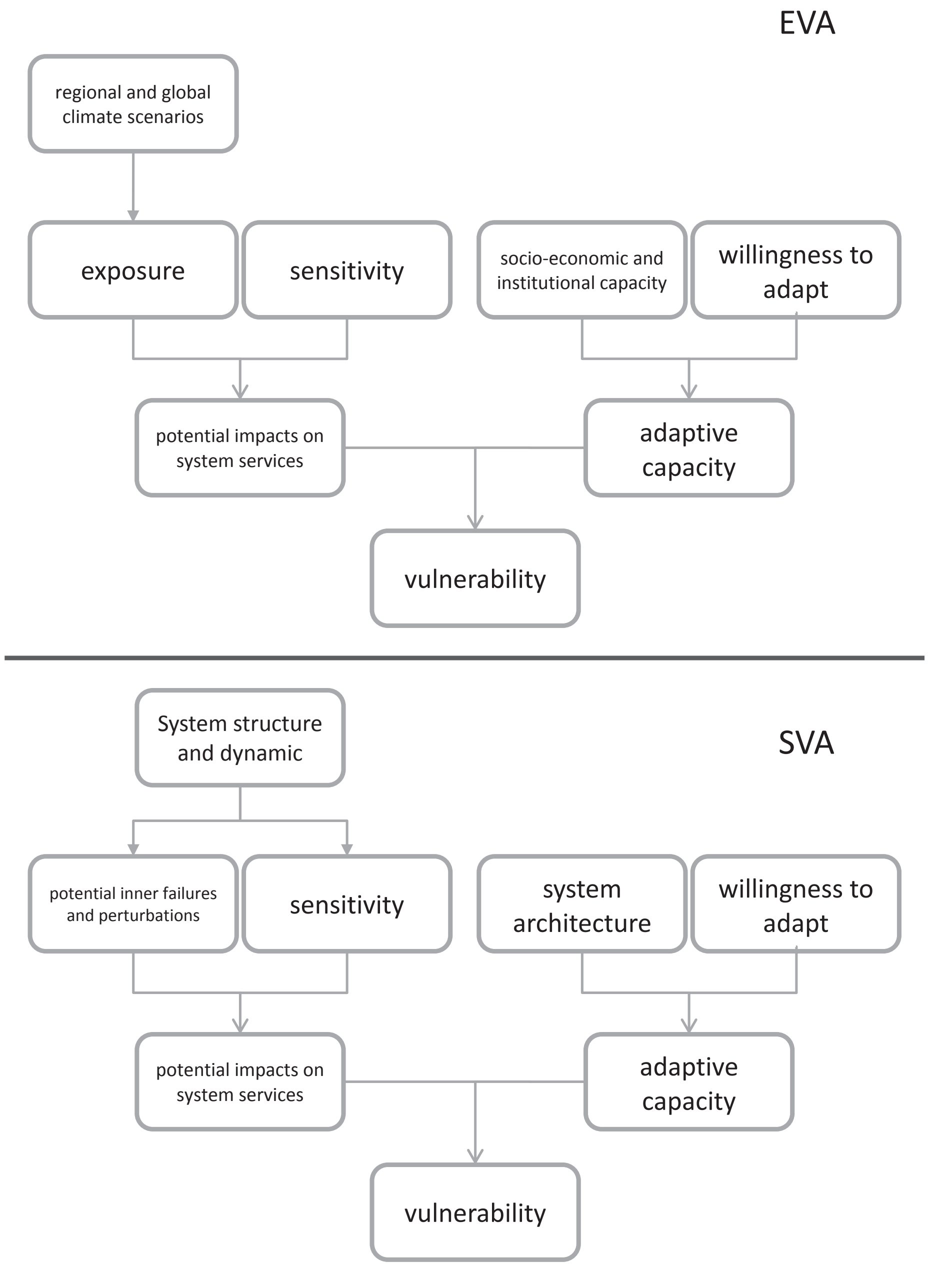

Fig. 1: Theoretical framework for the vulnerability assessment.
Source: Own representation based on Schuchardt et al. 2011 and Gleich et al. 2010b. Notes: EVA = Event-based vulnerability assessment; SVA = Structural vulnerability assessment

2.2 System services concept

Within the vulnerability assessment, system services are a central concept because potential impacts are evaluated against their effect on the services delivered by the system. For our purposes we have adopted and extended the well-known definition from the literature (MEA 2005, Banzhaf and Boyd 2007) to define generalized system services (cf Gößling-Reisemann et al 2013):

The system services of a (social-technical-economic-ecological) system consist of structures, products, goods or activities that are directly enjoyed or consumed by recipients and that have a technical or economic value to the recipient or otherwise increase their welfare.

The system services in this context are further characterized by a quantitative component ("what?" or "how much") and by a qualitative component ("how?"). Taking the provision of electricity as an example, the quantitative component is determined by the specific connected load agreed upon between user and supplier. The qualitative component is defined by two sets of parameters: by direct technical parameters (e.g. voltage level and frequency in this example) and by indirect parameters, like CO2 intensity, land use, socio-technical risks, and others, see Table 1.

Table 1: Example of the system service "electrical power supply" as used in the vulnerability assessment. For climate change impacts and structural weaknesses, the guiding question for the analysis is then: which criteria are affected to what degree?

What/How much	
Electrical power (as detailed by contract, e.g. 10kW guaranteed load)	
How	
Direct criteria	Indirect criteria
Frequency 50 +/- 0.2 Hz	Environmental criteria
Voltage e.g. 400 V +/- 10%	CO2-Footprint
Unavailability (SAIDI)	Nuclear waste
Location independency	Land use
	Economic criteria
	Costs/price
	Competitiveness
	Societal acceptance
	Risks

Note: Currently the SAIDI (System Average Interruption Duration Index) in the region is 5 minutes

The definition of the system services is thus explicitly dependent on the subjective view point of the "system user", and consequently the vulnerability of the system is intrinsically dependent on subjective or even normative value choices as well. We see this as an important point on the way to better understand and address the differences between interests of e.g. local governments, users and supply companies and to improve user involvement in the assessment. If and how a system is vulnerable is thus heavily dependent on the choice and weighting of the system services by the analyst. There is a danger that the vulnerability assessment is mistakenly interpreted as a purely objective scientific method, which is why we would like to openly address its intrinsic subjectivity. However, once the quantitative and qualitative criteria for the system services have been fixed, the vulnerability assessment for these system services can be carried out in an analytical way without further normative assumptions. For this article we take the quantitative and qualitative criteria for electricity and heat supply from Gleich et al (2010b) and focus on the analytical assessment.

2.3 Vulnerability assessment

The actual assessment of the regional energy system within the above mentioned project nordwest2050 was carried out along the supply chains of the main energy carriers: electricity, natural gas and district heat. The supply chains were followed back to the raw materials (for fossil based generation) or to renewable generation, respectively. In addition, certain energy end use aspects were also analysed, namely cooling services and demand side management. All assessments were based on various data sources: an extensive data search for describing the current situation of the regional energy system (power generation mix and diversity, length and type of networks, energy demand and profiles, etc), regional climate models evaluated for energy related indicators (e.g. heating degree days, cooling degree days, wind speeds, etc.), and technical models for specifying the direct impacts on potentially affected infrastructures in the region (power plants, wind energy convertes, photovoltaic modules, demand profiles, networks, etc.).

For linking the supply chain analysis with our overall vulnerability concept based on system services, we assessed for each stage in the chain, whether exposure and sensitivity could result in substantial impacts either on the quantitative supply with the respective energy carrier itself or on the respective quality criteria. The most transparent way to assess whether an impact on a system service is substantial or not would have been to set tolerable limits for all quantities and quality criteria of this system service, where the limits would have to be set involving the relevant stakeholder groups. This was not possible in the context of this study. Therefore, the classification of an impact as "substantial" was qualitative with the values "low", "medium" and "high", based on a comparison with the relevant literature, technical specifications, our own judgment and that of the experts from the Bremer Energieinstitut (cf. Gabriel and

Meyer 2010). **Potential impacts on a stage in the supply chain were rated as**

- **low** if neither the actual supply (quantity criterion) of the potentially affected service nor the services' quality criteria would be affected substantially,
- **medium** if the actual supply (quantity criterion) of the service was not affected, but at least one of the services' quality criteria would be affected substantially,
- **high** if the actual supply (quantity criterion) of the service would be affected substantially.

To determine the adaptive capacity potential, we first identified adaptation measures for each supply-chain stage. Here it is important to determine when and to which extent the identified adaptation measures can be implemented. In addition, we considered the potential for implementing adaptation measures in the form of the affected suppliers' and / or users' willingness to adapt. Part of this assessment stage was a check, whether the implementation of an adaptation measure could be hindered or even be prevented by economic and regulatory constraints or the decisions of certain key stakeholders. For example, the decision on certain measures within the operation of the electricity grid is solely taken by the network operators subject to regulatory constraints. In this case, this results in a low adaptive capacity. As before, we assessed the adaptive capacity qualitatively with the values "low", "medium" and "high", based on the literature review and interviews with experts: **The adaptive capacity of a supply-chain stage was rated as**

- **low** if neither an adaptation measure to avoid the potential impacts nor the willingness to adapt of the concerned supplier and / or user is given,
- **medium** if either an adaptation measure to avoid the potential impacts or the willingness to adapt of the concerned supplier and / or user is given,
- **high** if both an adaptation measure to avoid the potential impacts and the willingness to adapt of the concerned supplier and / or user is given.

In a final step, we combined potential impacts and adaptive capacity to evaluate the climate change related and the structural vulnerability for each supply-chain stage. A low adaptive capacity leads to a vulnerability rating one level above the rating of the potential impacts. A high adaptive capacity, accordingly, leads to a vulnerability rating below the rating for the potential impact, and an average adaptive capacity results in a vulnerability rating the same as that of the potential impacts (see Table 2).

Table 2: Scheme for determining the vulnerability from potential impacts and the adaptive capacity

Potential Impacts	Adaptive Capacity	Vulnerability
Low	Low Medium High	Medium Low Low
Medium	Low Medium High	High Medium Low
High	Low Medium High	High High Medium

This aggregation is based on the following logic: Even if there is a high adaptive capacity, it should be monitored whether high potential impacts are, indeed, remedied. And if no adaptation measure is available, it should be monitored whether potential impacts expected to be low, indeed, turn out to be low. In general, we propose the following interpretation of the vulnerability levels: **If the vulnerability of a supply-chain stage is rated as**

- **low**, then there seems to be no need for further action,
- **medium**, then the magnitude of the potential impacts should be monitored carefully and measures to increase the adaptive capacity should be considered,
- **high**, then measures to reduce possible impacts and to increase adaptive capacity in the supply-chain stage should be addressed in any case.

3 Results from the vulnerability assessment

There is only limited room here for presenting results from applying the methodology laid out above. We therefore restrict ourselves to summarizing the results, see Table 3, and discuss them only exemplary.

Table 3: Potential impacts, adaptive capacity and vulnerability in the MPR's energy sector

	Primary energy				Grid-bound energy / distribution			Demand / Applications	
	Coal	Gas	Wind	Biomass	Electric.	Gas	Heat	Cooling	DSM
Pot. impacts (climate)	Low	Low	Low	Medium	Medium	Medium	Medium	Low	Medium
pot. impacts (stuctural)	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium
Adaptive capacity	Medium	Medium	High	Medium	Medium	Medium	Medium	Medium	High
Climate Vulnerability	Low	Low	Low	Medium	Medium	Medium	Medium	Low	Low
Structural Vulnerability	Medium	Medium	Low	High	High	Medium	Medium	Medium	Low

Source: cf. Gößling-Reisemann et al (2013b).

Quite generally we can conclude that the climate change based vulnerabilities of the analysed supply chain elements are lower than the structural vulnerabilities. A prominent example is the provision of electrical energy from thermal power plants. They will be affected by increasing heat waves in the summer and possibly lower cooling water availability, combined with increasing mid-day peaks in the summer due to increased air conditioning and cooling loads. However, their vulnerability is low because of the foreseeable development of new power plants in the region being equipped with closed loop cooling (cooling towers) and the advent of alternative cooling and air-conditioning technologies (cooling with waste heat and geothermal cooling, for example). The structural vulnerability, on the other hand, is comparably higher for several reasons. Firstly, the diversity of the regional electricity generation is still rather low: after the shutdown of the only nuclear power plant in the region, regional generation mainly consists of coal based power plants and wind energy converters. The Shannon diversity index of the electricity generation is only 1.25, compared to 1.71 for Germany. Secondly, the structure of the regional electricity supply is heavily dependent on political frameworks and decisions that have been subject to heavy changes in the past and are very difficult to foresee at the moment, increasing the possibility of future bottlenecks and long-lasting path dependencies. Thirdly, the market structure for electricity generation is characterized by unflexible mechanisms, currently not allowing for the efficient integration of a growing share of intermittent generation. Fourthly, there is a borad range of unsettled conflicts around renewable and non-renewable electricity generation and distribution, from land-use conflicts between biomass production and food production to conflicts around the permitting schemes for new distribution and transmission lines.

In summary, while for most of the potential climate based impacts there exist technical or organizational solutions, which are either already in the planning phase or at least known to the actors in the field, this is not so for the structural weaknesses. Thus, the structural vulnerabilities of the regional energy system are higher throughout all the supply chain elements.

4 Conclusion

Learning from the vulnerability assessment, it seems wise to combine the necessary climate change adaptation with measures that increase the system’s overall capabilities to react to disturbances, manage uncertainty and at the same time maintain its services in quantity and quality. Innovative solutions have to be found that address the mentioned conflicts between stakeholders along the supply chain, while at the same time reconciling the seemingly opposing goals of energy supply security, ecological sustainability, social acceptance, and economic viability, and, as if this would not be enough, also make the system flexible and adaptive to handle surprises and uncertainties. Within nordwest2050, we are currently developing innovation paths centered on the idea of “resilient energy systems”, i.e. a regional energy system which not only is sustainable, but also fit to survive the foreseeable and many of the non-foreseeable future perturbations and turbulences. With similar approaches used in the other sectors in the region, the final goal is then to combine the analytical insights and practical experiences into a roadmap towards a more resilient Metropolitan region Bremen-Oldenburg.

The combinations of the climate based with the structural vulnerability assessment has proven to be very helpful in identifying solutions that address the long term needs of adaptation with the currently needed fixes for the weaknesses of the system. However, the methodology is not easily applied: it involves the development of accepted criteria for the system services’ quality aspects, an indepth analysis of the supply chain of the system services (a necessary step also to capture the non-regional climate impacts), expert support, reliable regional climate models and impact models for technical systems. Without the help of regional stakeholders, the assessment is probably not possible, especially not regarding the structural vulnerabilities. In particular, the assessment of the adaptive capacity within the supply chain elements can only be assessed when regional stakeholders can be actively engaged in the assessment. In our project, we found climate models and technical models to be helpful in engaging stakeholders.

In principle, the above described methodology should be transferrable to other economic sectors and regions without much change. The transferability will, however, hinge on finding an adequate definition of the sector specific system services. For systems delivering technical services, like gas, water, energy systems, this seems straightforward. It will probably get trickier for sectors with more complex services, like the agricultural and food sector (with its cultural co-services) or the health sector.

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Modelling Potential Impacts of Land-Use Change on BVOC-Emissions by Bioenergy Production in Germany

Rüdiger Grote, Edwin Haas

Abstract— Due to the rising energy demand from regenerative sources, short rotation plantations for biomass production are increasingly established in Germany and other European countries. Using species such as poplar or willow yields similar amounts of biomass than planting herbaceous species. However, in contrast to most agricultural and forest species, woody plantations emit large quantities of isoprene. Since isoprene is highly reactive and participates in photochemistry and aerosol formation, this may well have an impact on regional air pollution pattern or weather conditions. However, the potential quantities and their regional distribution that might be expected have not yet been explored.

We carried out a simulation study with a combined ecosystem – emission model in order to estimate the amount of isoprene emitted if poplar plantations if poplars would be planted on all areas currently used for agricultural production in Germany (about 12 Mha). As input we used the soil properties database developed by the EU integrated project NitroEuope and the interpolated climate data from 2000 to 2005. In order to be more realistic, we then differentiated this area into site productivity classes and selected the 10 (or 35) % of the sites that are least suitable for growing food.

The results show that the emission increase due to an extensive replacement of agricultural area and grasslands by poplar plantations is reaching a magnitude which can be expected to impact air pollution, i.e. to increase aerosol formation that are possibly affecting local weather pattern in turn. The effect is particularly high in hot summers because emissions increase exponentially with temperature. The emission increase is generally higher in the South and East of Germany. If restricted to the 35 % of least productive sites, the additional emissions would occur predominantly in northern Bavaria, Hesse and Saxony, partly in the vicinity of large anthropogenic emission sources. Thereby the results indicate the importance of future research to investigate the air chemistry impacts, feedbacks on vegetation, and regional climate responses, particular with respect to the spatial distribution of plantations.

Index Terms—Isoprene Emission, LandscapeDNDC, Short-Rotation Cropping, Poplar Plantations

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1 Introduction

According to the German Energy Transformation plan (Nitsch et al. 2010) a considerable land-use change is envisaged in order to increase the bioenergy production from about 800 to 1200 PJ a^{-1}. Part of this plan is to enlarge the area of short rotation coppice (SRC) from app. 10 kha today to 1 Mha in 2030. Estimates of potential area suitable for SRC are up to 2.2 Mha, approximately 35 % of total agricultural area incl. pastures (Aust 2012). The suitable species comprise poplar, willow or black locust all of which are exceptionally high isoprene emitters. Isoprene in turn is a major partner in photochemistry reactions that lead to ozone formation, is responsible for methane degradation, and takes part in the development of secondary aerosols (Claeys et al. 2004). However, the question if the expected land-use change may have an impact on air chemistry that is able to affect regional air quality or even weather patterns is largely unsolved.

Simulating isoprene emissions requires considering crown length, stand density, phenology and other growth stress factors such as drought that all affect the emission per area ground. For SRC, these factors cannot be kept constant since their development is very dynamic and also varies with site productivity. Therefore, we choose to employ a coupled ecosystem – emission model that calculates leaf area development and distribution as well as isoprene emission based on micrometeorological conditions, nitrogen- and water availability. Such an approach accounts not only for direct effects of site conditions (e.g. temperature) on the emission rate, but also for indirect effects such as a slow leaf area development and and less ground coverage due to smaller plant growth rates.

The model employed is the LandscapeDNDC model (Haas et al. 2012), which has been parameterized for hybrid poplar and applied on regional scales already (Werner et al. 2012). It is also equipped with model routines that estimate biogenic emissions of volatile organic compounds, especially isoprene, in dependence on temperature, radiation, seasonality, and drought.

2 Methodology

Within the LandscapeDNDC model the PSIM ecosystem module and the BIM (biochemistry isoprenoid model) module for biogenic emissions (Grote et al. 2006, 2009) have been employed. Parameters are taken from former publications with the same combinations regarding growth (Werner et al. 2012) and emissions (Behnke et al. 2012). Initialization is based on the European modelling database developed within the NitroEurope project (http://www.nitroeurope.eu) as used by Werner et al. (2012) and Cameron et al. (2012). The database consists of soil, land-use, climate, and management information based on NitroEurope Calculation Units (NCUs), spatial units of land with common soil or climatic conditions, comprising Germany from the full NitroEurope spatial database (data source: http:// afoludata.jrc.ec.europa.eu/index.php/experiment/detail/2) into 1442 polygons with contribution of agriculture. Although only NCUs are considered that contain arable land, many of these polygons also include other land-uses, including grasslands and forests. It should be considered therefore, that the coloring in Figures

3 and 4 is overemphasizing the simulated area since the whole plot is colored independent of the share of agriculture it contains.

Soil properties include organic carbon, clay content, soil pH, bulk density, and rooting depth which all were provided for different strata. Poplar saplings were initiated with 10,000 saplings per ha and 0.5 m initial plant height. Daily minimum and maximum temperature and precipitation data were provided for further calculations. Annual nitrogen deposition was applied as wet deposition (e.g., during rainfall events). No additional nitrogen fertilization was considered. To limit short-term climatic effects on the simulation outcome, we simulated biomass yields and isoprene emissions from short-rotation (6 years) poplar plantations for the time slice 2000–2005. The time step for all model processes is daily, except for photosynthesis and isoprene emission which are calculated hourly using temperature and solar radiation values derived from daily data.

All locations were ranked according to precipitation (precip), cumulative temperature during the vegetation period (=growing degree days, GDD) and soil organic carbon (corg) and an suitability index was calculated to characterize the site according to common agricultural practice: the P index (low: less suited for agricultural biomass production, high: well suited for biomass production):

$$P - index(0,1\ldots) = \frac{\frac{Precip}{Precip_{max}} + \frac{GDD}{GDD_{max}} + \frac{Corg}{Corg_{max}}}{Precip_{max} + GDD_{max} + Corg_{max}} \tag{1}$$

where: Precip = average annual precipitation, Corg = organic carbon content in topsoil. Max is maximum value of a given parameter for all calculation units located in Germany. This index is used to characterize marginal and high productive sites (which are likely to be used for food production also in the future) from the total dataset. Marginal sites are assumed to comprise the 35 % of sites (2.3 Mio ha-1) with the lowest P index.

3 Results

We analysed the simulation results according to basic relations between emissions and climate, seasonal developments and differences between years, and spatial distribution of annual emissions. Firstly, annual emission for each site and each year is plotted against GDD and precipitation in different years over all sites (Fig. 1). While the positive relation to temperature (top) is expected, the slightly negative relation to precipitation (bottom) indicates that total incoming radiation (which increases with decreasing precipitation) is more important than water supply. In fact, only the 2 % of sites that have a water holding capacity of less than 100 mm show a decreased annual growth and emission (not shown).

Fig. 1 also shows that the relation between emissions and climate is different in the first year of the simulation (2000) than in the following ones (shown only 2003 and 2005). This is due to the fact that the stand is not closed in the first year and the leaf area is not reaching the full potential (LAI of app. 4). Only at very few sites this difference still persists in the second year when trees have mostly reached a height larger than 3 m. Thus, for judging the site impact between years and sites, the first year is not used.

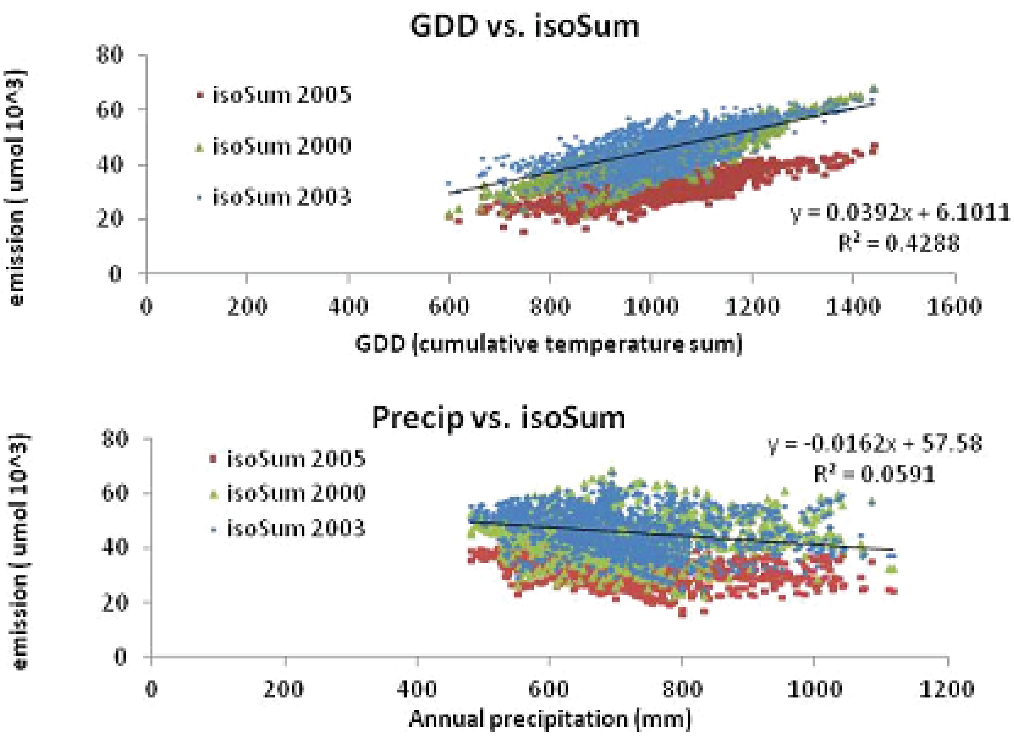

Fig. 1: Statistical relationships between environmental conditions and annual isoprene emission sums. Top: Growing degree days (GDD), bottom: Annual precipitation (Precip). Emissions of different years are presented in different colors.

The temporal distribution of emission varies with the temperature development of a year (Fig. 2). Therefore, it is generally highest in mid-summer and drops steeply towards the end of the vegetation period. The distribution is affected by the particular temperature pattern during the year, e.g. a warm period in autumn has postponed the decline in the year 2001, but can also be reduced during extreme drought periods such as in summer 2003, where emissions where highest in June and August.

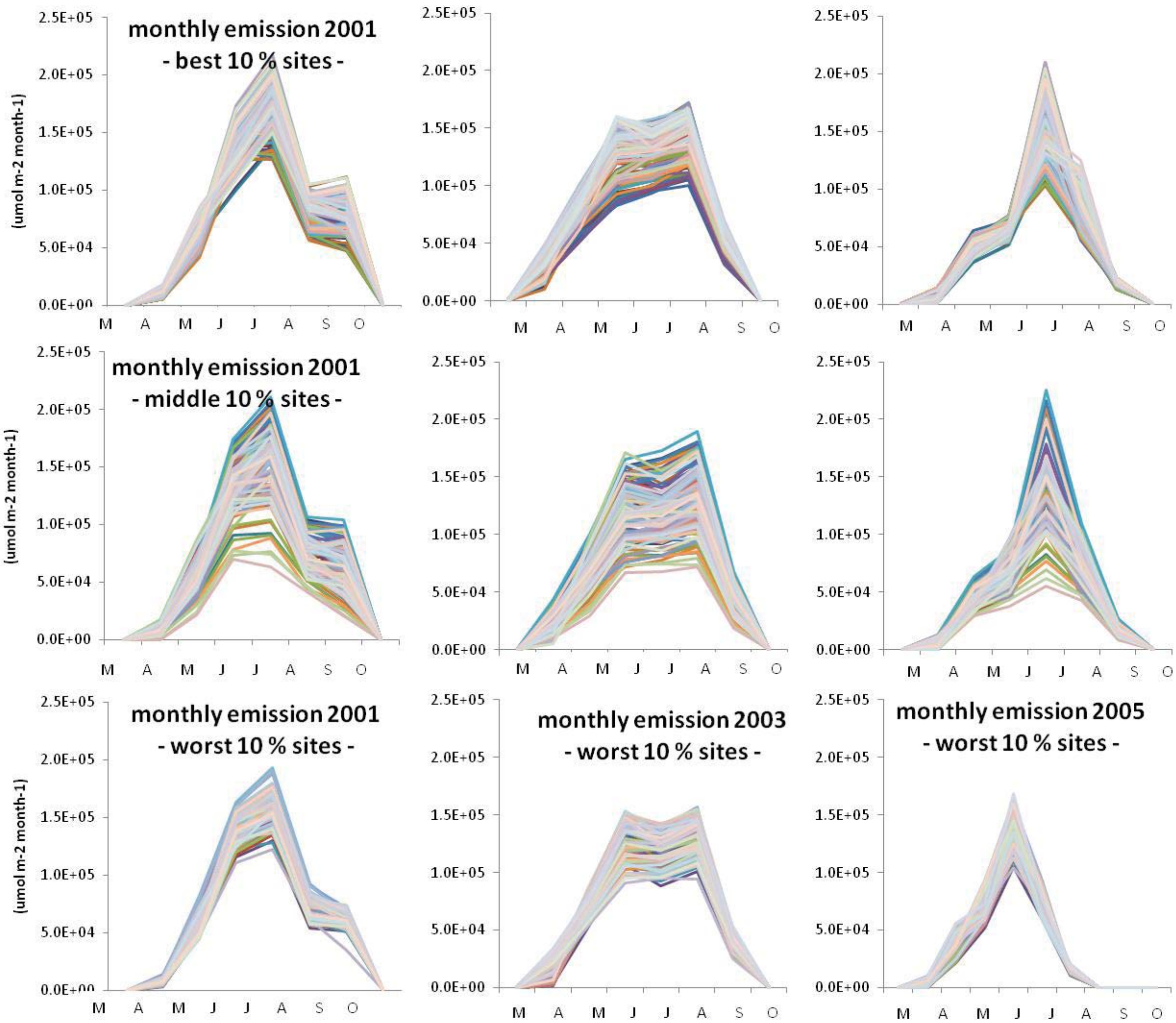

Fig. 2: Seasonal distribution of isoprene emission for 30 % of the investigated sites during three different years. Columns represent the different years 2001 (left), 2003 (middle), and 2005 (right). Rows represent emissions at sites with different site quality according to P-index valuation, showing sites of highest production (top), middle and smallest productivity (middle and bottom).

There are only small differences in the emission rates at sites of different agricultural suitability. However, the variation of emission within the top and worst 10 % sites (according to P index distribution) is considerable less than for the middle 10% of the sites, indicating a larger span of possible site condition combionations within this group. In addition, it is apparent that at the worst 10 % sites, cool yeasrs (2005) lead to shorter vegetation periods and thus to less spring and autumn emission than in the better ranked groups.

The regional distribution of emissions (Fig. 3) shows that an extensive replacement of agricultural area by SRC would increase isoprene emissions particularly in the Rhine valley, in Bavaria, and in Eastern Germany (Brandenburg, Saxony). This greatly corresponds with radiation and temperature distribution. As already apparent from Fig. 2, the cool conditions in spring and autumn also result in less total emissions per year compared to warmer years such as 2001 and 2003. , potential emissions rates would be very high in the vicinity of Berlin, Munich and Stuttgart, some of Germany's largest cities. This pattern changes a bit, if the land-use change is restricted to the areas with the lowest 35 % agricultural production (Fig. 4). In this case, eastern German emissions are largely decreased, while emissions still concentrate in Northern Bavaria, Hesse, and Saxony. Thus, considering only the most likely regions for SRC, emissions still concentrate in the vicinity of some large cities such as Leipzig and Frankfurt.

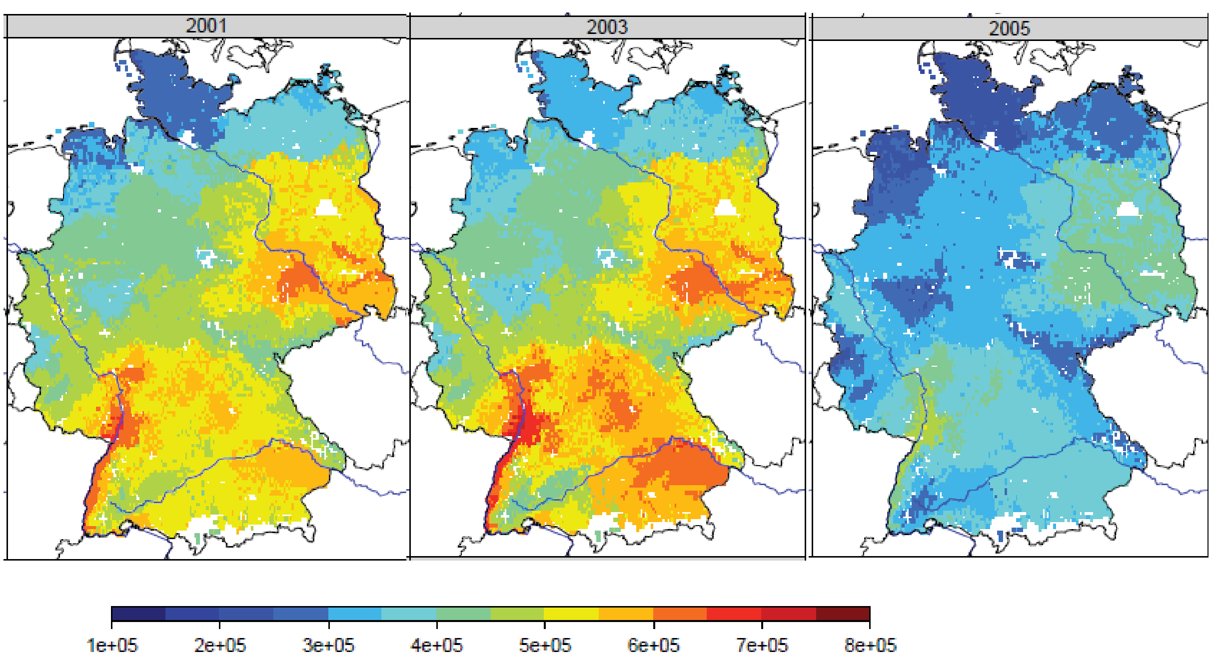

Fig. 3: Potential isoprene emission (µmol m^{-2} a^{-1}) inventory for three different years based on poplar short-rotation plantations fully covering the area of Germany.

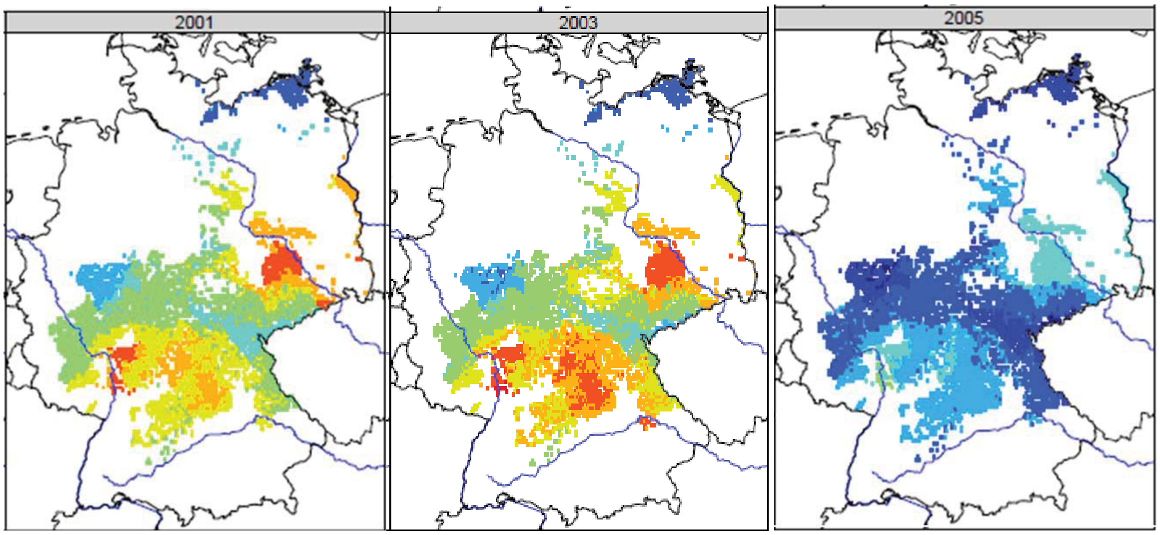

Fig. 4: same as Fig. 3 (including scale) but only the 35% marginal sites presented.

4 Discussion

Since it is expected that climate change will lead to higher temperatures so that summers similar to that in 2003 will occur much more frequently (Schär 2004), future environmental conditions will also be much more favourable for isoprene emission. At the same time it is envisaged to convert large areas currently occupied by low-emitting crops, grasses and herbaceous species with fast growing poplar (and other) plantations known as a high isoprene emitter. It remains an open question, to which degree and where this will actually happen. Besides site productivity other aspects such as topography and nature protection might need to be considered (Aust 2012). Nevertheless, a significant land-use change into SRC will inevitably lead to increased biogenic emissions. Our analysis – disregarding all simulation uncertainties – shows that at least some of the areas likely to be used for this change will be close to densely populated regions, where high NOx emissions provide the second ingredient for ozone formation.

Given the important role that isoprene plays in photochemistry and ozone production, future investigations should concentrate on the mechanisms that affect air quality – with potential impacts on human health and plant productivity. Using high resolution inventories and models that account for the direct microclimatic as well as indirect growth effects on emission such as LandscapeDNDC, the most important environmental impacts can be considered. The model is not restricted to geographical range or vegetation type as long as basic physiological parameters for the plant species in question are known. Also other emissions can be estimated, i.e. monoterpenes for storages or direct production and extreme drought events that might cut down the carbon and enrgy supply needed for the emissions can be considered (Grote et al. 2010). Further developments will be directed to also provide air chemistry feedbacks from CO_2 or ozone.

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Adaptation measures for the impact of climate change on global water resources—Option 2: Adding storage capacity

Naota Hanasaki, Yoshimitsu Masaki, Takahiro Yamamoto

Abstract—To reduce the projected damage of climate change, it is necessary to undertake adaptation measures. We conducted a global hydrological simulation to estimate how much additional water storage must be installed to adapt to the changing climate. The results suggest that if all land grid cells had water storage of 0.1% of local annual runoff, the water stress index would be almost stabilized at the same level as the base year (2000).

Index Terms— Adaptation, Climate change, Reservoir, Water

1 Introduction

Water is indispensable for most human activities. To reduce the projected damage of anthropogenic climate change, it is vital for workers in the water sector to undertake adaptive measures. Hanasaki et al. (2012a,b) conducted a global water scarcity assessment under the latest global climate change scenario (RCPs, CMIP5, and SSPs), taking into account daily variations in water availability and use. They found that water scarcity would increase in many parts of the world, even as global mean runoff increased, if no adaptation measures were taken. This suggests that water availability would not increase as needed because of the seasonality of river flows and water use. Here, we analyze how much additional water storage capacity is needed to stabilize the level of water scarcity globally throughout the 21st century.

2 Methods

We used the same model setup as Hanasaki et al. (2012a,b), but we added a new imaginary reservoir that can store local runoff to each grid cell of the model (note that this is different from individual large reservoirs of their model). Water stored in the reservoir could be used for municipal, industrial, and irrigation water when rivers are depleted (Fig. 1). In this simulation, the storage neither leaks nor evaporates, and it is used only for water supply. The concept of this modeling is described in detail in Hanasaki et al. (2010). We conducted five simulations in total. The NOADP simulation, which was identical to the original simulation, had no imaginary reservoir. In the ADP1, ADP2, ADP3, and ADP4 simulations, the storage capacity of the imaginary reservoir was set at 0.01%, 0.1%, 1%, and 10% of the annual total runoff of each grid cell (i.e., the global spatial distribution of water storage capacity was identical to that of annual total runoff), respectively.

Hanasaki et al. (2012a,b) performed simulations for as many as 30 combinations of various scenarios (five socio-economic scenarios, scenarios with/without climate policy, and three global climate models). Here, we used the SSP1 socio-economic scenario, a With Climate Policy, and the MIROC-ESM-CHEM model. This combination depicts a sustainable world, and the growth in future water use is at the lower end of all combinations. The climate policy assumes that world GHG emissions take the path of RCP2.6, which is the lowest of the scenarios.

Water scarcity was assessed using a Cumulative Abstraction to Demand (CAD) index. This was expressed as

$$CAD = \sum a_{DOY} \Big/ \sum d_{DOY} \quad (1)$$

where a_{DOY} and d_{DOY} denote the daily water abstraction and Day Of Year demand, respectively. Note that the condition $a_{DOY} \leq d_{DOY}$ is always satisfied. ∑ indicates summation throughout a simulation period. The index ranges between 0 and 1. A value of 1 indicates that water is sufficient throughout a simulation period, and 0 indicates the opposite. CAD enables us to detect sub-annual (e.g. seasonal) water shortage. This is important because the future temporal variation of precipitation is projected to increase due to climate change, and water storage fills the seasonal gap of water availability and use.

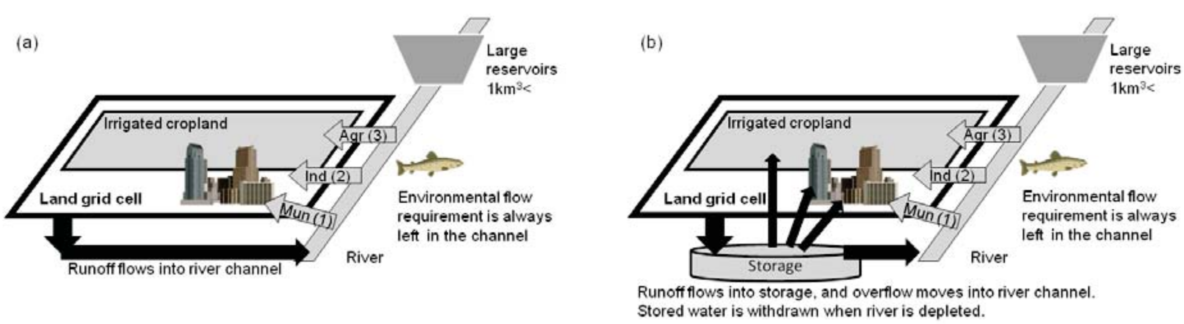

Fig. 1 Schematic of the water abstraction used in this study. Water abstraction of (a) Hanasaki et al. (2012a,b) which relies on rivers only, and (b) this study.

3 Results

Table 1 shows a summary of the simulations. In the base year (circa 2000), the water-stressed population, i.e., the population living in grid cells under the condition CAD < 0.5, was estimated at 2147 × 10^6. In the case of NOADP, the water-stressed population increased to 2804 × 10^6 during 2041–2070 and 2499 × 10^6 during 2071–2100. The addition of imaginary storage drastically decreased the water-stressed population globally. ADP1 succeeded in stabilizing the stressed population during 2071–2100, and ADP2 achieved this by 2041–2070. ADP3 and ADP4 further decreased the stressed population compared with the base year.

NOADP increased the potential water demand globally compared with that of the base year (1314 km^3 yr^{-1}) due to expansion of the irrigated area and growth of the population and economy (see Hanasaki et al., 2012a). Because additional water storage does not affect potential water demand, the demand of ADP1-4 is identical to NOADP. The ratio of actual water withdrawal to potential water demand drastically increased due to additional storage.

Table 1. Results. The upper and lower lines show results for 2041–2070 and 2071–2100, respectively.

	Base year	NOADP	ADP1	ADP2	ADP3	ADP4
Imaginary storage [km^3]	0	0	6	60	596	5960
Stressed population [$\times 10^6$]	2147	2804	2453	2121	1704	944
		2499	2196	1916	1522	872
Potential water demand (P) [km^3/yr]	1314	1505	1505	1505	1505	1505
		1631	1631	1631	1631	1631
Actual water abstraction (A) [km^3/yr]	568	603	617	660	737	926
		636	652	696	774	974
Ratio (A/P) [%]	43	40	41	44	49	62
		39	40	43	47	60

Fig. 2 shows the distribution of change in CAD. In NOADP, the CAD decreased (i.e., the water scarcity increased) in many parts of the world, particularly in the African continent. This is attributed to hydrological change due to climate change and increase in water use due to socio-economic change. Additional storage capacity increased the CAD substantially. The ADP1 added only 0.01% of the local total runoff, but it substantially increased the CAD in lower latitudes. In these regions, except South and South-East Asia, the mean annual runoff is high, and water use is comparatively low. Excess water in wet seasons is carried over by the imaginary reservoirs, effectively reducing water scarcity in dry seasons. However, there is no effect in dry regions such as Northern Africa, the Arabian Peninsula, Western North America, and Central Asia. Because of the low local total annual runoff, the additional storage did not contribute to the comparatively large amount of water demand in these regions. It would be more practical if the additional storage capacity was added to regions with strong inter-annual and inter-seasonal variability of runoff: stored water would be effectively carried over for drought years and seasons. In the case of ADP3 and ADP4, in almost all regions, the change in CAD became positive.

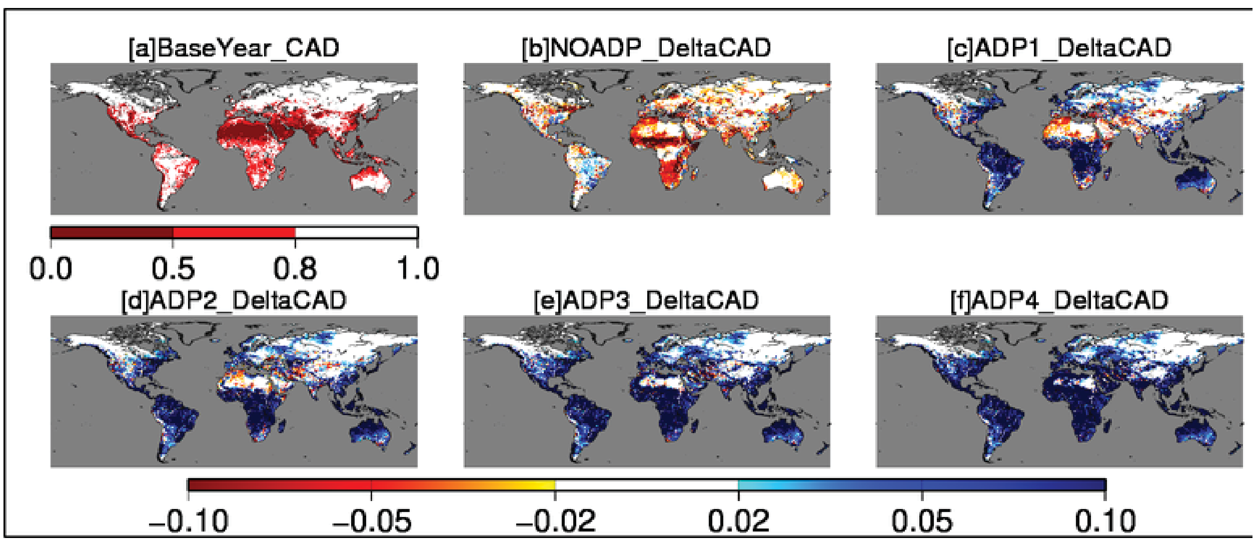

Fig. 2 (a) Distribution of CAD in the base year (2000). (b) Distribution of change in CAD for (b) NOADP, (c) ADP1, (d) ADP2, (e) ADP3, and (f) ADP4 in 2041–2070.

4 Discussion and Conclusion

The results suggest that an additional storage capacity of 0.1% of annual total runoff eases the additional water scarcity induced by climate change. Many reports have been published on the impact of climate change in the water sector, but less work has been done on adaptation strategies. This study quantitatively analyzed how much additional water storage is needed to adapt to climate change.

Because this study is a first step, readers need to be careful of the following three points. First, the storage discussed in this study is ideal. The storage is placed in all grid cells, neither leaks nor evaporates, and is used only for water supply. Moreover, the reservoir can collect runoff and distribute water everywhere within a cell, which is not physically possible. For water storage facilities in the real world, the capacity would need to be greater because of the above-mentioned losses. Second, a single index, namely the global total water-stressed population according to CAD, was used to evaluate adaptation in this study. As shown in Fig. 2, the effect of adding storage varied by region. Further spatial and temporal details are needed. Third, we focused on consumptive water use in this study. Water withdrawal is several times higher than consumptive water use, so additional water may be needed. These points will be tackled in forthcoming papers.

5 Acknowledgement

This research was supported by the Environment Research and Technology Development Fund (S-10) of the Ministry of the Environment, Japan.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Detection and attribution of climate change impacts – is a universal discipline possible?

Gerrit Hansen, Daíthí Stone, Maximilian Auffhammer

Abstract— In the context of impacts research, detection and attribution exercises evaluate whether aspects of human and natural systems are changing in response to the impetus of climate change. Concepts and methods for detection and attribution have been established in the physical science community, evaluating changes in the climate system due to anthropogenic forcing. In contrast, a conceptual framework for detection and attribution of climate change impacts that is consistent and applicable across disciplines is still lacking.

In an attempt to overcome this methodological deficit, this paper outlines the major challenges involved in and provides workable definitions of detection and attribution in the context of impacts. Reaching beyond the current focus of the literature on hydrology and ecological effects, it sets a focus on challenges that are inherent in the particular dynamics of human and managed systems, including non-stationary baseline behaviour, multiple drivers, and active adaptation.

Index Terms—Detection and Attribution, Human and Managed Systems, Multiple drivers, Confounding Factors, Observed Impacts of Climate Change

1 Introduction

In the context of climate change impacts, detection and attribution (D&A) exercises evaluate whether aspects of human or natural systems are changing in response to the impetus of climate change. Detection and attribution of impacts has evolved within a framework originating from physical climate science, which uses concepts and methods established for detection of a change in climate, and its attribution to anthropogenic forcing (IPCC 2010). Studies explicitly attributing observed impacts to anthropogenic forcing are very rare, and limited to freshwater resources (e.g., Barnett *et al.*, 2008; Hidalgo et al. 2009; Min et al. 2011), and ecosystems (e.g., Parmesan and Yohe 2003; Rosenzweig et al. 2008; Poloczanska et al. 2013). The latter mostly rely on spatial pattern analysis based on a wide range of regional and local impact studies that document responses to observed climate trends (see Rosenzweig et al. 2007).

In order to extend D&A analysis to other impact systems, particularly those directly involving humans, manifold challenges remain at a conceptual level, including terminology, the consistency and transferability of metrics, types of evidence, the treatment of confounding drivers and the interpretation of event attribution. The following discussion will focus on D&A in the context of human and managed systems, and adopt the definitions of detection and attribution proposed in Stone et al. (2013),

- Detection addresses the question of whether a system is changing beyond what might be considered normal behavior in the absence of climate change,
- Attribution addresses the question of whether climate change has contributed substantially to the detected change in a system.

Note that in practice, detection and attribution may not be mutually separable, given that both detection of a change, and the evaluation of cause and effect must be based on explicit examination of all drivers of change in the system.

2 Non-stationary baselines and expected system behavior: Detection

In the context of human and managed systems normal system behavior is mostly non-stationary, and can be measured in the form of changing means (e.g. trends) or changes in variability (e.g. changing variances). In order for an impact to be detected in such changing environments, the outcome of interest has to have departed from expected "normal" behavior in a way consistent with a response to climate change (see figure 1). For many natural systems, the question arises if normal behavior is defined as an idealized pristine state, or includes alterations due to human influence.

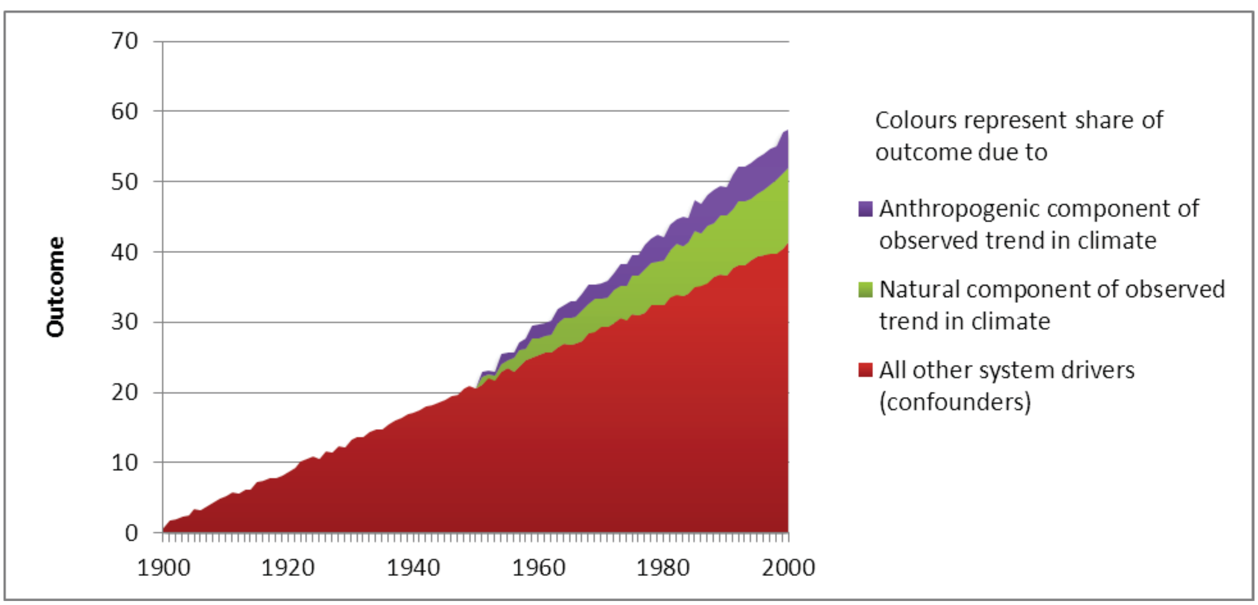

Figure 1 Illustrative example of a time series of a climate sensitive outcome, with red area representing the de-

velopment of that outcome under stationary climatic conditions, and the blue and green areas representing the change in the outcome due to recent climate change. The onset of deviation from normal system behavior can be clearly identified in the absolute outcome.

In order to identify "normal behavior" in the absence of climate change, substantial system process understanding is required, specifically that of the relative and joint roles of climate drivers and other, confounding drivers. No change from baseline in a (constant or trending) variable could still imply a detected change, if process knowledge indicates that (e.g. due to management changes, policy measures, introduction of a predator) there should have been a change (see Fig. 2).

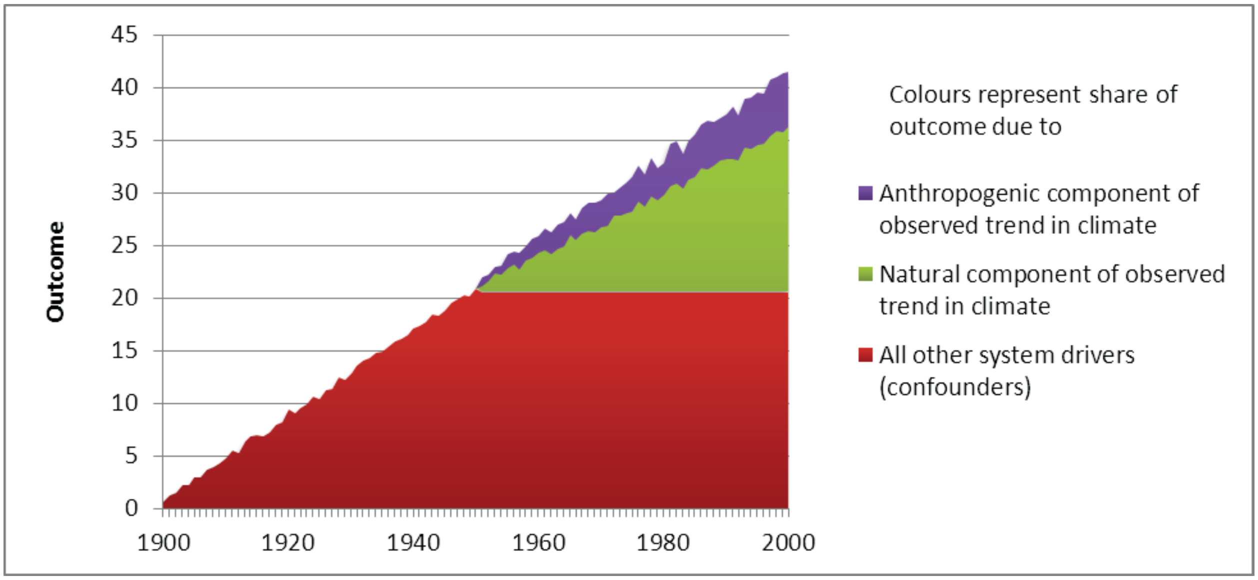

Figure 2 Illustrative example of a time series of a climate sensitive outcome, with red area representing the development of that outcome under stationary climatic conditions, and the blue and green areas representing the change in the outcome due to recent climate change. While the baseline conditions (red area) shows a dramatic change (e.g. due to a policy measure) from a trending to a constant outcome in the middle of the century, the overall outcome does not show any change, thus masking the existing climate change effect.

For example, it has been argued that changes in vulnerability (e.g. due to improved disaster risk management, or better building codes) are not properly represented in studies examining trends in normalized losses due to extreme weather events, although a systematic bias has not been found (Bouwer 2011). This also implies the question whether active adaptation resulting in no change in the observed variable constitutes detection (see section 8).

3 Relative contribution in a multi-driver context: Attribution

Attribution needs to examine all drivers of change that influence the system, and evaluate their relative contribution to the detected change. Attribution implies the testing of a hypothesis: stating attribution to climate change implies that the role of climate change cannot be excluded as the cause of an observed effect. Assessing the magnitude of climate contribution to an impact is a separate, but equally important matter in an attribution exercise.

Following from the above, an attribution statement needs a qualifier describing the relative importance of climate change to an observed impact. This involves either simply an ordinal statement (e.g. climate is the main influence responsible for a change) or a cardinal statement, which of course requires estimation of the exact relative magnitude of the contribution of climate change in relation to other drivers. A key challenge for all attribution exercises consists in accounting for non-additive effects of several interacting drivers.

4 Climate trends or anthropogenic forcing - to what are we attributing?

A fundamental issue for D&A concerns the appropriate end-point of attribution. For understanding current impacts in the context of future climate change, including calibration of estimates of future impacts, one needs to consider attribution to anthropogenic climate forcing. Given the impetus of D&A research originating from the United Nations Framework Convention on Climate Change, this end-point has often been considered the main goal (Zwiers and Hegerl 2008). However, another motivation for D&A research is to improve understanding of vulnerabilities to long-term climatic trends, informing decisions selecting adaptive measures for reducing vulnerability and increasing resilience. The tendency for these trends to continue in the future is certainly of interest, however it is not central to "bottom-up" adaptive planning (Hulme et al. 2011), while understanding interactions and non-additive effects of multiple drivers is a key concern (Parmesan et al. 2013). The implications of this distinction are reflected in conflicting viewpoints about the priorities for attribution research in the context of ecological impacts (see Brander et al. 2011; Hoegh-Guldberg et al. 2011; Parmesan et al. 2011).

5 How can we use existing observed evidence?

The signal of global (anthropogenic) climate change has emerged from the natural variability of the climate system over the past few decades. At the regional scale, evidence of climatic trends is less clear cut, and more difficult to attribute to anthropogenic forcing (Stone et al. 2009; Stott et al. 2010), though progress is being made in linking local temperature changes to climate change, and understanding their perception (e.g., Howe et al. 2012; Ruddell et al. 2012).

The impact of a comparatively weak climate signal is often concealed by the effects of other anthropogenic drivers, such as land use, pollution, or economic development (e.g., Nicholls et al., 2009; Bouwer 2011; Hockey et al. 2011). Also, autonomous or planned adaptation offset a share of the adverse effects, thereby masking impacts of climate change (see section 8).

Key challenges for current assessments therefore include the limited knowledge on processes and mechanisms involved in environmental systems undergoing change from multiple stressors, limited understanding of causality within complex networks of social systems, and how climate drivers and their perception influence those, as well as the limited availability of long-term observations. The need for long-term monitoring has been highlighted frequently (e.g., Rosenzweig et al. 2007; Rosenzweig and Neofotis 2013). Even if the monitoring is stable through time, the nature of the outcome being monitored may have changed, for instance through technological innovations.

Many complex systems lack clarity of the existence or nature of discrete components, or of rules governing behavior, particularly when humans are involved. Consequently, some research in the social sciences focuses on qualitative observations and descriptive, non-numerical understanding of how systems behave and interact. Given that "evidence-based strategies must not ignore the evidence" (Piontek et al. 2013), any comprehensive D&A framework will need to be able to accommodate both qualitative and quantitative evidence.

It follows that statistical signal detection methods using univariate time series data often provide an insufficient toolset for D&A. D&A of impacts must be a fundamentally cross-disciplinary effort, involving concepts, terms, and standards spanning the varied requirements of various disciplines.

6 Do Not Confuse Climate Sensitivity with Detection of Impacts

There is a large literature statistically estimating the sensitivity of human and natural systems to climate. This usually involves correlating outcomes with climate for observations across space and/or time. It is important to recognize that these studies do not necessarily estimate an impact of climate change.

There are cases where data are insufficient for quantitative measurement of an impact, while given climate trends and known sensitivity strongly suggests that climate change will have affected the system.

Another important issue is the treatment of the impacts of climate variability. In the context of human systems, impacts of extreme weather or climate shocks are the rare occasion where a climate related signal is emerging from the noise. However, it is important not to confuse such indications of climate sensitivity with detected impacts of climate change. Also, climate extremes can constitute a necessary but not sufficient condition for an impact.

7 Is adaptation something we detect, attribute, or adjust for?

Adaptation happens in response to an observed or anticipated change. Autonomous adaptation of species to warmer conditions, such as shifts in distribution or earlier onset of spring phenology events, has served as measures for detection of climate change.

In human systems, autonomous adaptation may also involve expectations about future developments. For example, farmers may plant different varieties in response to several dry years, but may decide to invest in irrigation equipment if they expect those conditions to continue. Generally, in systems where the precautionary principle is followed, such as the public health sector, any hint of detection will trigger measures to reduce exposure and/or vulnerability, with the intention of removing any response signal (Carson et al. 2006).

Planned adaptation may happen independently of any observed effects, or as a response to impacts that are anticipated to increase. As adaptation planning is becoming more commonplace, the effect of such measures designed to deal with future climate change will distort the observations of impacts through reductions in exposure and vulnerability, and increased resilience.

Unless adaptation can be accounted for in an appropriate and consistent way, D&A analysis may never be able to inform us whether climate change is impacting human systems, or whether our adaptation measures where successful. This has important implications for the assessment of costs of climate change, in the form of both adverse impacts, and investments in adaptive measures. Therefore, adequate metrics and a framework that allow for monitoring adaptation, and subsequent adjustment within impact studies, are urgently needed.

8 Conclusions

D&A of impacts is important to inform the political process, to evaluate scenarios and projections, and to improve system understanding in a multi-driver context.

Though ultimately, the outcome of D&A studies in human and managed systems may remain limited due to the challenges described above, such exercises are incredibly useful to improve system understanding, identify climate sensitivities, and critically evaluate what we know about vulnerability of human systems to climate change. The consistent treatment of adaptation constitutes a key challenge herein.

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Methodology of flood risk assessment in Tokyo metropolitan area for climate change adaptation

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Abstract— Flood is one of the most significant natural hazards in Japan. The Tokyo metropolitan area has been affected by several large flood disasters. Therefore, investigating potential flood risk in Tokyo metropolitan area is important for development of new adaptation strategy for future climate change, and socio-economic changes. We aim to develop a new method for evaluating flood risk in Tokyo Metropolitan area by considering effect of historical land use and land cover change, socio-economic change, and climatic change. Ministry of land, infrastructure, transport and tourism in Japan published "Statistics of flood", which contains data for number of damaged houses, area of wetted surface, and total amount of damage for each flood at small municipal level. Based on these data, we estimated damage by inundation inside a levee for each prefecture based on a statistical method. On the basis of estimated damage, we developed flood risk curves in the Tokyo metropolitan area, representing relationship between damage and exceedance probability of flood for the period 1976-2008 for each prefecture. Based on the flood risk curve, we attempted evaluate potential flood risk in each prefecture. By analyzing flood risk curves, we identified that prefecture with high (low) flood risk roughly corresponds to high (low) property. However, there are several exceptions. Although, property is relatively low in Saitama prefecture, flood risk is high. On the other hand, flood risk in Kanagawa prefecture is relatively low in spite of high property. We found out that both property and ratio of damaged housing units are high in southeastern part of Saitama prefecture. We indicated that this spatial consistency between property and ratio of damaged housing units seems to be a reason for high flood risk. On the contrary, high property area of Kanagawa prefecture is different from area with high ratio of damaged housing units. This spatial inconsistency seems to cause relatively low flood risk. We can pointed out that spatial consistency (inconsistency) between distribution patterns property and flood risk in each prefecture is also an important factor for explaining regional difference of flood risk.

Index Terms—Flood risk curve, Regionality, Innundation inside a levee, Tokyo metropolitan area

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1 Introduction

Tokyo metropolitan area has been affected by has been affected by several large flood disasters. Consequenlty, investigating potential flood risk is important for the development of a new adaptation strategy for rfuture climate changes , and socio-economic changes; such as land use changes, decreasing birth rate and aging population. Due to progress in development of river structures, flood caused by river breach and over flow, scarcely occurred in Tokyo metropolitan area since second half of the 20th century. Most of the flood events in the Tokyo metropolitan area since the 1950s have been caused by inundua-tion inside a levee. Ministry of Land, Infrastracture ,Transport and Tourism of Japan(2005) indicated that

80 % of flood damage in Tokyo has been caused by inundation inside a levee in the period from 1993 to 2002 . Consequently, it is important to develop a evaluating method for flood damage in Tokyo metropolitan area by inundation inside a levee. This attempt is important to establish a new adaptation strategy for future climate changes at each prefecture in Tokyo metropolitan area.

To evaluate regional differences of flood risk , it is one of the effective metods to creating a flood risk curve(Appel et al.,2006). Several studies have attempted to evaluate flood risk based on flood risk curve (Grinthal et al.,2006; Merz and Thieken 2009). However they focus on a specific period.Fujimi et al.,(2010) analyzed temporal variations of flood risk in Kumamoto City, southwestern Japan based on a flood risk curve. However they did not focus on regional difference of flood risk. Kazama(2008) attempted to evaluate flood risk all over Japan. However he did not discuss on regionality of flood risa between prefectures. In order to develop a new adaptation strategy for future climate changes and change of social economic conditions, we considered it is necessary to develop a new method that can evaluate potential flood risk and their regionality at municipal level.

In the present study, we aim to develop a new method for evaluating potential risk of inundation inside a levee and their regional differences in Tokyo metropolitan area based on flood risk curves.

2 Data and Methods

Ministry of land, infrastructure, transport and tourism in Japan published “Statistics of flood”, which contains data for flood causes, number of damaged houses, area of wetted surface, and total amount of damage for each flood at small municipal level. These flood data is thought to be useful for evaluating potential flood risk and their regionality in Tokyo metropolitan area.In the present study, we used data of “Statistics of flood” in our analysis.In the present study, we focus on regional difference in flood risk between five prefectures in Tokyo metropolitan area(Fig.1).

By using damage data in “Statistics of flood”, we calculated damage by inunduation inside a levee in each prefecture in Tokyo metropolitan area for the period 1976-2008 base based on “Frequency-Damage(F-D) method”. Basic idea of the F-D method is to caluculate damage by the product of frequency and damage of event. Annual damage for each housing unit is calculated by the flowing equation.

$$L=F\times D\times N\times E \tag{1}$$

*L;*Annual damage per one housing unit, *F*;Annual ratio of damaged housing unit, *D*;Annual raio of damage per one housing unit, *N;*Total number of housing units during study period. *E*;General prprerty per one housing unit during the study period.

Ratio of damaged housing unit(*F*)was calculated as the percentage ratio of number of damaged housing units against total number of housing units in each prefecture. Ratio of damage per one housing unit(*D*)was calculated as the percentage ratio of damage per housing units against general property values per housing unit in each prefecture.In order to evaluate (*F*) and (*D*) stochastically , we attempted to fit functions and selected log normal distribution for (*F*) and (*D*).By using this function, we generated randam numbers of (*F*)and (*D*) for 10000years based on Monte Carlo simulation. Then, we caluculated annual damage(*L*)for 10000years for each prefecture in Tokyo metropolitan area based on equation(1). On the basis of annual damage(*L*) for 10000years, we created flood risk curve, representing relationship between damage and exceedance probability of flood for each prefecture. Figure2 represents procedure for creating flood risk curve.

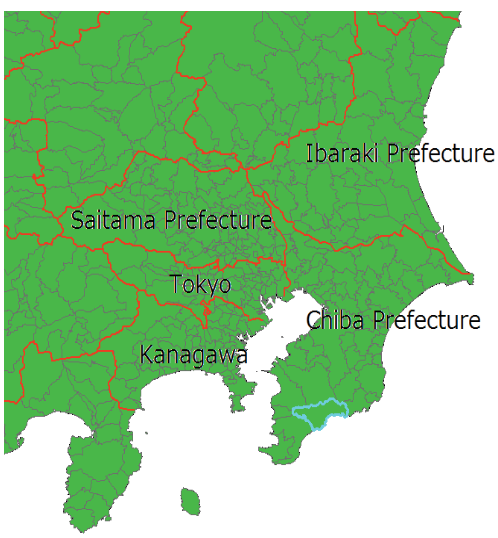

Figure.1 Study area of the present study.

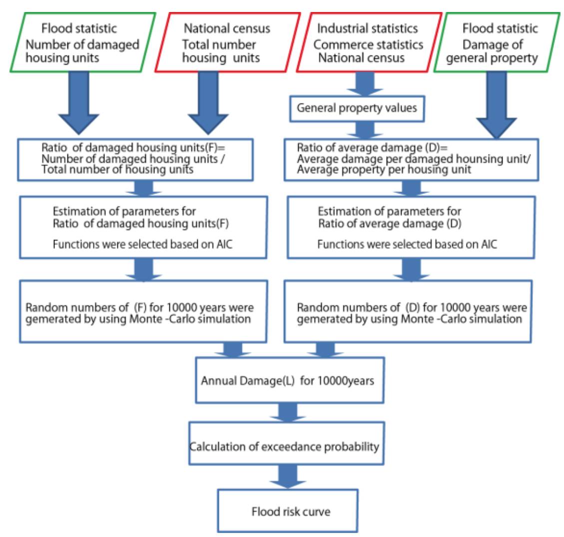

Figure.2 Procedure for construction of flood risk curve.

3 Results

Figure3 represents flood risk curves for each prefecture in Tokyo metropolitan area.We found out relatively high flood risk for Tokyo , and low flood risk in Chiba and Ibaraki Prefecture. Figure 4 represents total general property values for each prefecture. By comparing Figure 3 and Figure 4,high(low) flood risk in Tokyo(Chiba and Ibaraki) seems to be relate with high(low)general property. However, total amount of general property values in can not explain for degree of flood risk in all prefectures .We can not explain relatiuvely high flood risk in Saitama Prefecture, where general property is relatively low(Figure4). It is also difficult to explain relatively low flood risk in Kanagawa Prefecture, where general property is relatively high in Figure4. To explain possible cause of these exceptions, we consider that it is effective way to investigate detailed spatial distribution of property and flood risk within each prefecture.

Figure 5 and Figure 6 show spatial distribution of general property(*E*) and ratio of damaged housing units(*F*) for Saitama Prefecture and Kanagawa Prefecture, respectively. In Saitama Prefecture, we found out that both ratio of damaged housing unit(*F*)(Figure5(a)) and general property(*E*)(Figure5(b)) is high in southern east part of prefecture. This indicates that property in Saitama Prefecture is concentrated in high flood risk area. This facts suggests that consistent distributions between property and flood risk is one of the reason for high flood damage in Saitama prefecture. On the other hand, general property (*E*) in Kanagawa Prefecture is high in northeastern area(Figure6(a)), while flood risk is high in central and southern area(Figure6(b)).Consequently,we considered that inconsistency between spatial distribution of housing units(*F*)and general property(*E*) is a reason for relatively low flood damage in Kanagawa Prefecture. These results indicates that spatial distribution of flood risk and property values is a important factor for explaining degree of flood damage .

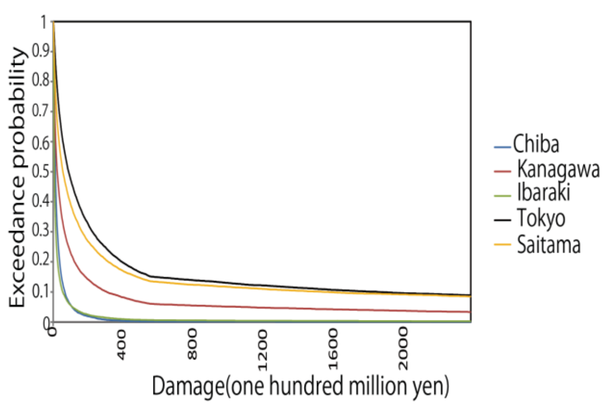

Figure.3 Flood risk curves

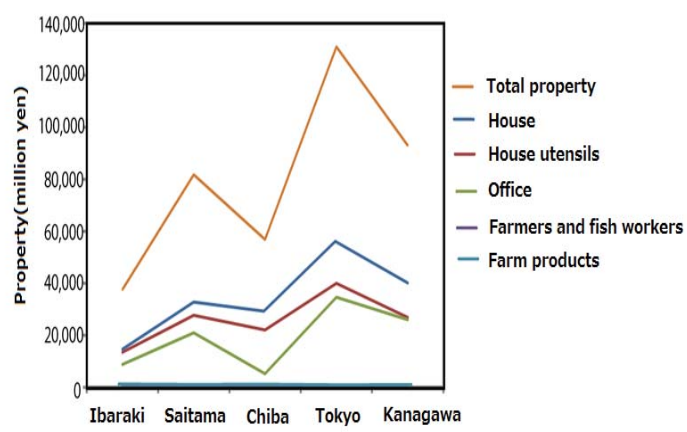

Figure.4 General property for each prefecture

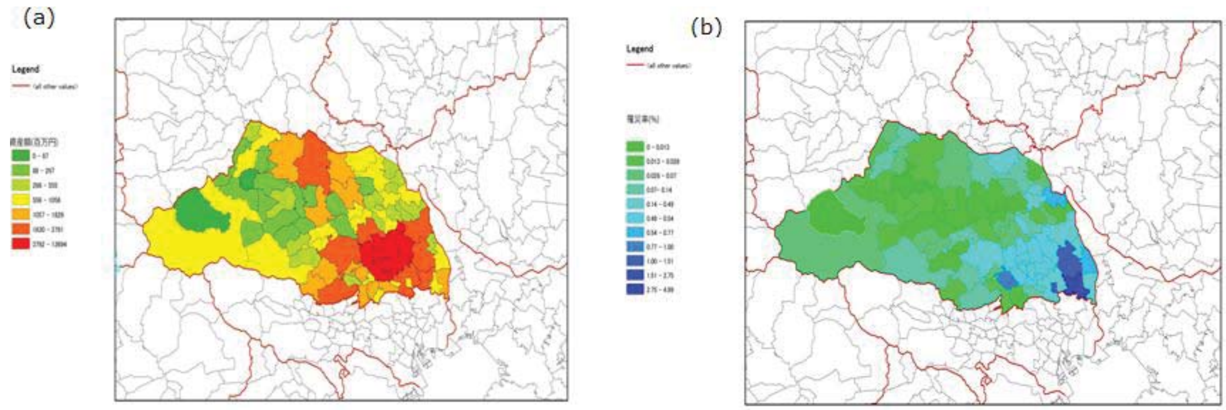

Figure.5 Distribution of general property (a) and ratio of damaged housing units(b) in Saitama Prefecture for the period 1976-2008.

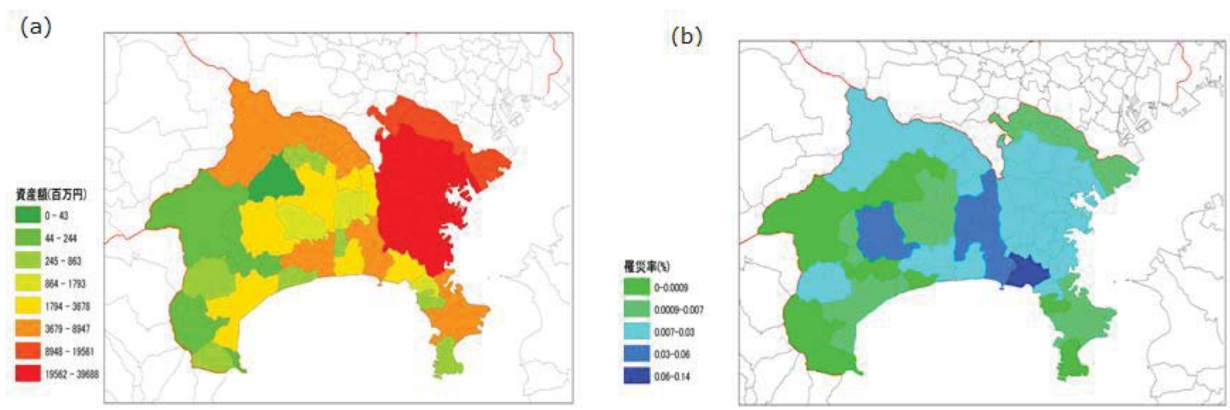

Figure.6 Distribution of general property (a) and ratio of damaged housing units(b) in Kanagawa Prefecture for the period 1976-2008.

4 Conclusions

In the present study, we developed an new method for evaluating regional difference of flood risk in the Tokyo metropolitan area, based on flood risk curve. By investigating regional difference of flood risk curves, we found out that prefecture with high(low) property roughly corresponds to high(low) flood damage. We also found out that consistency between spatial distribution patterns property and flood risk in each prefecture is also an important factor for explaining regional differences in estimated flood damage between prefectures. It is notable that consistency (inconsistency) distribution of high property area and high flood risk area could increase (decrease) total flood damage for each prefecture. We consider this fact is important for creating future regional planning that can adapt to future climate changes and changes of social economic conditions, such as land use change, population change. To provide useful scientific knowledge for future climate change adaptation, we consider it is next step to improve our methodology, that can reflect effects of future precipitation changes . In particular, it is important to consider effects of future changes in precipitation amount and precipitation intensity on flood risk.In the present study, we analyzed flood risk based on average values of general property(E)and ratio of damaged housing units(F) for the period 1976-2008. We consider further analysis is necessary to evaluate temporal changes of flood risk in Tokyo metropolitan area. It is also important to evaluate flood risk for several different spatial scales. In the present study, we created flood risk curves for each prefecture. We consider our methodology can be applied to evaluation flood risk in small municipal level. We consider such efforts will provide more detailed spatial-temporal information of flood risk in Tokyo metropolitan area.

Acknowledgement

Thanks are due to Dr.Kazuro Nakane and Dr. Nobumitsu Tsunematu for their constructive comments. This study was conducted as part of the research subject "Research Program on Climate Change Adaptation (RECCA) funded by Ministry of Education, Culture, Sports, Science and Technology of Japan.

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The impact of climate change on transport: current progress and future requirements

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Abstract

Transport is an economically and socially important sector for which climate change impact research is in its infancy. This paper uses the experiences gained on the four year FUTURENET project to discuss key progress in this area and to identify important research gaps. FUTURENET has assessed the potential impact of climate change on a multimodal route corridor between London and Glasgow in the UK. A multidisciplinary assessment framework has been created within which the FUTURENET project has: (i) determined relationships between observed weather and transport failure (ii) projected these relationships on to future climates using a journey resilience model (ii) extrapolated these impacts on to future climates using statistically downscaled climate projections and (iii) modified these impacts with future scenarios for transport use. Large ensembles of simulated journeys along the route corridor under present and projected future climates are subjected to synthetic weather and associated weather-related delays including those caused by infrastructure failure and behavioural change on the part of the driver, producing probabilistic projections for the future performance of the route for surface transport.

The project has identified a range of requirements for future research spanning the disciplines of civil engineering, transport studies, geography, future studies and climatology. Key amongst these is the creation of spatially-coherent weather generator output derived from overlying climate projections, essential for a network which is vulnerable to spatial hazards. Moreover, the handling of daily and hourly extremes by current generators is insufficient for many modes of infrastructure and transport failure. Comment is made on the current availability and suitability of transport data and how this should be improved to meet the requirements of impact assessment.

Index Terms – climate change impact assessment, transport, weather generator use, data quality, research gap identification

1. Introduction

1.1. Background

Compared to other economically important sectors such as energy, water resources and agriculture, the assessment of the potential impacts of climate change on transport is an area of research very much in its infancy. The increased demand for personal mobility (Banister, 2011), the dependence on reliable movement of goods and components in the supply chain (Hesse and Rodrigue, 2004) and the observed disruption that weather causes to these (Koetse and Rietveld, 2009) makes the study of current and future transport resilience essential. As such it has been noted that significant effort is required in developing novel and rigorous quantitative methods for climate change impact assessments (Koetse and Rietveld, 2009; Jaroszweski et al, 2010).

When assessing the current progress in understanding the potential impact of climate change on any system or sector it is useful to consider the conceptual frameworks within which climate change impact assessment (CIA) should ideally take place. Here we take the fundamental components of CIA to be those arising from Tol's (1998) conceptual framework. From this the process of CIA can be divided into three main tasks: (i) determination of relationships between weather and the sector or system in question (ii) extrapolation of these relationships onto future climate using climate projections (iii) modification of the projected impacts with reference to scenarios for development within the sector.

When viewed in this way transport reveals a decreasing base level of understanding from components (i) to (iii). Although the effect of weather on transport has been quantified in previous empirical studies (as reviewed by Thornes, 1992, Koetse and Rietveld, 2009 and Baker et al, 2010), the relationships are usually determined in isolation for a single mode of transport or type of infrastructure. Such relationships include those between high temperatures and rail buckling-related train delays (Dobney et al, 2009) and the effect of precipitation on railway embankments (Liu et al 2012). These often identify meteorological thresholds beyond which physical failure occurs. Below the threshold of physical failure exist many relationships between weather and transport that determine the efficiency and level of safety with which its operations are conducted. These often reveal a strong behavioural element such as the observed effect of rain on road traffic speeds (Hooper et al, 2012) and accident rates (Qiu and Nixon, 2008).

Similarly, where assessment of climate change impacts on transport has been made, this has often focused on a single type of impact such as weather-related road accidents (Hambly et al, 2013; Andersson and Chapman, 2012), heat-related rail buckling (Dobney et al, 2010) or engineered slopes (Clarke and Smethurst, 2010). These studies have direct relevance to stakeholders involved with these particular components, such as local infrastructure managers. However, from a policy perspective, assessment of the potential impact on transport's wider social and economic functions such as the maintenance of spatially extended social networks (Banister, 2011) and the transportation of freight (McKinnon, 2007) requires a holistic approach that considers transport as a system. In this way the effect weather has on the various infrastructural components within the system as well as the effect on driver behaviour (such as driving speed) must be handled simultaneously in order to determine the effect on transport's functions. Moreover, from this perspective the resilience of a transport system is not only quantified by the effect weather has on the physical infrastructure, but also on whether transport meets user's needs in terms of journey time and reliability. This perspective also implies that the definition of resilience varies between users and depends on the type of activity that they wish to carry out. This can be viewed as a longitudinal concept, with user expectations of transport potentially changing due to the development of the overlying socio-economic environment. This consideration, along with concurrent changes to the network that will affect transport's vulnerability to weather events has been absent from transport-based CIA work.

1.2. The FUTURENET approach

The FUTURENET project sought to address the identified gaps by developing a wide variety of quantitative and qualitative approaches to specific aspects of the impact of climate change on transport. FUTURENET indentified a number of potential stakeholder perspectives of resilience, and sought not only to meet the needs of network owners and operators, but also those of higher-level policy makers and travellers. To achieve this a framework was formulated within which a multitude of stand-alone physical process models and behavioural relationships could be combined to simulate journeys in the presence of weather to determine the impact of climate change on user-defined journey resilience.

Key to this was the selection of a multimodal route corridor along which the potential impact of climate change could be assessed. The Glasgow to London route corridor was used due to its economic importance to the UK and the climatic and geological variety it contains. The project included the following components:

- The development of a modelling framework using a standard systems engineering approach.
- A methodology for the development of social and transport scenarios to use in the model framework, that draw upon future social scenario development and a thorough study of current and likely future stakeholder requirements.
- The inclusion of traveller choices and perspectives, which were obtained from a major travel survey of the London-Glasgow route.
- The development of a number of specific physical process models to predict resilience, in terms of loss of capacity and route closure, for specific route sections. For example landslip models, pluvial and fluvial flood models, bridge scour models and track buckling models.
- The determination of transport behaviour relationships between weather and traffic speed and flow.

- The generation of weather time series for both specific localities along the route and for the complete route as whole. These were based on the UK Climate Impacts Programme climate scenarios and weather generator.
- The integration of the physical process models and the generated weather events to enable the resilience of an individual journey from London to Glasgow to be assessed in terms of the overall probability of delay or failure of the journey. This is termed the 'journey resilience' model.

The journey resilience model combines the physical and behavioural relationships between weather and transport with climate change projections in order to calculate delays on simulated journeys (both rail and road). In order to do this the road and rail routes between Glasgow and London were segmented into links, either between junctions for road or between stations for rail. The model uses the UKCP09 climate change projections (downscaled into synthetic weather) to determine whether a given threshold has been breached and will then modify the speed of the vehicle accordingly. If no threshold has been reached then the vehicle will travel at a normal speed. A journey will have been deemed to have failed if the total delay minutes at the end of the journey exceeds a pre-defined threshold (informed by a behavioural study carried out on residents in London and Glasgow). The model is designed to incorporate both catastrophic failure of infrastructures such as weather-related slope failure, as well as speed reduction relationships. Several hundred thousand journeys were simulated for each time step (baseline, 2050s, 2080s) and emission scenario (low, medium, high) using probabilistic synthetic weather. Development of the idealised framework was the primary objective of the project, although examples of simplified versions of the model for single modes and failure types were produced. For example Figure 1 contains journey failure projections based on the relationships between rainfall and driver behaviour, and displays diverging trends for summer and winter. In this case a failure threshold of 30 minutes delay has been set, based on results of the behavioural survey. It must be noted that these projections do not include the impact of flooding.

2. What is still missing?

The experience of the FUTURENET project helped to elicit a variety of methodological requirements necessary for a more realistic future impact assessment. These relate to observations about the spatial and temporal resolution of climate change projections and the quality of transport data. Recommendations are also made for further study on interdependencies between infrastructure, behavioural response to climate change and the use of climate change impact assessments in the transport sector.

2.1. Transport data

In forming relationships between weather and transport failure the FUTURENET project identified several shortcomings in both the availability and suitability of transport data. For example, the STATS19 road accident police reports were used with UK Meteorological Office surface stations to form relationships between weather and traffic accidents. However, it was apparent that the data contain a lag of variable length between the time of the incident and the time of report, which has an influence on the accuracy of the resulting relationships. Also, when forming relationships between rainfall and road traffic speed and flow it was observed that periods of low traffic speeds are not recorded or are substituted with historical data. Again, this makes forming accurate relationships difficult. Reliable asset data are also extremely important for calculating future resilience. However, these are not primarily recorded for this purpose, and as a result their suitability is often questionable. For example, the accuracy of road elevation data and drainage capacity are both essential for assessing flood risk. Unfortunately, data gaps and inaccuracies were found with both of these data types. Problems also arise in locations which include several types of infrastructure. For instance discrepancies are often apparent where road and rail infrastructure intersect.

Some of the required improvements to data collection would incur no or negligible costs. For example, the removal of post-collection modifications to road speed data would likely be fairly simple to implement. Failing this, access to the raw data should be provided. However, other improvements would require significant changes to current data collection techniques, and would require considerable time and resources to implement. Other improvements may incur greater costs and involve significant investment in new technologies and operating practice. For instance greater use of lidar would provide the requisite accuracy for flood risk modelling. It is likely that the trend towards greater sensorisation of infrastructure, the implementation of intelligent transport systems and the smart cities agenda may provide much greater quantities of accurate transport data for the assessment of current and future resilience. This trend should also improve the availability of asset condition data.

2.2. Improved synthetic weather

One of the greatest barriers to the implementation of the FUTURENET journey resilience model was the lack of sufficient reproduction of observed daily and hourly extremes and spatially coherent weather available through existing climate change impact assessment tools. The reproduction of high precipitation intensities is important both for behavioural responses such as speed reductions or traffic accidents (Hooper et al 2012; Hambly et al 2013), as well as the triggering of physical infrastructure failure (where antecedent conditions are also important). Although the UKCP09 weather generator used in the FUTURENET project produces 30 year time series of hourly synthetic weather, it does not reproduce daily or hourly extremes at sufficiently long return periods for many of the failure types of interest in this study (Jones et al, 2009). The lack of variables such as snow and wind (although a measure of this is available through evapotranspiration; Eames et al, 2011) also limits the transport failure types available to study.

The impact that weather has transport operations is in part determined by the spatial characteristics of the weather event in question. Transport is vulnerable to spatial hazards that cause multiple failures across the network. As a result, transport-based CIA requires spatially coherent weather generator output that is capable of reproducing the meteorological features that affect the transport network. The UKCIP09 weather generator used in this study produces weather for single sites, so realistic difference in weather along a given journey were not possible. The study used a single weather generator location in the centre of the route and modified this with change factors between London and Glasgow to account for differences in climatology during a given journey, but this does not meet the requirements for realistic weather. Spatially coherent weather based using correlations between observed weather have been developed for regional and city scales (such as the tool produced for ARCADIA project) but this statistical approach is not feasible over the distances studied in the FUTURENET project. It is possible that archiving the original regional climate model (RCM) runs used to inform CIA tools such as UKCIP09 may provide usable weather output at a national scale, as these runs are resolved at sub-hourly time steps.

2.3. Behavioural response

The FUTURENET project determined a number of behavioural relationships between weather and transport for inclusion into the journey resilience model. However, it must be remembered that as these relationships are based on the human response to a given weather hazard, these relationships are specific to the locations and populations from which they are derived. An important and under-research behavioural response arises from this in the context of climate change, that of autonomous adaptation. As the ability of a driver to cope in a given weather condition is partly determined by the frequency with which they experience this hazard (Elvik, 2006), any increase in the frequency of a hazard in future climates will have associated with it a reduction in the relative impact for a given event. Under this reasoning the opposite would be true for weather hazards that reduce in frequency. The inclusion of such considerations in future models will be important in achieving more realistic impact projections.

2.4. Use in the sector

Finally, further research is required to determine how probabilistic climate change projections are received and used in the transport sector. This is important as transport, unlike other sectors such as energy and water, has little experience using probabilistic projections. From the results presented in Figure 1 it is possible to see a wide range in the magnitude (and sometimes sign) of potential outcomes for transport when looking within the 10th and 90th percentiles. Although probabilistic projections are in part intended to utilise the full range of ensemble-based climate change approaches and provide much greater information on risk and certainty (Murphy et al, 2009), feedback from stakeholders suggested that the inclusion of several probability levels around the central estimate was confusing, especially when confronted with several emission levels. It was suggested by several stakeholders that either the central estimate alone should be used, or that the extremes could be seen as faming points, such as using the 90th percentile under the highest emission scenario as the criteria to build 'no-regret' adaptation policies to. Both approaches provide options for simplification, but both fail to utilise the full range of data available. It is possible that better communication of experiences with stakeholder engagement with probabilistic projections may help frame dissemination of projections more effectively.

3. Conclusions

Through the experiences involved in creating a multidisciplinary framework for the assessment of the potential impact of climate change on the transport sector several important methodological and data barriers have been identified which currently limit the success of transport-based climate change impact assessments. As well as modes excluded from the FUTURENET analysis such as aviation, cycling and walking, future research should centre around improving the climate projections available for impact assessments, understanding how improved transport data can be collected and further researching interdependencies between infrastructure. The creation of better spatially-coherent weather generator output is especially important. Much work is still required on how probabilistic impact projections are understood within the transport sector, with greater communication of experiences of stakeholder engagement with such projections being recommended.

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Figures

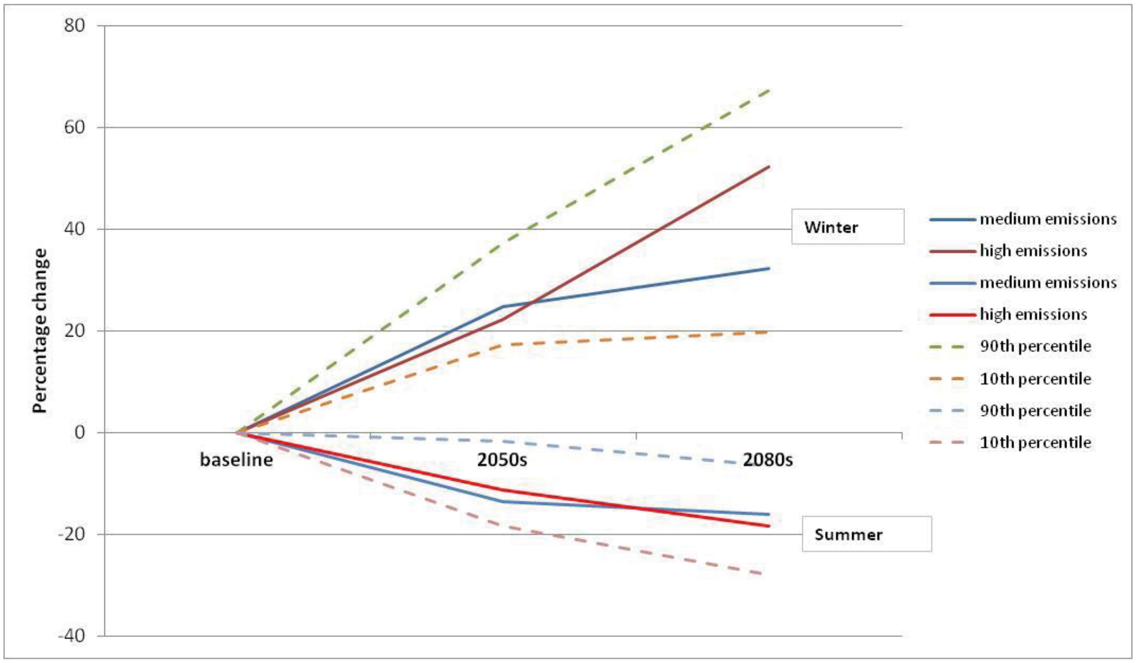

Figure 1. Projected rain-related road journey failures (30 minute threshold)

Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Towards a more consistent treatment of land-use change within climate assessment

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Abstract— To evaluate climate change impacts under a wide range of future socioeconomic and policy conditions, the IPCC "parallel" process (Moss et al. 2010) calls for the development of several scenarios, the Shared Socioeconomic Pathways (SSP's), each of which will meet the 21st century radiative forcing targets characteristic of one of the Reference Concentration Pathway (RCP) scenarios. Because the RCP's have been extensively evaluated by the climate and Earth system modeling community, this process is meant to efficiently match a variety of alternative socioeconomic futures with computationally expensive multi-model climate projections.

The measure of radiative forcing used to match the SSP and RCP scenarios does not currently include the direct effects of land-use change on climate, leading to inconsistencies between the RCP's and SSP's when their patterns of land-use change differ (Jones et al., in press). A first step toward remedying this problem is to consistently compute radiative forcing from land-use change across scenarios within future climate assessments. However, this may not be a complete solution because radiative forcing from land-use change and well-mixed greenhouse gases do not result in the same regional climate outcomes, and because radiative forcing does not fully characterize the myriad ways that land-use change influences climate (Pielke et al. 2002).

We explore two solutions. First, we test the effectiveness of a new method for quantifying radiative forcing from land-use change within integrated assessment models. The method relies on geographically differentiated estimates of radiative forcing associated with major land cover transitions. Second, we explore a fundamentally different approach to climate assessment that relies on pattern scaling of single-forcing climate responses to associate diverse scenarios with regionally specific climate projections.

Index Terms— Albedo, Climate Change Assessment, Land-use Change, Pattern Scaling

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1 Introduction

Climate change impacts and adaptation research requires the examination of diverse future socioeconomic and policy scenarios in order to characterize uncertainties and examine the consequences of climate change mitigation and adaptation measures. Different demographic and policy dynamics give rise to different climate outcomes and therefore different stressors and risks for human systems. Thus, a key step in the climate assessment process is to accurately associate these diverse scenarios with state-of-the-art climate change projections. It is particularly important that climate projections be accurate at the regional scales where climate impacts society. However, obtaining robust climate change projections is time consuming and computationally costly, as it requires coordination across multiple international climate modeling groups. This limits the number of fully consistent socioeconomic and climate scenarios that can be examined in a reasonable time frame.

The IPCC parallel process (Moss et al. 2010) was formulated to address this challenge by mapping many different socioeconomic scenarios onto a limited number of climate projections. According to this protocol, the climate modeling community has focused on four Representative Concentration Pathways (RCPs) (van Vuuren et al. 2011), each of which blends unique demographic, technological, and policy change assumptions to reach one of four end-of-century anthropogenic climate change targets. The targets, ranging from 2.6 to 8.5 W/m^2, are characterized by the ubiquitous radiative forcing metric, which measures disruptions in Earth's radiative energy balance – in this case, resulting from changes in the Earth's atmospheric composition relative to preindustrial. The assumption underlying this approach is that scenarios achieving the same radiative forcing target will result in similar patterns of climate change.

Land-use change presents two challenges to the parallel process as it is currently formulated. First, the direct physical forcing from non-greenhouse gas aspects of land-use change is not currently included in the targets used to develop and compare scenarios. Recent work (Jones et al., in press) shows that the exclusion of land-use change from forcing targets can lead to significant climate projection errors when following the IPCC parallel process. Specifically, Jones et al. (in press) examine two scenarios: the standard RCP4.5 scenario, and an alternative socioeconomic pathway featuring large-scale deforestation. Despite reaching the same nominal 4.5 W/m^2 forcing target (excluding land-use change), the climate of the second scenario is significantly cooler at both the global (0.5 C) and regional level (up to 5 C in some locations).

Correcting this first problem is relatively straightforward. Models must simply begin accounting for and reporting land-use forcing, as they already do for greenhouse gases and aerosols. We demonstrate a proof-of-concept of this approach using the Global Change Assessment Model (GCAM) (Kim et al. 2006, Calvin et al. 2012) in section 2.

The second challenge that land-use change presents for the IPCC parallel process stems from the relationship between radiative forcing and climate outcomes. Due to the highly regional nature of land-use change (Bonan 2008; Bala et al. 2007), it is questionable whether radiative forcing from land-use change and other forcing agents, such as greenhouse gases, result in equivalent climate outcomes. Furthermore, land-use change influences climate through a variety of mechanisms, some of which cannot be characterized in terms of radiative forcing (e.g. changes in hydrology) (Pielke et al. 2002). To the extent that forcing from different agents leads to different regional climate outcomes, the fundamental assumption behind the IPCC parallel process breaks down. We note that this problem is not unique to land-use change; aerosol forcing is known to impart regionally differentiated climate responses as well. To address this more challenging and fundamental problem, we outline an alternative assessment approach based on pattern scaling theory in section 3.

2 Solution 1: Systematically account for land-use forcing in scenarios

To demonstrate the viability of accounting for land-use change forcing within the metrics currently used to characterize assessment scenarios, we incorporate dynamic land-use change radiative forcing estimates into GCAM, one of the integrated assessment models used to generate the RCPs. This not only allows us to more fully characterize the climate forcing present in future scenarios, but to explore policy scenarios in which the non-greenhouse gas climate aspects of land-use change are accounted for. We note that the greenhouse gas forcing due to land-use change is already accounted for in GCAM and the IPCC assessment process. Our method permits the additional inclusion of direct physical forcing, (i.e. albedo forcing) from land-use change.

2.1 Land-use (albedo) forcing factors

We use GCAM 3.0, which considers land-use dynamics within 151 regions formed by intersecting 18 global agro-ecological zones (AEZs) with 14 geopolitical regions. The AEZs are regions of relatively uniform bio-climatic characteristics derived from a combination of growing season length and temperature data (Lee et al. 2005; Monfreda et al. 2009).

Within each of these 151 regions, we obtain estimates of radiative forcing due to land conversion from woody vegetation (forests and/or shrublands) to non-woody vegetation (grassland and/or cropland) (shown in Figure 1). We do this through a series of simulations with the Community Earth System Model (CESM) (Bitz et al. 2012; Gent et al. 2011), a global earth system model. The simulations are designed to first isolate the surface albedo associated with the mix of woody vegetation and non-woody vegetation present within each approximately 1-degree gridcell. We then estimate the top-of-atmosphere radiative flux change that would result from conversion of woody vegetation to non-woody vegetation (or vice versa) using an offline radiative transfer model (Conley et al. 2012) that holds atmospheric conditions fixed while allowing the surface albedo to change. These methods are similar to those described in Jones et al al (in press).

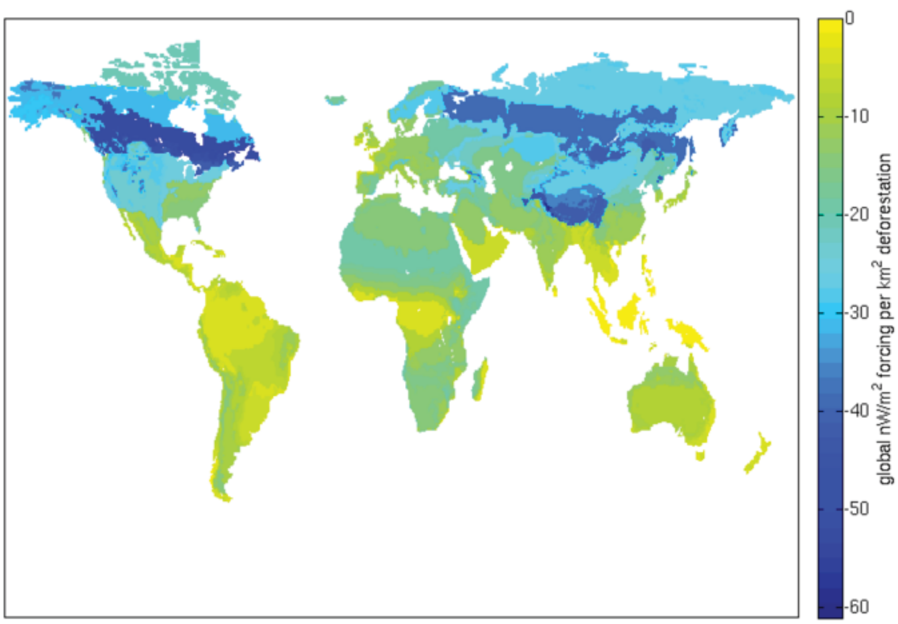

Figure 1: Model-derived estimates of radiative forcing due to land conversion from woody vegetation (forest or shrub) to non-woody vegetation (grass or crop). Mean values are shown for each of the agroecological zones used to represent land-use within the Global Change Assessment Model. Values signify the global change in forcing (in nW/m^2) for each km^2 of land conversion in a given location.

As seen in Figure 1, the forcing factors vary significantly by region. The magnitudes of these forcings are greatest in the Boreal forest regions and the Tibetan plateau where the contrast between dark trees and light snow is most pronounced. At very high latitudes, forcing diminishes. This is likely due to a combination of factors including lower incident solar radiation and less dense woody vegetation.

2.2 Scenarios

By default, the GCAM model only considers historical albedo forcing. In this mode, a default value of -0.2 W/m^2 is held constant in future scenarios, even in those with dramatic changes in landcover. In our modified version of GCAM, which we refer to as GCAM-ALB, land-use change forcing is dynamically updated at each timestep according to the regionally specific factors described above.

We examine three scenarios types: 1) a reference case with no climate policy, 2) a climate stabilization scenario that reaches a 4.5 W/m^2 forcing target via a universal carbon tax (UCT) that taxes emissions of both fossil fuel and terrestrial carbon emissions at the same rate, and 3) another 4.5 W/m^2 stabilization scenario employing a carbon tax on fossil fuel and industrial emissions only (FFICT). The UCT scenario is comparable to the standard RCP4.5 in its formulation, but uses GCAM 3.0, a newer version of GCAM than the official RCP4.5, and includes albedo forcing in the 4.5 W/m^2 target. We examine each of these three scenarios in both the default GCAM model and GCAM-ALB, yielding six core scenarios (REF, REF-ALB, UCT, UCT-ALB, FFICT, FFICT-ALB). As a sensitivity analysis, we consider a seventh scenario in which agricultural yields do not increase over the 21st century as in the other scenarios (FFICT-ALB-LOW). We expect this scenario to yield the highest rate of deforestation since additional land will be required to meet food and biofuel demands.

2.3 Results

We find that the land-use change in the scenarios that we examine is of sufficient extent to induce albedo forcing of the same order-of-magnitude as the estimated historical negative forcing of -0.2 W/m^2 since pre-industrial (Figure 2). In the UCT-ALB scenario, which features nearly 10 million km^2 of additional forest area by the end of the century, approximately three quarters of this historical negative forcing is reduced in magnitude. Compared to the standard UCT scenario, this means that energy and industrial sectors must mitigate more aggressively in order to meet the 4.5 W/m^2 target. Despite this, the trajectories of forest cover present in the default UCT and UCT-ALB scenarios do not differ significantly (Figure 3), indicating that land consuming mitigation measures (e.g. afforestation, biofuels) are not chosen to meet these additional demands. .

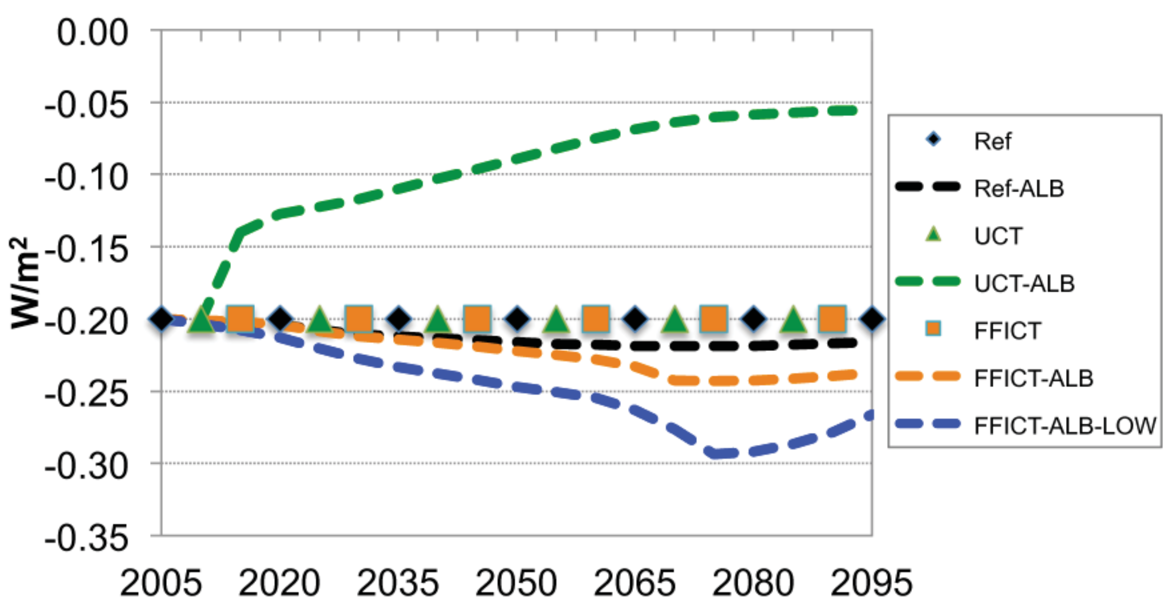

Figure 2: Albedo forcing over time in each of 7 future socio-economic scenarios. Scenarios lacking endogenous albedo calculations remain at the current level of -0.2 W/m^2. Albedo forcing in GCAM-ALB scenarios reflects the degree of deforestation (resulting in incrementally negative forcing) or afforestation (resulting in incrementally positive forcing) in those scenarios.

The FFICT scenario yields deforestation on the order of 6 million km^2 at its greatest point. When the additional negative forcing from deforestation is accounted for in the FFICT-ALB scenario, the level of deforestation is reduced (Figure 3). Negative forcing reduces pressure on energy intensive industries to meet the 4.5 W/m^2 target, reducing the demand for biofuels and therefore land for agriculture.

Compared to previous work with the GCAM model (Wise et al. 2009; Jones et al., in press), we find less deforestation in the FFICT scenario and more afforestation in the UCT scenario. This is likely due to more optimistic assumptions regarding the productivity of marginal lands in the newer AEZ-based version of GCAM that we use. In order to explore the conditions under which higher rates of deforestation might occur, we examine a modified FFICT case in which crop yields are frozen at 2005 levels. Compared to the standard FFICT case, this results in approximately twice the additional negative forcing from land-use change, but only slightly more deforestation, indicating that the inclusion of dynamic albedo forcing acts as a strong negative feedback on deforestation in FFICT scenarios.

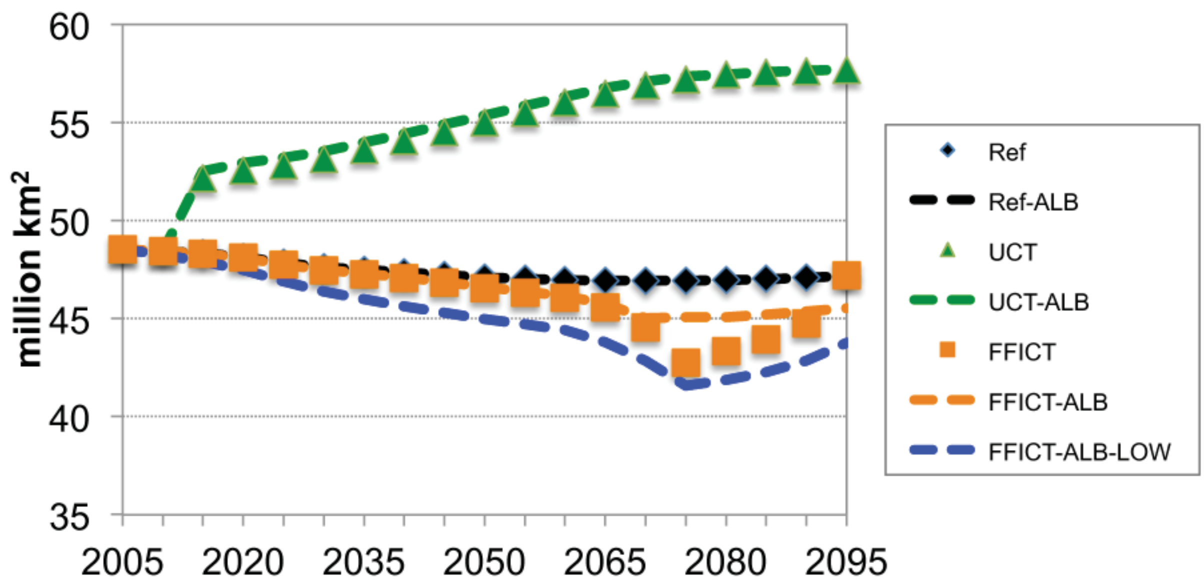

Figure 3: Forest cover over time in each of 7 future socioeconomic scenarios. Despite generating the largest albedo forcing signal, the UCT-ALB scenario does not differ significantly from the default UCT scenario in terms of forest cover.

As a next step, we intend to examine the climate outcomes of these scenarios in the Integrated Earth System Model (iESM) framework (Jones et al., in press), which is capable of replicating the RCP coupling procedure between GCAM and the CESM. Because changes in albedo forcing in the UCT-ALB and FFICT-ALB scenarios are balanced by changes in greenhouse gases and other forcings, we expect that their associated climate outcomes are more consistent than the default GCAM UCT and FFICT scenarios, at least at the global mean level.

3 Solution 2: Re-design assessment process around single-forcing pattern scaling

Under the "parallel" process (Moss et al. 2010), diverse alternative socioeconomic scenarios are to be linked with climate projections from one of the four RCPs (van Vuuren et al. 2011). However, it is unlikely that the full range of potential socioeconomic scenarios maps cleanly onto one of these four scenarios, especially considering the regionally specific nature of forcing from land-use and aerosols. This raises the possibility that the IPCC climate assessment process will need to be re-conceived in order to better account for regionally heterogeneous forcing agents such as land-use change and aerosols.

An alternative approach would be to derive spatially explicit climate response functions for each of several potential forcings (e.g. greenhouse gas, Boreal deforestation, East Asian aerosol emissions, North American irrigation). According the pattern scaling approach (Mitchell 2003), these independent response functions can be combined and scaled according to novel forcing scenarios, essentially yielding a reduced form model that maps a collection of forcing values onto spatially resolved multi-model climate projections.

The assumptions of linear scaling and climate response additivity underlying this approach have been shown to hold for a variety of forcing agents for changes in local mean temperature and, for the most part, local mean precipitation (Shiogama et al. 2012). For this approach to be viable, more work will be needed to explore the extent to which these properties hold for scaling of extreme event distributions, as this information is critical for impacts and adaptation research. Implications of the heterogeneity among Earth system models also needs to be explored, since models are known to yield a diversity of responses to land-use change forcing (Pitman et al. 2009).

While the 5th Coupled Model Intercomparison Project (CMIP5) (Taylor et al. 2012) does feature single-forcing experiments, these are oriented toward characterizing climate response to past forcing.

4 Synthesis

We demonstrate the viability of including spatially differentiated albedo forcing estimates within the metrics used to drive future socioeconomic scenarios. This is a critical first step toward producing more climatically consistent scenarios and it allows the exploration of policy scenarios in which non-greenhouse gas climate aspects of land-use change are valued. However, in order to associate diverse future scenarios with robust multi-model climate projections as accurately as possible, a fundamentally different approach to climate assessment may be necessary. Pattern scaling of single-forcing climate responses is a promising approach, but the assumptions underlying this approach deserve more careful scrutiny.

5 Ackowlegments

This research was supported by the Office of Science of the U.S. Department of Energy as part of the Integrated Earth System Modeling Project. This work used the Community Earth System Model, CESM and the Global Change Assessment Model, GCAM. The CESM project is supported by the National Science Foundation and the Office of Science of the U.S. Department of Energy. This research used resources of the National Energy Research Scientific Computing Center, which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors acknowledge long-term support for GCAM development from the Integrated Assessment Research Program in the Office of Science of the U.S. Department of Energy. The Pacific Northwest National Laboratory is operated for DOE by Battelle Memorial Institute under contract DE-AC06-76RLO 1830. Lawrence Berkeley National Laboratory is supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Barriers to the uptake of actions on climate change adaptation in developing countries: the case of Tanzania

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Abstract

Climate change is considered as one of the most serious global threats to sustainable development. Currently, knowledge on how to adapt social and natural systems to climate change and build resilience against its impacts is plentiful. However, putting that expertise into practice remains a problem around the world, especially in the least developed countries. Scientific reports confirm least developed countries being at high risk of suffering seriously as a result of climate phenomena. This study aims to contribute to empirical evidence on the barriers that constrain a smooth deployment of and uptake of adaptation actions in developing countries. The purpose is to identify practical examples on the ground to support international initiatives on adaptation in developing countries with appropriate actions that are successful. The study used in-depth semi- structured interviews with 15 experts of environmental management, natural resources, climatology, meteorology, and community development from Tanzania. The interviews focused on the investigation of the country's barriers and how the government attempted to overcome them. While adaptation is recognized as an important climate risk management strategy, the findings indicate that on the ground there is no clear guidance as to what scale adaptation actions would be, what form adaptation action would take, and what they would aim for. The experts are against large-scale actions which seem to originate from the developed world with little support from local government; they are difficulty to operationalise in the local context. They prefer small-scale actions, such as use of indigenous knowledge to adapt to drought and food crisis as these can easily be implemented within the local capacity and have a short turnover period. These findings have implications on how to better integrate developing countries into adaptation actions.

Keywords: *adaptation, barriers, climate change, developing countries*

1 Introduction

Adaptation is currently given uttermost importance from global to local levels, not only because of new challenges introduced by climate change, but also for supporting sustainable development (Füssel 2007). The challenge of adaptation is not new. Humans have been adapting to their environments throughout history (Smit & Wandel 2006; Dovers 2009), by developing practices, cultures and livelihoods suited to local conditions (Stringer et al. 2009). Currently, adaptation practices are mainstreamed all over the world in development practices (Halsnæs & Trærup 2009), motivated by ongoing global climate change negotiations at international levels led by United Nations Framework Convention on Climate Change (UNFCCC). At present, adaptation actions, performance and success in developing countries, especially the least developed countries, has been very limited (Kerr 2011). As noted by Mertz et al. (2009), adaptation in developing countries so far has been donor driven because those countries do not consider climatic change as one of their greatest concerns.

While there is a significant push all around the world for adaptation processes at local and national levels, implementation has been short of the potential due to a number of implicit barriers in developing countries. Even where there is implementation, success is contrary to the expected outcomes because of lack of basic knowledge, both technical and financial, and the inherently challenging nature of solving environmental crises. Little research has examined empirical evidence on the slow progress or even failure to uptake adaptation activities in developing countries. Most importantly, work on adaptation so far has addressed the impacts of climate change with strong coverage and focus in developed regions compared to developing ones (Grothmann & Patt 2005).

The main impetus of this paper is to identify and discuss the discourse of climate change adaptation in developing countries, using Tanzania as a case study. In particular, this work seeks to contribute to adaptation knowledge for policy makers on how to remove barriers and scale up adaptation actions. While the global political process has been slow in making meaningful progress in tackling climate change over the years, this paper argues that there was a lack of options on the type of adaptation actions and scale that needed to be implemented in a particular context, despite massive negotiations and lobbying at international platforms.

2 Methodology

This paper is based on qualitative expert interviews (Morgan et al. 2006) with 15 people who have deep knowledge of the phenomena of climate change in Tanzania. The word 'expert' denoted individual with specialized knowledge, and for this research on issues relating to mainstreaming climate change adaptation activities, with reputable experience in climate change-activities, projects and/or publications (Table 1). In general, they were purposively chosen, and were interviewed using semi-structured questions to elicit their expert knowledge on the country's ability to remove barriers and create opportunities for integrating climate change adaptation into its development planning and decision-making processes. Expert elicitation was appropriate for this study because of the interests in the views of experts on technical topics (potential barriers to slow uptake of adaptation actions).

Table 1. Overview of interviewed experts

Gender	Education	Area of expertise	Affiliation
Male	Ecologist	Human ecology	Stella Maris University College-Mtwara
Male	Agricultural engineer	Irrigation	Government
Male	Fisheries and aquatic marine conservation	Water quality and coral reef health	NGO
Female	Community development	Livelihood	Government
Female	Environmental Sciences	Environmental impact assessment	Government
Male	Chemical Engineer	Chemical and environmental remediation	University of Dar es salaam
Male	Water management	Water quality and safety	Regional organization
Male	Forestry	Forest and range ecology	
Male	Natural resources management	Wildlife and forest management	Sokoine University
Male	Economist	Valuation of natural resources	NGO
Female	Meteorologist	Weather events reconstruction and forecasts	Government

Male	Animal science	Livestock development	NGO
Male	Climatology	Climate modelling	Regional organization
Male	Development Studies	Vulnerability and poverty reduction	Sokoine University
Male	Climatologist	Ecosystem-hydrology climate interactions	Government

3 Findings and discussions

3.1 Overview of adaptation efforts

The government of Tanzania, with support from development partners and Non-Governmental Organisations (NGOs), has invested to manage climate impacts. These investments included and are based on the institutional set-up, adaptation priorities and mainstream activities. Table 2 below provides an overview of some adaptation efforts in Tanzania as mentioned by the interview's respondents.

Table 2. Some adaptation efforts in Tanzania

Category	Adaptation effort	Anticipated benefits	Implementation challenges
Policy	Incorporation of climate change issues into policies and planning processes	Devise appropriate climate risk measures	Climate change activities coordinated only by the Department of Environment, and little fund to sector ministries to implement climate change agenda
	Ratification of climate change based conventions such as CBD, UNFCCC, UNCCD	Developing functional system for climate change under the international framework	Lack of technical capacity and know-how
	Establishement of a National Climate Change Steering Committee, National Adaptation Strategy, a REDD task force	Harmonization and mainstreaming of climate issues	Lack of coordination among lead sectors and conflicting interests
Sectors	Incorporation of climate change into agricultural	Achieving sustainable resource development	Lack of strong intersectorial coordination re-

	policy	and management	sponse, hence duplication of efforts and conflicting policies
Infrastructure	Sea walls construction against sea level rise	Protecting coastal community and structures	Lack of fund
Protection of livelihoods	Improvement of food crop farming systems by traditional methods	Enhance resilience of livelihoods and poverty reduction	Heavy reliance on natural resources based livelihoods
Biodiversity and environment	Restoration of mangroves	Protect against storm surges and coastal inundation	Illegal marketing of mangroves poles

3.2 Barriers to adaptation

Experts identified a number of barriers which affect adaptation actions in Tanzania. In fact, their general opinion was that adaptation can be impeded by one barrier or interaction of multiple barriers. Table 3 below summarises some of the barriers identified.

Table 3. Selected barriers to adaptation actions

Type	**Example**
Policy	Existing policies especially those on natural resources have regulations which hinder adaptation to climate change
Governance and institutional	Inflexible planning systems e.g. if coastal erosion affects land boundaries
Behaviour	Local communities place priority on short term gains and make decisions contrary to their long term benefits; People process climate change information based on their existing attitudes
Inadequate adaptive capacity	People find it more difficult to identify climate risks they face because of multiple vulnerabilities

3.3 Potential elements of local conditions for successful adaptation to climate change

The majority of the interviewees (78 percent) mentioned clearly some local conditions which favour adaptation but are neglected by donors and international agencies working on climate change. For example, they mentioned a number of issues mainly neglected in adaptation actions already implemented in Tanzania to include local power differences, local structure inequalities, local networks and associations, and divergent interests in the community.

Most experts echoed the suite of current coping strategies such as water storage facilities and use of drought resistant seeds; and said that it would be better to facilitate those strategies rather than imposing new ones, which in most cases are decided at the national level without consulting local stakeholders, thus missing local buy in for implementation to work. These findings suggest that adaptation actions are necessarily site-specific. Despite adaptation actions beginning to be mainstreamed in development policies for developing countries (Stringer et al. 2009; Sovacool et al. 2012), as in Tanzania (GCAP 2011), there should be a better understanding of the fundamental processes underlying adaptation on the ground.

3.4 Issues motivationg people to adapt to climate change

In coastal areas for example, fishermen experienced a decline in their catch due to increasing sea temperatures (GCAP, 2011). Over 90 percent of respondents said that the ongoing changes in local climatic conditions are exposing individuals and communities to ever increasing risk and threatening the very sources of livelihood; leading to food security problems and a rise in poverty levels. Interestingly, expert opinions showed that the level of awareness and knowledge held by individuals on climatic change is still low and rudimentary; at least in comparison between urban and rural areas as found by Ahmed et al. (2011). Findings from this study concur with evidence that people have diverse meanings and attach nuances to specific aspects of their way of life (Wolf et al. in press), which have implications for adaptation. Indeed, several respondents highlighted the need for enhanced provision and access to information and knowledge on climate change, including on best lessons from similar situations and the demonstrated benefits.

3.5 Slow uptake of measures to adapt to climatic impacts

Nearly two-thirds of respondents agreed that members of local communities are quite aware of climatic changes that have taken place, and they have been trying to adapt accordingly. However, they emphasized that it is only a few individuals that claim to be familiar with climate change (*mabadiliko ya tabia nchi*) and adaptation (*kuhimili madhara yatokanayo na mabadiliko ya tabia nchi*) in national language franca despite efforts made by the government to translate climate change technical terms in Swahili (national language).

The opinions of experts were that, climate change discourse had been *Swahilized* but not localized. Yet, experts expressed their dissatisfaction on few policy initiatives for adaptation. So far, climate adaptations actions are marred by absence of specific information needs in regard to a better understand of climate change in a local language. Conequently, people perceive adaptation as borrowed idea, coming with big scale objectives contrary to the small ones they are used to.

3.6 Government role in adaptation activities to climate change

The government is basically motivated by the climate discourse elsewhere in the world, leading it to frame climate change as an urgent and generalized threat to the national development in its National Adaptation Programme of Action (NAPA) (URT 2007). However, the NAPA is not a strategic policy document, and has not been able to motivate or guide national efforts to address climate change. Respondents were disgusted by the absence of national climate change policy policy as well as a national adaptation plan of action. When compared with other equally important and pressing issues, development of climate change policy has taken so long. For example emergent issues such as natural gas have received urgency attention as immediate as possible in policy and national dialogue as compared to climate change, which seems to be accepted but without being embraced.

4 Conclusion

The empirical findings of this study serve to underscore the complexity of the actions to adapt to climatic changes in the context of a developing country. The study highlights the need to build on existing practices and local knowledge, and to further engage with large scale adaptation activities such as those supported by the Adaptation Fund and other funding commitments by the UNFCCC. This study proposes further research on reforms that would address barriers that reduce the ability of the local community to deal with current extreme weather events and those that would prepare the community for future climate change.

5 Acknowledgements

Funding for this work was provided by the Intergovernmental Panel on Climate Change (IPCC) scholarship programme for doctoral studentship in climate science studies through the Prince Albert II of Monaco Foundation.

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Genetic adaptive response: missing issue in climate change assessment studies

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Abstract — Two misconceptions on the adaptive potential of forests occur in climate change impact assessments. The first is that forests would be unable to adapt genetically, as climate change occurs within the lifespan of trees. However, selection takes place continuously in the regeneration phase of the forest when the number of individuals are reduced from many thousands seedlings to several hundred trees per hectare. Thus, although an individual tree might face century or more changing climate, the population where this tree dies may already strongly deviate in its genetic make-up compared to the population in which the tree germinated. The second misconception is that differences between tree species or woody plant functional types are more important for climate change assessments than differences within a tree species. However, there is ample evidence that provenances have adapted to their local environment and consequently differ in their response to climate change. The ForGEM model attempts to accommodate for both misconceptions by combining a classical process-based individual-tree model with a quantitative genetic model. The model parameters can be characterized by the genetic model and result in local adaptation. Key-results of the application of the ForGEM model in climate change assessment are that genetic adaptation is indeed possible within a few generations for important adaptive traits such as phenology and water use, and that the rate of response of adaptive traits to climate change is strongly affected by forest management. We argue that, based on: 1) observational findings of different responses of populations of the same species to climate change due to local adaptation, 2) the simulated findings of adaptive responses within the time frame of climate change, and 3) the vast technological development in genome wide association studies, it is necessary and feasible to include genetic adaptive processes in cross-sectorial climate change assessment studies.

Index Terms— adaptation, adaptive capacity, climate change, extreme events, genetic diversity

1 Introduction

Genetic diversity is the ultimate source based on which species adapt to climate change (Geburek and Turok, 2005). Evolution resulted in the adaptation of plant species to local climatological conditions and consequently they respond differently to climate change. Also within plant species, local adaptation has occurred over time. Transplantation trials of tree species throughout Europe have shown that provenances, transferred within the geographic range of the species, differ in degree and even in sign of their response to changes in precipitation and temperature (Mátyás, 1996). This genetic diversity within a species, as a result of adaptation to local environmental conditions, is important at the limits of species distributions (Hampe and Petit, 2005). Genetic diversity is typically lowest at the expanding front of the species' distribution and highest at the retreating limit, thereby affecting the survival of the individual trees and thus the rates of expansion and retreat, respectively (Petit and Hampe, 2006). In the centre of the species distribution, it is particularly the vulnerability to extreme events and the capacity to recover from these events, where genetic diversity within a species plays an important role (Parmesan et al., 2000, Bengtsson et al., 2000). Management can have a major impact on the genetic diversity of perennial plant species (Valladares, 2008). Selection aiming at maximization of productivity of forest- and fruit trees and nut-bearing trees reduces genetic diversity. Also management measures to mitigate climate change impacts by means of assisted migration outside the existing species range, may decrease the capacity of the species to adapt to on-going climate changes because of a too low initial genetic diversity (Leech et al., 2011, McLachlan et al., 2007).

Current climate change assessment modelling ignores local adaptation of long living perennial plant species, such as trees. In this paper we argue that genetic diversity is an important issue that needs to be included in cross-sectorial climate change impact assessment studies. We indicate how adaptive capacity and adaptation, in a genetic sense, can be included in climate change assessment models to attain more useful local predictions.

2 Modelling adaptive capacity and adaptation

2.1 Quantitative genetics

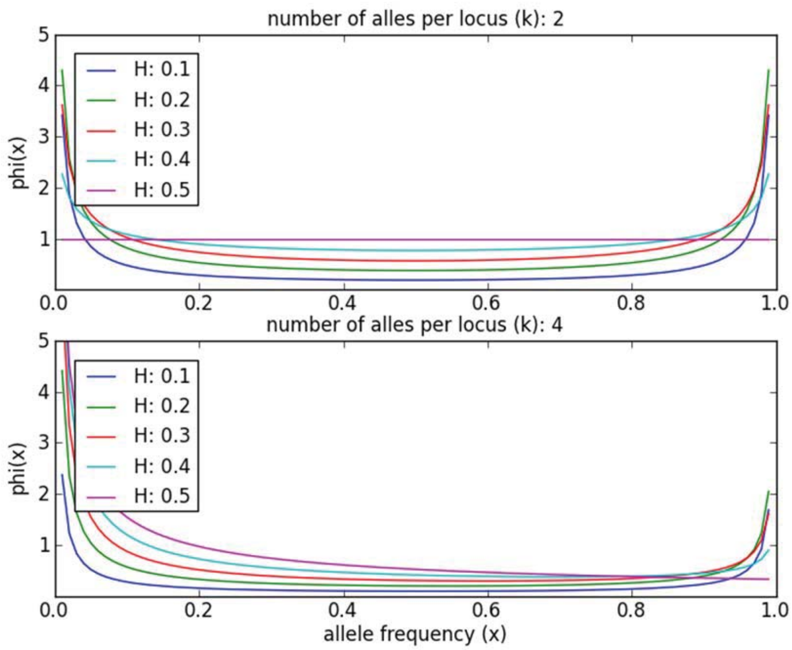
Adaptation is the dynamic evolutionary process that leads to a trait becoming adapted to local environmental conditions by means of natural selection, i.e. differential survival as a consequence of differences in values of the trait under selection. Adaptive capacity in its genetic sense is potential of a population to respond to an environmental change by having its genetic composition modified and, as a consequence, also the phenotypic expression of functional traits. The population thereby becomes better adapted to the new environmental conditions.

Quantitative genetics is the part of genetics that studies polygenic traits, *i.e.* traits that are under the influence of many loci (i.e. the location of the genetic information of a trait on the DNA string), each locus with two to many alleles (i.e. variation in the genetic information for that locus in the population). As there are many loci and potentially many alleles, the contribution of a single locus and allele on the phenotypic expression of the trait is only small. The contribution of the alleles and loci to the phenotypic values of a trait can be partitioned into additive, dominance (allele x allele interactions), epistasis (locus x locus interactions) and a remaining non-genetic component (Falconer and Mackay, 1996). Quantitative genetic studies are often restricted to additive effects because this is the component being inherited, and the determination of dominances and epistasis requires extensive experimental designs. As the additive allelic effects are considered constant, a particular combination of alleles over the loci determine the genotypic value of the traits, which, enlarged with the environmental component, defines the phenotypic value of a trait for an individual organism. Differential survival as a consequence of climate change, results in changes in the frequency of the alleles and thereby a change of the distribution of phenotypic values of a population. Thus, the population adapts to local environmental conditions. As a consequence of adaptation, some alleles will be lost from the population, either because these allelic effects are unfavourable under the new conditions or because of genetic drift. This loss in genetic diversity results in a reduced adaptive capacity to future environmental changes. Genetic processes to increase genetic diversity of adaptive traits are immigration of genetic material by gene flow from other populations, and mutation. In case of perennial plants, gene flow means input of pollen and seeds, or planting of new genetic material. Considering mutation, the low natural rate of mutation makes that this is in a time frame of a few generations relevant only for very large randomly mating populations.

2.2 Bridging eco-physiology and quantitative genetics in plant models

Dynamic global vegetation models assume a unique set of parameter values to characterise a plant functional type. At the global scale, the interest is in predicting shifts of the boundaries between plant functional types. It is unlikely that genetic processes determine the rate of change of boundaries between major vegetation zones under the influence of climate change, however, it is affected by adaptive capacity of the species. Also in the centre of the species area, adaptive capacity may have an important effect on the rate of adaptation of resource acquisition and therefore competitive ability of the species, and on the response to extreme events.

An individual-plant model in which process-based modelling is connected to a quantitative genetic representation of eco-physiological parameters is the ForGEM model (Kramer et al., 2008, Kramer and van der Werf, 2010). In principle each of the model parameters can be characterized by the genetic model and evolved due to environmental change. The genetic system can be initialised (determining initial allele frequencies and assigning allelic effects) either by taking a statistical approach or by using observed allele frequencies and allelic effects for Quantitative Trait Loci (QTLs) or Candidate Genes (CGs) determined in experimental populations (Brendel et al., 2008). As the initial distribution of allele frequencies has a strong effect on the simulated rate of the adaptive response, we currently assume on theoretical considerations that initially the allele frequency distribution follows a U-shaped beta distribution, *phi*. (Fig 1.) The allele frequency distribution is a function of the heterozygosis of the traits (H) and the number of alleles (k) (Nei, 1987). Inverting the cumulative distribution of *phi* leads to the initial allele frequencies (Fig. 2, see (Kramer et al., 2008) for details). Reasonable values for quantitative traits are: number of loci, *nLoci* =10, H=0.25 and k=2 (Kramer et al., 2008).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H: 0.4
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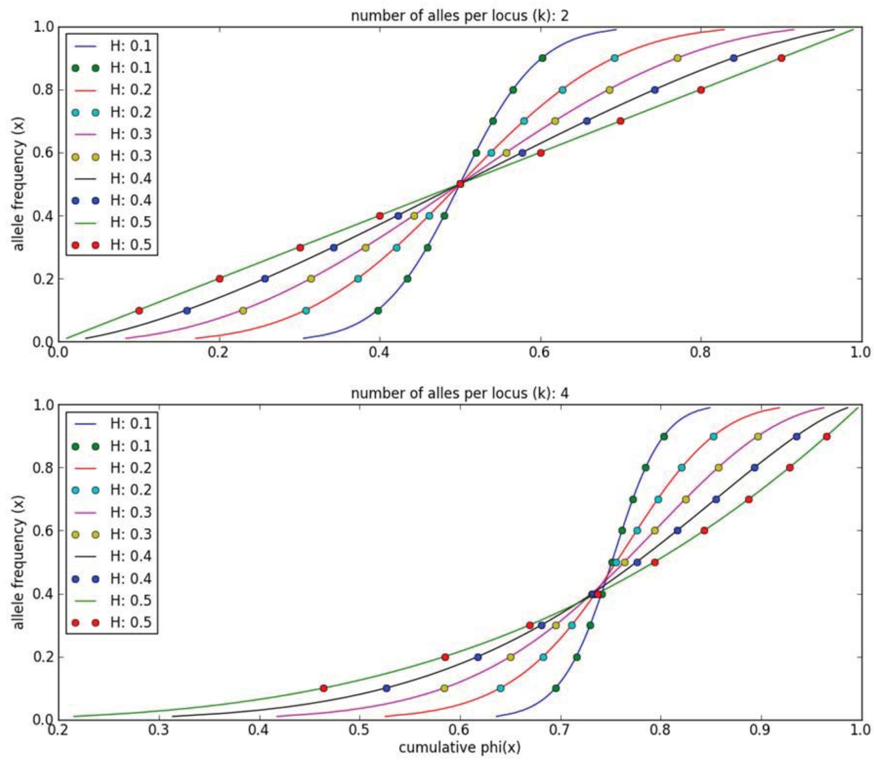
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allele frequency (x)
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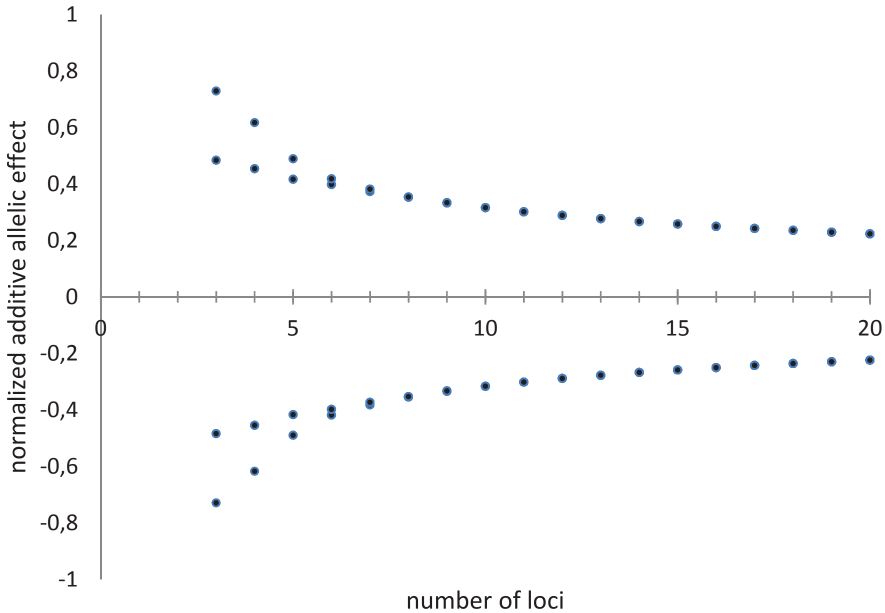

Fig. 3. Normalised additive allelic effects assigned to di-allelic multi-locus traits, under the constraint of the distribution of allelic frequencies as indicated in Figs. 1 and 2 with k=2 and H=0.25. With a low number of loci (*nLoci* < 7) two symmetric allelic effects are attained. At higher values for the number of loci per trait, all alleles have virtually the same effect on the genotype.

Currently all information is available to initialise the ForGEM model at the European scale, though such model runs have yet to be made. Daily meteorological parameters are obtained from the ISI-MIP database. The initialisation of forest stands is based on a database containing the abundance of 20 tree species at a 1x1 km resolution over Europe (Brus et al., 2012). Using species abundance at a location, a plot with observed stand information from a National Forest Inventories (NFI) database is selected with approximately the same species abundance. The statistics of the NFI plot are then used to generate a forest stand with statistically the same characteristics (Fig. 4). Soil characteristics required are those to determine water availability according to pedotransfer functions (Wösten et al., 1999, Wösten et al., 2001). For forest management, we follow the classification of Forest Management Approach (Table 1, (Duncker et al., 2012)), projected to the European scale (Fig. 5, (Hengeveld et al., 2012)). This approach can accommodate scenario assumptions on changes in forest management due to policy and market developments. As simulations at the European scale for each km^2 grid cell is too calculation intensive, a stratified sampling scheme is used based on the Global Environmental Stratification (Metzger et al., 2005, Metzger, in press).

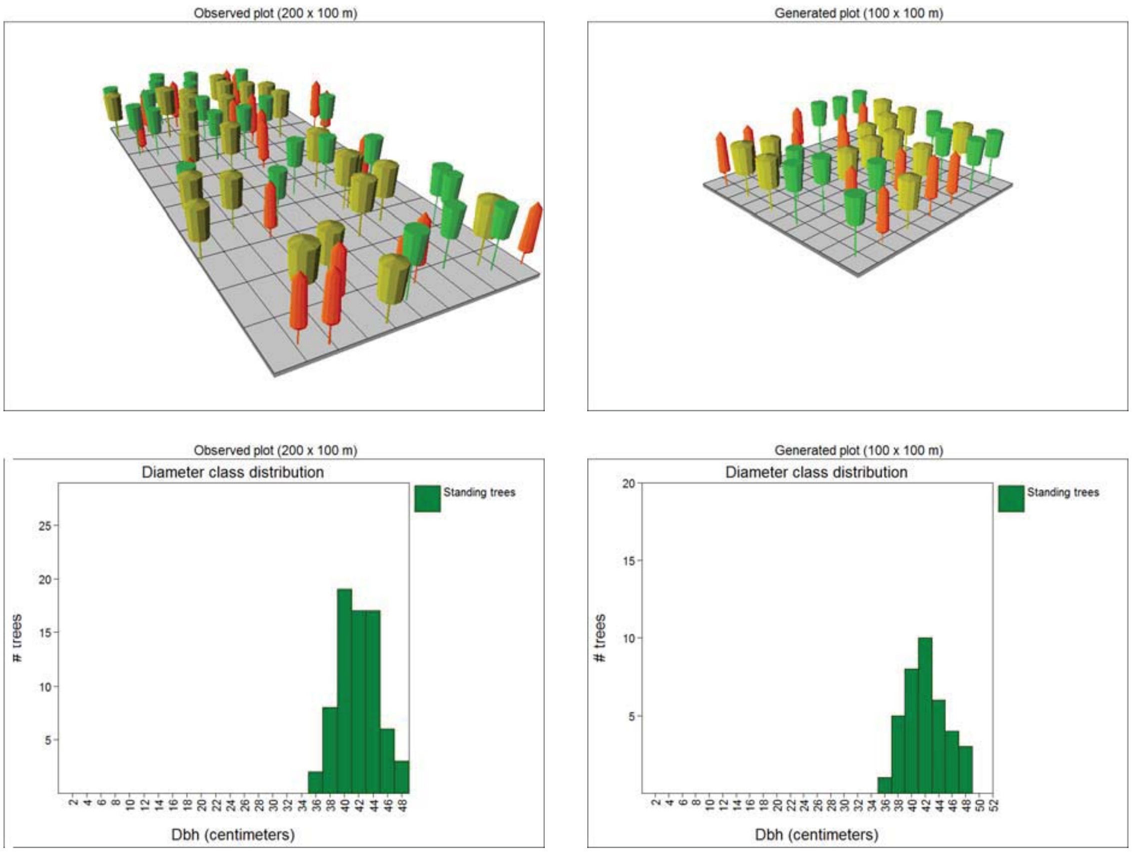

Fig. 4. Visualisation of a stand used to initialise the ForGEM model. Spatial distribution of trees and diameter distribution of observed plot with individually measured trees and the same representation of a generated plot based on stand statistics (density per species, mean and coefficient of variation of height and diameter at breast height) of the observed plot. Note that spatial structure is not accounted for in the generated plot. Yellow trees – *Quercus robur*; Orange trees – *Fagus sylvatica*; Green trees – *Fraxinus excelsior*. Visualized with Stand Visualisation System SVS, (McGaughey, 1997).

Table 1. Characterisation of Forest Management Approaches (FMAs) (Duncker et al., 2012).

FMA	**title**	**management intensity**	**objective**
1	unmanaged forest / nature reserve	passive	to allow natural processes and natural disturbance regimes to develop without management intervention
2	close-to-nature forestry	low	to manage a stand with the emulation of natural processes as a guiding principle; any management intervention in the forest has to enhance or conserve the ecological functions of the forest
3	combined objective forestry	medium	a mix of different objectives, additional objectives to timber production can be water and soil protection, mushroom production, habitat protection, avalanche prevention, game management and nature protection, fire prevention and/or recreation, and are adapted to the local situation
4	intensive even-aged forestry	high	to produce timber
5	short rotation forestry	intensive	to produce the highest amount of merchantable timber or wood biomass

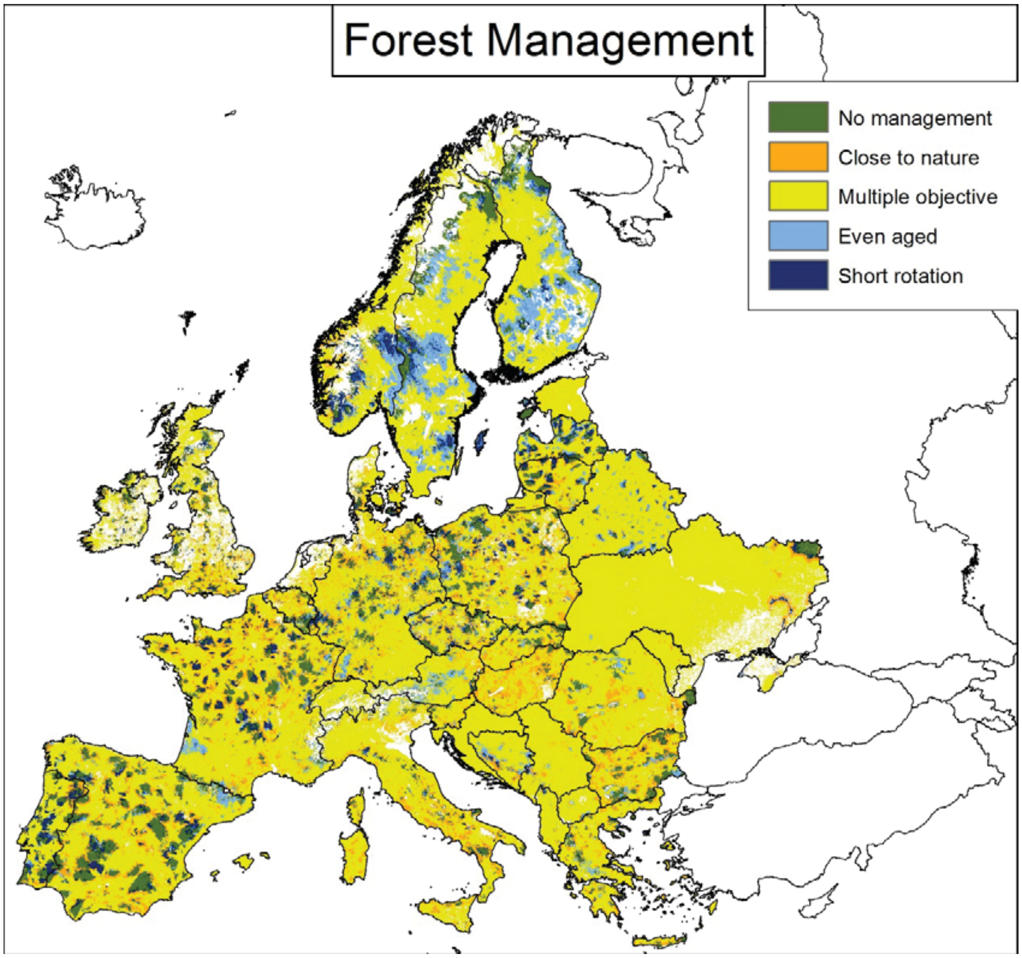

Fig. 5. Distribution of Forest Management Approaches (FMAs) over Europe (Hengeveld et al., 2012). See Table 1 for a characterisation of the FMAs.

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3 Discussion and Conclusions

The overall conclusions based on applications of the ForGEM model for climate change assessment studies at stand level are, firstly, that genetic adaptation of forest trees is possible within two to three rotations for important adaptive traits as phenology and water use; secondly, that the rate of response of adaptive traits to climate change is strongly affected by forest management (Kramer et al., 2010). The currently on-going whole genome studies will vastly increase the rate at which associations between QTLs and CGs and functional traits are found. Therefore,, a large amount of directly useable genetic information is likely to emerge in the near future for many economically important tree species (Neale and Kremer, 2011). That will improve the initialisation of the genetic system in ForGEM for local populations and thereby increase the accuracy of the adaptive responses to climate change. In combination with the observed findings that different provenances of the same species of trees can strongly differ in their response to a similar change in the climate (Mátyás, 1996), this means that it is necessary and feasible to include genetic processes in climate change assessment studies. Individual-based models are essential for such analyses, as both climate envelop models and process-based models that include parameters that can only be determined at the population level, may predict local extinction even if growing conditions improve (Kramer et al., 2012).(Kramer et al., 2012).

Cross-sectorial analyses can be performed with less uncertainty by including genetic processes in existing individual-, process-based climate change assessment models. In particular market sectors such as forestry, agro-forestry, and agricultural systems with fruit trees and nut-bearing trees can only respond with adaptation and mitigation measurements if uncertainties for alternatives of local trees are reduced. Overall, a stable environment in terms of perennial plant species is an essential requirement for human well-being, health, survival, migration and social stability. Genetic diversity of these species is an important aspect of environmental sustainability (Kremer, 2006) and resilience (Kramer, 2007) in the face of climate change, and needs to be taken account in cross-sectorial analyses and modelling inter-comparisons.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Climate change impacts on agriculture, adaptation & the role of uncertainty

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Abstract— Despite climate change impacts of -21% to +3% in vegetal production by 2050, the food system could keep pace with an increasing demand for agricultural products at reasonable prices, thanks to a large number of autonomous adjustments in the food system. However, uncertainty about the future climate change impacts could reduce their effective occurrence or their adequacy. Using the EPIC-GLOBIOM model, we evaluate resilience properties of the food system and the required adaptations under various climate change scenarios. Due to the high dispersion of biophysical impacts between crops, regions, and climate change scenarios, we diagnose non-marginal and significantly uncertain changes in the location and specialization of production systems, which may thus present rigidities, or reveal adequate to a limited part of potential climate change trajectories. In such cases, the assumption of a climate change-resilient food system does not hold as prices are significantly affected, with various adverse impacts, contrasted among actors (consumer vs. producer) or regions. Our results suggest that building a climate change-resilient food system under an uncertain climate change remains an underestimated challenge, requiring dedicated research efforts and policy implication towards robust solutions for production systems.

Index Terms—Climate change impact, Uncertainty, Adaptation, Food system, Resilience

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1 Introduction

Recent results confirm potential yield losses over low latitude areas even under a local increase in temperature below 3°, and global-wide losses under higher local temperature increase (Gornall et al. 2010; Rosenzweig et al. 2013; Iglesias et al. 2011). These impacts should not hamper the ability of the food system to keep pace with growing demand by 2050, with a small induced increase in food prices (Godfray et al. 2010; Fischer et al. 2005; Parry et al. 2004). Such resilience relies on a large number of adjustments assumed to occur autonomously, and ranging from adoption of alternative crop management practices, to market-driven adjustments in the location and specialization of production, in trade flows, and to targeted research and development efforts (Antle & Capalbo 2010; Smit & Skinner 2002; Easterling et al. 2007).

However, it has also been recognized that the uncertainty concerning climate change impacts and adaptations implies a higher probability for both reduced and inadequate adaptations in the food system, (Antle & Capalbo 2010; Adger et al. 2007; Howden et al. 2007; J. M. Reilly & Schimmelpfennig 2000; M. Reilly & Willenbockel 2010; Tol et al. 1998; Adger et al. 2012; Barnett & O'Neill 2010). Firstly, uncertainty in the impacts of a single climate change scenario could threaten the design of adequate adaptations, due to either significant uncertainty in local impacts, or significant changes in the local economic value of production associated with regionally heterogeneous impacts across the globe, as mediated through markets. Secondly, even if adequate adaptation measures are clearly identified under a specific change in climate, they could vary substantially among climate change projections. These uncertainties could (i) form a barrier to adaptation by requiring substantial awareness and learning (e.g., adaptation of production orientation), (ii) delay the implementation of long-lived adaptation that require substantial investment (e.g., relocation of agricultural activities and processing chains, or building basin-scale water resource management structures) due to the option value to information, (iii) alter the nature of adequate adaptation by enhancing the range of potential climate conditions a climate-ready food system need to cope with.

In this paper we set out to investigate the potential for and the consequences of both reduced and inadequate response of the food system to climate change. We use a modelling framework coupling the EPIC crop model and the GLOBIOM bottom-up partial equilibrium model of the agricultural sector, under a wide range of climate change projections provided under the ISI-MIP project. This analysis enables us to answer the following questions: what is the range of climate change impacts and adequate adaptations at the scale of production systems? What are the implications of disregarding rigidities impeding full adaptation, or non-robust adaptations, and can we identify adverse lock-in situations to be avoided?

2 Methodology

In addition to a no climate change reference, we considered 9 scenarios for the future climate, as estimated by a range of five different climate models (GCMs) under a single perturbation trajectoriy RCP 8.5

(Van Vuuren et al. 2011)), and four RCPs for one GCM (HadGEM2-ES). Their biophysical impacts on crop productivity and input requirements have been estimated for 18 crops using the EPIC crop model (Izaurralde et al. 2006), accounting the effect of CO_2 on crops, under three crop management systems (irrigated and rain-fed high fertilization systems, and rain-fed low fertilization systems). We assume a limited adaptation of crop management practices, e.g., moderate shifts in crop calendar, and in water and fertilizer application rate (within crop management system boundaries). The global recursive dynamic partial equilibrium model Global Biosphere Management Model GLOBIOM (Havlík et al. 2011) was used to derive the consequences of such biophysical impact for the agricultural sector up to 2050. Implicit product supply functions are based on detailed, geographically explicit Leontieff production functions, while demand is included explicitly through CES functions. Prices and international trade flows are endogenously determined for the respective 30 aggregated world regions. The reference projections of the agricultural sector's driving forces, affecting the demand for food, feed and bioenergy uses, and the production possibilities (e.g., technological progress) are based on the quantitative projections of the 'Middle of the Road' Shared Socio-Economic Pathway SSP2 (O'Neill et al. 2011). More details on the modelling framework are provided in the appendix.

Modelled adaptations of agricultural systems rely on endogenous variables: the share of cropland and grassland within available heterogeneous land categories, and its allocation to various types of production (crops and livestock) and management systems. We considered 3 different adaptation assumptions: (*i*) producers have full reactivity, with prefect knowledge of the actual consequences of a specific climate change scenario (FULL ADAPT scenario); (*ii*) producers face constrains that prevent any adaptation relative to climate change consequences (BARRIER scenario, producers' behavior constrained to the optimal solution under no climate change reference, full adaptation in trade and consumption); (*iii*) producers misinterpret the on-going climate change, and adapt proactively to a climate change scenario different from the one materializing (MALADAPT scenario, producers' behavior constrained by the optimal solution under another climate change scenario, full adaptation in consumption and trade).

3 Results

3.1 Biophysical impacts

By 2050, the biophysical impact on global vegetal production ranges from -11% to +3% for various climate change scenarios (Fig.1, -21% if no CO_2 effects), which is comparable to previous estimates. The impact is more sensitive to the choice of the GCM than to the choice of the RCP, significantly sensitive to CO_2 effects, and significantly variable aross crops (Sup. Table1 in appendix). The range of local impact across crops is superior to 30% in many places, while it is lower than 15% across crop management systems across in most places (Sup. Fig.1). Lastly, there are significant differences across GCMs in the local averaged impact (Sup. Fig.1), whose sign can be opposite between scenarios for large regions.

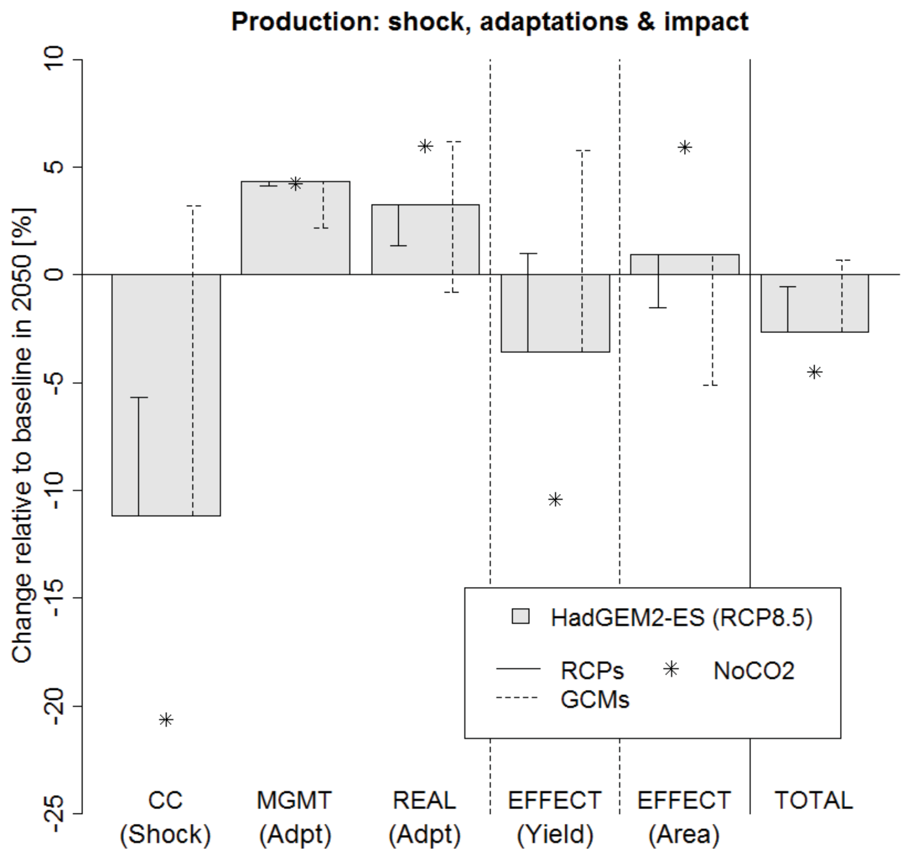

Fig.1: Decomposition of climate change and full adaptation impacts on world vegetal calorie production, in percentage of change relative to the reference without climate change in 2050, into biophysical effects on productivity (*CC Shock*), changes in the allocation of crop management systems (*MGMT Adpt*), and production relocation (*REAL Adpt*) summing up to global change cropland productivity (*EFFECT Yield*). Global cropland extent (*EFFECT Area*) is further adapted to provide the final impact (*TOTAL*). Bars present GCM HadGCM2-ES under RCP 8.5, while error bars denote the range for 4 other GCMs under the same RCP (dotted) or 3 other RCP under the same GCM (solid). Stars represent values under the HadGCM2-ES GCM and RCP 8.5 without CO_2 effects.

3.2 Autonomous adaptation and food system resilience

Under FULL ADAPT, the final impact on production is much smaller than the biophysical impact (-5% to +1%, last column in Fig.1), food consumption is weakly affected (-3% to +0%), while effects on world price indices range from -1% to +5% (for crop products) and from -1% to +3% (for livestock products). These results are consistent with earlier findings that by 2050 the final climate change impact on global food consumption would not decrease more than a few percent with limited price increases, if accounting for adjustments in the food system (Easterling et al. 2007).

Using a decomposition method, we estimated the effects of different adaptation mechanisms on global vegetal calorie production (Fig.1), as:

- Adjustment of global cropland productivity (assuming reference cropland by 2050, 4th column, YIELD effect), through changes in crop management (2nd column, MGMT), and reallocation of cropland across crops and agricultural land units (3rd column, REAL), in contrary to reallocations (from -1% to +6%), which rely twice as much on intra-region than inter-region reallocations.

- Adjustment of global cropland extent (assuming reference productivity by 2050, 5th column, AREA effect). Both beneficial and detrimental yield effects are compensated: for almost all GCMs under RCP 8.5, cropland is reduced (up to -5%) due to yield gains, while for HadGEM2-ES cropland is increased (up to +6% without CO_2 effects).

3.3 Potential for and consequences of reduced or inadequate adaptation

The range across GCMs under RCP 8.5 of required adjustments in the area allocated to the dominant crop (Figure 2a) represent by 2050 more than two thirds of local reference cropland extent in many parts of the world. The range of regional-scale changes in total cropland is also significant (Figure 2b), in contrary to adaptations in crop management systems. There is consequently a high potential for reduced or inadequate adaptation concerning the adjustment in the location and specialization of production systems, due to the uncertainty concerning future climate.

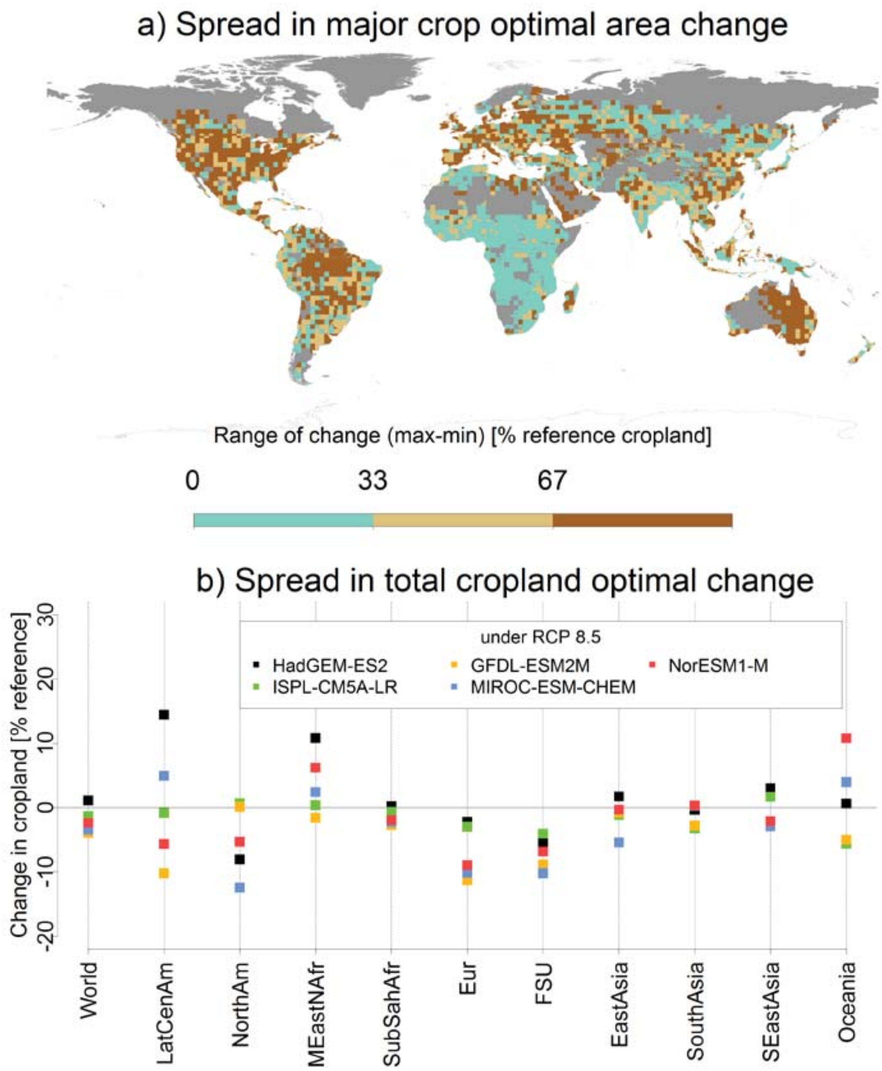

Fig. 2: Spread of optimal land allocation adjustments across climate change scenario. a) Spread of optimal change in the area allocated to the major crop by 2050, i.e. difference between maximum and minimum change in area allocated to the major crop by 2050 across 5 GCMs under RCP 8.5 (in percentage of reference cropland). **b) Spread of optimal change in total cropland by region and GCM**, computed by 2050 as the relative difference between reference and GCMs specific values of the total regional cropland values (under RCP 8.5).

If considering reduced adaptation (BARRIER scenario), final changes in vegetal production follow the biophysical effect (-11% to +3%), and world price indices significantly deviate (from -32% to +28% for crop products). If adapting to a climate change different from the one materializing (MALADAPT), changes in vegetal production range from -15% to +9%, while crop price indices range from -40% to +63%. In both cases, the food system cannot be considered as resilient to climate change anymore, and asymmetric impacts appear between producers and consumers (Fig.3): food consumption losses occur if not adapting to a pessimistic climate change (e.g., HadGEM2-ES under RCP 8.5, -6%, or -13% if no CO_2 effects), or if anticipating a climate change scenario more optimistic than the one materializing (e.g., anticipating GFDL-ESM2M under RCP 8.5 while another one materializes, -1% to -9%), while it is the opposite for producers' revenue. Locking into the adaptation to a wrong climate change trajectory is always worse than not adapting for either producers or consummers: from the producer (resp. consumer) point of view, it is worse (rep. better) to anticipate a pessimistic climate change scenario than not adapting, and the way around if anticipating an optimistic scenario.

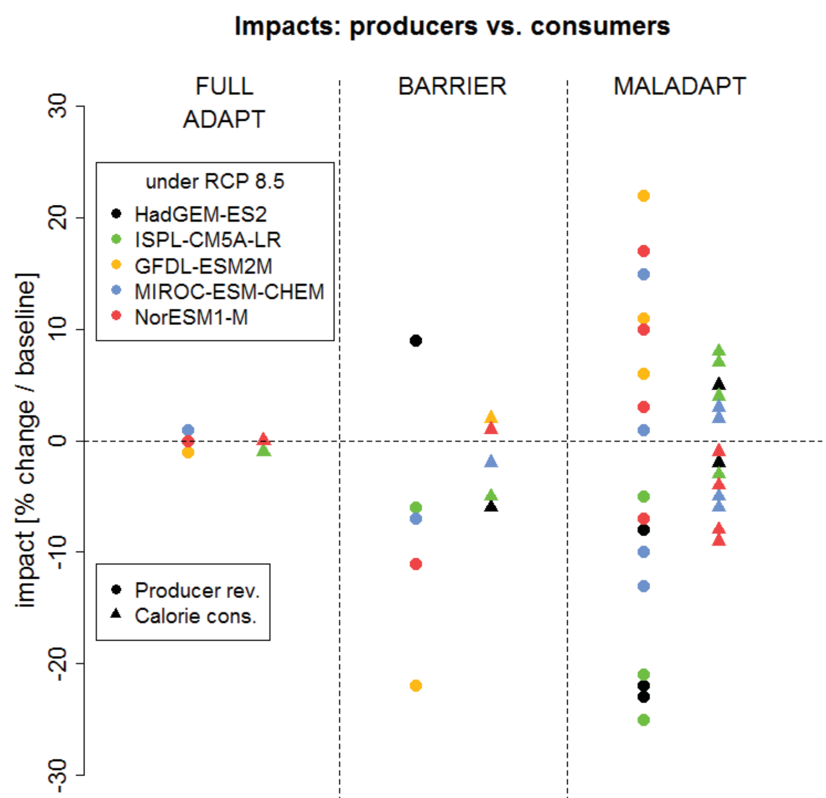

Fig. 3: Consequences of various adaptation scenarios for producers and consumers. Circles (respectively triangles) display the change at world level in producers' revenue (resp. calorie consumption) for a specific (climate change x adaptation) scenario compared to the reference. Vertical dashed lines separate the different adaptation assumptions. Colors tag the actual climate change scenario occurring (except MALADAPT), or the anticipated climate change scenario (MALADAPT).

4 Concluding remarks

We show that by 2050 climate change impacts on vegetal production are significant but uncertain: while global potential losses range from -21% to +3%, the impacts are locally particularily variable across crops, and show large regional differences across climate models. The adequate adaptations at the scale of production systems are consequently both non-margnial and widely uncertain by 2050, with significantly climate model-dependent changes in the location and specialization of production, and a more robust rise in irrigated systems.

The optimal path of adaptation will be difficult to embark upon under such uncertainty, and our results suggest a potential for reduced or inadequate adaptation. Under such assumptions, the commonly acknowledge resilience of the food system to climate change by 2050 appear overly optimistic, as production levels and prices are widely affected. Adverse consequences can be expected between regions or actors of the food system (producers vs. consumers), meaning that it is not possible to identify a reduced part of potential changes in climate to which anticipated adaptation would reveal robust for everyone. Indeed, such strategy would even always be worse than not adapting for either producers or consumers at the world level.

On the basis of our results, it is our firm opinion that building a climate change-resilient food system has been an underestimated challenge, which requires larger and adequate policy and research efforts. Firstly, lowering the potential for reduced or inadequate adaptations through climate impact research is needed, but achievements could be limited (Roe & Baker 2007), and designing robust systems under uncertainty requires the mobilization of appropriate concepts (S. Hallegatte 2009). Secondly, our understanding of adaptation is limited, and significant research is needed to identify and overcome barriers to adaptation (Biesbroek et al. 2013), and move towards an understanding of dynamic adaptation pathways (Downing 2012). Lastly, food system resilience need to be evaluated under wider assumptions (e.g., socio-economic pathways, or the achievement of environmental targets), alltogether challenging our understanding and ability to sustainably manage the biosphere (Rounsevell et al. 2012).

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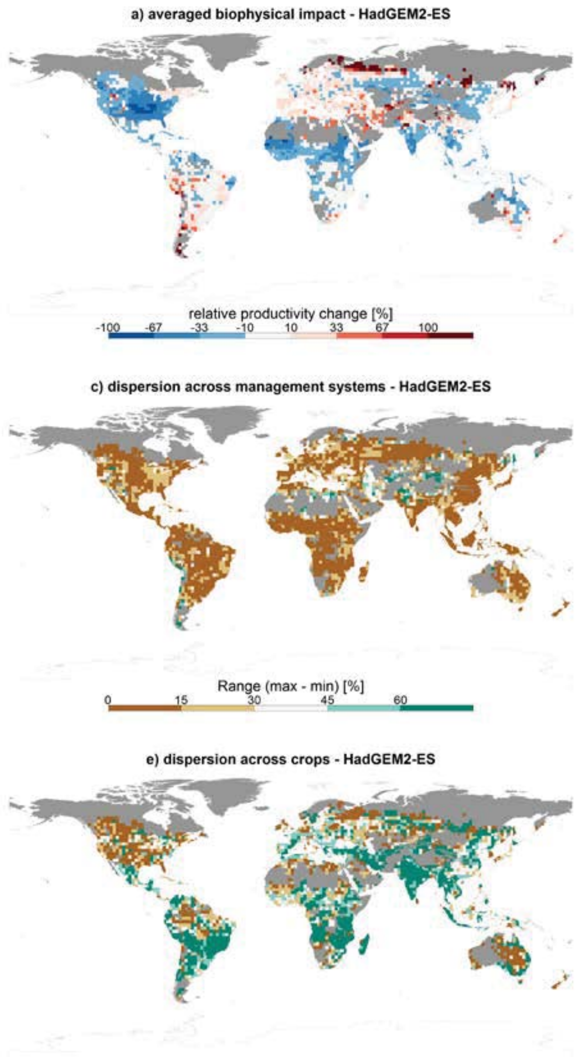
6 Appendix

	All scenarios with CO_2 effects					*Spread GCMs (RCP8p5) with CO_2 effects*					*Spread RCPs (HadGEM2-ES) with CO_2 effects*					*CO_2 effect (HadGEM2-ES; RCP8p5)*	
	m.	mi.	ma.	R (*)	S (†)	m.	mi.	ma.	R (*)	S (†)	m.	mi.	ma.	R (*)	S (†)	yes	no
CEREALS	-5	-9	7	16		-2	-9	7	16		-6	-9	-4	5	x	-9	-19
Barley	13	6	26	20	x	21	9	26	20	x	11	6	15	9	x	15	-6
Corn(‡)	-11	-21	8	29		-9	-21	8	29		-14	-21	-11	10	x	-21	-27
Wheat	3	0	10	10	x	3	0	10	10	x	3	1	6	5	x	3	-7
Rice	-5	-9	3	12		-2	-9	3	12		-6	-9	-4	5	x	-9	-22
Millet(‡)	-14	-27	9	36		6	-27	9	36		-19	-22	-11	11	x	-22	-31
Sorghum(‡)	-18	-28	-1	27	x	-15	-28	-1	27	x	-20	-28	-17	11	x	-28	-30
ROOTS	-6	-8	7	15		2	-8	7	15		-7	-8	-6	2	x	-8	-21
Cassava	-13	-17	6	23		-2	-17	6	23		-16	-17	-14	3	x	-17	-29
Potato	-4	-10	2	12		-4	-10	2	12		-5	-8	-3	5	x	-8	-21
Sweet potato	5	1	16	15	x	7	1	16	15	x	5	4	7	3	x	7	-8
PULSES	1	-4	10	14		1	-4	10	14		-1	-3	2	5		-3	-19
Dry beans	5	3	17	15	x	8	3	17	15	x	4	3	5	2	x	3	-14
Chick peas	-17	-28	-5	23	x	-17	-28	-8	20	x	-14	-19	-5	14	x	-19	-31
OIL. OTHER	-9	-15	-2	13	x	-5	-15	-2	13		-11	-15	-9	6	x	-15	-21
Cotton	-17	-28	-4	24	x	-16	-28	-4	24	x	-19	-28	-13	15	x	-28	-24
Groundnut	-22	-32	-15	17	x	-17	-32	-15	17	x	-25	-32	-19	13	x	-32	-28
Oilpalm (§)	-26	-34	-17	17	x	-25	-34	-17	17	x	-27	-34	-23	11	x	-34	-39
Rapeseed	16	6	23	17	x	17	6	23	17	x	16	10	23	12	x	23	11
Sunflower	4	-4	22	26		13	-4	22	26		-2	-4	2	6		-4	-19
Soya bean	-5	-14	4	18		-2	-14	4	18		-8	-14	-5	9	x	-14	-22
SUGAR	-21	-37	-11	26	x	-26	-37	-20	17	x	-16	-26	-11	15	x	-26	-32
Sugarcane(‡)	-21	-37	-11	26	x	-26	-37	-20	17	x	-16	-26	-11	15	x	-26	-32
C3 CROPS	-1	-4	5	9		2	-4	5	9		-3	-4	-1	3	x	-4	-16
C4 CROPS	-14	-23	0	23		-14	-23	0	23		-15	-23	-12	11	x	-23	-28
ALL	-6	-11	3	`14		-4	-11	3	14		-7	-11	-6	5	x	-11	-21
DVPD	-8	-24	17	41		-2	-24	17	41		-18	-24	-10	14	x	-24	-33
DVPG	-4	-11	1	12		-4	-11	1	12		-5	-8	-3	5	x	-8	-18

(*) The Range (R) is defined as (max – min).
(†) The Sign (S) is noted as 'x' if and only if the sign is the same for all scenarios.
(‡) Crops having a C4 photosynthesis pathway; all remaining crops have a C3 photosynthesis pathway.
(§) Oilpalm is not simulated by EPIC, and was computed in each (spatial x management) unit as the mean impact over groundnut, soybean, rice, and wheat.

Sup. Table 1 – Biophysical impact on crop yields by 2050, for 18 vegetal products, in percentage of change relative to the reference scenario by 2050. The first 5 columns of figures provide the median (m.), minimum (min), maximum (max), range (R), and sign (S) values, for all scenarios considered except the no CO_2 experiment under HadGEM2-ES and RCP8p5 (*All scenarios*). The two next groups of 5 columns provide the median (m.), minimum (mi.), maximum (ma.), Range (R) and Sign (S) values for respectively the 5 different GCM under RCP8p5 (*Spread GCMs*), and for the 4 RCPs under HadGEM2-ES (*Spread RCPs*). The last two columns displays the effect of not accounting for CO2 effects on plant growth (*no*), in the case of climate change scenario HadGEM2-ES x RCP8p5, in comparison with its accounting (*yes*). Values are globally (or over developed and developing countries for 2 last rows) aggregated values (over crops and space) from EPIC derived shifters, and weighted by the distribution of yields in 2050 under the no climate change scenario in kCal/ha over land units, crops and crop management systems (and thus embedding the effect of technological change).



Sup. Fig.1 – Maps of climate change impacts on crop productivity by 2050, under RCP8.5 as seen by GCMs HadGEM2-ES (left panels) and GDFL-ESM2M (right panels): **(upper panels) averaged climate change impact** on crop productivity (averaged over reference distribution of yields across crops and management systems within cropland, by 2050 in kCal/ha); **(middle panels) dispersion of the impact across crop management systems**, i.e. local difference between maximum and minimum impact across management systems (aggregated over crops); **(lower panels) dispersion of the impact across crops**, i.e. local difference between maximum and minimum impact across crops (averaged over management systems). The resolution used here is an aggregation of cropland simulation units over the intersection of country boundaries and a 0.5 x 0.5 degree latitude-longitude grid. Grey color indicates non-agricultural land for all panels.

Simulating climate change impact on crops with EPIC

EPIC simulates geo-referenced and management-related impacts of global climate change on crop parameters (yield, N-fertilizer input, P-fertilizer input, and irrigation water input) for 17 crops, representing more than 80% of the 2007 harvested area as reported by FAO (barley, cassava, chickpeas, corn, cotton, dry beans, grain sorghum, millet, groundnuts, potatoes, rapeseed, rice, soybeans, sweet potatoes, sugarcane, sunflower, and wheat). These impacts have been simulated for three mutual exclusive input systems: *rain fed automatic nitrogen fertilization* (automatic N-fertilization rates allowing N-stress free days in 90% of the vegetation period, with crop specific thresholds, and up to 200 kgN/ha/y), *automatic nitrogen fertilization and irrigation* (in addition to automatic fertilization the irrigation rates allows water-stress free days in 90% of the vegetation period, with crop specific thresholds, and up to 500 mm/y), and *subsistence farming* (no N fertilization, and no irrigation).

EPIC uses the daily climate input data of solar radiation, tmax, tmin, precipitation, relative humidity, and wind speed. The Penman-Monteith potential evapotranspiration equation is used to account for the full CO_2-fertlizer effect. The accounting for nutrient constraints does not have a direct impact on CO_2 fertilization. EPIC selects the most limiting stress out of temperature, nitrogen, phosphorus, water, and aeration stresses on each day to lower the potential biomass accumulation. Therefore, the accounting for nutrient constraints has an effect on the sensitivity of EPIC for climate stresses, but not for CO_2. Hence, it can be expected that adverse impacts of CC on crop yields are larger in non-nutrient limited environments, than under sufficient nutrient inputs.

In addition to possible crop management system specific adjustments in input use, annual planting and harvesting dates are automatically triggered, when a certain fraction (crop specific and constant over time) of total heat units is attained. It should thus be clear that the impact simulated by EPIC already include basic adaptation of crop management practices, such as adjustments in crop calendar, and in input use (within crop management system specific boundaries).

Modeling adaptations in the food system

The Global Biosphere Management Model (GLOBIOM) is a global recursive dynamic partial equilibrium bottom-up model integrating the agricultural, bio-energy and forestry sectors. Prices and international trade flows are endogenously determined for the respective 30 aggregated world regions. Product supply functions are included implicitly and are based on detailed, geographically explicit Leontieff production functions. Demand is included explicitly in the form of constant elasticity of substitution functions of time dependant parameters. The supply of modeled products needs to meet final demands for human consumption, livestock production, and bio-fuel production. Endogenous variables related to the agricultural sector include the share of cropland within available land, its allocation to various types of production and management, and its repartition across biophysically heterogeneous land categories, as well the animal capital detailed by category, and their repartition across management systems. Land use change possibilities are limited through explicit constraints on conversion from one land use to another.

GLOBIOM thus integrates endogenous adaptive behaviors in the agricultural sector. Consumers can modify their consumption volume by type of product. Producers adapt to changes in local production possibilities and costs (affected by climate change through inputs from EPIC), and to all other changes in final demand and trade possibilities, transmitted by markets.

GLOBIOM-EPIC integration

Basic cropland spatial units in GLOBIOM are delineated at the level of 5 arcminutes pixels by the intersection of administrative boundaries, classes of soil, altitude and slope information, and of a regular 0.5 x 0.5 degree latitude-longitude grid. In addition to the delineation of such spatial units, the model considers 4 main types of crop management systems, corresponding to subsistence systems, rain fed low fertilization systems, rain fed high fertilization systems, and irrigated high fertilization systems (see Skalský et al., 2008). For each of the 18 crops modeled, we use EPIC outputs *Y* to alter 4 input parameters for GLOBIOM: yields [tDM/ha], N-fertilization rate [kgN/ha], P-fertilization rate [kgP/ha], and irrigation rate [1000m^3/ha]. It has to be noticed that in EPIC, management related parameters are identical under subsistence and rain-fed low fertilization systems (subsistence farming mentioned above).

The mean value of each output averaged across the 5 GCMs as simulated by EPIC for the historical period (average over 1980-2010) is implemented as initial value for year 2000, $Y(C,p,m,2000)$, for each output *Y*, pixel *p*, management system *m*, and crop *C*, after a national-scale correction accounting the deviation to FAO data.

Under each climate change scenario (i.e., GCM x RCP combination), outputs *Y* were then computed by EPIC for each spatial unit x management combination, for 3 time periods (2005-2035, 2035-2065, 2070-2099). For each output, crop, climate change scenario, management system, and time horizon, the relative output value is divided by the historical value, and averaged for each time horizon. We then linearly interpolated at a 10 year time-step these values, to generate shifters $\Delta Y(C,s,p,m,t)$ for each crop *C*, climate change scenario *s*, pixel *p*, management system *m*, and 10-year time step *t*. These shifters were limited by a factor 10 (i.e. an increase of 900%).

These relative climate change impact were cumulated multiplicatively with the effect of technological progress $\Delta Y^{Tech}(C,t)$, to generate final GLOBIOM values:

for each crop *C*, climate change scenario *s*, pixel *p*, management *m*, and time step *t*,

$$Y(C,s,p,m,t) = Y(C,p,m,2000) \cdot \Delta Y(C,s,p,m,t) \cdot \Delta Y^{Tech}(C,t)$$

Skalský, R., Tarasovičová, Z., Balkovič, J., Schmid, E., Fuchs, M., Moltchanova, E., Kindermann, G., et al. (2008). *GEO-BENE global database for bio-physical modeling v. 1.0 (Concepts, methodologie and data)*. The GEO-BENE database report, International Institute of Applied System Analysis, Laxenburg (Austria), available at http://www.geo-bene.eu/files/Deliverables/Geo-BeneGlbDb10(DataDescription).pdf

Reference socio-economic assumptions

The reference projections of the agricultural sector's driving forces, affecting the demand for agricultural goods for food, feed and bioenergy uses, and the production possibilities (e.g., technological progress) are based on the quantitative projections of the 'Middle of the Road' Shared Socio-Economic Pathway (SSP2, (36)), whose quantification lead to a forecasting of a 9.2 billion population by 2050, and more than a doubling of income per capita compared to 2000. These projections were then translated in GLOBIOM into appropriate assumptions (e.g., technological progress, food diets, etc.), and further details can be found here:
https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=welcome

Analyzing the climate change and adaptation effects

Decomposing effects on global vegetal calorie supply. In figure 1, we use a methodology providing a simple and approximate decomposition of the difference between a climate change scenario *s* and the reference scenario *b*, by 2050, in total vegetal calorie supply *V*. For a given scenario, *V* is defined as the product of the total area used to produce vegetal calorie *A* and its globally averaged yield *Y*, expressed in Calorie.ha^{-1}.

Under the assumption that by 2050 the deviation to the reference *b* of the global vegetal calorie supply $\Delta V(s)$ induced by a specific climate change scenario *s* is small enough, and assuming that at the global level *A* and *Y* are independent, we can use a differential form and write:

$$\Delta V(s) = V(s) - V(b) = A(b) \cdot \Delta Y(s) + Y(b) \cdot \Delta A(s) \equiv \ \Delta V(s)^{yield} + \Delta V(s)^{area}$$

Under these assumptions, the total change in supply can thus be approximated as the sum of a change in yield assuming reference total cropland ($\Delta V(s)^{yield}$), and a change in total cropland assuming reference yield ($\Delta V(s)^{area}$). These two effects will hereafter be referred to as the *yield* and *area* effects. One can then further investigate the yield effect by splitting the change in yield in separate into *biophysical climate change impact*, and *adaptation* effects:

$$\Delta Y(s) = \Delta Y(s)^{CC} + \Delta Y(s)^{Ad}$$

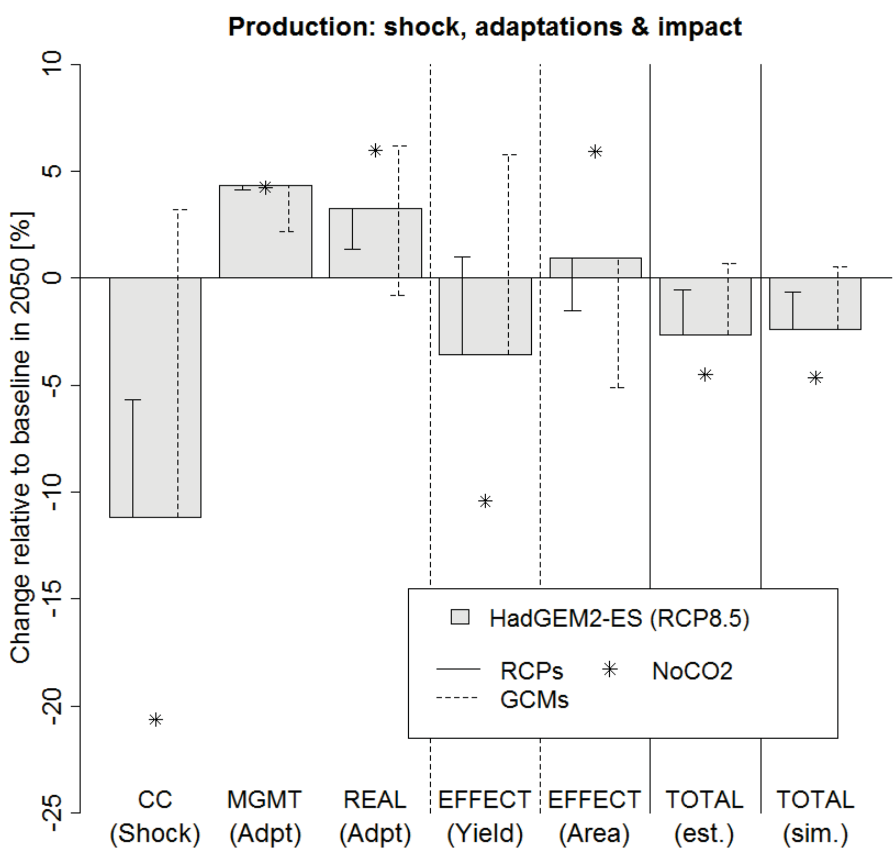
where the climate change $\Delta Y(s)^{CC}$ term is computed as difference between the reference yield of each spatial unit and management system, after and before it has been multiplied by the climate change shifter, and aggregated using reference land use. The adaptation term $\Delta Y(s)^{Ad}$ corresponds to the effects of subsequent changes in the share of management systems within a pixel, on climate change affected yields $\Delta Y(s)^{mgmt}$ (computed over pixels having a non-null area in both reference and *s* scenarios, and aggregated using reference land use), and the effect of crop relocations across pixels $\Delta Y(s)^{reloc}$, computed as the remaining part of the adaptation term.

$$\Delta Y(s)^{Ad} = \Delta Y(s)^{mgmt} + (\Delta Y(s)^{Ad} - \Delta Y(s)^{mgmt}) \equiv \Delta Y(s)^{mgmt} + \Delta Y(s)^{reloc}$$

We can computed in post-treatment of our simulations five different terms easily interpretable, and providing insight into the impact on the evolution of the total global vegetal calorie supply of climate change, and further separate adaptation mechanisms: a pure biophysical climate change impact metric ($\Delta V(s)^{yield,CC}$), 3 adaptation impact metrics ($\Delta V(s)^{yield,mgmt}$, $\Delta V(s)^{yield,reloc}$, and $\Delta V(s)^{area}$), and finally the total simulated change $\Delta V(s)$. If the residue between this last term and the sum of all four other ones remains small, this decomposition provide a somehow complete description of the climate shock and the modeled adaptation. If not the case, it means that some of the assumptions insuring equality are violated, and that our decomposition is not so informative because not able to explain the capture the final model response.

$$\Delta V(s) - [\,\Delta V(s)^{yield,cc} + \Delta V(s)^{yield,mgmt} + \Delta V(s)^{yield,reloc} + \Delta V(s)^{area}\,] = ResTerm(s)$$

It is thus important to control for the size of the residual term *ResTerm(s)* for each scenario. Sup Fig.2 below displays the same information as in figure 1, plus a last term which is the exact simulated climate change impact (TOTAL Sim), and allow us to measure the size of the residual term (by a comparison to the sum of total decomposed effect TOTAL Sum), and thus the interpretability limit to our decomposition method. The residual is always less than 1% of reference global calorie supply in all scenarios considered. While the final decomposed effect seems slightly underestimating the final supply value (as it can be seen for example for the central scenario RCP8.5 under HadGEM2-ES), it preserves the range and absolute effects of changes in supply due to the consideration of different climate models, RCPs, and no-CO_2 sensitivity experiment.



Supplementary Figure S2- Decomposition of change in world per capita vegetal calorie production vs. exact simulated value. See legend of Fig. 1. The figure is completed by a last bar on the right side (TOTAL Sim.), displaying the exact simulated value, to be compared with the total decomposed effect (TOTAL est.), to obtain the residual term.

Climate-induced human migration: a review of impacts on receiving regions

Rachel Licker and Michael Oppenheimer

Abstract – Climate change is expected to alter human migration flows by changing the conditions that lead to population movement. For example, changing crop-growing environments may prompt rural inhabitants to seek different sources of income in other rural or urban communities. Additionally, some coastal areas may become less habitable as a result of sea-level rise and increasingly intense storms. However, the consequences of climate-induced migration for receiving regions are not clearly understood. Some reports that examine the interactions between environmental change and human migration indicate that increased population flows may complicate the ability of local governments in urban areas to provide sanitation infrastructure or other human services, and may result in environmental degradation. However, these conclusions typically rely upon information from few studies and do not offer insight into the range as well as the magnitude of potential impacts. In this article, we carry out a more comprehensive examination of how human migration – not specific to climate change – has affected receiving regions. We compile information from studies of regions that have already experienced population influx and show how flows of migrants can significantly influence a variety of factors, including public health, security, labor markets, and natural resource bases. In addition, we show that the impacts of migrants on receiving regions depend on the nature and context of the migration flow. This study provides a basis for anticipating the secondary impacts that regions may experience as a result of populations migrating in response to changing climate – impacts that will need to be addressed together with those due to local changes.

Index Terms – Climate change, human migration, secondary impacts

1 Introduction

Climate change has the potential to dramatically alter human migration flows at many locations by acting upon existing drivers of migration (Foresight, 2011). Insights into mechanisms driving migration associated with climate *variability* (such as reduced crop yields) provide a partial basis for estimating the extent to which climate *change* may lead to increases or decreases in future migration flows (for example, see Feng et al. 2010 on Mexico; Kniveton et al. 2012 on Burkina Faso; and Barrios et al. 2006 on sub-Saharan Africa). That changing crop-growing environments may prompt rural inhabitants to seek different sources of income in other rural or urban communities has also been observed within Bangladesh (Gray and Mueller, 2012) and the United States (Feng et al., 2012). Broad-scale, econometric models have also been developed to estimate the impact of climate change and environmental variables on international migration flows. With such a tool, Marchiori and Schumacher (2011) observed a significant increase in mobility as a result of changes in climate and Beine and Parsons (2012) conversely detected a limited impact on international migration, but an increase in within country movement as a result of natural disasters. Other studies have examined how coastal communities will respond if areas become less habitable as a result of sea-level rise and increasingly intense storms. Based on interviews, Mortreux et al. (2009) considered how climate change influences the migration intentions of residents of Funafati, Tuvalu, and concluded that climate change is not currently a significant element of people's decision-making frameworks. Conversely, another interview-based study of Tuvaluan residents and Tuvaluan individuals residing in New Zealand found that while people have not migrated solely in response to climate change, it is an important factor driving migration between the two locations (Shen and Gemenne, 2011).

The implications of such altered migration flows for sending and receiving regions in the context of future climate change are largely unexplored. But a comprehensive modeling approach to climate change impacts would account for these indirect effects. In this review, we undertake an investigation of this issue and examine in particular the impact of migration on receiving regions. We do so by compiling information from studies of regions that have already experienced population influx (not necessarily as a result of climate change), and consider how flows of migrants have affected a variety of factors, including public health, security, labor markets, and natural resource bases. Through this review of impacts (positive and negative), we identify the secondary impacts that regions may incur as a result of populations migrating in response to climate change – impacts that, together with local impacts of climate change in receiving regions, can form a comprehensive basis for modeling, as well as for policy responses.

2 Forms of Migration

People typically migrate for multiple and varied reasons (Koser and Martin, 2011), which we will demonstrate later, can lead to a range of impacts on receiving regions. While it is not always possible to neatly classify migration flows, human mobility has, for example, traditionally been characterized as voluntary or forced, the latter of which can also be referred to as displacement (Foresight, 2011). Whether migration is permanent or temporary forms another continuum of migration behavior (Bell and Ward, 2010). Additionally, human mobility can be international (with individuals moving across nation-state boundaries), or can occur internally (within a country), although even this distinction can be unclear when migrants carry out several moves (King and Skeldon, 2010).

3 Public Health Impacts

Depending on the conditions in sending regions and their differences from those in receiving regions, migration can introduce infectious diseases that are either not endemic or are otherwise under control in receiving regions (Gushulak and MacPherson, 2004). For example, increasing immigration from regions where Chagas disease is endemic to countries where it is not (for example, the United States and Canada) is causing an increase in the numbers of infections in receiving regions (Rassi et al., 2010). In 2009, there were an estimated 300,167 individuals with Chagas disease (or *Trypanosoma cruzi* infection) living in the United States, with a majority of those individuals having emigrated from regions in Latin America where the disease is endemic (Bern and Montgomery, 2009). This rise in incidences of Chagas disease is creating concern among blood donor and transfusion programs in the United States (Leiby et al., 2002) and is creating new challenges for healthcare professionals (Bern et al., 2007).

In addition to the new diseases and management challenges that migration can create for public health institutions in receiving regions, the conditions of migration can affect the health of migrants themselves in receiving regions. Refugees, displaced persons, and other forced migrants face a number of adverse circumstances in receiving regions. Overcrowding, poor sanitation infrastructure, lack of access to clean water and food, and low rates of immunization in refugee camps can lead to infectious disease outbreaks, including meningitis, tuberculosis, measles, and acute respiratory infections, as well as diarrheal diseases particularly amongst children (Toole and Waldman, 1997; Connolly et al., 2004; McMichael et al, 2012). The implications of migration on the health of migrants are also dependent on the cultural attitudes and official policies of receiving regions. The perception of forced migrants including refugees and asylum seekers as separate, and in turn not fully entitled to care, can result in a lack of access to healthcare services as well as exacerbated physical and psychological health conditions among these populations (Grove and Zwi, 2006).

4 Security Impacts

Similar to the public health arena, impacts of migration on the security of receiving regions are contingent on the context of the migration flow. First, whether groups of displaced persons are relocating as a result of conflict can have implications for security. In some instances, refugees from conflict ridden sending regions can cause an increase in conflict, crime, and violence in receiving regions as a result of, for example, military attacks from sending regions that extend beyond the bounds of refugee camps (Jacobsen, 2000; Jacobsen, 2002). Additionally, refugee camps can also act as a destabilizing force in receiving regions with existing political problems, where people and materials from refugee camps can find themselves exploited and incorporated into local conflicts (Jacobsen, 2000). Refugees in camps also often find themselves victims of crimes and intimidation (Jacobsen, 2000). In Kenya's refugee camps, sexual and domestic violence, as well as armed robbery are perpetrated on a regular basis (Crisp, 2000).

A global, empirical analysis of conflict and refugee flows in the latter half of the twentieth century found that refugees from neighboring states significantly increase the likelihood of violent conflict in host nations through many of the mechanisms discussed above (Salehyan and Gleditsch, 2006). At the same time, this study also demonstrated that a majority of refugees do not engage in violent conflict and a majority of refugee flows do not result in violent conflict. Thus while the impact of influxes of forced migrants on the security of host nations is a well-founded concern, violent conflict is not a certain outcome, and is partially dependent on the actions taken by the governments of receiving regions (Salehyan and Gleditsch, 2006).

5 Land Use and Natural Resource Impacts

Migration is one of the most important demographic factors driving land cover change around the world (Lambin et al., 2003). In an analysis of incidences of tropical deforestation largely in the twentieth century, in-migration was an important driver of land conversion to pasture and cropland, particularly in Africa and Latin America (Geist and Lambin, 2002). Other work has shown that the majority of tropical deforestation occurs as a result of "frontier migrants" who establish new enterprises in unsettled forest (Carr, 2008). Migration can also affect land cover change in other biomes. In Ghana's savannah-dominated Volta Basin, declining soil fertility in sending regions has sparked new seasonal migration flows, with individuals seeking new land to cultivate (Braimoh, 2004). This practice has resulted in the conversion of large tracts of woodland to cropland in the region.

The impact of migration on the natural resource bases of receiving regions depends in part on how individuals settle in receiving regions and how they are integrated into host communities (Jacobsen, 1997). Black and Sessay (1998) found that the influx of Mauritanian refugees to the Senegal River Valley in West Africa in the late 1980s resulted in an increase in the absolute pressure on natural resources in the region, largely as a result of the migrants practicing agricultural and pastoral based livelihoods. However, because refugees settled in a dispersed manner and because there were strong ties between refugees and the local populations that led to coordinated land use, the total impacts were relatively small. Furthermore, the per capita impacts of refugees and local residents on natural resources were found to be similar. Conversely, the establishment of refugee camps within the Democratic Republic of Congo's Kahuzi-Biega National Park and UNESCO World Heritage Site in the mid 1990s significantly reduced the populations of large mammals like elephants and gorillas, and led to the collapse of park management (Sato et al., 2002).

6 Labor Market and Economic Impacts

The effect of migration flows on the economies and wages in receiving regions depend in part on the skill structure both of the receiving region and the immigrants (Dustmann, 2008; Borjas, 2009). However, immigration does have the propensity to decrease the wages of competing, native workers (Aydemir and Borjas, 2007; Borjas, 2009). At the same time, migrants can lead to reduced rates of unemployment. An analysis of British Columbia, Canada's labor market showed that immigration increased unemployment rates in the short-term, but in the long run, led to a decrease as the presence of immigrants ultimately stimulated job creation (Gross, 2005). In Tanzania, a mass migration of more than one million refugees in the mid 1990s from Rwanda, Burundi, and the Democratic Republic of Congo resulted in the creation of numerous well-paid jobs for local residents by international aid agencies and NGOs (Whitaker, 2002). However, some local institutions lost employees to these higher-paying positions. Immigration can also benefit host countries through the professional contributions made by individuals. In the United States, the number of skilled immigrants is positively correlated with innovation levels (Chellaraj et al., 2005), with individuals sparking innovation both through their own contributions, as well as through spillover effects that increase innovations produced by native workers (Hunt and Gauthier-Loiselle, 2009).

7 Conclusions

Through this review, we have demonstrated that migration can have a range of impacts on receiving regions, both beneficial and harmful. This study also highlights the importance of considering the nature of a migration flow when examining the implications for receiving regions. Whether migration is planned and voluntary, or forced; whether it occurs in response to conflict, whether a receiving region is stable, has a strong public health infrastructure, or is itself suffering from conflict will result in different outcomes. While migration flows cannot necessarily be neatly categorized (for example as fully voluntary or forced), it is important for future research to explicitly consider the contexts in which climate-induced migration is most likely to occur. This may help to better anticipate the challenges and benefits that climate-induced migration may present in different locations, as well as the secondary impacts that climate change may have as a result of populations migrating in response to changing climate.

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Adaptation measures for the impact of climate change on global water resources— Option 1: Reducing water use

Yoshimitsu Masaki, Naota Hanasaki

Abstract—To reduce the projected damages of climate change, adaptation measures are necessary. We conducted a global hydrological simulation to estimate how much water use must be reduced to adapt to the changing climate. In this study, we mainly focused on the world's irrigated area and crop intensity because these are two key factors in irrigation water consumption. The results suggest that if both factors changed at a rate of -0.2 % year^{-1}, the water-stressed population (2041-2070 and 2071-2100) would be almost stabilized at the same level as the base year (2000). To meet the food demands of the future, the reduction in irrigated area would need to be compensated by other measures to increase crop production.

Index Terms— Adaptation, Climate change, Food, Water

1. Introduction

Even if the best available measures were implemented to reduce greenhouse gas emissions, the global mean air temperature would keep increasing during the 21st century due to the inertia of the climate system. Therefore, global adaptation measures are vital.

Hanasaki et al. (2012a,b) conducted a global water scarcity assessment for the whole 21st century. First, they projected future sector-wise water withdrawals and consumption compatible with the latest global socio-economic scenarios, called Shared Socioeconomic Pathways (SSPs; O'Neil et al., 2012). The five SSPs describe worlds with substantially different socio-economic views. They developed scenarios for irrigated area, irrigation efficiency, crop intensity, industrial water withdrawal, and municipal water withdrawal. The former three factors were used to estimate the irrigation water withdrawal. Each scenario was developed from a formula that contains one parameter (Equations 1–5 of Hanasaki et al., 2012a). Different parameters were assigned for each SSP to harmonize with its narrative scenario. Second, they conducted hydrological simulations, including human water dynamics using H08 (Hanasaki et al., 2008). They assessed the location, timing, and magnitude of water scarcity globally using an index, called the Cumulative Abstraction to Demand ratio (CAD), under various combinations of socio-economic and climate change scenarios. They found that water scarcity would increase globally in every combination of scenarios, including SSP1-RCP2.6, if no adaptation measures were undertaken. Here, we expand their work to analyze how to adapt to global change or how to keep the CAD at the same level as at present throughout the century by reducing water use.

2. Methods

For this study, we added adaptation measures to the original simulation performed by Hanasaki et al. (2012a,b). We focused on their SSP1-RCP2.6 simulation, which produced the least change in climate and water use. Although this scenario showed the lowest water stress, the simulations indicated an increase in water stress partly due to increased irrigation water use. Here, we change the parameters of irrigated area and crop intensity to represent adaptation measures by water conservation.

We conducted four simulations (Table 1). NOADP (short for "no adaptation") is identical to the original SSP1-RCP2.6 simulation of Hanasaki et al. (2012a,b). They assumed that the growth rate of irrigated area (a) and crop intensity (i) are +0.06% year^{-1} and +0.2% year^{-1}, respectively. ADP1 sets the parameter for irrigated area at a rate of -0.2% year^{-1}, and ADP2 sets the crop intensity at the same rate. ADP3 decreases both factors by the same rate. The rates of ADP1 and ADP2 were derived from a recent publication by Hayashi et al. (2012). Hanasaki et al. (2012b) used three global climate models. In this study, we only used the results of MIROC-ESM-CHEM. The irrigated area (A) and crop intensity (I) of year t is expressed as

$$A = A_0 \times (1+a)^{t-t_0} \tag{1}$$

$$I = I_0 \times (1+i)^{t-t_0} , \tag{2}$$

where A_0 and I_0 are the irrigated area and crop intensity of the base year (t_0 = 2000), based on Siebert et al. (2005) and Döll and Siebert (2002), respectively. The irrigated area of the first (A_{first}) and second crops (A_{second}) are expressed as

Table 1 Simulation names and their settings on future growth rates of irrigated area and crop intensity (NOADP for no adaptation, ADP1-3 for adaptation).

Simulation names	NOADP	ADP1	ADP2	ADP3
Growth rate of irrigated area [% year^{-1}]	+0.06	-0.2	0	-0.2
Growth rate of crop intensity [% year^{-1}]	+0.2	0	-0.2	-0.2

$$A_{first} = \begin{cases} A & I \geq 1 \\ A \times I & I < 1 \end{cases} \tag{3}$$

$$A_{second} = \begin{cases} A \times (I-1) & I \geq 1 \\ 0 & I < 1 \end{cases} \tag{4}$$

Water scarcity was assessed using the Cumulative Abstraction to Demand (CAD) index, which was expressed as

$$CAD = \frac{\sum a_{DOY}}{\sum d_{DOY}}, \tag{5}$$

where a_{DOY} and d_{DOY} denote the daily water abstraction and Day Of Year demand, respectively. Note that the condition $a_{DOY} \leq d_{DOY}$ is always satisfied. ∑ indicates summation throughout a simulation period. The index ranges between 0 and 1. A value of 1 indicates that water is sufficient throughout the year, and 0 indicates the opposite.

3. Results

Table 2 shows a summary of the simulations. In the base year (2000), the global total number of water-stressed people (the population living in the cells where CAD falls below 0.5) was 2147 × 10^6. In the NOADP scenario, the number increased to 2804 × 10^6 (+31% compared with the base year) during 2041–2070 and decreased slightly to 2499 × 10^6 (+16%) in 2071–2100. In the ADP1 and ADP2 scenarios, the numbers were smaller than for NOADP because the total irrigated area (A_{first} + A_{second}) decreased at a rate of -0.2 % year^{-1}. In the case of $I < 1$, since the second crop was not cultivated, the results of ADP1 and APD2 were the same. In the case of $I \geq 1$, under ADP1 the irrigated area decreased for both the first and second crops at the same rate, whereas under ADP2 only the second crop intensity decreased (Eqs. 3 and 4). The second crop requires much more water than the first crop because the first crop is relatively cultivated in less water-stressed seasons. Different irrigation water use makes different projections in water stress. This explains why the water-stressed population under ADP2 was smaller than that under ADP1. The results suggest that reducing crop intensity has a larger impact than does reducing the irrigated area on the CAD. Under ADP3, although the number of water-stressed people during 2041–2070 exceeded that of the base year (2455 × 10^6, +14%), it stabilized throughout the century to the same level as the base year.

Table 2. Simulation results on water stressed population and water amounts for irrigation. For comparison, the current values (1971-2000) are also shown. The upper (lower) lines show results for 2041–2070 (2071–2100).

Simulation names	1971-2000	NOADP	ADP1	ADP2	ADP3
Water stressed population [$\times 10^6$]	*2147*	2804	2597	2548	2455
		2499	2208	2119	2024
Potential irrigation water demand (*P*) [$km^3\ yr^{-1}$]	*1314*	1505	1186	1163	1047
		1631	1116	1081	908
Actual irrigation water abstraction (*A*) [$km^3\ yr^{-1}$]	*568*	603	507	505	465
		636	485	478	419
Fulfillment ratio (*A*/*P*) [%]	*43*	40	43	43	44
		39	43	44	46

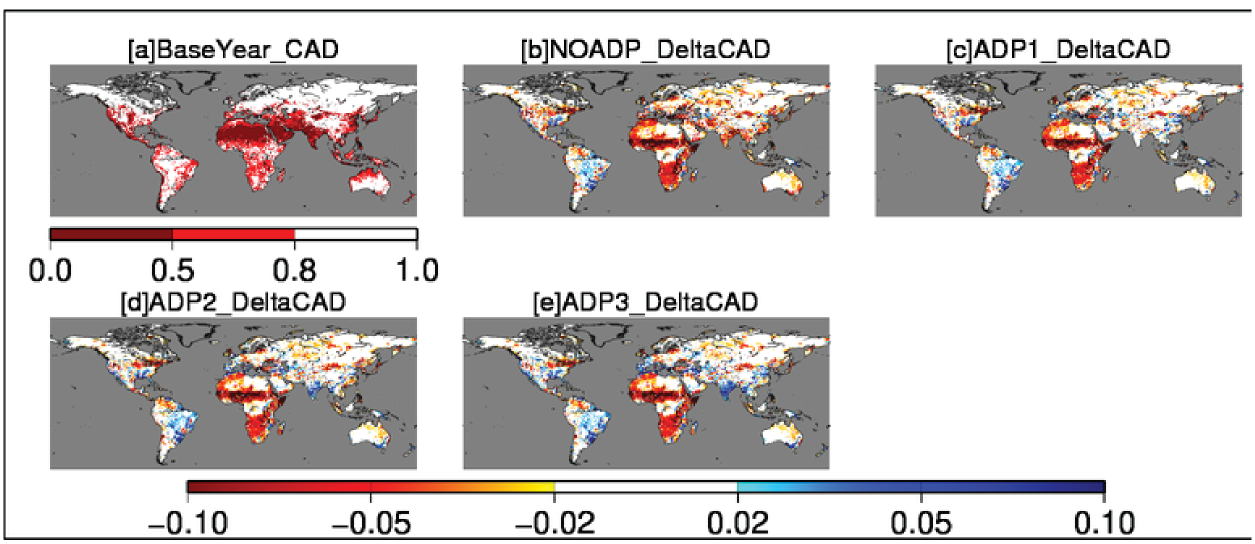

Fig. 1 (a) Cumulative abstraction to demand (CAD) index of the base year (2000). Changes in CAD with (b) NOADP (no-adaptation scenario) and three adaptation scenarios of (c) ADP1, (d) ADP2, and (e) ADP3 for 2041–2070 are compared with the base year.

The potential irrigation water demand *P* (the water needed to fulfill consumptive irrigation water demand) sharply decreased when adaptation measures were taken. The actual irrigation water abstraction *A* decreased accordingly. However, the fulfillment ratio *A*/*P*, which is defined as the actual irrigation water abstraction over the potential irrigation water demand, slightly increased with adaptation.

Fig. 1a shows the global distribution of the CAD of the base year. The CAD is small in lower latitudes. The NOADP simulation decreased the CAD globally, except in some parts of Southern America (Fig. 1b). The ADP1 and APD2 scenarios increased CAD for many parts of the world (Fig. 1c–d). In India, ADP2 increased the CAD more than did ADP1, probably because the second crop requires more water than the first crop in this region. In both cases, the CAD in Africa increased. This was partly due to the strong seasonality in rainfall and increase in other water uses (e.g., industrial and municipal) there.

4. Discussion and Conclusion

A series of simulations were conducted to examine adaptation to climate change by reducing water use. The results indicate that when the growth rate of irrigated area and crop intensity were both -0.2% year^{-1}, the water-stressed population calculated by the CAD index almost stabilized at the same level of the base year. To meet food demands in the future, the reduction in irrigated area needs to be compensated by other measures to increase crop production.

The above conclusion is based on some important assumptions. First, the regional differences were not taken into account in this study. As clearly shown in Fig. 1, in some regions, the adaptation measures were too little or too much for stabilization. Further temporal and spatial detail is needed. Second, in this study we only used one combination of scenarios (i.e., the socio-economic scenario SSP1, the greenhouse gas concentration scenario RCP2.6, and the global climate model MIROC-ESM-CHEM). Simulations using other scenarios should also be performed. Third, the conclusions were mainly derived from a single indicator, namely the total water-stressed population of the CAD. Other indices should be included for a more comprehensive assessment. Finally, technical, financial, and social feasibility should be taken into account to judge whether the measures discussed are practical.

5. Acknowledgements

This research was supported by the Environment Research and Technology Development Fund (S-10) of the Ministry of the Environment, Japan.

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Development of a global climate–crop coupled model for paddy rice

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Abstract—It has been recently recognized that there is an interaction between crop and climate. Not only are crops affected by climate, but they also affect climate through biophysical and biochemical processes. The climate-crop interaction might change the impact of climate change on crops. However, nothing is known about the influence of the climate-crop interaction on the impact of climate change on crops. A climate-crop coupled model, in which a crop growth model is coupled to a climate model, is one tool to assess the influence of the climate-crop interaction. Until now, two global climate-crop coupled models have been developed. However, paddy rice is not included in the models. Paddy rice is one of main crops for Asian people and is widely planted over Asia. Furthermore, paddy rice is generally planted in a flooded field. Hence, the influence of a paddy field on climate might be different form the other crops. I have developed a new global climate-crop coupled model for paddy rice. In the new coupled model, a crop growth model for paddy rice and a flooded surface are integrated into a land surface model in a climate model, MIROC5. In the present paper, I explain the general description of the new global climate-crop coupled model and present a preliminary result of a simulation.

Index Terms—Climate model, crop model, land surface model, and rice

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1 Introduction

It has been well known for a long time that crop productivity is affected by climate. A large number of crop models based on the fact have been developed. These models have been used for the assessment of the impacts of climate change on crop productivity, and have offered us much knowledge on the impacts of climate change. On the other hand, it has been pointed out that crops affect climate through biophysical and biochemical processes (Betts 2005; Desjardins et al. 2007; Loarie et al. 2012).

There have been few studies about the climate-crop interaction. Osrbone et al. (2009) showed that the climate-crop interaction could significantly affect a yearly variation in crop productivity. Their study indicates the climate-crop interaction is an important factor, which determines crop productivity and the stability. There is no doubt that the climate-crop interaction will affect them in future climate conditions. Furthermore, it is likely that climate change will change the climate-crop interaction. However, nothing is known about the impact of climate change on the interaction.

A climate-crop coupled model, in which a crop growth model is coupled to a climate model, is one tool to assess the influence of the climate-crop interaction on crop productivity and the stability. Only two global climate-crop coupled models have been developed until now. However, these two models do not focus on paddy rice. Paddy rice is one of main crops for Asian people and is widely planted over Asia. The most distinctive feature of paddy rice is that paddy rice is planted in a flooded field. Hence, the influence of a paddy field on climate is different from the other crops.

In the present paper, I first introduce a new global climate-crop coupled model for paddy rice, the MIROCrop-Paddy (Masutomi et al. in prep.). Then I present a preliminary result of a simulation with the new coupled model.

2 Model

2.1 MIROCrop-paddy

A new global climate-crop coupled model for paddy rice, MIROcrop-paddy (Masutomi et al. in prep; See Fig. 1) is based on the MIROC5 (Watanabe et al. 2011), which is a global climate model developed by the Japanese research community. The MIROC5 has three main components of models, which are atmosphere, ocean, and land surface models. The land surface model embedded in the MIROC5 is the MATSIRO (Takata et al. 2003). In the original MATSIRO, all types of crop fields are treated as one land use type, i.e., cultivation. I first integrated a crop growth model for paddy rice and a flooded surface into the original MATSIRO. The modified MATSIRO is called MATCRO-paddy (Masutomi et al. in prep.), which is explained in the following section. Then, combining the MATCRO-paddy with the atmospheric model of the MIROC5, I developed the MIROCrop-paddy (Masutomi et al. in prep.).

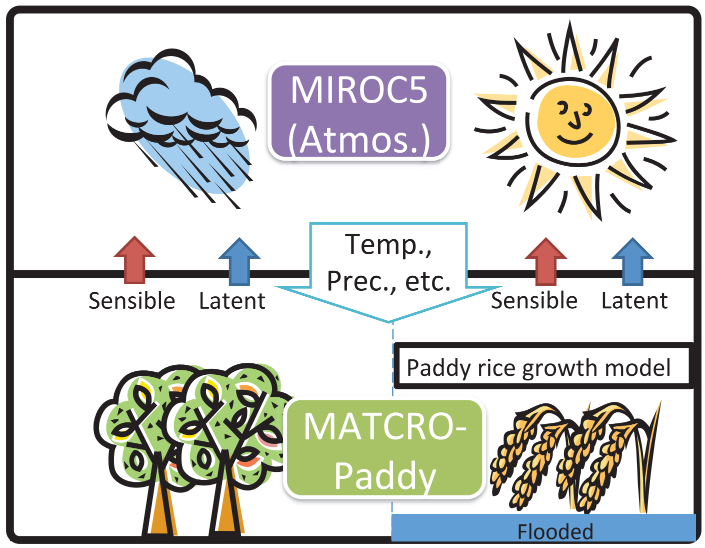

Fig. 1 Schematic diagram of the MIROCrop-paddy

2.2 MATCRO-paddy

The MATCRO-paddy consists of two components: a modified MATSIRO and a crop growth model for paddy rice (See Fig. 2). The modified MATSIRO is a land surface model to which a flooded land surface is added. In addition, the values of physical and physiological parameters in the original MATSIRO are modified by reference to literature. The inputs of the modified MATSIRO are a leaf area index (LAI), a crop height, and root distribution, while the output is gross primary production (GPP).

The crop growth model for paddy rice has two components: a development index module and an assimilate partitioning module. The development index module is based on SIMRIW (Horie et al. 1995), which is widely used for rice growth simulations in Japan. The assimilate partitioning module is based on MACROS (Penning de Vries et al. 1989) and Oryza2000 (Boumann et al. 2001). The values of parameters in the assimilate partitioning module are identified by observations. The input of the crop growth model for paddy rice is GPP from the modified MATSIRO, and then the crop growth model partitions them into each organs, such as leaves, stem, roots, and panicles. Leaf biomass estimated in the assimilate partitioning module are used to calculate a LAI and a crop height, which are passed into the modified MATSIRO.

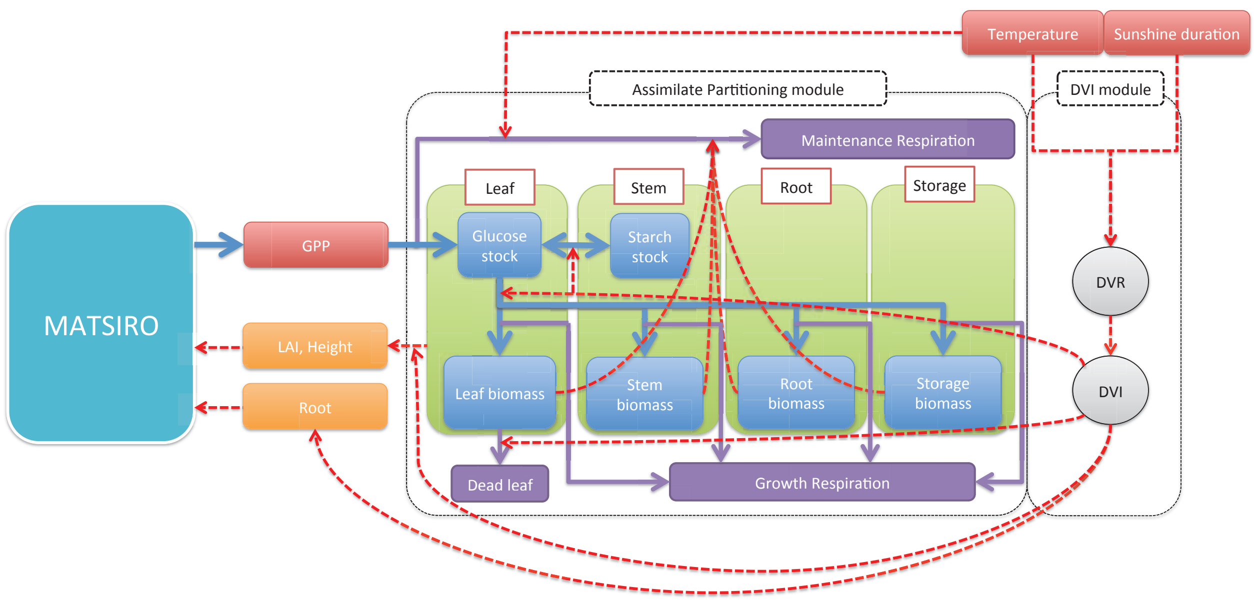

Fig. 2 Schmatic diagram of the MATCRO-paddy

3 Preliminary result

As a test simulation, I ran the coupled model and the uncoupled model, and then compared the simulations. Because paddy rice has been only considered in the MIROCrop-Paddy, all croplands were assumed to be paddy rice fields (Fig. 3).

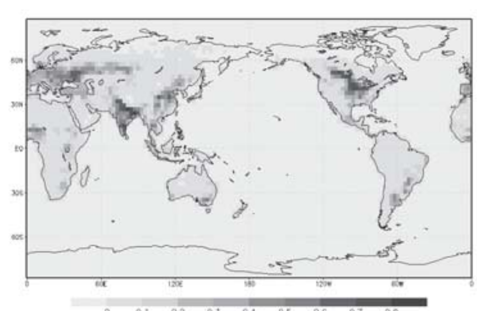

Fig. 3 Assumed fraction of paddy rice fields in the simulations

The simulation period was only one year, 2007. The spatial resolution was T42 (≅ 300km).

Fig. 4 shows the difference of 2m temperatures in August between simulations with the coupled and uncoupled models. It can be seen that there are large differences between the two simulations. Especially, decreases in temperatures were large at high latitudes in the northern hemisphere. Interestingly, the regions are located in the north of areas with a high fraction of croplands. Large increases in temperatures is also observed in Antarctic regions. These decreases and increases in temperatures can be attributed to the effect of paddy rice fields and natural variations in climate.

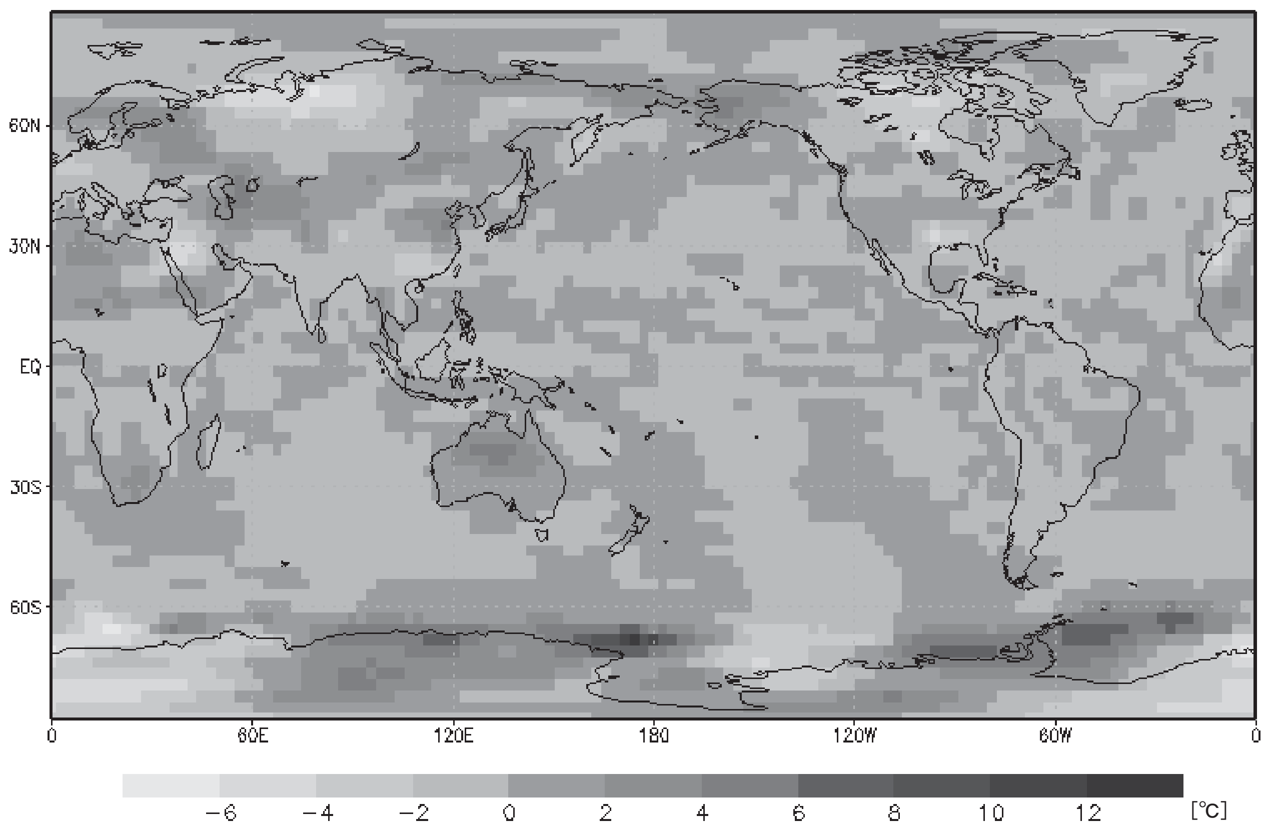

Fig. 4 Difference of 2m temperatures in August between simulations of coupled and uncoupled models

4 Summary

In the present paper, I introduced a new global climate-crop coupled model for paddy rice, MIROCrop-paddy. It can be hoped that the coupled model is used for studies on the interaction of climate and paddy rice fields. The preliminary result showed that there were large differences in temperatures between the coupled and uncoupled models. At present, it can not be concluded that these differences are attributed to the effect of paddy rice fields, because these differences included natural variations in climate. Therefore, important future challenges are to conduct long-term simulations and to extract the effect of paddy rice fields from these differences.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Assessing climate change and policy impacts on protein crop production in Austria

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Abstract—Simulated annual crop yields of two periods (1975-2005 and 2010-2040) are used to show the impacts of climate change on Austrian crop supplies. We consider the conversion of fallow land for the production of protein crops to account for recently announced discretionary agricultural policy changes and estimate the costs of expanding protein crop production. Crop supply balances are used to single out the effects of crop output changes on supply and demand ratios and trade balances. The analysis shows that the expansion of protein crop production on fallow land could turn Austria from a net importing to a net exporting country for protein crops apart from defatted soybean meal used for livestock feed. Regional climate change affects both, the levels and the variability of crop yields implying new challenges for domestic food supply balance management though to a lesser extent than policy induced output changes.

Index Terms—crop supply balance analysis, climate change impacts, Common Agricultural Policy

1 Introduction

Climate change is likely to impact regional, national, and global food and feed production (Tubiello & Fischer 2007; Misselhorn et al. 2012) as well as regional disparities in food and feed availability (Ziervogel & Ericksen 2010). The level and volatility of food and feed production mainly depends on bio-physical parameters (e.g. soil type, elevation, slope), weather and climate parameters (e.g. temperature, precipitation, solar radiation, relative humidity), and farm management and techniques (e.g. crop rotation, tillage, fertilization, irrigation), whereas food and feed availability also includes distribution and exchange (Gregory et al. 2005). In Europe, an increasing variability of inter-annual crop yields is expected because of changes in agro-meteorological conditions, and in magnitude and frequency of extreme weather events (Battisti & Naylor 2009; Trnka et al. 2011). Consequently, more volatile crop yields and thus supplies are expected such that the role of storage and trade will increase.

Not only climate change but also policy changes will have an impact on agricultural commodity supplies. Recently, the Council of the European Union has agreed on a negotiating position for the reform of the Common Agricultural Policy (CAP). In the future, farmers will either have to set aside a certain share of agricultural land or use this land for producing protein crops in order to qualify for direct payments (Council of the European Union 2013). The regulation is intended to increase domestic protein crop production in the EU and thus decrease the dependence on protein crop imports and the vulnerability to world market price volatility (European Parliament 2011). Currently, European agriculture provides about 30% of the protein crops for domestic use, with a downward trend in the last ten years leading to a high dependence on imports (European Parliament 2011). Though the Austrian self sufficiency rate is significantly higher (usually exceeding 70%), Austria has been a net-importer of protein crops since decades (Statistics Austria 2012).

We perform a comparative static analysis of Austrian crop supply balances to quantify the effects of climate change and agricultural policy and apply an economic land use optimization model to compute the marginal costs of expanding protein crop production on cropland. In response to the recent agreement at EU level on stimulating protein crop production, we focus our analysis on soybean and other protein crops. Even if Austria is a small country, its domestic supply balance has spill over effects on international markets and therefore affects global food security.

2 Data and methods

Three major data sources are used for the analysis:

(a) Historical data on prices and production costs of major crops are used to derive the marginal costs of an expansion of protein crops in Austria. The price/cost scenario assumes constant levels compared to the reference period 2008-2010 in order to facilitate the interpretation of the results.

(b) The second data set is derived from the agricultural supply and feed balances provided by the Austrian Statistical Office. Supply balances summarize domestic production, domestic use (e.g. human consumption, seeds, animal feed, industrial uses), storage, and net imports and exports of a given commodity. In our comparative static analysis we keep domestic use and storage constant. Thus changing domestic production will affect net imports and exports as well as the self sufficiency rate, i.e. the ratio of domestic production (which is variable in our analysis) and domestic use (which is fixed in our analysis) after accounting for storage and trade flows.

(c) The third data set is derived from climate change impact simulations with the bio-physical process model EPIC (Environmental Policy Integrated Climate; Williams 1995). The EPIC model has already been applied several times at national and regional level and validated for the Austrian conditions (e.g. Strauss et al. 2012; Stürmer et al. 2013). EPIC was applied on 1 km cropland pixels to simulate – inter alia – annual dry matter crop yields. EPIC integrates information on weather, soil, topography, and crop management to simulate bio-physical processes such as respiration, mineralization, nitrification, evapotranspiration, runoff, and erosion. Relevant input data are derived from (i) the digital soil map of Austria, (ii) the digital elevation map, (iii) the Integrated Administration and Control System, (iv) expert knowledge, and (v) a statistical climate change model for Austria (Strauss et al. 2012, 2013). The EPIC simulations have been performed for a 30-years reference period (1975-2005) and for three climate change scenarios covering the period 2010-2040.

The climate change scenarios have been selected in order to cover a broad range of the potential climate change spectrum in Austria. According to Strauss et al. (2012, 2013), the average temperature is predicted to rise by ~0.05 °C per year until 2040. The uncertainty about the levels and distributions of precipitation is captured by scenario assumptions on annual precipitation sums and seasonal patterns such as:

- climate change scenario sc01 assumes similar mean annual precipitation sums as in the reference period 1975-2005,
- climate change scenario sc05 assumes an increase in daily precipitation by 20% compared to sc01, i.e. seasonal precipitation patterns are similar to those in sc01 with increased daily and thus seasonal and annual precipitation sums,
- climate change scenario sc09 assumes a decrease in daily precipitation by 20% compared to sc01, i.e. seasonal precipitation patterns are similar to those in sc01 with decreased daily and thus seasonal and annual precipitation sums, and

Higher CO_2-concentration in the atmosphere and its fertilization effect is accounted for in the EPIC simulations. In our analysis, we also consider the potential supply of soybean, horse bean, and field pea on land that was previously set aside. Accordingly, crop rotations in the EPIC model have been adapted and the model output of expected annual dry matter crop yields was used as input to the spatially explicit economic land use optimization model for Austria (BiomAT). BiomAT maximizes total gross margins of crop production subject to spatial resource endowments considering land qualities at 1 km grid resolution. It was developed to estimate the marginal costs of an expansion of energy crop production under climate change in Austria (Asamer et al. 2011; Stürmer et al. 2013) and is now applied for protein crops.

We investigate the isolated supply effect of climate change and the latest policy change in a comparative static analysis keeping all the other variables constant. For instance, demand shifts, progress in breeding or price changes in future do not enter our analysis. The quantity structure of the 2008-2010 agricultural supply balances of Austria is used for quantifying the impacts of crop yield changes on self sufficiency rates with a particular focus on protein crops.

Table 1 summarises the data used for the comparative static analysis. The first two columns report the averages of the Austrian crop supply balances for the period 2008-2010. Simulated climate change impacts on average crop yields and standard deviations (stdev) for major crops in Austria are reported in the other columns. The data show that the self sufficiency rates ranged between 45% and 65% for winter rape, sunflower, and soybean and exceeded 85% for grains and potatoes in the period 2008-2010. Winter wheat and durum wheat even reached self sufficiency rates above 100%. The climate change scenario sc01 (similar precipitation) shows relatively little impact on mean annual crop yields compared to the period 1975-2005 except for potatoes (+17%), and winter rape (+7.5%) which is probably due to their sensitivity to changes in mean temperature, growth period, and CO_2-concentration. An increase in annual precipitation sums (sc05, +20% precipitation) mainly results in increasing mean annual crop yields (between 1.2% for field peas and 19.9% for potatoes) except for oats and sunflower which show slightly decreasing crop yields. Decreasing precipitation (sc09, -20% precipitation) leads to decreasing yields for all crops. The highest yield declines are expected for durum and winter wheat, field pea, and winter rape.

Table 1. Self sufficiency rates (SSR) and trade balances for the period 2008-2010 as well as simulated crop yield changes between the periods 1975-2005 and 2010-2040 for climate change scenarios sc01, sc05, and sc09 in per cent.

	SSR	balance	mean	stdev	mean	stdev	mean	stdev
	2008-2010		sc01		sc05		sc09	
	%	1.000 t	crop yield change in % to averages of the period 1975-2005					
winter wheat	107	95.6	1.3	-13.1	9.3	-42.8	-15.9	20.3
durum wheat[1]	103	-2.0	-3.9	0.2	8.3	-25.2	-28.8	19.4
winter rye	85	-35.5	0.7	15.5	5.1	-8.8	-7.7	36.0
barley	94	-64.0	-2.3	14.7	-0.1	4.6	-11.6	46.8
oats	95	-5.2	-1.0	15.3	-2.7	24.3	-1.5	23.5
maize	89	-272.0	-1.9	13.2	2.6	-6.0	-12.1	34.7
triticale	99	-3.1	1.6	14.6	3.2	8.6	-2.7	26.4
soybean[2]	58	-51.6	4.0	17.0	6.1	6.0	-2.3	36.5
horse bean[3]	n.a.	n.a.	1.0	2.4	4.6	-12.0	-8.4	43.4
field pea[3]			-2.6	19.1	1.2	8.7	-13.8	44.5
potatoes	92	-64.9	17.1	-4.7	19.9	-15.2	5.1	10.9
sunflower	65	-44.7	-1.8	30.1	-3.7	19.4	-9.7	87.3
winter rape	45	-201.0	7.5	-20.2	15.5	-40.7	-12.3	2.7

Source: Statistics Austria (2012) and authors' calculations.
Notes: A positive trade balance implies a surplus of exports; a negative trade balance implies net imports. [1]Negative trade balance and SSR greater 100% are due to storage. [2]Soybean is classified as "oil crop" in the Austrian supply balance. Nevertheless it is classified as a protein crop in this analysis. [3]Horse beans, field peas and other pulses are summed up to "pulses" in the Austrian supply balance. The SSR of pulses in the period 2008-2010 was 95%. Defatted soybean meal used for livestock feed is not accounted for in this supply balance analysis.

3 Results

Using the data and tools presented in the previous section, we developed two types of results:

a) marginal opportunity costs with respect to additional protein crop production;

b) effects of additional protein crop production on land use change, crop management intensity, and environment.

Figure 1 shows the marginal costs of expanding protein crop production on cropland in Austria. The three lines indicate the marginal costs of protein crop production in the three climate change scenarios SC01, SC05, and SC09.

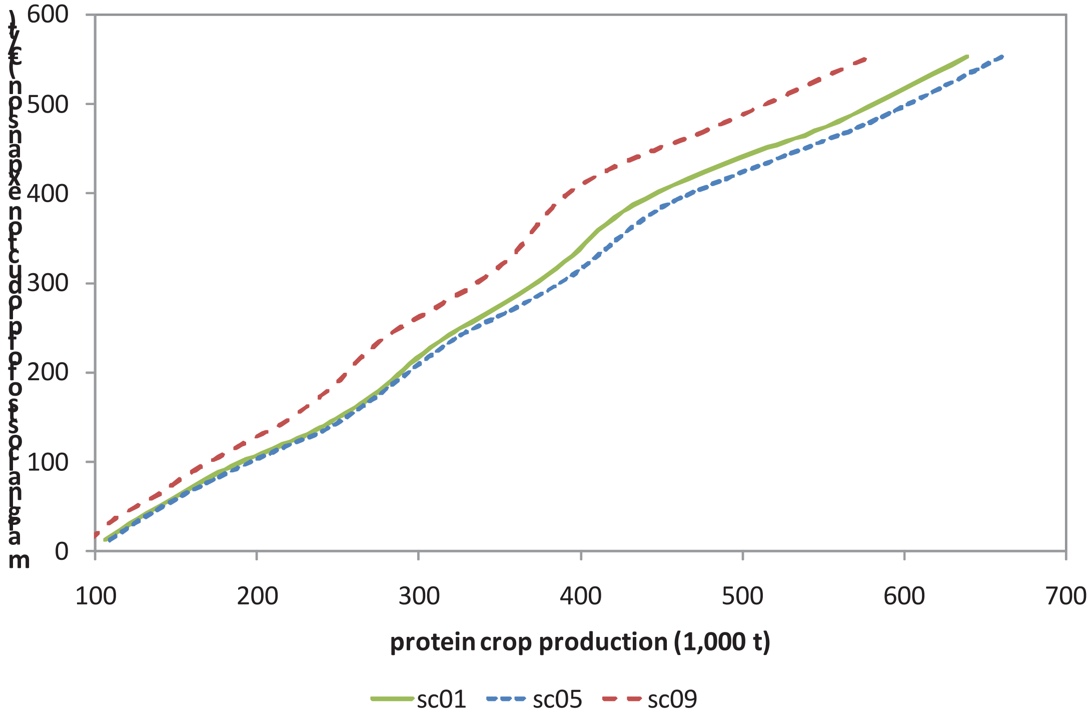

Fig. 1: Marginal costs of protein crop production on cropland for three climate change scenarios (SC01, SC05, and SC09) assuming crop prices observed in the period 2008-2010.

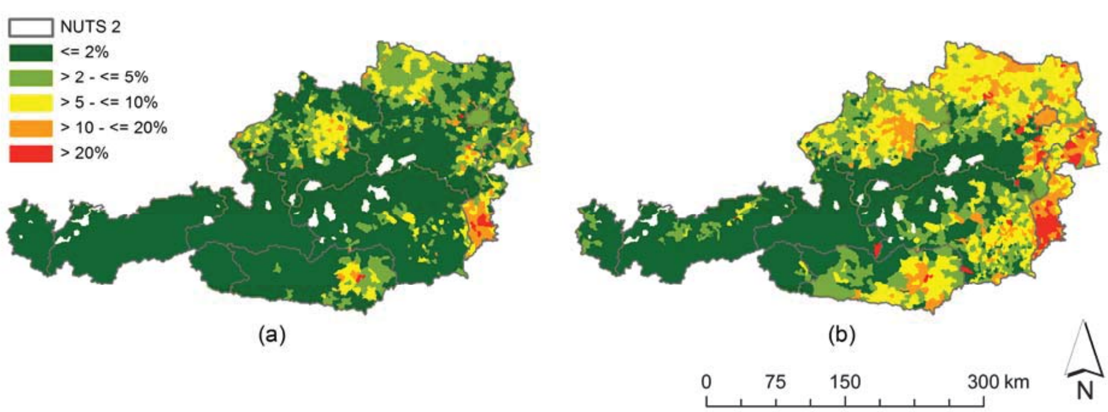

Fig. 2. Shares of cropland used for cultivating protein crops, i.e. field pea, horse bean, and soybean, in municipalities (a) in the past and (b) when fallow land is made available for protein crop production; no cropland in white areas.

Figure 2 depicts (a) current and (b) potential regional characteristics of protein crops production. Currently, protein crops are concentrated on a few small regions in the provinces of Upper Austria, Burgenland, Lower Austria, and Carinthia. If fallow land with similar characteristics as the land currently used for protein crop production will be used for an expansion, the share of cropland used for cultivating protein crops can be increased to 5% or more in a large number of regions. Such a land use change is realistic because protein crops were planted on a much larger acreage around 1990 compared to today levels.

Deviations (in percentage points) from the self sufficiency rates in the reference period are reported for the mean and median of simulated crop yields of the scenarios in Table 2. In the climate change scenario with similar precipitation (sc01) most crop outputs are slightly lower compared to the past. Self sufficiency rates are sensitive to the chosen parameter, therefore choosing the median of expected annual crop yields instead of the mean makes a difference which is usually very small but pronounced in some scenarios.

If we relax the assumption on land use and allow protein crops to be expanded on fallow land as recently decided by the EU farm ministers, we expect that Austria will become a net exporter of protein crops (apart from defatted soybean meal used for livestock feed). Depending on the scenario, output almost could double.

Table 2: Percentage point changes of self sufficiency rates of the climate change and policy change scenarios using the mean and median of simulated yields from 2010-2040.

	relative to	mean			median		
	ref	sc01	sc05	sc09	sc01	sc05	sc09
winter wheat	Ø2008-10	1	10	-18	2	10	-20
durum wheat	Ø2008-10	-3	6	-21	-4	4	-27
winter rye	Ø2008-10	1	6	-9	-2	6	-11
barley	Ø2008-10	0	3	-6	-1	0	-7
oats	Ø2008-10	-1	-3	-2	-1	-3	0
maize	Ø2008-10	-1	1	-8	0	3	-7
triticale	Ø2008-10	2	3	-3	2	3	-3
soybean	Ø2008-10	2	3	-1	3	4	-2
pulses	Ø2008-10	0	4	-10	0	4	-11
cereals	Ø2008-10	1	5	-12	1	6	-10
protein crops	Ø2008-10	2	4	-5	2	4	-4
protein crops	Ø2008-10 + fallow land	97	103	81	97	103	80

Source: authors' calculations.
Notes: "ref (Ø 2008-10)": acreage set to observed averages of 2008-2011; "ref (Ø 2008-10) + fallow land": acreage of protein crops expanded on fallow land.

4 Conclusions and outlook

We present simulation results of crop yield responses of various climate change scenarios for Austria. The analysis is focused on protein crops in order to show economic implications. Our interest in protein crops is motivated by a recent decision of agricultural ministers, which will likely stimulate the production on land that was previously set aside.

We report supply effects and the consequences for self sufficiency rates of crop commodities assuming that domestic use and storage are kept constant. The results of our comparative static analysis indicate that additional protein crop production on fallow land has a larger impact on self sufficiency rates than climate change will likely have in the next three decades. Thus, the recent agreement on stimulating protein crop production in the EU could contribute to a substantial reduction of protein crop imports.

An increasing share of protein crops will likely changes the opportunity costs of production as well as the environmental impacts. A benefit of increasing protein crop production not accounted for in the analysis is that the input of nitrogen fertilizer and the associated emissions of greenhouse gases could be reduced. Accordingly, such a mitigation effort could reduce negative environmental effects though the net outcomes will depend on the applied crop management practice. However, the announced changes in agricultural policy might re-ignite the discussion on the competition for land arising from increasing demand for food and feed as well as bioenergy, also referred to as the 'food, energy, and environment trilemma' (Tilman et al. 2009).

Assuming inelastic demand, higher crop yield volatility is likely to induce higher price volatility as well. Crop yield volatility is affected by temperature and precipitation patterns, whereby their uncertain future development – especially of the latter one – impedes predictions of crop yield volatility. The current knowledge about agricultural production risks emphasizes the importance of further investigations on domestic crop yield and supply volatility as well as the roles of storage and trade.

5 Acknowledgements

This research has been supported by the research project Climate change in agriculture and forestry: an integrated assessment of mitigation and adaptation measures in Austria (CAFEE) funded by the Austrian Climate Research Programme (ACRP), by FACE MACSUR – Modelling European Agriculture with Climate Change for Food Security, a FACCE JPI knowledge hub and the Federal Ministry of Agriculture, Forestry, Environment and Water Management of Austria as well as the Doctoral School of Sustainable Development (dokNE).

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Human Ecological Implications of Climate Change in the Himalaya: Pilot Studies of adaptation in Agro-ecosystems within two villages from Middle Hills and Tarai, Nepal.

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Abstract— Climate change is interpreted as one of the most serious environmental problems for the 21st century. Changes in climate are now generally accepted. However, the rate of change has spatial characteristics and is highly uncertain. The Himalaya is experiencing abrupt change; vulnerability and adaptation studies have become crucial. This pilot study presents initial findings of the research project entitled 'Human Ecological Implications of Climate Change in the Himalaya.' A study of climate change perceptions, vulnerability, and adaptation strategies of farming communities of cool-wet temperate (Lumle) and the hot-wet sub-tropical (Meghauli) villages in Central Nepal has conducted. The findings are derived from the analysis of temperature and precipitation data of last 40 years, and primary data collected in September 2012. Focus Group Discussions, Key Informant Interviews, and Historical Timeline Calender were applied. The changes perceived by the communities are fairly consistent with the meteorological observations and changes are challenging the sustainability of social-ecological systems and communities' livelihoods. Farming communities have adopted some strategies to minimize vulnerability, but the adopted strategies have produced both negative and positive results. Strategies like flood control, shifting crop calendars, occupational changes and labour migration have produced positive results in livelihood security. Occupational changes and labour migration have also negatively impacted local agricultural economies. Early-harvesting strategies to reduce losses from hailstorm have reduced food and fodder security. Lack of irrigation for rice-seedlings is severely affecting the efficacy of shifting the rice-transplantation calendar. Conclusions suggest that while farmers have practiced strategies to better manage farms, livelihood strategies are reaching thresholds of efficacy due to the changing conditions.

Index Terms—Adaptation, Climate Change, Human Ecological, Nepal, Vulnerability

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1 Introduction

1.1 The Context

Recent and rapid changes in climate systems are becoming vital issues of social, economic, political, and scientific discussion. Climatic changes are already affecting ecological and human systems, such that they are now seen as the most important environmental threat to social ecological systems. The implications are most serious in highly climate sensitive environments like the Himalayas, where climatic exposure coincides with poverty, subsistence agro-based livelihoods, and poor levels of techno-economic and politico-institutional development. However, studies on implications of climate change on social ecological systems are still largely absent in the Nepali Himalaya. This study, 'Human Ecological Implications of Climate Change in the Himalaya' examines the temperature and rainfall trends, seeks to understand the perceived changes and experienced vulnerability, and explores adaptation responses. This paper is structured into three sections: the introduction outlines the research context, issues in the literature and the methods and materials applied; the analysis section discusses upon changes in climate, local vulnerability, and adaptation responses; and the final, discussion and conclusion elaborates on major findings.

1.2 The Issues

Major global reviews of global climate change have provided considerable evidence of rapid, recent change to climates (Stern 2006; IPCC 2007a; NRC 2012), which are interpreted as environmental threats to social-ecological systems (Hare et al. 2011; IPCC 2007b; Urry 2011). Among others, the Himalaya[1] is reported as the region experiencing the highest rate of warming (NRC 2012; Shrestha et al. 1999) and concentrates many negative impacts (Gentle & Maraseni 2012; Manandhar et al. 2011).

Any shift in climate over time, whether due to natural variability or as a result of human activity is climate change (IPCC 2007a). However, the meaning differs with the society, since climate is a constructed idea having complex physical and cultural connotations (Hulme et al. 2009; Rayner 2003). Therefore, understanding social perceptions along with environmental changes are important aspects of climate change research that promote adaptation actions (O'Connor et al. 1999; Hulme et al. 2009).

[1] The Himalaya is the mountain systems of the Central Asia, originated at Pamir-Knot in the north-west and extended over 1500 miles towards the east (boarder of Aasham). This system generally includes major four different physiographic features namely Outer Himalaya (the Southern *Churiya* range), Lesser Himalaya (the Middle hill or *Mahabharat Lekh*), the Greater Himalaya (Northern snow capped mountains), and Trans-Himalaya (Northern Himalayan valleys and foot hills) along with river valleys, *Duns*, and *Tars* in between the mountains.

Climate change induced vulnerability is not new to human societies, as ancient civilizations like Mayan, Indus, Mesopotamia were strongly affected (deMenocal 2001; Lal 2011; Sluyter 1997). The magnitude of present changes are however beyond the range of the historical change and are likely to be severe, and non-linear for many social-ecological systems (Beck 2009; Dovers 2009; IPCC 2007a; Salinger 2005). Also, the impacts interact strongly with local socio-economic and political structures and means of livelihoods (Head 2010; Fischer et al. 2005; Mubaya et al. 2012; Thomas et al. 2007); with vital issues emerging for Himalayan social-ecological systems (Chaudhary et al. 2007; Gentle & Maraseni 2012; Ghimire et al. 2010). It is possible to conclude, therefore, the adaptation responses in the Himalaya are urgent.

Many scholars have documented a wide range of adaptation strategies adopted in different societies. These strategies can be grouped in: adaptation through bio-physical resource management (Bardsley & Thomas 2005; Grasso & Feola 2012; Ramirez-Villegas et al. 2012; Schoene & Bernier 2012; Wreford et al. 2010); adaptation through social and institutional support (Adger 2000; Adger & Barnett 2009; Hanak & Lund 2012; Mortimore 2010; Onta & Resurreccion 2011); and adaptation through livelihood diversification and migration (Black et al. 2011; Hugo 2011; Hulme 2008; McLeman & Smit 2006; Piguet et al. 2011; Tacoli 2009). The literature reviewed has demonstrated the emerging complex trends of studying social perceptions, vulnerability and adaptive responses. In following section, the methods and materials applied in this paper are presented.

1.3 Methodology

This study is conducted in two villages in different ecological zones (Lumle in the temperate Hills and Meghauli in the sub-tropical Tarai) in Nepal (Fig.1). Linear trends and the Coefficient of Variation (R^2) of annual average temperature and precipitation recorded for the last 40 years (1971-2010) were explored. The Mann-Kendall method was used to evaluate the trends in temperature change. The results of the meteorological analysis are compared with community perceptions. Perceptions depend on the memories of the respondents (Adger 2000; Hulme et al. 2009; Nelson & Stathers 2009); so the perceptions analysis focused on the previous decade.

The primary data was collected as a pilot study of a larger PhD project. The field work was conducted in September 2012. Two Focus Group Discussions, 4 Key Informant Interviews, and 2 Historical Timeline Calenders in each village were undertaken. Despite having a small sample size, the results cover many aspects of climate change and the interactions with local socio-ecological systems. Although of limited scope; scholars have argued that the results of pilot study can be published with due acknowledgement to its limitations (Lanphear 2001; Morgan 1998; Thabane et al. 2010).

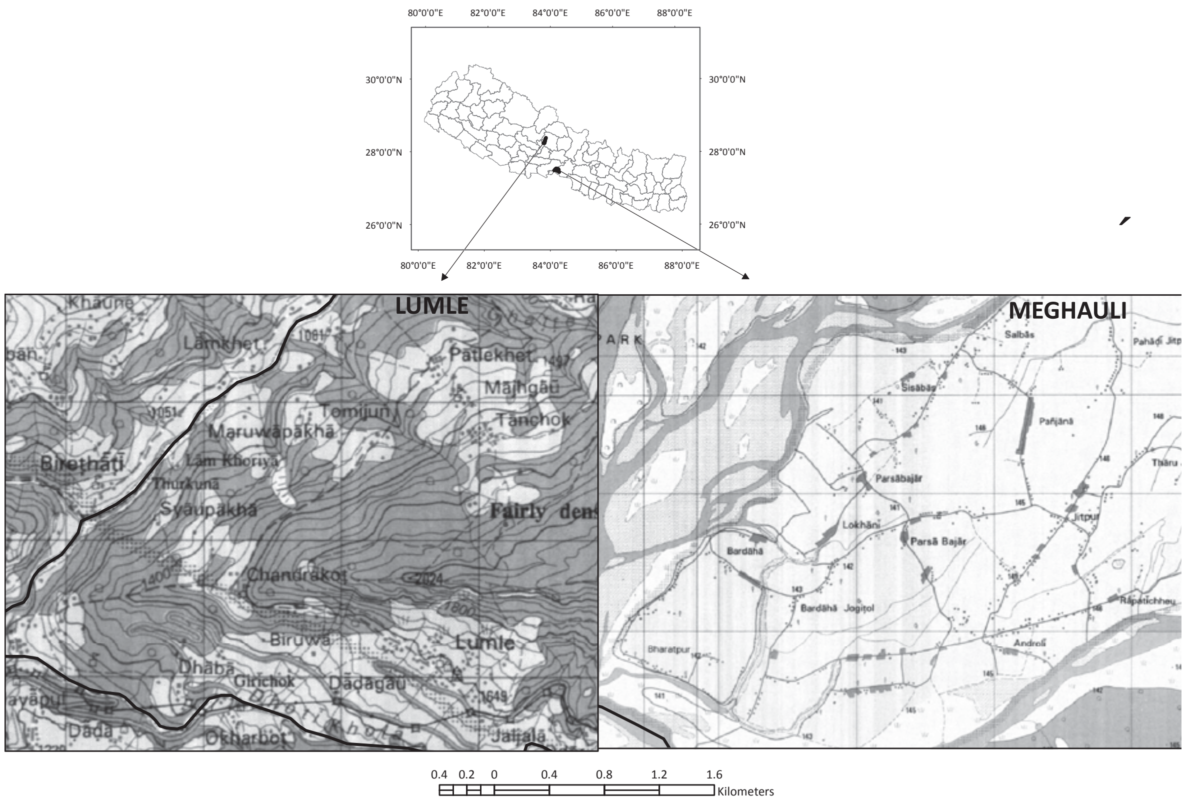

Fig.1 Location of Study Areas in Nepal

2 Analysis and Results

2.1 Climate Change Trend

Demographically, Meghauli is inhabited by 16252 individuals with the sex ratio of 102 males per 100 females and an average household size of 5.8 people (VDC Profile 2068BS). Lumle is inhabited by 5757 individuals with a sex ratio of 104 males per 100 females, and 5.1 people per household (VDC Profile 2067BS). Both of the villages have been consisting poor farming households making up over 90%. Their agro-based livelihoods are assisted by income from wage labour and remittances.

Analysis of maximum and extreme maximum[2] temperatures of both places show a warming trend, with higher warming in Lumle (Fig.2). In case of minimum and extreme minimum temperatures, a higher warming is detected in Rampur[3] (Fig.3). The Mann Kendall's estimation demonstrates a significant connection between mean temperature increase and year for maximum temperatures at Lumle, but is limited to the monsoon and post monsoon seasons in Rampur. In the case of minimum

[2] Maximum / minimum temperature is the annual average of daily maximum /minimum temperatures, whereas extreme maximum / minimum temperature is the annual average of monthly maximum / minimum temperatures
[3] Rampur is the nearest meteorological station to Meghauli, located ~10km away within the Tarai

temperatures, warming throughout the year is observed in Rampur, but is limited to the monsoon period in Lumle (Table 1). Annual precipitation is highly variable in both locations (Fig. 4).

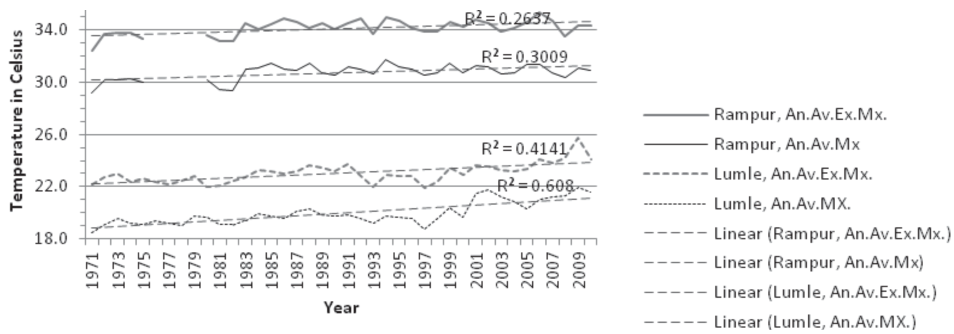

Fig. 2 Annual average of maximum and extreme maximum temperatures (1971-2010)

Data Source: Department of Hydrology and Meteorology, GoN

Note: An.Av.Ex.Mx. stands for Annual Average of monthly extreme maximum temperature, An.Av.Mx. stands for Annual Average of daily maximum temperature

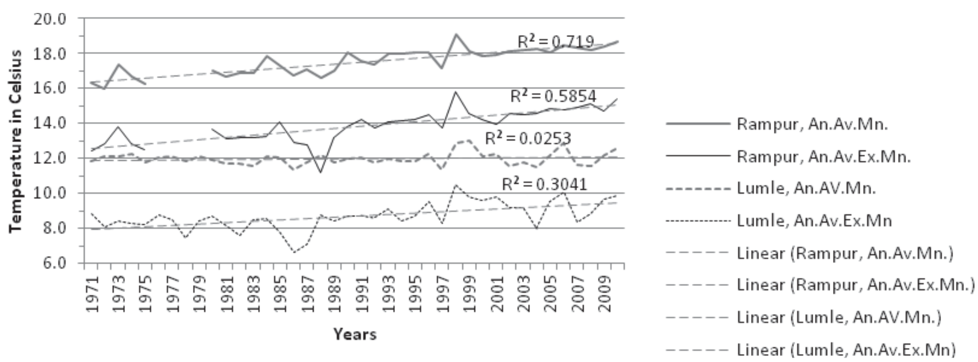

Fig. 3 Annual average of minimum and extreme minimum temperatures (1971-2010)

Data Source: Department of Hydrology and Meteorology, GoN

Note: An.Av.Mn. stands for Annual Average of daily Minimum temperature, An.Av.Ex.Mn. stands for Annual Average of monthly Extreme Minimum temperature

Table 1 Mann Kendall's Estimation of Trends in Temperature Change (Independent variable/ Time: Year and dependent variable: Temperature of the Months)

Months	Correlations	Monthly Average of Maximum Temperature		Monthly Average of Minimum Temperature	
		Stations		Stations	
		Lumle	Rampur	Lumle	Rampur
January	Correlation Coefficient	0.298**	-0.032	0.056	0.293*
February	Correlation Coefficient	0.276*	0.191	0.047	0.414**
March	Correlation Coefficient	0.299**	0.179	-0.076	0.299*
April	Correlation Coefficient	0.282*	0.038	-0.108	0.240*
May	Correlation Coefficient	0.373**	-0.026	0.016	0.236*
June	Correlation Coefficient	0.465**	0.134	0.164	0.297*
July	Correlation Coefficient	0.454**	0.403**	0.431**	0.471**

August	Correlation Coefficient	0.298**	0.277*	0.491**	0.521**
September	Correlation Coefficient	0.473**	0.560**	0.330**	0.444**
October	Correlation Coefficient	0.422**	0.330**	-0.020	0.326**
November	Correlation Coefficient	0.467**	0.242*	-0.050	0.506**
December	Correlation Coefficient	0.501**	0.173	0.014	0.362**

N=40 for Lumle and 36 for Rampur
*. significant at the 0.05 level (2-tailed).
**. significant at the 0.01 level (2-tailed).
*- significant at the 0.05 level (2-tailed) but Negative

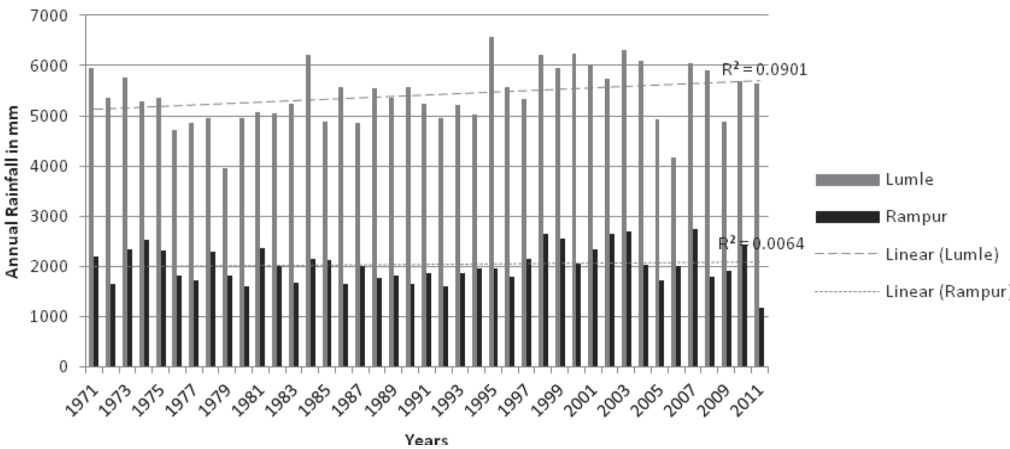

Fig. 4 Annual precipitation in (1971-2011)
Data Source: Department of Hydrology and Meteorology, GoN

The studied communities perceived increased temperature trends for winter and the pre-monsoon season. Lumle has not experienced snowfall for many years, although it was common in the past. At the same time, perceived incidents of hailstone have increased and have become irregular[4] in Lumle. Increasing irregularities in seasonal and annual rainfall were perceived in both places. Respondents reported that the characteristics of monsoon rainfall have also changed: smooth and continuous rainfall events are lacking; erratic rainfall has increased; the monsoon is reduced in length by about two weeks; more dry weeks within the season; reduced winter and pre-monsoon rainfall; and the stress of drought is increasing. The effects of such changes have observed impacts upon social ecological systems, leading to increased livelihood vulnerability.

2.2 Climate Change Induced Vulnerability

Initial findings suggest that climate change is impacting on the social ecological systems of the villages. Floods and drought in Meghauli, and landslides, seasonal drought, heavy rain and hailstorm

[4] Respondents of Lumle stated that since 1990-1992 they have experienced incidents of hailstorm outside of spring and autumn seasons, and also during night time, which was completely unusual for them. According to them hails used to occur only in the day time and in spring and autumn previously.

in Lumle are reported as major drivers of vulnerability. About 150 hectares of farmland in Lumle has been transformed to waste land due to landslides in the last 40 years. In Meghauli, almost 200 hectares of farmland are being lost annually due to erosion by rivers. Communities of both places claim that climatic elements have become more severe and that has badly affected rural livelihoods over last decade. Poor infiltration of monsoon rain had lead to both the drying-up of permanent springs in Lumle and deepening of groundwater in Meghauli. Poor decomposition of compost manure due to reduced soil moisture has resulted in declining soil fertility. Also, invasive species (Fig.5) in farmlands and forest are emerging that may be partly due to climatic change. Snails damage crop quality in Meghauli; especially after the flooding of 1996. According to participants of Focus Group Discussion in Meghauli and Lumle, all these forces have contributing to a reduction of production by 20-25% in both places. Moreover, due to male outmigration and scarcity of water for irrigation areas fallow land has increased.

Fig.5 Invasive Species *Nilo Gandhe* (small blue-white flowers), *Ban Mara* (bunch), and *Marati Jhar* (single stem)

Human casualties over the last 20 years have been reported with one death in Lumle caused by landslide and 3 in Meghauli due to flooding. The forced displacement of 25-30 households annually in Meghauli due to river erosion is a major challenge. Also, incidents of viral fever, problems with mosquitoes, and water borne gastrointestinal health problems have increased. Livestock is the integral part of farming communities' livelihoods, death due to flooding, landslides, and thunder strikes were also reported. In face of these implications, farming communities are making efforts to adapt to change.

2.3 Adaptation Responses

The farmers have applied some adaptation responses to reduce the vulnerability of affected systems. For example, the crop-calendar has changed especially for rice. Farmers have compressed the working days for rice transplantation: "rice transplantation usually lasted for a month some years before, which is reduced to a week now"[5]. Reduced and changing patterns of rainfall are sometimes compensated by shallow tube-well irrigation in Meghauli. Nevertheless, the cost of such irrigation is so high it is not commonly practiced. Farmers of Meghauli have increased the amount of chemical fertilizer to fulfil the minimum requirement of production for household as participants of FGD at Meghauli stated that: "previously, rain fed water used to be helpful in rice production, which is completely dependent on the use of chemical fertilizer in these days". In Lumle, farmers have reported that they have increased the amount of compost manure. In Lumle, farmers have recently started cultivation of off-season vegetables under plastic tunnels, applying more mulch, and using drip irrigation to maintain soil moisture. Accordingly, the average depth of shallow tube-wells has increased by 3-5 metres in recent years in Meghauli to ensure steady supply of drinking water.

To mitigate flood risk, gabion construction along river banks, construction of shelters, and structural changes for houses have been initiated in Meghauli. The Government is providing technical support and construction material, while the community contributes free labour to construct the walls. Meghauli has Community Based Hazard Management Committees; although its programs are reactive to hazards. At the private level, efforts are made to raise houses by about a metre to reduce the risk of flooding in Meghauli, although poorly practiced because of limited financial resources.

To reduce crop losses from hailstorms, farmers in Lumle are adopting early rice harvesting and thrashing techniques. However, these strategies have affected farmers negatively as the quality of rice and straw is reduced. Populations of cows, oxen, and buffaloes have reduced, but are compensated for increased number of goats and poultry in both villages. Beyond these adaptation responses, diversifying income options through labour migration is becoming a vital response in both villages.

3 Discussion and Conclusion

The climate is changing in the Nepali Himalaya. The increase in maximum temperature in Lumle corresponds with previous studies (Shrestha et al. 1999) and future projections (Agrawala et al. 2003). However the data from Rampur contradicts these earlier studies, which argue that warming in the Tarai is lower than in the Hills. There are consistencies between scientific and perceived climate change in cases of winter rainfall; prolonged drought; increased extreme rainfall events; warming in winter and pre-monsoon months; and increased autumn precipitation. However, the data are contradictory in relation to the reduced annual rainfall and a shifted/reduced monsoon. The

[5] In previous period, rice field used to be prepared by ploughing at least 3 times; allowing water logging over a week to facilitate decomposition of weeds and herbs decomposed and supply organic manure. The cost of ploughing, and uncertain rainfall at present lead to single time ploughing and transplanting rice immediately

consistencies correspond with the findings of Chaudhary et al. (2011); but the contradictions are new findings, probably caused by the different meanings given to monsoon[6] by the communities.

Climate change has impacted the systems of the communities due to the loss of livelihood capitals, changing agro-livestock conditions and the emergence of invasive species; but perhaps not all experienced ecological change is driven simply by climate change. The communities have made some efforts to adapt to the changes although they are not sufficient. More worriesome is that the adaptation knowledge has not been translated into practice because of the non-linearity in experienced change, and the encounters with socio-cultural, techno-economic, politico-institutional, and financial adaptation limitations. Also, the deviation of young adults from agriculture to labour migration as a relatively easy adaptation strategy has reduced the scope of agricultural adaptation.
Similar to the findings of previous studies (Bardsley & Hugo 2010; Gentle & Maraseni 2012; Ghimire et al. 2010; Manandhar et al. 2011; McDowell et al. 2012; Onta & Resurreccion 2011), this study has found that climate change is putting further pressure on sensitive social ecological systems in Nepal. Successful adaptation requires strong institutional support especially from the state, which is generally lacking in Nepal. Socio-economic and techno-political factors interact with climate change impacts to lead socio-ecological systems to thresholds of vulnerability. Nevertheless, studies of the issues, as are beginning to be unwrapped here, are required to understand the complex implications of climate change and guide responses in the Himalaya.

Acknowledgements
We would like to acknowledge to the Discipline of Geography, Environment and Population, Adelaide University for the partial financial support under the Charles and Frank Finner Postgraduate Research Grants.

[6] Though measured rainfall could be notable in torrential rainfall events that last just for few minutes, farming communities do not consider it as monsoon rain. The meaning of monsoon rain for farmer is the smooth and continuous rainfall for several hours and / or days, increase infiltration, and natural springs so there is steady supply of water for seasonal irrigation, and rice field preparation and transplantation.

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The two faces of climate change impacts on Europe's forests: Interactions of changing productivity and disturbances

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Abstract— Forest productivity and disturbances in Europe have increased in the past and these trends may continue in the future. Studies of climate change impact on forests usually only consider either the effects of changing productivity or disturbances. However, productivity and disturbances are intrinsically linked. We present here a theoretical framework of the possible interactions of changing productivity and disturbances under climate change and provide a short, non-exhaustive list of examples from the literature for each type of interaction of chaging productivity and distrubances. Our synthesis framework distinguishes between: 1) Direct effects of productivity on disturbances, 2) Indirect effects of productivity on disturbances, 3) Direct effects of disturbances on productivity and 4) Indirect effects of disturbances on productivity. We do not yet have a comprehensive picture of the mechanism through which changing productivity and disturbances interact. Unraveling these mechanisms is crucial for a better understanding and quantification of climate change impacts on forest ecosystems and the associated risk for ecosystem functions and services. Furthermore, disturbances are often not occurring in isolation but interact and influence each other through time and space. Thus, understanding the spatial and temporal interaction of disturbances and their interaction with changing productivity is another research challenge.

Index Terms—Climate Change Impacts, Europe, Forests, Interactions of productivity and disturbances

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1 Introduction

In the 20th century, forest productivity in Europe has increased (e.g. Spiecker et al. 1996; Boisvenue & Running 2006). This has positive effects on wood availability and carbon sequestration in forests. At the same time damage to forests from disturbances has also increased (Schelhaas et al. 2003) leading to fluctuating wood prices and carbon release to the atmosphere. Both trends, increasing productivity and changing disturbance regimes, are partly associated with a changing climate (Boisvenue & Running 2006;

Seidl et al. 2011) and future projections mostly agree on a continuation of productivity (Wamelink et al. 2009; Reyer et al. submitted.) and disturbance changes (e.g. Lindner et al. 2010; Jönsson et al. 2009, 2012) under ongoing climate change.

2 What is still missing?

Studies of climate change impact on forests usually only consider either the effects of changing productivity (e.g. Wamelink et al. 2009; Reyer et al. submitted) or disturbances (Schelhaas et al. 2003; Jönsson et al. 2009). However, productivity and disturbances are both dynamically changing processes over stand development (Gower et al. 1996; Ryan et al. 1997; Urban 1987) and intrinsically linked since disturbances are usually coupled to a certain forest state and productivity determines how long a forest remains in a specific state and thus how susceptible it is to a certain disturbance (Dale et al. 2000; White & Jentsch 2001). For example, tree height determines the susceptibility to wind damage (Cucchi et al. 2005; Gardiner et al. 2010; Albrecht et al. 2012) and forests which are more productive may reach critical heights faster and may even grow higher (e.g. Blennow et al. 2010a, b). Conversely, in managed, even-aged forests, younger, denser forest stands are more susceptible to forest fires and higher productivity may enable them to grow out of this susceptible state faster (Gonzalez et al. 2006).

Thus, in reality, changing productivity and disturbances interact. This has important implications for the assessment of climate change impacts on forest products and services. On the one hand, higher productivity may mean that more damage can be done, i.e. more is at risk (Schelhaas et al. 2002, 2003). On the other hand, reduced productivity may mean that less damage may occur but also that what is damaged is more valuable. Therefore, it is necessary to interpret climate change-induced productivity and disturbance changes jointly to capture the full range of climate change impacts on forests and to plan adaptation (e.g. increase harvest and shorten rotations to balance increasing risks).

To this end, we present here a theoretical framework of the possible interactions of changing productivity and disturbances under climate change and provide a short, non-exhaustive list of examples from the literature for each type of interaction of chaging productivity and distrubances.

3 Theoretical framework of the interaction of productivity and disturbances

We define disturbance as synthesized by Seidl et al. 2011 from White and Pickett 1985; Gunderson 2000; Grime 2001; White & Jentsch 2001 as “a discrete event in time that disrupts ecosystem structure, composition and/or processes by altering its physical environment and/or resources, causing destruction of plant biomass." This definition is neutral and excludes implicit valuation whether the effects of disturbances are good or bad.

We understand productivity in a broad sense as the accumulation of photosynthetic products in biomass minus autotrophic respiration. However, for the description of specific interactions of productivtity and disturbances more narrow definitions are necessary. For example, if the effects of disturbances affect the allocation of productivity within a tree. In such cases we highlight which specific component of productivity (e.g. stem growth) we are referring to.

Theoretically, disturbances may interact with forest productivity in several ways (Fig. 1). Our synthesis framework distinguishes between:

1. Direct effects of productivity on disturbances.
2. Indirect effects of productivity on disturbances.
3. Direct effects of disturbances on productivity.
4. Indirect effects of disturbances on productivity.

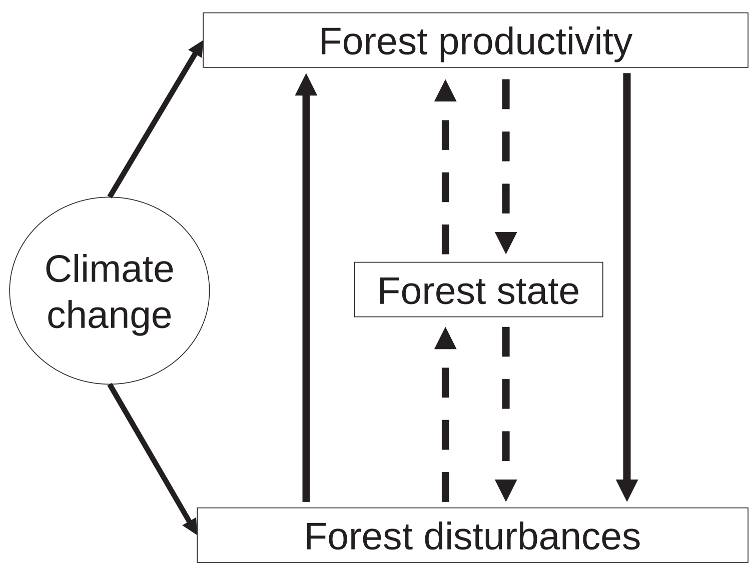

Fig. 1 Conceptual model of potential interactions between forest productivity and forest disturbances under climate change. Solid arrows indicate direct effects; dashed arrows indicate indirect effects mediated through the state of the forests.

4 Examples for the different types of interactions of productivity and disturbances

4.1 Direct effects of productivity on disturbances

A direct effect of increasing productivity is that trees may be able to better resist disturbances. For example, trees maybe more vital and hence better able to cope with insect attacks due to an increasing availability of carbohydrates for defense (Wermelinger 2004). With regard to herbivory by insects, changing productivity may influence leaf element stoichiometry and hence influence the palbability and nutritional value of leaves for herbovores (Ayres & Lombardero 2000; Netherer & Schopf 2010).

4.2 Indirect effects of productivity on disturbances

Changing productivity may alter key structural features of a forest which directly determine its susceptibility to disturbances. Increasing productivity under climate change in Sweden leads to increasing height growth and tree heights which increases the probability of wind damage (Blennow et al. 2010 a, b). Conversly, it is also possible that higher productivity leads to a lower height-diamter ration and hence less storm damage.

4.3 Direct effects of disturbances on productivity

Besides killing trees which immediately decreases productivity to zero, there are also more subtle effects of disturbances on the productivity of trees. Insect defoliation for example may reduce the amount of absorped photosynthetic active radiation, the carbon uptake, the stored carbohydrates and, in coniferous trees, nitrogen remobilization, thus reducing overall productivity (Pinkard et al. 2011) and stem growth in particular (Jacquet et al. 2012, 2013). Similarly Seidl and Blennow (2012) showed that important growth reductions occurred in trees that survived a storm in Sweden due to root breakage. At the landscape level, model simulation show that reductions in productivity due to disturbances over longer time frames may be small (Pan et al. 2009) but other studies highlight that this depends on the disturbance type and frequency (Chertov et al. 2009).

4.4 Indirect effects of disturbances on productivity

Indirect effects of disturbances on productivity refer mostly to changes in forest structure and composition. Disturbances may for example alter the species composition of a forest (Bolte et al. 2009) which changes its productivity. A disturbance may also change the age structure of a forest (or a forest landscape) and thus influence its productivity. At the individual tree level, wind damage may limit height growth (although not height growth rate see Mencuccini et al. 2005) and thus limits tree productivity. In the example of storm damage to surviving trees in Sweden by Seidl and Blennow (2012), the indirect effect of the storm on stem growth was substantial since surviving trees allocated more carbon to repair roots damage which even further decreased stem growth.

5 Conclusion and what is still, still missing?

We have shown that there are numerous ways how changing productivity and disturbances may interact. Our theoretical framework provides a useful synthesis to guide observational and experimental studies as well as to lead model development. Furthermore, our synthesis shows that studies on the adaptation and the mitigation potential of forest ecosystems should consider the interaction between productivity and disturbance changes to paint a realistic picture of climate change impacts on forests and the goods and services they provide.

However, our synthesis also shows that we are far from having a comprehensive picture of the mechanism through which changing productivity and disturbances interact. Unraveling these mechanisms is crucial for a better understanding and quantification of climate change impacts on forest ecosystems and the associated risk for ecosystem functions and services. Moreover, this understanding is also important to answer ecological questions regarding the drivers of tree death.

Furthermore, disturbances are for example often not occurring in isolation but interact and influence each other through time and space (Dale et al. 2001; Hanewinkel et al. 2008). Wind-blown or drought-stressed trees for example provide breeding material for insects that may even attack fully vigorous trees (e.g. Schroeder and Lindelöw 2002; Gaylord et al. 2013). Newly created forest edges after a storm may expose formerly rather protected trees to the subsequent storms. Thus, understanding the spatial and temporal interaction of disturbances and their interaction with changing productivity seems to be another research challenge.

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Challenges for Agro-Ecosystem Modelling in Climate Change Risk Assessment for major European Crops and Farming systems.

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Abstract— Modelling European Agriculture with Climate Change for Food Security (MACSUR) is a knowledge hub exploiting and improving data, methods and modelling tools for a detailed climate change risk assessment. The hub comprises 73 interacting agricultural (crop, livestock, trade) scientific and modelling research groups from 16 European countries and Israel. The crop modelling (CropM) component of MACSUR concentrates on overcoming weaknesses in crop modelling approaches and tools with specific attention to exploiting data on important European field crops, crop rotations and farming systems, and the modelling of diverse (mitigative) adaptation options. CropM outputs are scaled up to farm, regional and (supra-) national level as required for concerted integrated studies on the European agri-food sector and its contribution to global food security under climate change. The specific objectives of CropM are: (i) to conduct crop model intercomparisons to detect deficiencies, (ii) compile data in support of model improvements, (iii) advance scaling methods and model linkages, (iv) improve climate scenario data and impact uncertainty analysis, (v) build research capacity in these areas, and (vi) combine new knowledge and tools with those from livestock and trade modellers to allow interdisciplinary studies and interaction with a diverse range of stakeholders for climate change impact assessments. We identify requirements for improving model simulations, e.g. concerning impacts of heat and drought stress as well as intense rainfall and warm winters on crop yield. We show possibilities for enhancing methods of linking models and data of different resolutions. Finally, we give examples of how to improve quantification and reporting of crop impact uncertainties including the contribution from various sources (i.e. emission scenarios, climate modelling, downscaling of climate model data and crop impact modelling itself).

Index Terms— Adaptation, climate risks, crop model improvement, uncertainty analysis

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1 Introduction

In 2011, the European Union (EU) contributed 20% of global cereal production and 19% of global meat production (www.faostat.fao.org). Concurrently, while agricultural production is intensifying in Northern Europe, declining productivity has been indicated in some southern and south-eastern regions of Europe (Porter et al., 2013). During recent decades, variability in European crop yields has already increased due to more frequent extreme climatic events, which are likely to increase in the future (Field et al., 2012). At the same time, growth in cereal yields have declined considerably in Europe, especially for wheat (Olesen et al., 2011). Questions arise such as (i) how to increase agricultural production and Europe's share in global food supply security while concurrently reducing greenhouse gas (GHG) emissions from agriculture?, or, (ii) what land and water resources, efficiency gains, agro-technologies, investments and institutional settings are required to, at least, double EU's agricultural production by 2050 without increasing GHG emissions (Tilman et al. 2011)? MACSUR as a whole is interested what the agricultural development pathways for the EU should be to fulfill such goals in the face of climate change. It has been argued that the EU should first invest in sustainable intensification on the most suitable land in order to best utilize agriculture's mitigation potential and contribute to global food security (Soussana et al., 2012). Under such a research and development agenda, agro-ecosystem models (AEMs) must provide much more than just information on crop yields. Model outputs on crop water use, nitrogen and carbon balances, to name a few, will be equally important (Fig. 1) (e.g., Eckersten et al., 2001).

In this paper, we identify requirements for AEMs to support multiple (agri-environmental) goal analysis (Müller & Lotze-Kampen, 2012) with focus on how to overcome model deficiencies (Section 2), and how to link AEM with socio-economic analysis for conducting integrated climate risk assessment (Section 3). With respect to gaps in climate impact research for agriculture, we especially address what is needed to better understand impacts of climatic variability and extreme events, and, how AEMs could be applied in studies that aim at quantifying challenges and solutions for food security.

2 How to overcome deficiencies in agro-ecosystem modelling ?

In order to eliminate deficiencies of AEMs for climate change impact and risk assessment, two international research networks, AgMIP (Rosenzweig et al. 2013) and FACCE JPI knowledge hub MACSUR (www.macsur.eu; this paper) have recently been launched. Common goals are to compare

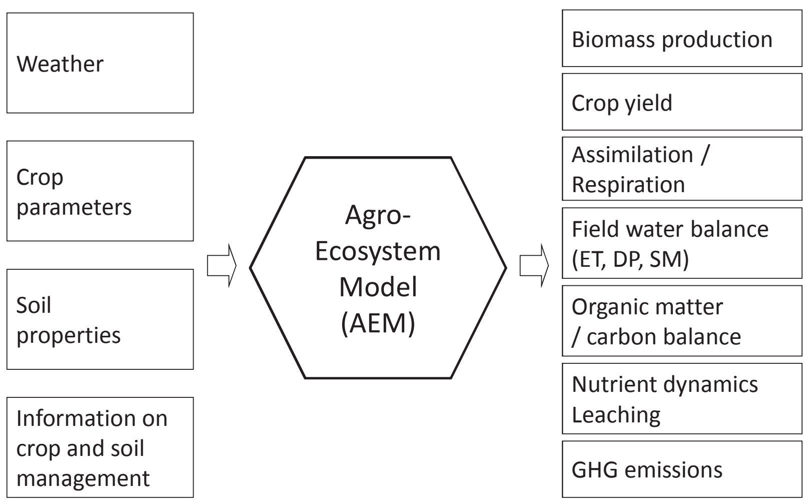

Fig. 1. Schematic overview of Inputs and outputs of Agro-Ecosystem Models (AEMs). Abbreviations: ET = Evapotranspiration; DP = Deep Percolation; SM = Soil Moisture; GHG = Greenhouse gases

crop, livestock and trade models, identify deficiencies and improve models *vis a vis* real world observations. While WGII of IPCC AR4 (Easterling et al. 2007) concluded that agricultural production will be mainly reduced in developing countries if global warming remains below 3^{o}C, later studies suggest higher risks. Due to increased climatic variability with more frequent and severe extreme weather events (Field et al. 2012), more rapid and severe yield reductions are expected across the world than previously anticipated (Lobell et al. 2011). Some of these are related to the sensitivity of crops when certain temperature thresholds are exceeded (e.g. Moriondo et al. 2011; Semenov & Shewry, 2011); in practice, often both severe heat and drought (e.g. during certain times of the day) are responsible for non-linear, negative impacts on yield (Reyer et al. 2013). Moreover, effects of intensive precipitation and flooding on plant physiological (oxygen stress) and soil processes (nitrate leaching) may significantly reduce crop yields. All these effects induced by increased climatic variability are not yet adequately captured by current AEMs, which recently led to calls for "overhauling" them and apply multi-model approaches (Rötter et al. 2011a). Considerable uncertainty also exists with respect to modelling CO_2 effects (Kersebaum & Nendel, 2013) and the

Table 1. Summary of type of extreme events and crop species to be considered and receive first priority for overcoming model deficiencies in CropM (based on literature and expert review by MACSUR consortium)

Extreme event	**Development stage**	**Main physiological process**	**Crop species**
Severe drought (weeks) and chronic (weeks-months) high temperature	Vegetative growth	Tillering (small grain cereals) and leaf expansion /senescence - C and N assimilation and partitioning - Lack of vernalisation (winter cereals) - accelerated rate of development	Wheat Barley
			Oil-seed rape
			Olive Grapevine
		accelerated development and tuber mass	Sugar beet Potato
	Reproductive growth	Canopy senescence - C and N assimilation and partitioning - Anthesis/silking interval (maize) – Grain/fruit development	Wheat Barley Maize Rice Oil-seed rape
			Sunflower Olive Grapevine
Short (hours-days) heat shocks	Anthesis	Floret mortality - Pollen viability (maize) - Potential grain size	Wheat Barley Maize Rice Sunflower
	Reproductive growth	Starch granule and gluten protein size distribution	Wheat
Short and chronic very cold spells	Vegetative growth - anthesis (grapevine, olive)	Cold hardening (winter cereals, frost damage or winter-kill) - Fruit mortality (grapevine, olive)	Wheat Barley
			Grapevine Olive
Heavy rain and storm	Vegetative / reproductive growth - ripeness (grapevine)	Stem lodging (small grain cereals, interaction with N fertilization) - Water logging-oxygen stress - Post-maturity losses from delayed harvest - Disease losses from wet conditions	Wheat Barley Oil-seed rape Potato

interactions between temperature and CO_2 (Asseng et al. 2013), calling for further research. A pre-requisite for elimination of model deficiencies and ensemble modelling are proper model intercomparison studies. CropM will, therefore, carry out model intercomparisons in combination with exploiting untapped experimental data on major European crops and crop rotations. Currently new data sets are being compiled with focus on improving model descriptions regarding impacts of different extreme events (Table 1). These will be utilized to identify and overcome model deficiencies. Improved or new algorithms to account for the effects of extreme events on crops will be implemented in AEMs most commonly used. After evaluation, multi-model simulations of an ensemble of improved models will be performed, with focus on the most important crops/crop rotations in the EU. Outputs will lead to robust yield estimates and enable better reporting of their uncertainties (Fig. 2) (Section 3.4).

3 Towards integrated climate risk assessment

3.1 Modelling future genotype by environment by management (GxExM) interactions

AEMs will be further developed to allow simulation of different future adaptation measures such as the interactions of new crop cultivars with adjusted management practices (sowing, tillage, fertilizer use) under possibly amplifying environmental stress factors (see, e.g. Rötter et al. 2011b; Semenov & Shewry, 2011). New experimental data (Section 2) will be exploited to improve the representation of processes in the models. Empirical-statistical approaches will be utilized to complement AEMs

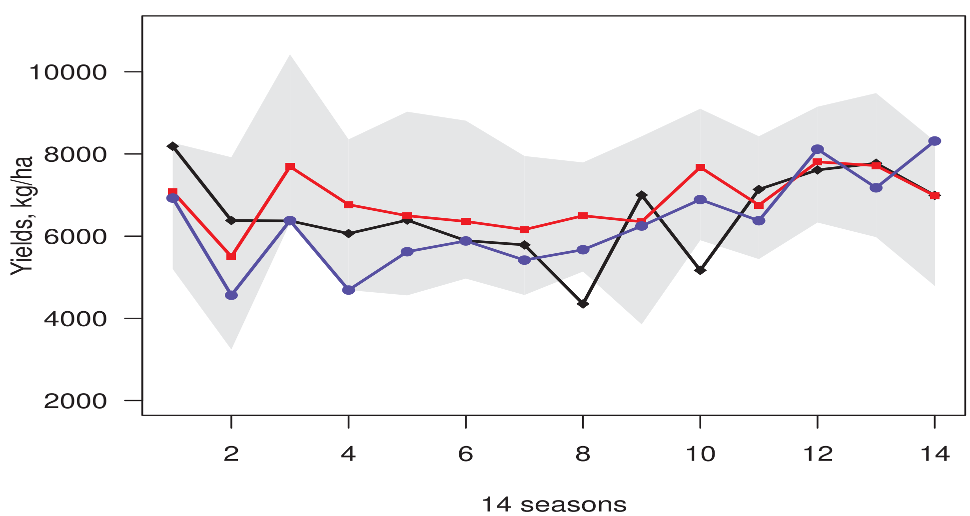

Fig. 2: Ensemble crop yield simulations: Multi-model mean (blue line, squares), model range (grey shaded area; spread of models) and best model (red line, circles) versus observations (black line, diamonds) at a single site (n=8 crop models; based on Palosuo et al., 2011).

for climate impacts that are difficult to simulate (e.g. harvest losses by heavy rains). To evaluate the performance (mean and variability) of various adaptation strategies for crops and crop rotations under different climate and technology development scenarios probabilistic assessment methods will be applied (Section 3.4). Most challenging will be to establish those crop and cultivar-specific critical thresholds (for heat, frost, water deficits and excess) that, if exceeded, lead to marked negative impacts on growth and yield. A range of data sources will be explored to define such thresholds and their genotypic dependency, including variety experiments from across Europe and controlled experiments applying specific stresses to plants.

3.2 Crop rotation modelling

Diversified crop rotations and their management are usually considered key to achieving multiple sustainability goals of future agricultural land use, including long term productivity increases under climate change. However, there is little evidence to support the extent to which such benefits can be obtained in practice and how diverse crop rotations will respond relative to more simplified systems. Modelling alternative crop rotations and their impact on the carbon and nitrogen cycle is therefore a particular focus of CropM, as it allows to thoroughly explore synergies between adaptation and mitigation and enhance resilience of production systems to climatic risks (Smith & Olesen, 2010). In addition to crop yields, nutrient and carbon balances and greenhouse gas emissions need to be simulated, taking into account varying agro-management practices – which calls for multi-model use (Section 3.4). CropM will for the first time systematically intercompare models for crop rotations (see, Kersebaum et al. 2007 for previous work) – based on local crop and soil data from crop rotation experiments collected in Europe.

3.3 Integration of AEM with farming system modelling

Eventually, we need to develop improved (scaling) methods to enable us to estimate large-scale regional crop productivity. AEMs have typically been developed for the application at field scale. As Ewert et al. (2011) indicated, improved estimates of regional productivity cannot be obtained only by considering biophysical aspects and their variations. Farm management as well as other socio-economic information needs to be linked with AEMs to estimate climate change risks and opportunities at higher aggregation levels. Integration of different information relevant for evaluating options of mitigative adaptation is most needed at farm scale, where the final decisions on agricultural production and resource management are taken. To realize this, robust AEMS and farming system models can be combined to assess farmers' decisions on achieving production and various sustainability goals (Janssen & van Ittersum, 2007). In Fig. 3, hypothetical outputs from such farm type modelling (to be upscaled to regions) are presented. Preliminary analysis (for a Finnish site) suggests that under current climate and by utilizing available production technology, considerable yield gaps could be closed (see, Palosuo et al., *this conference*) with markedly lower GHG emissions and N leaching than by (sub-optimal) average farmers practices. Technology advancements expected for 2030s would further increase productivity and income while improving environmental goals (Fig. 3).

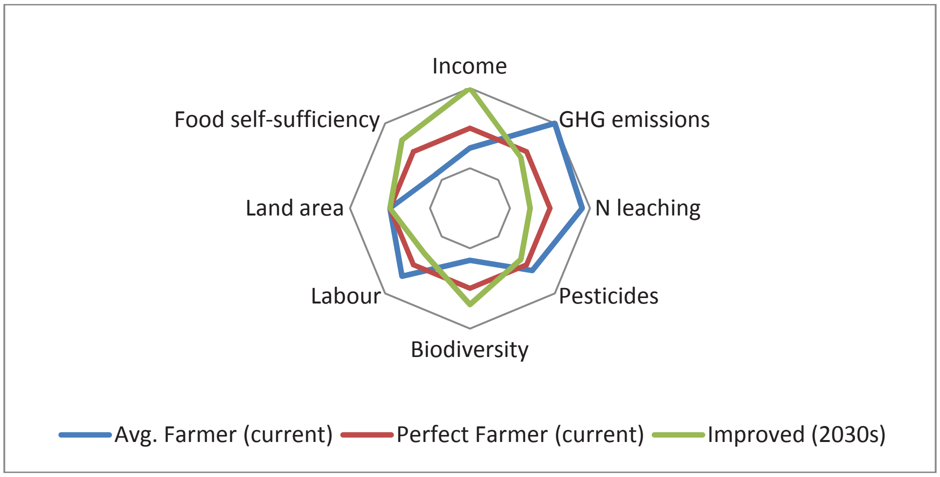

Fig. 3: Qualitative illustration of how environmental sustainability and economic viability goals can be achieved under alternative agro-management practices including average farmer's practices and perfect management (under current climate) and improved practices for the 2030s (after Rötter et al. 2005).

3.4 Improving quantification and reporting of uncertainties

Fig. 2 shows for models applied with limited calibration that uncertainties in simulated yields are considerable, but the multi-model mean is fairly close to observed yields and a better predictor across all 14 seasons than the "best model". Similar results were obtained from other crop model intercomparisons (e.g. Rötter et al. 2012) and studies with climate models (Tebaldi & Knutti 2007). The latter authors argue that the multi-model mean or median is superior to any "best model", especially if more than one output variable is of interest and since a number of different errors tend to cancel each other out. Whether crop model uncertainties can be adequately quantified by using multi-model ensembles depends on whether the models included are well-calibrated and not biased and their number is sufficient to adequately represent available modelling approaches. Finally, there is a need for quantifying the degree of uncertainty resulting from crop models and its relative importance in impact assessments (Asseng et al. 2013). One approach to this is to overlay impact response surfaces (IRS) of simulated crop yields with probabilistic information on future changes in temperature (T) and precipitation (P). IRS represent crop responses to systematic changes in T and P under given atmospheric CO_2 concentrations, while uncertainties in T and P changes over a future time, presented as joint probabilities are derived from climate model ensemble simulations (Fronzek et al., 2010; Carter et al., 2011; Carter et al. 2012). What has been missing is simultaneous use of multi-crop model ensembles for determining confidence intervals for yield IRSs and application of the method for different agricultural input levels, that is, not only for irrigated or rainfed potential production situations, but also under average farmers' practice as illustrated in Fig. 4. The method can also be employed for evaluating adaptation options, e.g. for different future cultivars by showing cumulative probabilities of their responses over time.

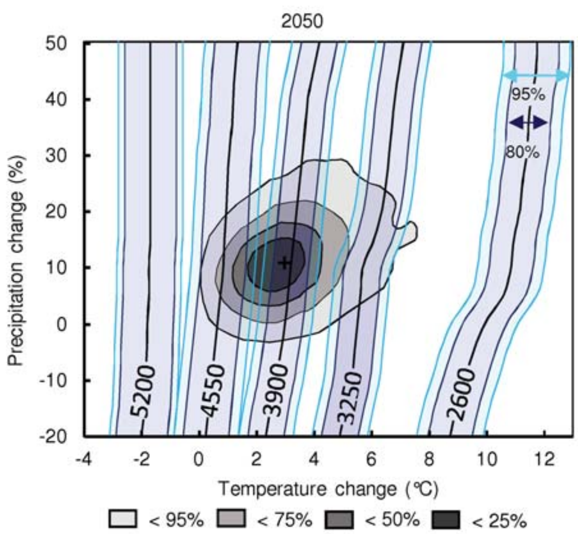

Fig. 4. Impact response surface of simulated rainfed potential barley yields (kg ha^{-1}) with respect to changes in annual T and P for given CO_2 level (525 ppmv) for time slice 2040-59 multiplied by 0.6 to account for yield gap (0.4) under average farmer's practice (black numbered isolines) with hypothetical, 80% and 95% confidence intervals (gray and blue shaded area, respectively) and relative frequency of annual T and P changes for same period relative to 1971-2000 (circled areas) at Jokioinen, Finland (modified from Carter et al. 2012).

4 Discussion

Most challenging for CropM will be to collect and exploit high quality data for model intercomparison and improvements as needed to better capturing crop impacts of increased climatic variability and extremes, and advance crop rotation modelling in the EU. New data sets will have to be generated to fill knowledge gaps. Progress is expected according to the following time frame:

- Objectives 1 and 2 (intercomparison and improvement) require several iterations with notable success expected during 2014-17.
- Major progress with respect to objectives 3 and 4 (improved scaling and uncertainty analysis) should be visible by 2014-15.
- As for objective 5 (capacity building), a new generation of integrative modellers is likely to operate in 5 to 10 years time.

MACSUR will benefit from international collaboration with consortia like AgMIP and CCAFS in the fields of improving scaling methods, uncertainty analysis and reporting, and exchange of data. International collaboration will also be needed to achieve objective 6, i.e., to develop and apply integrative assessment tools that link AEMs to socio-economic analysis from farm to (supra-)national levels. It has been questioned, whether model intercomparisons can reduce uncertainties? The answer is “No”. The only way to reduce impact uncertainties is through improving AEMs and the way these are applied in integrated climate risk assessments. However, model intercomparison provides the foundation against which this model improvement can and must be made.

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Advancing and facilitating the use of RCM data in climate impacts research

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Abstract— The use of Regional Climate Model (RCM) output for climate impacts research is a promising cross-cutting approach with mutual benefits for both, the climate modeling and the climate impacts communities. However, so far this scientific potential is by far not fully tapped. Here, we aim at identifying the main hurdles and challenges associated with the use of RCM data in fields of climate impacts and adaptation research and discuss strategies to overcome them.

Index Terms—Regional Climate Model (RCM), impacts research, adaption, scientific collaboration between the disciplines

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1 Introduction

Regional Climate Models (RCMs) are important tools to provide quantitative, physically consistent estimates of regional climate change. Therefore, RCM output is increasingly used as input for regional and local climate impacts models. During the past years, several comprehensive international efforts that aim at providing RCM data for climate impacts research have been implemented, e.g. ENSEMBLES (van der Linden and Mitchell, 2009), NARCCAP (Mearns et al. 2009) or CORDEX (Giorgi et al. 2009). Accordingly, it is a matter of mutual interest of the climate modeling and climate impacts communities that this expensively acquired RCM output is used efficiently for application in impacts studies.

It is thus remarkable that the scientific potential associated with the use of RCM output is only partly tapped so far. Just as the data flow between climate models and impacts models is usually unidirectional, there appears only little feedback from impacts modelers or “end users” back to the climate modeling community. Moreover, only comparatively few impacts scientists are working directly with raw RCM output, and scientific teams that include researchers from both communities are still rare, as can be deduced from the author lists of many conference contributions and publications.

Motivated by this context, a three-day workshop on ‘Regional climate model data for climate impacts research’ has been jointly organized in February 2013 by the project TEMPS (‘The Evolution of Mountain Permafrost in Switzerland’; a *Sinergia* programme of the Swiss National Science Foundation) and the Center for Climate Systems Modeling of ETH Zurich (C2SM). The workshop's objective was to bring together researchers from various impacts disciplines to provide basic training for the handling, pre-processing and evaluation of RCM generated data, and to identify and discuss challenges and hurdles that impede their application for climate change impacts studies. 24 impacts researcher from different fields such as glaciology, hydrology, agriculture, ecology, biology, meteorology and climatology participated in the workshop. Most of the participants had already used RCM output or plan to use it for future work. Actual and planned uses range from applying raw RCM output to utilizing sophisticated climate scenario products, and cover the whole spectrum of spatial and temporal scales (from 3-hourly to decadal mean) as well as a great number of available variables. This article summarizes some of the main outcomes of the workshop, complemented by experiences collected by the authors over the past years. In this regard, the intention of the present article is (i) to provide an overview and an analysis of the barriers that impede the adoption of RCM simulation results by impacts researchers, and (ii) to initiate the discussion on how to improve communication and collaboration between the communities in order to tap the full potential of climate model data in general and of RCM data in particular.

2 Basic Challenges

2.1 The heterogeneity of the impacts community

The term 'climate impacts research' suggests a well-defined research direction and a community with clear objectives, a common methodological toolbox, and well-defined input data needs. However, the climate impacts community is in fact a highly heterogeneous group that includes natural and social scientists, economists and decision makers and which correspondingly exhibits a rich diversity of research objectives, methods and data requirements (Fig. 1). A scientifically oriented user might for example utilize RCM output to drive a model of ground surface temperature at a number of specific permafrost sites to enhance the understanding of this specific process (e.g. Salzmann et al. 2007, Scherler et al. 2013). Or an economist might want to use gridded RCM output that covers a national economy to derive the best estimate of an index variable, such as heating degree days, as input to an economic integrated assessment model (e.g. Gonseth and Vielle, 2012).

This broad range of applications in concert with an often sub-optimal understanding of the characteristics of RCM output makes it difficult for the impacts community to specify simple, clear, and unambiguous common requirements for the data input to be provided by the climate modelers. Those, in turn, often lack the expertise in the specific fields of impacts research that would be necessary to advise the 'end users' in that regard. These deficits form a major impediment for the use of climate model output in impacts research.

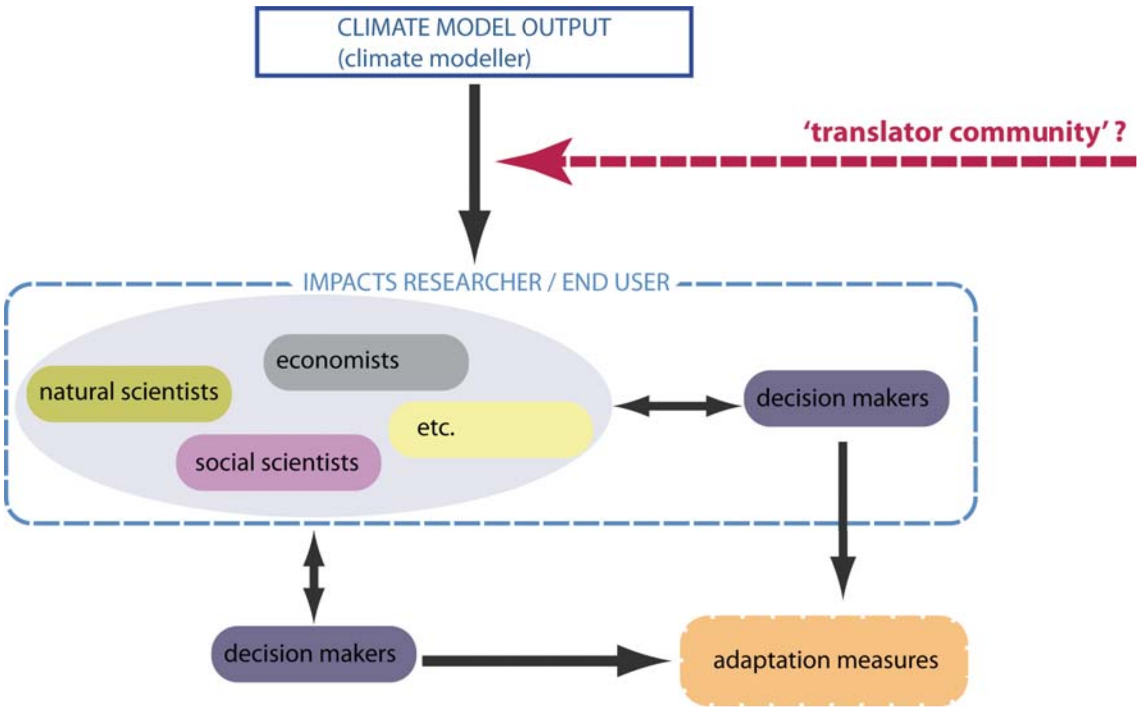

Figure 1: Context and current data delivery procedures of using climate model output for subsequent application in impacts and adaptation research. Black arrows indicate data/information transfer.

2.2 Technical issues

The data formats, software tools and conceptual approaches for data representation and modeling used by impacts researcher can vitally differ from those used by climate modelers. For example the NetCDF data format used to represent gridded, time dependent climate datasets differs significantly from what many impacts researchers are used to work with, e.g. ASCII formatted data for station (point) climate data or special vector data formats used in Geographic Information Systems. As a consequence, processing (raw) climate model output into a shape ready to be digested by impact modelers' tools often requires a great initial effort.

The option of using post-processed RCM data in form of readily available scenario products, such as the Swiss Climate Change Scenarios (CH2011, 2011), is thus attractive for many impacts researcher. However, it remains to be discussed whether this approach is flexible enough to be recommended as a general strategy (see section 4).

2.3 The ‘one-directional data-delivery’ procedure

Currently, the modus operandi of how RCM data is provided for further use in impacts research is a one-way process from the climate modeling community to the impacts community. Usually, there is no feedback channel which would provide ‘end users’ with an opportunity to voice their specific requirements, report problems, or obtain in-depth information, for example regarding the data’s exact meaning, its suitability for specific applications, or the associated uncertainties. Thus, potentially valuable information for both communities and an opportunity for stimulating scientific exchange are lost.

3 Analyses of current hurdles faced by the impacts modeler

It is a challenging task for impacts modelers to assess the characteristics of RCM output. This includes the representativeness of gridded data, the uncertainties inherent in the climate model output, and the identification, correction and extrapolation of model biases. Climate model validation exercises that are routinely applied by climate modelers, such as the validation over large domains and/or aggregated time periods (monthly, seasonal, 30-year mean, etc.) for main variables such as air temperature and precipitation, are hardly sufficient for regional-to-local scale impacts studies. They require a domain- and process-specific RCM validation that ideally would be carried out in a collaborative effort between climate modeler and impacts researcher.

Many impacts researcher typically work with point data (i.e. climate station). Using gridded data instead (often with a spatial resolution on the order of 20 – 50 km) raises various challenges related to the representativeness of a grid point and respective validation procedures, downscaling techniques, extreme values, and finally the application to regional-to-local scale impacts models. This becomes particularly evident in complex mountain topography (e.g. Kotlarski et al. 2012; Salzmann et al. 2012) but also in remote locations, where appropriate observations for model validation are usually scarce or even lacking. Yet, it is often in such regions where climate model output and reanalysis products become interesting for impacts researchers, because no other data for the past and present are available. Here, collaboration with the climate modeling community is of utmost importance because only an intimate knowledge of model parametrizations, assumptions, inherent and scale-dependent uncertainties, and other dependencies on data reliability and robustness will guard against grave mistakes. Moreover, the performance of RCMs regarding the realism of statistical properties of the simulated time series such as variance, autocorrelation structure, spectral characteristics, or occurrence of extremes is often not clear to many impacts researchers, but fundamental for numerous impacts processes. A particular challenge in that regard is the proper use of the information contained in multi-model ensemble simulations. Multi-model averages have been shown to be more accurate than single model predictions in many cases (Knutti, 2010 and references therein), but the averaged time series also exhibit less realistic properties, such as reduced variability, which might be important for impacts applications. Model averaging and associated methods are highly technical and present significant obstacles for the non-specialist. While the representativeness of gridded climate model data with respect to local extremes is not clear for the past, it is even more difficult to assess it for future scenarios. Furthermore, particularly in the case of extremes, clarity on the definition of 'extremes' in each community is crucial. Here, the potential for misunderstanding due to the use of different terminologies is obvious.

Associated with the 'point vs. grid' issue is the topic of bias correction and/or further downscaling, here referred to as 'empirical-statistical' approaches. Empirical-statistical downscaling can be applied at different levels of complexity (e.g. Benestad et al. 2008, Maraun et al. 2010). Impacts researcher depend on expert judgments with regard to the potential, the limits, and the optimal choice of the empirical-statistical post-processing of RCM data for their respective applications. Particularly for the more complex approaches, a small community is about to be formed within the recently launched COST Action VALUE (Validating and Integrating Downscaling Methods for Climate Change Research; *http://www.value-cost.eu*).

4 Is there a need for a 'translator community'?

It is obvious that both communities benefit from enhanced collaboration but that also certain efforts are required from both sides.

Although the impacts community is highly diverse and common needs are difficult to formulate, each discipline clearly needs to assess the sensitivities of their specific processes and models with respect to changes in related key climate variables. Knowledge about the particular sensitivities will help to communicate with the climate modelers and to handle the uncertainties of RCM data for impacts research.

With increasing climate model resolution and the constant incorporation of additional and/or improved parameterization schemes, extended process knowledge and expertise outside the field of atmospheric research will become increasingly important for climate model development. Many impacts researcher can provide knowledge and data on such processes and thus are potentially important partners for the climate modeling community.

In general, members from both communities need to invest time and efforts to improve their understanding of the concepts and models of each other. This requires participating at dedicated conferences, reading specific literature and publishing jointly. For many community members such an endeavor is not an option, though. Therefore, the concept of a 'translator community', formed by scientists from all involved disciplines, and advance and facilitate collaboration between the communities, needs to be pushed forward. Even though this idea has been entering the discussion at times (e.g. Leung et al. 2003) and scattered efforts exist, the growth of such a community to a well visible and significant size is also hampered in the current scientific setting, where highly specialized research is typically most prestigious. Therefore, explicit stimuli by funding agencies, universities and research institutions, for example through dedicated research programs and chair offers, might tip the scale. Linking these endeavors to current efforts in the field of climate change impacts and adaptation is particularly promising.

Initiatives such as the Swiss Climate Change Scenarios project (CH2011, 2011) might be seen as an alternative to a 'translator community'. Here, vastly post-processed RCM data in form of tailored scenario products were provided to the impacts community. This product, based on the ENSEMBLES set of multi-model GCM-RCM chains (van der Linden et al. 2009), was developed in an elaborate process that stressed the assessment and the communication of uncertainties, limitations and areas of applicability. Such data is highly appreciated for its ease of application by many users, particularly by those outside academia, e.g. consulting companies and government agencies. An important part of the CH2011 scenario development was the intensive discussion between climate modelers and potential end-users in order to identify their specific needs. Public climate scenario initiatives are thus not an alternative to scientific collaboration, but are rather a service for practitioners who don't have the resources for scientific examination. However, the scientific potential associated with the collaborative analyses and use of raw RCM output in climate impacts research, which aims at enhancing the understanding of physical key processes, is certainly not fully tapped by such initiatives.

5 Conclusions

There is a high scientific potential in the use of climate model output in impacts research, with mutual benefits for all involved communities and likely important inputs for the pressing challenges related to climate change impacts and adaptation.

Establishing a dedicated 'translator community' is probably an optimal strategy to advance and facilitate cross-cutting science between climate modeling and impacts research. However, readiness of scientists from all involved disciplines, ideally stimulated by funding agencies and research institutions, are badly needed to give such efforts the required weight in science.

Initiatives such as CH2011 certainly respond to the needs of practice-oriented 'end users', but are not an alternative to the enhanced scientific collaboration between research communities.

Furthermore, large programs, such as ENSEMBLES or CORDEX, that provide 'raw' RCM output should extensively document the provided model results with metadata that could be useful for impacts modeler, such as known caveats, limits of applicability, biases for certain regions and variables, and known sources and estimated magnitudes of uncertainties. Naming of contact persons for specific questions could also prove very useful.

Finally, it is obvious that not all of the needs formulated by impacts researchers are realizable. Therefore, enhanced collaboration and communication is indispensable to improve mutual understanding towards mutual benefits.

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Nested scenario meta-analyses to systematically address individual and societal consequences of climate change

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Abstract— Many important socioeconomic determinants of vulnerability across scales – such as styles of governance, power differentials, or indicators of social cohesion – may be better represented qualitatively. However, qualitative factors can pose challenges for traditional approaches to aggregation (e.g. downscaling, upscaling). Nevertheless, approaches for aggregating findings from localized case studies are needed to arrive at a comprehensive view of the individual and societal consequences of climate change. Where the ability to aggregate difficult-to-quantify factors is desired, nested scenarios containing both qualitative and quantitative information may fill the gap. In this paper, recent scholarship is summarized that demonstrates (1) there may be inherent limitations to current approaches for aggregation and cross-scale bridging for some important socioeconomic determinants of vulnerability that are difficult to quantify, (2) through new scenario methods that are more objective, socioeconomic scenarios containing qualitative components can be shown to be internally consistent, and (3) such scenarios developed at more than one scale could be coupled in an internally consistent way. These new conceptual and methodological developments point the way toward systematically addressing individual and societal consequences of climate change across scales and potentially to improving analytical tools for identifying socio-ecological tipping points.

Index Terms— cross-impact, meta-analysis, shared socioeconomic pathways, scenario

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1 Introduction

New global socioeconomic scenarios for climate change research, so-called Shared Socioeconomic Pathways (SSPs), are rooted in a new fundamental logic: Socioeconomic *challenges to mitigation* and socioeconomic *challenges to adaptation* (O'Neill et al. forthcoming). Rothman et al. (forthcoming) situated the new concept of challenges to adaptation in the context of existing literatures related to adaptation, vulnerability, and resilience. Key conclusions include (1) that, in SSPs, careful consideration must be given to socioeconomic and (non-climatic) biophysical factors that differ across scales, as well as cross-scale interactions, and (2) that representations of challenges to adaptation require characterizations of both quantitative and qualitative factors. To obtain a truly comprehensive view of socioeconomic challenges to adaptation, Rothman et al. also called for closing the iterative loop between global and more localized (or sector-specific) analyses based on SSPs. Traditionally, there has been a unidirectional relationship between global and localized scenario studies, where global scenarios acted as boundary conditions for local scenarios (van Vuuren et al. 2012). Under this convention, global scenarios learn little from local scenario studies. Rothman et al. stopped short of suggesting specific methodologies for realizing such cross-scale integrations, but this paper builds upon their conclusions and recommendations to focus on the following questions:

1. Are current models the adequate tools to identify biophysical and/or social tipping points? If not, what else is needed?
2. What is needed to systematically address individual and societal consequences of climate change impacts? What methods are appropriate for this?

2 Limitations of current approaches for aggregation and cross-scale bridging

Currently, many models are scale-specific, but cross-scale interactions are also important for a comprehensive view of vulnerability (Adger et al. 2005, 2008; Ford et al. 2010; Turner 2003). In comparison to current models, tools for investigating cross-scale interactions are underdeveloped.

In addition, some factors important for vulnerability assessments do not lend themselves well to quantification, which can pose challenges to current approaches for aggregation (e.g. downscaling, upscaling; see Table 1). To illustrate this, Table 1 provides examples of socioeconomic factors at local and large scales relevant for adaptive capacity (left and right columns respectively), which has become a central focus of recent vulnerability research. Adaptive capacity emphasizes the potential for individuals and societies to respond to current and future changes in climate. Efforts to classify and categorize such factors converge on eight categories: (1) natural resources, (2) human resources, (3) material resources, (4) social resources, (5) political resources, (6) economic resources, (7) Institutional resources, and (8) cognitive/cultural resources (Brooks & Adger 2005; Eakin & Lemos 2006; Yohe & Tol 2002). Within each category, particular factors listed in the far left column of Table 1 are often the focus of localized case studies, as they often differ between particular exposure units (i.e. individuals, communities, sectors) and over time. In the far right column, related factors within each category may be the same or slightly different due to data limitations or changes in the meaningful representation of the local factor at a broader scale (and vice versa). For some factors (see examples of institutional and cognitive/cultural resources), there may be no meaningful representations at the broad scale.

The mismatch between meaningful representations of factors at local and broad scales may inhibit the identification of biophysical or social tipping points in the face of climate change, as systematic investigation of individual and societal capacities (or alternatively barriers) may be difficult in some cases with quantitative aggregation or downscaling. However, the fact that some factors are difficult to quantify or bridge across scales need not mean necessarily that cross-scale investigations must remain out of reach. In many future-oriented impact studies, such difficult-to-quantify factors have typically been related to models through qualitative scenarios. Current approaches for the cross-scale bridging of such scenarios include developing nested or weakly linked scenarios across scales (e.g. Zurek & Henrichs 2007). However, a major limitation to this approach is the low comparability or questionable internal consistency of such scenarios across scales.

3 A new method for internally consistent scenarios in environmental change research

The blending of qualitative scenarios and quantitative simulations in climate change research is based on the Story and Simulation approach (Alcamo 2008). A potential benefit of this approach is that qualitative stories may establish the plausibility of the future conditions that quantitative models, such as integrated assessment, simulate. The dominant method for developing the qualitative aspects of scenarios (i.e. the stories or narratives) is a creative approach called Intuitive Logics (Rounsevell & Metzger 2010). However, some have questioned whether intuitively derived stories identify appropriate boundary conditions for quantitative simulation (Kok 2009; Morgan & Keith 2008). Recently, the application of a formalized and systematic technique for qualitative scenarios – cross-impact balance (CIB) analysis (Weimer-Jehle 2006) – has been demonstrated for scenarios in climate change research (Schweizer & Kriegler 2012). Schweizer and Kriegler (2012) re-examined the 40 scenarios from the IPCC *Special Report on Emissions Scenarios* (SRES, Nakicenovic et al. 2000) and used the CIB method to rank them in terms of internal consistency. It was found that not all SRES scenarios are equally internally consistent, which casts doubt upon claims that they should be considered equally plausible. A subsequent comparison of the techniques for developing the qualitative aspects of global socioeconomic scenarios (i.e., Intuitive Logics versus CIB analysis) concluded that CIB is more objective primarily due to (1) procedural transparency, which enhances the replicability of deriving and comparing qualitative scenarios, and (2) the public accessibility of judgments for the interrelationships between scenario parameters (Lloyd & Schweizer, forthcoming). A study applying the CIB method to the new SSPs has also been performed (Schweizer & O'Neill, forthcoming).

Table 1. Examples of socioeconomic determinants for adaptive capacity according to eight categories and two scales, local (left column) and broad scale (right column). Note that the manifestation can change across scales; in some cases, the local manifestation loses meaning at the broad scale.

Local-scale manifestation (e.g. individuals, neighborhoods, municipalities)	Ease of local-to-broad cross-scale bridging (and vice versa), e.g. aggregation, downscaling	Broad-scale manifestation (e.g. nation, region, worldwide)
1. Natural resources (biodiversity, water quality)		
Ecosystem services	Difficult	Environmental quality
Food availability	Taking place	Food availability
2. Human resources (labor, skills, abilities)		
Educational attainment	Taking place	Educational attainment
Mobility	Difficult	Migration
3. Material resources (infrastructure, communication technologies, other technology)		
Built environment	Possible	Urbanization
Availability of sanitation	Possible	Availability of sanitation
Technological diffusion	Possible	Technological change
4. Social resources (relationships)		
State-society relations	Possible	Governance indicators
Kinship networks	Difficult	
Institutional networks	Difficult	
5. Political resources (power, rights, claims)		
Social difference (e.g. gender)	Difficult	Parity (gender)
Political participation	Possible	Policy implementation
6. Economic (and financial) resources		
Distribution of wealth	Possible	GDP/capita
Access to credit	Difficult	
Access to markets	Difficult	
7. Institutional resources (e.g. entitlements)		
Property rights	Difficult	
Pooled risk (e.g. insurance)	Difficult	
8. Cognitive/cultural resources		
Attachment to place	Difficult	
Values	Difficult	

4 Systematically addressing individual and societal consequences with nested scenario meta-analyses

Because the CIB method requires an explicit record of the interrelationships between scenario parameters to perform internal consistency tests, it also shows promise as a systematic technique for investigating cross-scale interactions in scenarios (Schweizer, in preparation). Schweizer (in preparation) showed that the original CIB method could be modified to perform nested, cross-scale internal consistency tests that can be aggregated into internally consistent multi-scalar scenarios. Potentially, the systematic technique of CIB could be used to conduct nested scenario meta-analyses that address the limitations of current cross-scale linking methods, namely questionable internal consistency and low comparability. Schweizer's current work demonstrates the multi-scalar potential of CIB for scenario parameters that are linked statically; however, future research should investigate linking that is more dynamic. Dynamic linking may not necessarily require highly complex models. Potentially, multiple models of intermediate or even lower complexity could be run iteratively to investigate the consequences of different socio-ecologic contingencies and of the impacts of climate change (for a related discussion, see Kosow 2011).

5 Conclusion

Recent scholarship on cross-scale linkages suggests that current models may not be adequate tools for identifying biophysical and/or social tipping points. This is because models tend to be scale-specific, while interconnectedness across systems of different scales may introduce additional or novel sensitivities, thereby increasing vulnerability. Thus the things that are missing analytically are tools for systematically investigating cross-scale interactions for the determinants of such vulnerability. Because tools of this type are underdeveloped, we may currently be unaware of true major factors affecting systemic vulnerability and resilience, particularly what the appropriate system parameters are, detection or attribution of disruptive or potentially transformational trends, or potential failure points. Directing future research toward such questions will be important. Moreover, some salient socioeconomic (or socio-ecologic) determinants of vulnerability are better represented qualitatively, which can pose challenges for traditional approaches to aggregation or cross-scale study. Such challenges inhibit the systematic investigation of individual and societal consequences of climate change impacts due to low comparability or questionable internal consistency across studies at different scales. However, a promising methodological development for the systematic investigation of cross-scale interactions may be cross-impact balance (CIB) analysis. CIB analysis requires an explicit record of the interrelationships between scenario parameters to perform internal consistency tests. Despite being a new approach, CIB has been employed in studies on the SRES scenarios and the new SSPs. Additionally, the CIB method is now being extended into a multi-scalar direction. Potentially, meta-analyses of scenario studies performed at different scales – with the internal consistency of their linkages guided or verified by CIB – could be powerful vehicles for arriving at a holistic view of climate change impacts, major cross-scale factors that affect systemic vulnerability and resilience, and opportunities for intervention. Such meta-analyses could be community activities following the institutional examples set by various model intercomparison projects. In any case, further use and development of the CIB approach for multi-scalar (and multi-sectoral) studies will determine whether it lives up to the potential of being an appropriate method for systematically addressing individual and societal consequences of climate change impacts and for identifying biophysical and/or social tipping points.

6 Acknowledgments

We thank Dale Rothman, Paty Romero-Lankao, Brian O'Neill, and one anonymous reviewer for helpful comments.

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Investigating impacts and developing adaptation strategies on local scale – An example

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Abstract—Due to increasing greenhouse gas concentrations global climate is changing. Climate change is driven by processes on global scale. Knowledge about impacts of climate change, however, is often needed on regional or local scale. Thus research on local impacts and adaptations strategies has to deal with processes across several scales. In the end researchers are often expected to make statements about impacts and potential adaptation strategies on a very local scale. Keeping in mind the uncertainties adding up by going step by step from large scales to smaller scales it is hard to make clear statements. With the help of an example, we present a method that starts from the local scale on that impacts and adaptation strategies are relevant.

Due to climate change water levels during storm surge events along the North Sea coasts could reach higher levels than today. Adaptation strategies will be needed to protect the densely populated areas along the coast of the German Bight and the banks of the estuaries. In a first step we carry out a sensitivity study to identify areas that are vulnerable in case of future storm surges. Using hydrodynamic numerical models we perform different simulations varying external parameters such as mean sea level, changes in freshwater discharge and changes of the local wind field. In a second step we investigate the efficacy of different adaptation measures by repeating selected simulations of the sensitivity study. This time, however, adaptation measures are included in the model simulations. Although it is still impossible to exactly predict how high water levels will be in future, the sensitivity study presents a way of dealing with uncertainties in an efficient way. By using the same numerical model to investigate impacts and adaptation strategies we are able to directly evaluate adaptation measures.

Index Terms—estuary, hydrodynamic numerical model, sensitivity study, uncertainty range

1 Introduction

Due to increasing atmospheric greenhouse gas concentrations global climate is changing. Even if greenhouse gas concentrations would be kept constant from today on climate change could not be prevented (Meehl et al., 2007). Impacts of climate change will affect current and future generations. Whereas climate change involves processes on global scale, impacts of climate change need to be assessed for continents, countries, states, communities, and people on regional or local scale. Thus research on impacts and adaptation strategies has to deal with processes across several scales. One way of dealing with the different scales is to downscale the global climate projections step by step onto the appropriate regional or local scale. Using this approach global climate projections, that simulate climate up to the year 2100, are transferred to smaller scales using regionalisation methods and impact models. The idea is that at the end of this cascading process the results tell us how climate change will affect, for example, water levels in a local river. On the basis of this knowledge vulnerabilities can be identified and appropriate adaptation strategies can be developed. In practice this approach involves some drawbacks. It is very complex and produces results with large ranges of uncertainties (Carter et al. 2007, Wilby and Dessai 2010). By going step by step from large scales to small scales uncertainty ranges expand more and more. We need a way to investigate climate change impacts on local scale and potential adaptation strategies without getting lost in big ranges of uncertainties.

If we are primarily interested in identifying vulnerabilities and developing adaptation strategies on a local level, it could be better and more straightforward to start from the local scale on that the adaptation problem arises (e.g., done in the Thames Estuary 2100 project, Reeder and Ranger). In this paper we want to present a way how to tackle the problem by starting from the local scale. The presented method combines the investigation of climate change impacts and the development of adaptation strategies in a direct way. We explain the method with the help of an example. In the example we focus on climate change impacts on the coasts of the North Sea. In particular we look at the German estuaries of Elbe, Weser and Ems during storm surge events. The main objective is to develop adaptation strategies and learn about their advantages and disadvantages.

2 Estuaries during storm surge and climate change

Due to climate change global mean sea level and with it mean water level in the North Sea will rise. In combination with extreme wind conditions this increase in mean water level can lead to higher water levels during storm surge than today. Higher wind speeds or future extreme precipitation events in the catchment areas causing high river discharge could further increase the risk of high water levels. Although the exact changes in sea level, river discharge and local wind field are not known several basic questions arise. How far will the effects of sea level rise reach into the estuary during storm surge? Is it feasible just to add sea level rise to high water levels? How does sea level rise influence tidal dynamics? How far will the effect of high river discharge reach in downstream direction, when sea level rises?

Adaptation strategies will be needed to protect the densely populated areas along the coast of the German Bight and the banks of the estuaries against higher water levels. Besides raising the dike level adaptation measures such as a storm surge barrier or structures narrowing the mouth of the estuary are imaginable. For the evaluation of such measures it is important to learn about basic hydrodynamic processes involved and their advantages and disadvantages.

3 The method and some results

Instead of downscaling the climate projections of the global climate models by using a row of numerical models, we start from the local scale on which adaptation strategies need to be developed. A schematic diagram of the used method is shown in Fig. 1. In a first step we identify the main drivers of the local system that are presumably affected by climate change. The main drivers are the most important external parameters forcing the processes on local scale. In our example the main drivers are sea level at the mouth of the estuaries, river discharge entering the estuary from the landward side and the local wind field.

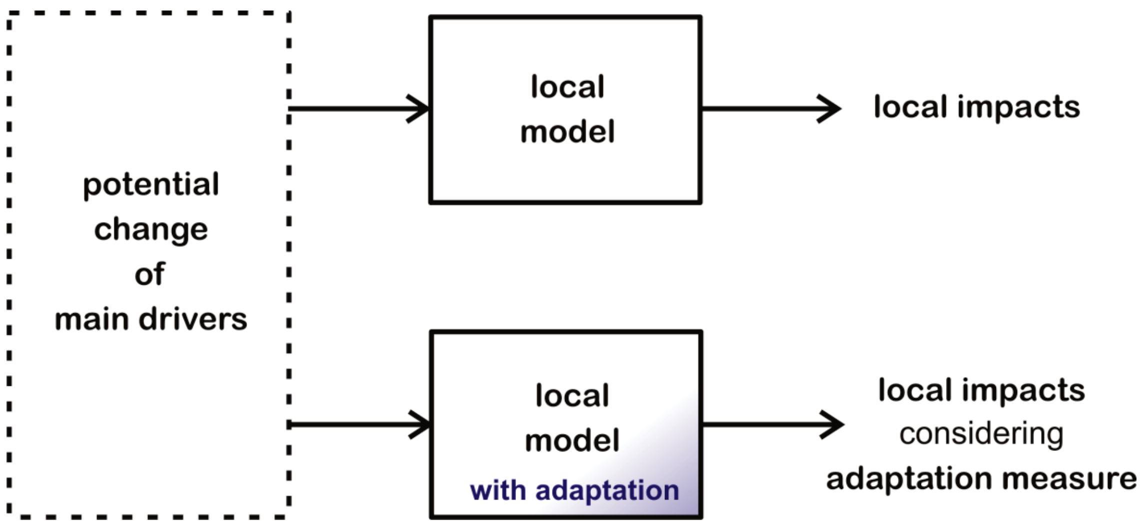

Fig. 1 Schematic diagram of the used method

In the next step we directly apply a detailed model of the local system. Using the local model we carry out a sensitivity study to learn about potential climate change impacts on local scale. Within this sensitivity study we vary the main drivers in the range of possible values expected in future climate. Here we have the chance to expand the range of variation to also allow for extreme values. It is possible to explore parameter space comprehensively and reveal critical thresholds.

For all numerical simulations described within our example we use the hydrodynamic numerical model UnTRIM (Casulli and Walters, 2000). This semi-implicit finite difference model solves the three-dimensional shallow water equations on an unstructured grid. For each estuary we have an individually calibrated model. We perform different simulations increasing mean sea level, river discharge and intensity of the local wind field. The analysis of these simulations provides evidence how the system could respond to changes in climate (Rudolph et al., 2012). Generally, we find an increase of high water levels. High water levels occur earlier. Water levels above a certain threshold last longer (see Fig. 2 for an example). The influence of sea level rise on high water levels reaches far inside the estuaries Elbe and Weser (Fig. 3). In the Ems estuary the storm surge barrier near Gandersum protects the area upstream of the barrier. High water levels at the upper end of the estuaries are dominated by the amount of river discharge. The influence of river discharge on high water levels vanishes in downstream direction (not shown).

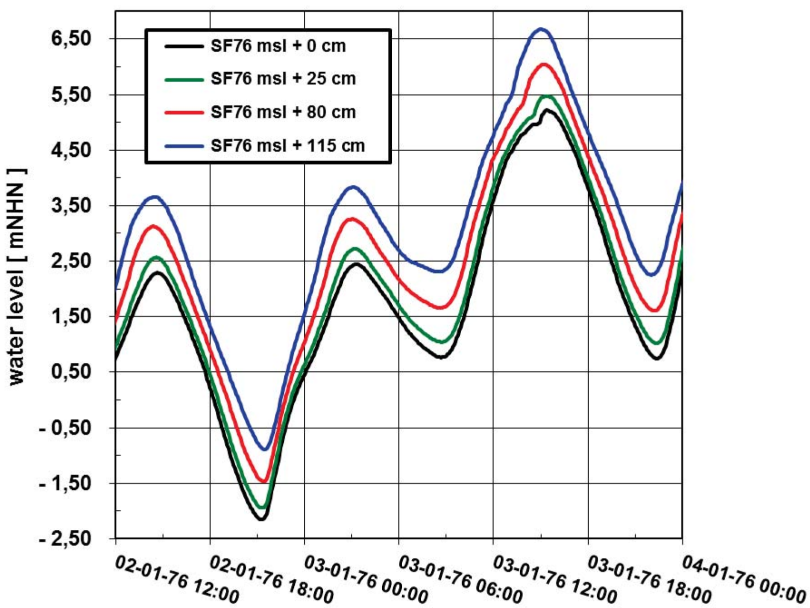

Fig. 2: Time series of water level at one point (near Brake) in the Weser estuary, Shown are results from simulations of a storm surge event in January 1976 with and without mean sea level (msl) rise.

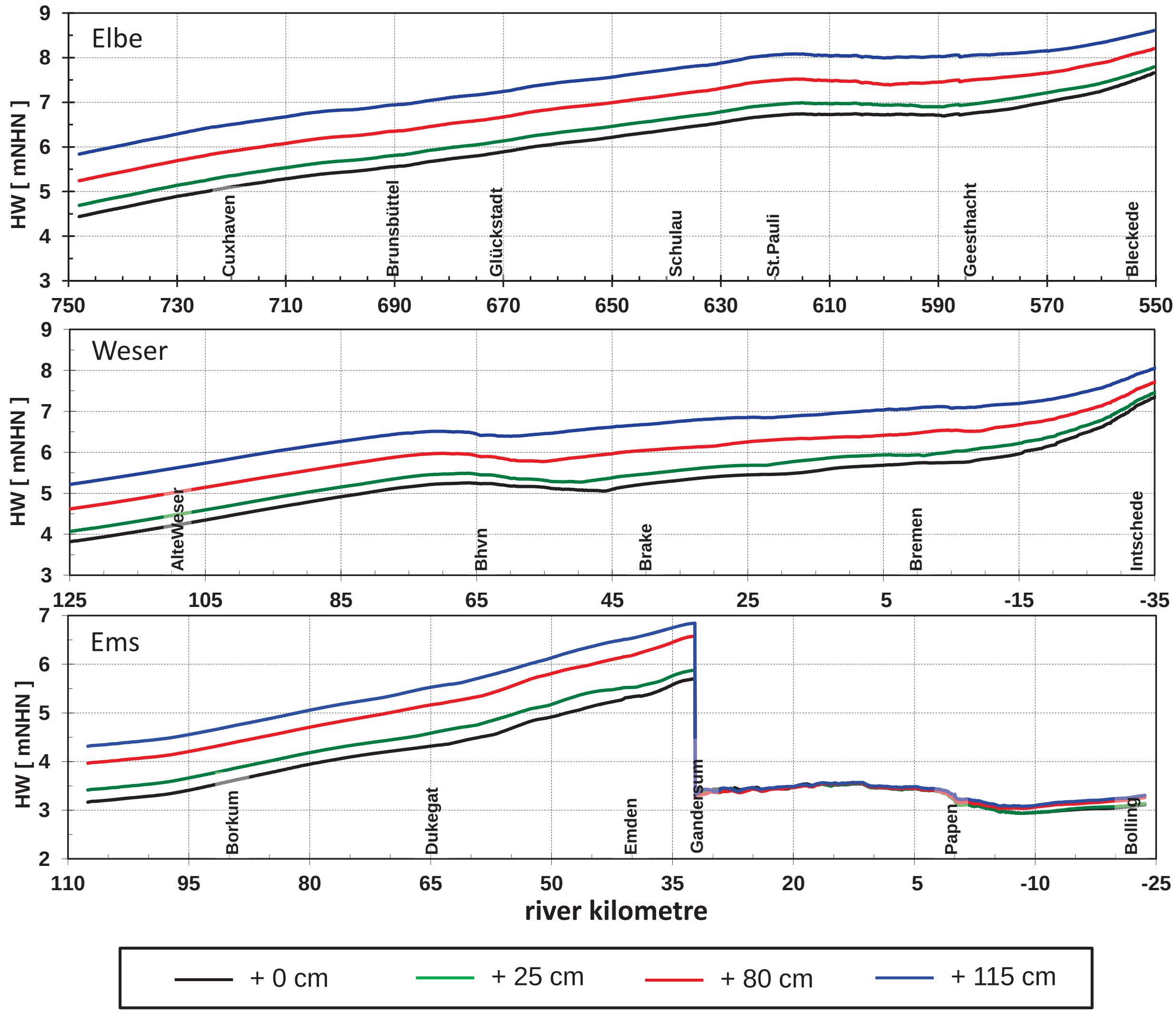

Fig. 3: High water levels (HW) along each estuary for simulations of a storm surge event with and without sea level rise

The sensitivity study helps to understand basic processes of the local system and reveals potential vulnerabilities. In the next step we develop ideas for adaptation measures and investigate their efficacy. We repeat selected simulations of the sensitivity study. This time adaptation measures are included in the local model.

Similar to the storm surge barrier in the Ems estuary a storm surge barrier in the Weser estuary could be an option. We carry out simulations with a storm surge barrier south of Bremerhaven (Bhvn) without sea level rise and with a sea level rise of 80 cm. The barrier would effectively reduce high water levels upstream of the barrier (Fig. 4). Downstream of the storm surge barrier enhanced high water levels can occur. These increased high water levels are partly due to a deformation of the tidal curve and partly caused by a surge wave. The surge wave is triggered when the barrier is closed during flood current. For a comprehensive analysis of the storm surge barrier more simulations than mentioned here are needed (e.g. with different sea level rises, different closure procedures, different locations of the barrier). The presented results serve primarily for the demonstration of the used method. Note that other aspects apart from the hydrodynamic efficacy (e.g. socio-economic aspects) will also be relevant in the decision process.

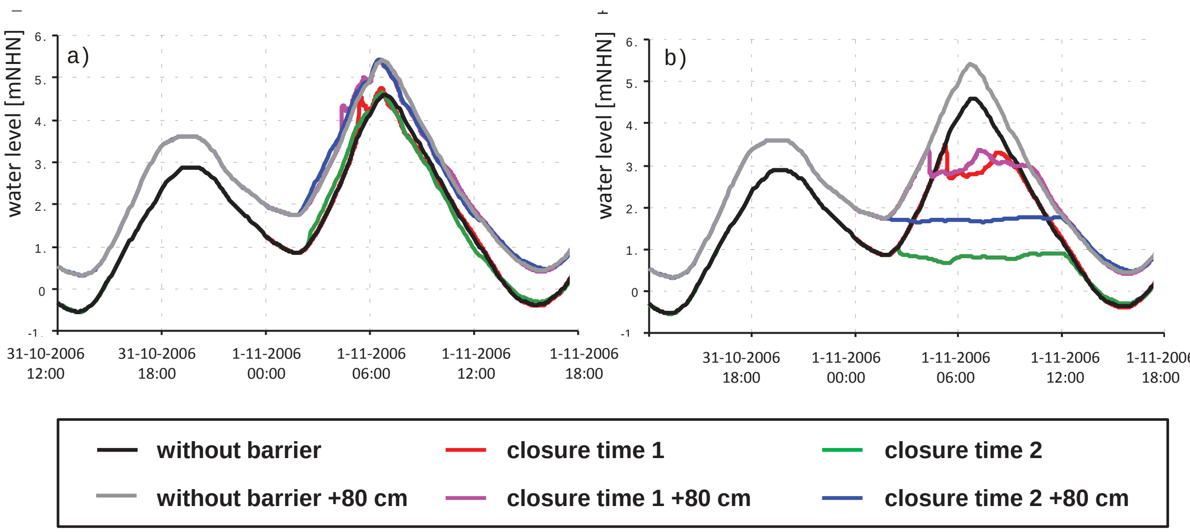

Fig. 4: Time series of water level with and without storm surge barrier and sea level rise a) downstream of barrier, b) upstream of barrier

Another adaptation strategy could be to narrow the mouth of the estuary. The narrowing damps the incoming storm surge. We investigate structures differently located in the mouth of the Elbe estuary. The structures located more in the interior of the estuary narrow the flow cross section more effectively than the structures located further in seaward direction. The more the structure is narrowing the cross section, the more high water levels are reduced. These results present a basis for further development and optimisation of such adaptation measures.

4 Discussion and conclusions

In this paper, we have presented a method for investigating climate change impacts and developing adaptation strategies on local scale. It directly combines a sensitivity study and the testing of adaptation strategies. The sensitivity study provides an easy way to study local processes responsible for climate change impacts. Nevertheless, it has some drawbacks. If the simulations carried out within the sensitivity study are limited to short periods of time or single events, as in our example, it is not possible to make specific statements on future statistics. With the aid of the sensitivity study we are not able to, e.g., provide numbers on future probability of extreme high water levels in the estuary. Another aspect to keep in mind is that the sensitivity study takes no feedback processes between local and global scales into account. For example, if the local hydrodynamic processes within the estuary had an effect on sea level in the North Atlantic Ocean, we would not be allowed to study local impacts in the described way.

Generally, it is difficult to make clear statements about future climate in 50 or 100 years. Specific statements on local impacts and suitable adaptation strategies are even more challenging. However, it is not a good option to wait and see until maybe in a few years uncertainties associated with climate projections reduce. Very likely this will not happen. The method presented in this paper enables us to learn about basic processes connected with climate change. We can easily test several adaptation strategies and learn about their advantages and disadvantages. It presents a way to deal with uncertainties in an efficient way. The results are no prediction, but they are clear if-then statements. In the case that climate research provides updated climate projections, the if-then statements will still be valuable. This kind of method is well suited to test different scenarios (e.g., different increases of sea level) and determine the appropriate adaptation strategy for each scenario.

5 Acknowledgments

This work has been carried out within the research programme KLIWAS 'Impact of climate change on waterways and navigation' and KLIMZUG-Nord 'Regional strategies concerning climate changes in the metropolitan area of Hamburg'. We thank Annkathrin Schüßler, Anika Johannsen, Ayla Johanna Bockelmann and all co-workers of the KLIWAS/KLIMZUG-Nord team at the Federal Waterways Engineering and Research Institute in Hamburg for their support and carrying out some of the simulations. KLIWAS is financed by the German Federal Ministry of Transport, Building and Urban Development; KLIMZUG-Nord is supported by the German Federal Ministry of Education and Research, the city of Hamburg and the metropolitan area of Hamburg.

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Uncertain impact if “forest and adaptation” is not taken in consideration in the Congo Basin

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Abstract-Several interventions targeting forest management had been initiated in the Congo Basin in the perspective of conserving and use sustainably forest resources. During the last 2 decades, biodiversity conservation had been at the center of these initiatives with impacts mediated by several Global/regional/national socio-economic and institutional factors. This had been mainly in line with the objectives of the CBD (Convention on Biological Diversity). With UNFCCC (United Nations Framework Convention on Climate Change) becoming important in the international arena, REDD+ (Reduced Emissions from Deforestation and Forest Degradation and conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) had become a priority in the countries of the region with the perspective of saving forest biodiversity. Those forest resources targeted in REDD+ are also sensible to climate and thus vulnerable to climate change. What is missing on forest and climate change debate and/or actions in the region is the impact of climate change on forests and implication on communities that depend on these natural resources. The current paper summarizes some of the activities within “Congo Basin Forest and Climate Change Adaptation” (Cofcca, http://www.cifor.org/cofcca/home.html), a first project on forest and adaptation in Central Africa. The forest related sectors (Food Security, Water, Energy, Health) identified during the science policy dialogue in the region as most vulnerable to climate change underlies the linkage between forest and development. Because of the multiplicity of sectors only a pluri-disciplinary and multi-institutional approach can help in addressing the climate change impact in the sustainable manner. The place of forest resources in the region is so important that ignoring it in the adaptation to climate change policy and research may lead to an uncertain future for natural resources and communities.

Index Terms-Forest, Congo Basin, climate change, Mitigation, Adaptation to climate change, forest communities.

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1. Forest and rural livelihood

In the Congo Basin, the importance of forests for rural livelihood is certain. For instance, forest foods contribute significantly to the diet of many rural and urban households (e.g., Debroux et al. 2007, Ndoye and Tieguhong 2004). During periods of crop failures especially in agricultural communities, forest foods are most extensively used to help meet dietary shortfalls. In the Congo Basin, forest ecosystem services provide security portfolios for over 80% of the predominantly rural communities contributing to poverty alleviation and national development (Sonwa et al. 2012, Bele et al. 2011, Nkem et al. 2007). Thus, life would be virtually impossible for most of the peoples living in rural areas in the Congo Basin without the availability of forests. They use wild plants to meet some of their health and nutritional needs. Commodity items inevitably become too costly or even unavailable in remote rural areas, so that people are heavily dependent on the forest products. The extraction, processing, and trading of non-timber forest products (NTFPs) is often the only employment available for the population in remote rural areas. However, nearly all the livelihood activities are seasonal and climate sensitive. If several studies had been made to understand the linkage of socio-economic dynamics on forest, this had not been always the case with climate.

2. Exposition to climate change and impact

Although climate-change projections for Africa are highly variable, the average increase in temperature on the continent is likely to be higher than the average increase globally (IUFRO 2010). In the Congo Basin, mean temperature is projected to substantially increase in the future independent of the scenario, with a stronger increase under the high emission scenario. While number of cold days and nights are projected to decrease, number of hot days and nights are projected to increase. A very moderate change in total precipitation is projected to occur in the future. In addition, temporal distribution of rains is likely to be less uniform in the future (GIZ Fact Sheet 2012). All this will have a significant risk that the adaptive capacity of many African forest ecosystems to provide vital goods and services will be exceeded.

Recent science-policy dialogue during the Cofcca project implementation revealed that in the Congo Basin, sectors such as food security, energy, health and water closely link with forest are the more sensible to climate change/variability (Sonwa et al. 2012). Rainfall negatively affects hydropower leading to more pressure on forest for fuel wood. Modifications of rainfall and temperature also have serious impact on agricultural sector. For instance, in Cameroon, statistics show that rainfall has already decreased by over 2% per decade since 1960 (Molua and Lambi 2007). Crop yields have been poor; in particular the cash crop has been affected by unsteady rains. Climatic impacts on food productions and its costs are projected to be exacerbated in Cameroon and beyond the Central African sub-region. Current climate variation is already altering the types, frequencies, and intensities of crop and livestock pests and diseases, the availability and timing of irrigation water supplies, and the severity of soil erosion. Several tropical pathology such as Malaria, cholera, etc. are closely linked with season and see their peak with events such as extreme drying/rainfall season.

The impacts of climate change on humans will be certain and in places drastic. People in some areas may benefit from climate change but the great majority will struggle to cope with its effects. Adaptation strategies in these sectors (food security, energy, health and water) closely linked to the development, need to take in consideration forest management.

3. Current response to climate change

Studies carried out within the framework of the Cofcca project (http://www.cifor.org/cofcca/home.html) revealed, among others, that the importance of forests is overlooked in national development processes such as policy dialogues on climate change and poverty reduction strategies (Bele et al. 2011). The lack of coordination at the regional and local levels in responding to climate change leads to the weakness of response to climate change (Brown et al. 2010). Several countries of the region may fall under what is named as “fragile states” (See Debroux et al. 2007 for the forest institutional sectors in DRC) in which institutions are not resilient enough to help respond to climate chock. Climate change is an additional burden to conflict and post conflict context in some Congo Basin countries. The international community and stakeholders in the region put a lot of emphasis on REDD+ with the perspective of protecting forest biodiversity habitat of the Congo Basin (Somorin et al. 2012). Some NAPA (National Adaptation Program) had been developed without necessarily taking in consideration forest resources. Some research initiatives such as Cofcca & COBAM (lead by CIFOR), Scenarii changement climatique (lead by GIZ) had been initiated. Adaptation responses in general and oriented toward forest are still at the early stage. During the cofcca project in DRC, Central Africa Republic (RCA) and Cameroon, efforts had been mainly put on modeling of future climate, identification of communities vulnerability related to forest, understanding of policy and institutional context, capacity building, , initiation of pilot project activities on adaptation in forest landscape, etc…

4. Uncertainty in the nearest future

Forest and rural communities are not out of climate change/variation (Bele et al. 2010). Livelihood of the forest communities been associated with season, climate perturbation will lead to perturbation of forest communities. Several countries of the region want to become emergent in one/two decades. Many of the development activities are linked to climate and it will thus be difficult to reach their goal if adaptation is not taken in consideration. Biodiversity conservation also depends on season and it is evident that climate change will lead to modification of forest habitat and increase/decrease of some taxa. The impact seeking in REDD+ is rendered uncertain if we are not sure of the resilience of natural/planted forest. This lead CIFOR to initiate the COBAM project (www.cifor.org/cobam) to explore the synergy between adaptation and mitigation in biodiversity landscapes in the Congo Basin.

Without adaptation the effort in CBD (Biodiversity), UNFCCC (REDD+) and Millennium Development Goals (Rural livelihood), will be at risk in the Congo Basin (http://blog.cifor.org/13523/trouble-ahead-if-forests-and-adaptation-are-not-considered-in-the-post-rio20-era/). Effort for the future need to continue what are already started within Cofcca project, and also taking the rural forest area as a complex landscape in which forest is only one issue. This thus underlines the need of a holistic approach when looking for solution to climate change in the forest landscape of Central Africa.

5. Conclusion and way forward

The Congo Basin which is known already for his role in biodiversity conservation is expecting to play a role in climate mitigation through REDD+ by providing some funds to support livelihood of forest rural communities. Unfortunately this may be impossible if adaptation to climate change is not taken into consideration. The livelihoods of the rural poor are highly dependent on climate-sensitive resources. These same livelihood resources contribute a significant proportion of the Gross Domestic Product of the country, making national development also susceptible to climate change uncertainties. Therefore, considering the vulnerability of forests to climate change and given their vital role in the household livelihood and food security in the Congo Basin countries, climate change and climate variability measures have to be taken seriously and for adaptation strategies need to be integrated into project development planning. In addition, forestry activities should be used to reduce vulnerability and variability of both natural and social systems.

Acknowledgement.

This study was conducted within Cofcca (Congo Basin Forest and Climate Change Adaptation) of the ACCA (Adaptation to Climate Change in Africa) program funded by the International Development Research Centre (IDRC) and Department for International Development (DFID).

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http://www.cifor.org/cofcca/publications/articles.html)

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A safety-critical systems approach to analysing, managing and explaining climate change and other complex socio-ecological problems

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Revised version 3.1

Submitted to the

Impacts World 2013 International Conference on Climate Change Effects

Potsdam, Germany   May 27-30, 2013

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Abstract

Massive socio-ecological problems like climate change are difficult to model because they involve multiple interacting systems with complex, non-linear dynamics. The resulting scientific uncertainty confuses public discourse and delays mitigation. We urgently need both better models and clearer ways of explaining the global environmental emergency.

Many diverse arenas (e.g. medicine, energy, aerospace and defence) have developed systems-based methodologies for assessing risks and managing critical, complex projects ranging from emergency surgery to space stations. For example, aerospace design starts with establishing critical parameters for safe operation. The "Safety Case" determines design requirements. "Mission Assurance" methodologies are then used to build, operate and maintain vehicles to standards that ensure that essential human and mechanical systems always function within wide safety margins. Similar proactive risk management methods can be applied to critical socio-ecological problems.

The first step is to define the critical biophysical and social parameters of a sustainable global system. We can then assess major environmental, economic and social trends in terms of whether they support or threaten systemic viability. This will indicate if essential parameters will be breached and determine the likely timelines and impacts of these tipping points. Multiple trends and their relative strengths can then be modelled using a combination of causal-loop diagrams, stock and flow diagrams and Bayesian networks.

Safety-critical, whole-systems modelling will improve our understanding of the implications of cross-sectoral interactions, including the probability and consequences of disruptive, non-linear events. It will also improve our ability to design interventions capable of improving systemic resilience and preventing catastrophic failures.

This approach reframes climate change as a security issue. It focuses attention on managing dangerous risks and ensuring a safe future. While it will not eliminate all uncertainties, it will help clarify risks, timelines, costs and options, and assist policy-makers in understanding and explaining both dangers and opportunities.

Keywords: safety, critical, risk, complex systems, non-linear, parameters, climate change, tipping points, viability, socio-ecological, proactive, security, causal-loop diagrams, Bayesian networks.

The need for a new approach

The problem

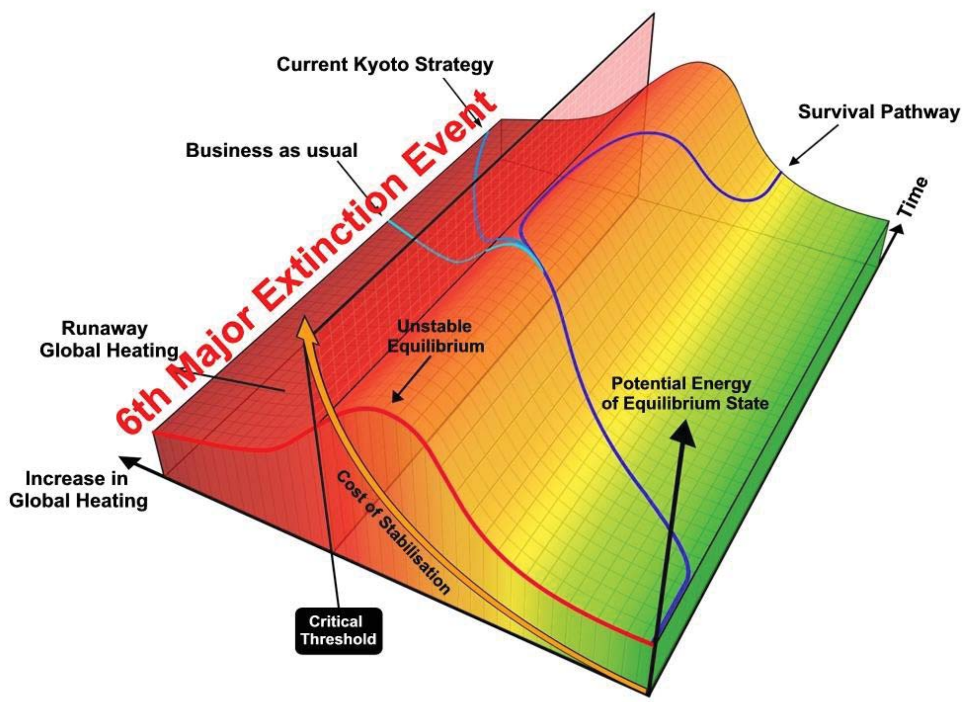
UN Secretary-General Ban-Ki Moon warns about "the gathering threat of climate change":

> Scientists have long sounded the alarm. Top-ranking military commanders and security experts have now joined the chorus. Yet the political class seems far behind.... Too many leaders seem content to keep climate change at arm's length, and in its policy silo. Too few grasp the need to bring the threat to the centre of global security, economic and financial management (Moon 2013).

Adaptation, although necessary, will not prevent dangerous climate change (Ackerman & Stanton 2013). We risk passing irreversible tipping points, such as the release of methane from permafrost (Schuur & Abbott 2011) and ocean acidification (Hönisch 2012).

With mitigation options rapidly shrinking (Stocker 2013), international intervention is urgently needed. However, the political will to act is missing.

Fig. 1 (Wasdell 2006). An illustration of the dynamics and risks of non-linear climate change.



The need to aim for a safe climate

Despite many high-profile international conferences and the warnings of peak international organizations (Richardson 2012), concern about environmental issues is lower than 20 years ago (GlobeScan 2013).

Why?

Doug Miller, chairman of GlobeScan, says "Evidence of environmental damage is stronger than ever, but our data shows that economic crisis and a lack of political leadership mean that the public are starting to tune out" (Masters 2013).

Many studies have been done on the economic, institutional and cultural factors blocking constructive intervention (e.g. Figueres & Ivanova 2002, Jinnah et al. 2009, CRED 2009, Goldenberg 2013). But is systemic resistance enough to explain why decades of work by thousands of scientists have failed to alter the current trajectory of climate change? Kevin Anderson and Alice Bows suggest that most policy-makers are not advancing realistic solutions:

> [W]hile the rhetoric of policy is to reduce emissions in line with avoiding dangerous climate change, most policy advice is to accept a high probability of extremely dangerous climate change rather than propose radical and immediate emission reductions (Anderson & Bows 2011, p. 40).

It should be obvious that we will never achieve a safe climate unless we make safe, viable outcomes our goal and priority.

Using a safety-critical approach

Managing risk

Climate change is not only humanity's "greatest market failure" (Benjamin 2007), but also our greatest failure in risk management. Although sophisticated tools for evaluating and managing risk are used in many arenas (e.g. aviation, insurance, finance, health, project development), we are not applying the same methods and standards to humanity's biggest risks—the potentially catastrophic threats posed by climate change (FAO 2011) and other major socio-ecological problems (such as the loss of biodiversity and growing resource shortages).

Large global problems are frequently viewed as too complex to allow risk to be accurately evaluated, let alone managed. However, Nick Mabey and his colleagues argue:

> Public policy decisions (ranging from military procurement, to interest rates, to financial system regulation) are taken under higher levels of uncertainty than exists over climate change science, impacts or policy choices. In fact the range of uncertainty in climate change is generally smaller than that common in long-term security analysis (Mabey et al. 2011).

The enormous cost of mitigation is also seen to be a barrier to managing climate change risk. This view is countered by Frank Ackerman and Elizabeth Stanton:

> Protection against threats of incalculable magnitude – such as military defense of a nation's borders, or airport screening to keep terrorists off of planes – is rarely described as "too expensive." The conclusion that climate policy is too expensive thus implies that it is an option we can do without, rather than a response to an existential threat to our way of life. (Ackerman & Stanton 2013)

Political priorities can rapidly shift when leaders believe that there is a threat to national security. Whole economies can be mobilised to meet emergencies, as occurred in the Second World War, when many nations allocated 40%-75% of their GDP to military production. Following the '911' attack on the United States, and the global financial crisis of 2008, politicians quickly overcame normal budgetary constraints, allowing trillions of dollars of new funds to be accessed.

Most decision-makers are unlikely to take urgent action on climate change unless it is framed as a security threat (i.e. reframed from being a primarily environmental issue). This will require a change of approach from reducing risks and damages and maximising adaptation (e.g. US Department of Homeland Security 2012) to ensuring viability.

To do this policy advisors will have to focus on risk assessment and management: identifying both dangerous threats and the requirements for safe outcomes.

Fortunately, proven tools for managing risk already exist.

Ensuring safe outcomes

Fields such as aerospace, medicine, business, energy and defence have sophisticated, proven methods for analysing complex problems, managing risk and ensuring safe outcomes (e.g. Bowen & Stavridou 1993, Fowler 2004, U.S. Department of Defence 1993). Many of these "best practices" can be usefully applied to managing complex socio-ecological issues where viable outcomes are essential.

For example, when designing or modifying an airplane or space vehicle, aerospace engineers begin by establishing the critical parameters for its safe operation – the "Safety Case". The Safety Case determines the design requirements. "Mission Assurance" methodologies are then used to build, operate and maintain the vehicle to standards that ensure that essential human and mechanical systems always function within wide safety margins (Alberts & Dorofee 2005).

We should take a similar safety-critical approach to designing a safe future for humanity. We need to start with a complex systems approach that establishes the critical biophysical and social parameters of a sustainable global system; then use this Safety Case to determine its design requirements; and then use Mission Assurance methods to strengthen systemic resilience (Evans & Steven 2009) and ensure that every critical element always functions within wide safety margins (Smith 2006).

Managing crises—the Apollo 13 example

The story of the 1970 Apollo 13 moon mission demonstrates how a safety-critical approach can be used to manage an emergency (NASA 2001). After an oxygen tank exploded, NASA's challenge was to devise a way to keep the astronauts alive and return them safely to Earth. Their successful crisis management approach can be summarised as:

- First determine the essential requirements for mission viability;
- Then determine critical timelines;
- Then determine available resources;
- Then design a solution that restructures available resources within the required timeframe to meet critical mission requirements.

The current global emergency is similar in nature to the Apollo 13 crisis. Spaceship Earth's life-support systems are failing and we also need to rapidly reconfigure existing resources in order to re-establish a safe, livable environment.

Unfortunately, unlike Apollo 13, Spaceship Earth does not have a proactive management team that is united around the goal of ensuring safe outcomes. Reactive, piecemeal methods based on obsolete mental models prevent us from recognizing the severity and immanence of the global emergency, let alone manage it (Taylor & Taylor 2007, Evans & Steven 2009).

Modeling for risk management

The difficulties with solving 'wicked' socio-ecological issues like climate change are not primarily biophysical, but economic and political. For this reason it is not enough to focus on quantitative targets: we also need to understand trends and system dynamics.

The challenge is to identify constructive and destructive dynamics and then intervene to shift vicious cycles to virtuous cycles. Traditional statistical modeling fails to adequately analyse risks, which are often non-linear. For this we need not only causal models but also methods for determining likelihood and consequences. This can be done by using causal loop diagrams (to explain system dynamics) in combination with stock and flow models (to quantify dynamics and determine dominant trends) (Sterman 2000; Maani & Cavana 2004). Bayesian networks can then be used to assess the probabilities of multiple non-additive interactions (Leidloff & Smith, 2010).

To avoid missing non-linear developments, it is necessary to understand cross-sectoral causal relationships. In particular, we need a better understanding of political and economic tipping points, which can rapidly shift system dynamics. (For an example of work in this area see Lagi et al 2011).

We can also develop a diagnostic approach similar to that used in medicine, where health issues are evaluated in terms of how constellations of risk factors affect systemic health. For example, blood pressure is not examined as an isolated, fixed set of data, but looked at in terms of both (a) ranges (dangerously low, low, safe, high, and dangerously high); and (b) associated risk factors (overall health, age, family history, etc.). This life-critical approach can be applied to socio-ecological issues and used to develop models and diagrams which integrate and explain multiple forces and issues in terms of critical system parameters, risks, timelines and options.

This approach should enable us to develop a diagnostic algorithm (a decision logic framework) based on criticality analysis. This will help us evaluate risks and likely failure points, identify key issues, prioritise responses, and design viable interventions. [My methodology applies diagnostic principles used in emergency medicine (e.g. Bosker et al, 1996) to the analysis of critical, complex socio-ecological issues.]

While a whole-systems approach is necessary, this does not involve modeling everything (Sterman 2000), but instead modeling only the environmental, economic and social factors essential to the understanding and management of dangerous climate change.

The first step is to define the critical biophysical and social parameters of a sustainable global system (Folke 2013, Raworth 2012). We can then use evidenced-based probabilistic methods to assess whether major trends support or threaten systemic viability. This will indicate if essential parameters will be breached and determine the likely timelines and impacts of these tipping points.

Understanding probable trends, timelines, tipping points and consequences will allow us to evaluate possible policy options and their costs and benefits; and from this determine priorities, high leverage points, intervention strategies and policies (Marten 2008). This approach focuses attention on strategic threats and what must be done to ensure a safe future. It will not eliminate all uncertainties, but it will highlight major dangers and opportunities and clarify risks.

After the critical requirements for sustainable socio-ecological outcomes have been determined, backcasting can be used to design structures and processes capable of meeting these requirements. [This approach applies standard outcomes-based architectural and engineering design methods (e.g. Smith 2006, Birkeland 2008) to the proactive management of socio-ecological problems.]

These new methods can be integrated with proven business, industrial and defence approaches—e.g. scenario simulation (Gilad 2008, Herman & Frost 2008, Schwarz 2009) to help decision makers better understand complex socio-ecological problems and design sustainable solutions.

Examples of modeling

N.B. The following diagrams are not factually accurate: they are provided solely to illustrate diagrammatic methods.

Fig. 2 illustrates causal relationships among some environmental, economic and political tipping points.

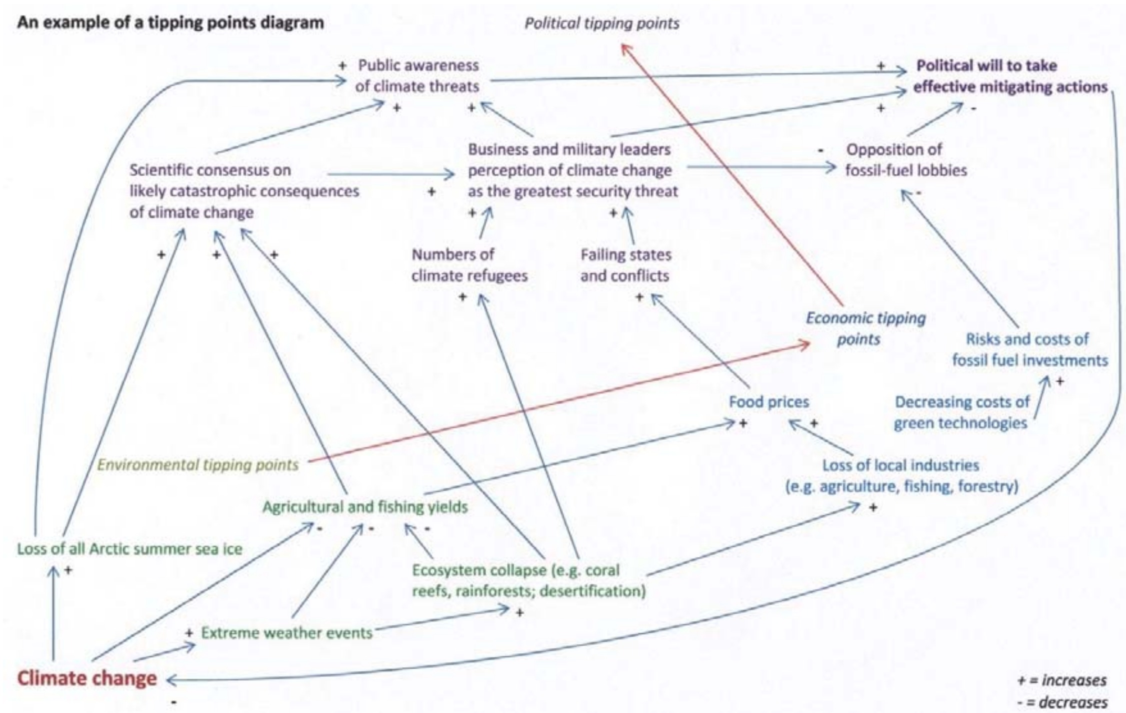


Fig. 3 illustrates a tipping point and the effect of one factor on the viability of an ecosystem.

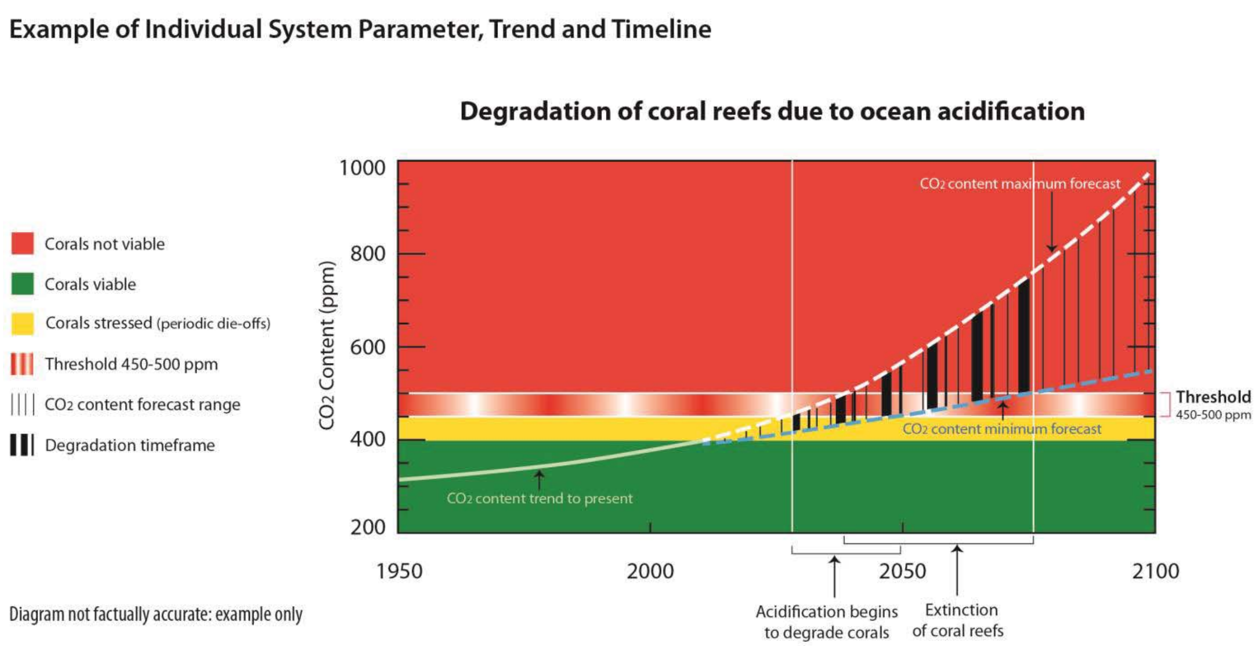
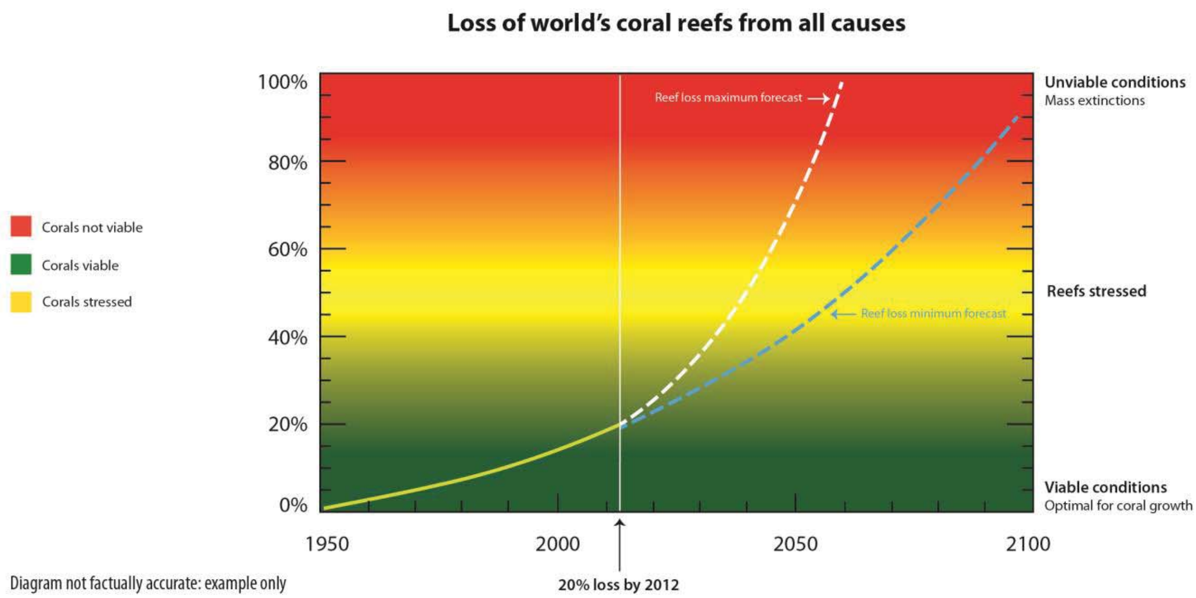


Fig. 4 shows the total impact of multiple factors on a system's viability.

Example of Multiple Factors Viability Chart



The need for a transformational narrative

Climate mitigation requires a paradigm shift in the way we produce and consume energy and other resources—the cultural, economic and technological transformation of our consumer society to a conserver society (Taylor 2008; Beddoe et al. 2009). This will not happen until people are convinced that change is both necessary and beneficial.

In particular climate change needs to be reframed in terms of superordinate goals (common needs and values) capable of bridging the current environmental/economic divide. To reduce their resistance to change, vested interests also need to be provided with constructive alternatives (Taylor 2013).

Conclusions

This approach is proactive rather than reactive. It recognizes that current methods and structures are failing to solve ’wicked’ environmental and social problems. It starts by examining what is necessary to prevent potentially catastrophic risks rather than what is presently possible (Dunne & Martin 2006). Climate change is reframed as humanity’s greatest security threat. Proven safety and mission critical methods are used to manage critical socio-ecological problems and ensure safe, viable outcomes (Sheard & Mostashari 2008, Sage & Rouse 2009).

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Towards a European assessment of health risks of climate change

Tanja Wolf, Gerardo Sanchez, Vladimir Kendrowski, James Creswick, Bettina Menne

Abstract – Health is the most important good we have. Our health is at the end of the impact chain of climate change and only in the past decade the important health risks of different facets of climate change have been taken into account. Impacts of climate change on human health are increasingly evident. Research has looked into health effects of extreme events (heat-waves, cold spells, flooding, storms), temperature related mortality, morbidity and performance as well as impacts on vector-borne and other climate sensitive infectious diseases, algae blooms, food production, allergies and more. Research has also attempted to express observed and modelled health damage in economic terms. While there is agreement that potential health benefits for some populations will be outweighed by the substantial risks for others, there is also increasing awareness of the win-win options where mitigation or adaptation measures can have significant health benefits.

The EU funded project IMPACT2C models the climate and its impacts in a 2°C warmer world, including the health effects in Europe. Using the climate models from IMPACT2C and the new SSPs, estimates of health risks will be developed. As not all relevant health impacts in Europe can be quantified and modelled this way, the assessment will be enriched by the set up of a network of scientific experts to maximise the knowledge on health effects of climate change in Europe.

At the same time, good living conditions and good health and population prosperity and growth are to some extent result of development. Considering the limits of growth and carrying capacity, sustainable development and to lead by example in the health sector are crucial to contribute to avoiding the unmanageable.

Index Terms – burden of disease, climate change, extreme weather events, green health services, health, sustainable development,

1 Introduction

Healthy and sustainable development offers an umbrella for a joint vision for the next century. This paper outlines the activities in the field of climate change and sustainable development of the WHO European Centre for Environment and Health in Bonn, which is part of WHO Regional Office for Europe. Their challenge is to bridge science and policy and can contribute to the climate policy through close links to the scientific community and its member states (in particular ministries of health and ministries of environment) as well as links to other regions. Partnerships are an important component in seeking intelligent and innovative ways of sharing knowledge and experience to be integrated into decision making.

The health sector needs to lead by example by reducing its own emissions of greenhouse gases. Health systems are in a unique position to put health concerns high in the climate change agenda, implement strategies to limit the health impacts, advocate action in other sectors to benefit health and lead by example, as highlighted in section 2.

Health could and should be a common concern and interest of many actors in climate change policy. Climate change affects population health through different pathways, with far-reaching economic and ethical implications as summarized in section 3. Health adaptation mainly consists of strengthening health systems' capacity and resilience, generally a worthwhile investment regardless of future climate changes. Furthermore, several strategies and measures to mitigate climate change can improve health at the same time and can have further benefits for the society or the environment as well (WHO 2011).

1.1. Political context and WHO

Health is a cross-cutting issue and it is crucial to integrate it into the agenda of other sectors as well as considering climate and global changes in health planning (WHO Regional Office for Europe 2008). Especially in the health sector, responses to climate change are long overdue (Menne 2005). The core functions of WHO in public health include providing leadership on global health matters, shaping the health research agenda, setting norms and standards and articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends. These core functions have been applied to the challenge of climate change and health in the European Regional Framework for Action, which sets the foundation of the work presented here.

The European Regional Framework for Action aims to protect health, promote health equity and security and provide healthy environments in a changing climate. It is designed to support action by Member States, the WHO Secretariat and other partners. Consistent with the WHO global workplan, it sets out its aim and key principles, five strategic objectives, specific actions to achieve the objectives and implementation. The five key objectives are to:

- Put health issues high in the climate change agenda;
- Strengthen their systems and services to prevent and limit the health impacts;
- Advocate mitigation and adaptation action in all sectors to benefit health;
- Lead by example reducing greenhouse emissions
- Share best practice, data and information at all levels.

2. Greening health services

As a resource-intensive sector, health care can have a significant impact on the environment through the generation of greenhouse gas emissions, pollution and waste. About 4.2% of total WHO European Region greenhouse gas emissions are produced by the health care sector. Importantly, many of the actions health care organizations can take to improve the environmental sustainability of their operations can have immediate health benefits (e.g. through active travel), significant financial and resilience benefits (e.g. through improving energy efficiency and generating onsite electricity from renewable sources) and important social benefits (e.g. through local procurement of goods and services). These benefits offer significant incentives to redesign health systems to be resilient to future changes and operate in a sustainable manner to ensure long-term provision of health care and to reduce the environmental externalities from health care, now and into the future. As a respected sector within society, the health system is well placed to lead other sectors in the transition to financial, social and environmental sustainability and move the sustainable development agenda forward (WHO Regional Office for Europe & NHS Sustainable Development Unit forthcoming).

3. Assessment of climate change related health risks

There are three main areas of current public health concern related to climate change: extreme weather events, climate-sensitive infectious diseases, and air quality, food and water security. Heat-waves, cold-spells, floods, droughts and fires are increasing in frequency, intensity and duration, endangering fundamental health determinants and increasing threats of injuries, communicable and non-communicable diseases, infrastructures damage and deterioration of mental health.

3.1 Observed and projected health effects

Air quality, food and water security are fundamental to good health. These three major determinants of human health and wellbeing are significantly altered by long-term changes of local and global climates as well as by sudden extreme weather events. Research has created evidence and improved knowledge on the observed effects and estimated future impacts of climate change on health.

Episodes of high temperature can significantly affect mortality and morbidity in the population. In the EU, mortality has been shown to increase 1-4% for each one-degree increase of temperature above a threshold. Over 70 000 excess deaths were observed in 12 European countries in the heat-wave summer of 2003 (Robine u. a. 2008). The ClimateCost project has estimated that heat related mortality under a medium to high emission (A1B) scenario, with no mitigation or adaptation, causes an additional 26000 deaths per year from heat by the 2020s (2011-2040), rising to 89 thousand per year by the 2050s (2041-2070) and 127 000 per year by the 2080s (2071-2100) (Kovats et al. 2012).

Mortality due to coastal flooding is associated with direct health impacts including fatalities. The ClimateCost study has assessed the impacts of climate change (sea level rise leading to ‘deeper’ storm surge). Climate and socio-economic change is estimated to lead to 130 deaths per year in the EU by the 2050s and 650 deaths per year in the EU by the 2080s (A1B) with two thirds of these arising in Western Europe.

Vector and rodent-borne, food and water-borne, as well as respiratory diseases are changing in temporal and geographical scale. A combination of climate change, trade and travel has made it possible for some diseases to create localized outbreaks. Projections include a further change in the distribution of vectors with localized risks of dengue and other outbreaks. Tick-borne diseases, including Lyme borreliosis and tick-borne encephalitis, are also projected to change their distribution due to climate change (EEA 2012). The estimates for Salmonellosis as temperature sensitive and important food borne illness in Europe suggest that under the A1B scenario, climate change could lead to an additional 7000 cases per year of salmonellosis in EU27 by 2020s, rising to 13000 by the 2050s and 17000 by the 2080s, if the incidence remains at current levels, however, declining levels are likely in some parts of the region (Kovats et al. 2012).

3.2 IMPACT2C

The EU funded project IMPACT2C models the climate and its impacts in a 2°C warmer world, including the health effects in Europe. Using the climate models from IMPACT2C and the new SSPs, estimates of health risks will be developed. In this context WHO is currently developing a European Assessment of health risks of climate change in the context of the EU-funded project IMPACT2C follows a series of impact assessments (cCASHh, CIRCE, CEHAPIS, PESETA, ClimateCost) and will take stock and will review current evidence on health risks of climate change globally and in Europe and add knowledge with a quantitative and qualitative assessment of health risks of climate change in Europe. Where feasible, WHO methodologies to estimate burden of disease will be applied; limits in their application will contribute to identifying research and data needs.

Although largely based on published scientific literature, the assessment will be enriched with information and data from national vulnerability assessments and adaptation strategies as well as WHO national country profiles on climate change and health. A scientific network will be set up to review the assessment and to further contribute to updating the rapidly emerging knowledge in the field of climate change and health. This will not only contribute to generation and sharing of information but includes capacity building and awareness raising activity at national levels. We warmly invite the community to participate to this process.

4. Conclusion

Revocating the mandate of WHO in the field of health and climate change and providing selected examples of WHO activities highlights that WHO is already contributing to all aspects raised in the background document to the IMPACTS WOLRD 2013 conference “Climate Impacts Research: A vision for the Next Decade”. In response to the questions raised in the background paper, some comments on the role of WHO are summarised here.

1. Taking Stock: With health impact and economic assessments WHO and others have take stock- but the time to take action has come long ago, especially in the health sector where precautionary principle invites to not wait for certainties on health risks before investing in strengthening health and resilience.

2. Time to respond: Consistent information is at hand and first steps have already been taken: An important step after the IPCC report (2007) were the World Health Assembly on Climate change and health (2008) and the European Framework (2009), which set the basis for most current activities.

3. Grand challenges ahead: Can we integrate our existing knowledge across sectors and “how certain are we”?

Health is the ultimate argument for both, individuals and societies, to take responsible and sustainable decisions- more than ever in the light of climate change. Health can integrate knowledge and action across sectors and even when uncertainties prevail, many sustainable investments in health have win-win potential for individual health and socioeconomic development of the society and the environment. To protect health from climate change is the challenge of this century- and health can be part of the key to turn the future into a green and sustainable one. The European Environment and Health process shows how cooperation of national ministries assisted by WHO can steer developments while the close cooperation of WHO’s regional offices with the global headquarter illustrate a way to bridge the divide between regional and global. Accordingly, we claim "health" to be central for the steps into the future. This understanding of the important role that the health sector can play is however still missing and the role of WHO in this should be strengthened, for example in contributing to developing health specific (regional) shared Socio-Economic Pathways.

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Topic 4:

What is still missing?

Comparing climate impacts in four large African river basins using a regional eco-hydrological model driven by five bias-corrected Earth System Models

Valentin Aich, Stefan Liersch, Shaochun Huang, Julia Tecklenburg, Tobias Vetter, Hagen Koch, Samuel Fournet, Valentina Krysanova and Fred F. Hattermann

Abstract— The river basins of the Niger, Blue Nile, Ubangi and Limpopo cover a wide spectrum of climates, topographies and ecological conditions as well as different stages of water management applied in Africa. Under consideration of these characteristics the semi-distributed eco-hydrological model SWIM was set up and adapted to the particular conditions and requirements of each basin in order to examine and compare climate change induced trends in river discharge. The individual set up of SWIM includes not only specific calibration but also adjustment of input data and adaptation of the model. Main extensions comprise water management infrastructures such as reservoirs and irrigation schemes as well as wetlands and their inundation dynamics. For the trend projection analysis the model was driven by downscaled climate projections of five Earth System Models.

The validation shows model efficiencies ranging from adequate to good, depending mainly on quality and availability of input and calibration data. Based on this comprehensive validation the trends in mean discharges, seasonality and hydrological extremes were compared. The projections agree mostly in the direction of trends; however the ranges of uncertainty for the simulations driven by different climate models are wide. Despite the strong warming a considerable probability for an increase in river discharge for means and extremes was found across all four basins.

Index Terms— Africa, river basin, regional scale, hydrological modeling, climate impact, uncertainty.

1 Introduction

Climate impact studies in Africa generally focus on specific regions depending on research interest and motivation. Each region has its individual conditions and challenges and a comparison of impacts in these different regions is not trivial. However, when trying to bridge the divide between regional and continental scale in order to coordinate and harmonize climate change adaptation, a comparison of impacts on the basin scale may reveal hotspots or commonalities of climate change challenges more profoundly than global impact models can do. On this account we set-up an eco-hydrological model for the rivers Niger, Blue Nile, Ubangi and Limpopo and compared the projected climate impacts. The analysis of common and particular sources of uncertainty shall prepare the ground for a joint interpretation of the results among the four basins. On this basis general challenges for adaptation to climate change in Africa can be identified.

2 Model and Data

All four African basins were modeled using the eco-hydrological model SWIM (Krysanova et al. 1998). This semi-distributed model is based on the models SWAT (Arnold et al. 1993) and MATSALU (Krysanova et al. 1989) and is maintained mainly by the Potsdam institute of Climate Impact research (PIK). SWIM is process-based and simulates the hydrological cycle, vegetation growth, erosion, and nutrient dynamics at the river-basin scale with a daily time step. The model is described in detail in Krysanova et al. (2000). Recent model developments that are relevant for this study include a reservoir module for integrating reservoir management (Hagen Koch et al. in press), a simple abstraction function from river reaches for irrigation and a 2-dimensional inundation module for periodically inundated areas (Liersch et al. 2012). For each African basin the model has been individually adapted and calibrated in regard of its geographical and bio-physical setting.

For all four regions a digital elevation model constructed from the Shuttle Radar Topography Missions' 90 m resolution (SRTM n.d.) was used. Soil parameters were derived from the Digital Soil Map of the World (FAO n.d.). Land use data were reclassified from the Global Land Cover (GLCF n.d.).

For the calibration of the model a climate data set produced within EU FP6 WATCH project (WATCH n.d.) was used. Observed river discharge data from the Global Runoff Data Centre were applied to calibrate and validate the model (GRD n.d.).

Climate scenarios were provided by the ISI-MIP, the Inter-Sectoral Impact Model Intercomparison Project. The scenarios were created by five Earth System Models (HadGEM2-ES, IPSL-5 CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) which have been downscaled using a trend-preserving bias-correction method with the WATCH reanalysis data and have been resampled on a 0.5°x0.5° grid (Hempel et al. 2013). "Representative Concentration Pathways" (rcp) cover different emissions and land-use change projections, and in this study the low emission rcp 2.6 and the high end scenario 8.5 were used.

3 Study sites and model set-up

3.1 Hydrology of the basins

All four rivers are characterized by a unique hydrological regime caused by a wide spectrum of climates, geographical and ecological conditions, and their role in the life of the riverine population (**Fig.1** & **Tab.1**)

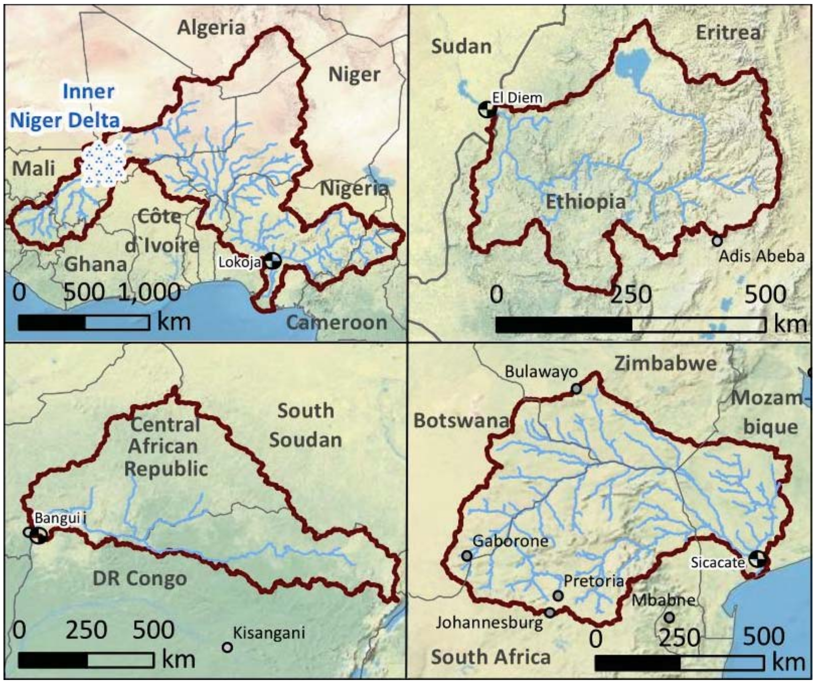

Figure 1 Map of the four modeled basins: Niger, Blue Nile, Ubangi, Limpopo (top left to bottom right).

The basin of the Niger spreads over six different agro-climatic and hydrographic regions of which each has individual drainage characteristics. Besides this heterogeneous setting the regime of the Niger is substantially influenced by the Inner Niger Delta (IND) (Ogilvie et al. 2010). The Ubangi is located in Central Africa and contributes to the Congo River. Its regime follows the regional rainy season with highest discharges from August to December (Vanden Bossche & Bernacsek 1990). For the Upper Blue Nile catchment the most important influences on the hydrological regime are the distinct topography of the Ethiopian highlands as well as the effects of the summer monsoon during the rainy season (Conway 2000). The hydrology of the Limpopo is characterized not only by a typical subtropical intra-annual but also a very distinct inter-annual variability of flow (UN-HABITAT 2007).

Table 1 Basin characteristics

	Niger	**Blue Nile**	**Ubangi**	**Limpopo**
area in km²	2.156.000	167.000	489.000	185.000
alt. range in m a.s.l.	0 – 2961	526 - 4187	341 – 2046	0 – 2326
mean temp. in °C	28	19	25	21
mean temp. warmest/ coldest month in °C	32 in May / 24 in Jan.	21 in April/ 17 in Dec.	26 in March/ 24 in Dec.	25 in Feb./ 15 in July
mean prec. in mm/ a	682	1382	1507	530
dominant land uses	cropland: 20% grassland: 18% savannah 14%	cropland: 57% savannah: 30%	forest: 50% cropland: 32%	forest: 34% cropland: 32%, savannah: 20%

3.2 Water management in the basins

The intensity of human influence on the hydrological processes differs remarkably in the four basins. The Limpopo catchment has the strongest anthropogenic factor with over 160 dams built mainly for irrigation and/or hydropower. Water resources including groundwater are heavily utilized due to the densely populated area and many irrigation schemes (UN-HABITAT 2007). This holds only partly for the other three rivers where water management yet plays a moderate role. However, the Niger and the Blue Nile still have a large potential for water management and new irrigation schemes as well as additional reservoirs are recently under construction or planned (Niger: Andersen 2005; Blue Nile: Awulachew et al. 2007). In the Ubangi basin consumption and small-scale irrigation along the river play a minor role and the influence on the discharge and the hydrological regime is slight (Vanden Bossche & Bernacsek 1990).

3.3 Model adjustment and set-up in the basins

The individual set up includes adjustment of input data and adaptation/ extension of the model. For the Niger the inundation module was integrated for modeling the IND, and five large reservoirs were simulated with the reservoir module. For the Blue Nile and the Ubangi catchments, the WATCH data set underestimates the global radiation significantly and therefore this parameter was derived using the method of Hargreaves (1982). As the SWIM vegetation module has not been adapted yet to tropical evergreen vegetation, the vegetation dynamics have not been simulated in the Ubangi catchment. Instead, the effects of vegetation on the basin's hydrology were included directly by using their statistical characteristics. In the Limpopo basin, eight reservoirs and 27 irrigation schemes have been included.

The model was calibrated for four basins using different numbers of gauges, depending on their availability. For the validation, the gauging station at the outlet of each catchment was used (Niger: Lokoja; Blue Nile: El Diem; Ubangi: Bangui, and Limpopo: Sicacate) (see Fig.1).

4 Results

4.1 Calibration and validation

For all basins the modeling strategies focused mainly on the hydrology of the basin. Discharge rates in the catchments are extremely heterogeneous ranging from about 13 mm per year in the Limpopo catchment to 270 mm per year in the Blue Nile. The SWIM model was basically able to reproduce the hydrological characteristics of each basin. However, the validation using a different time period than the calibration period shows heterogeneous results in terms of the Nash and Sutcliffe efficiency, ranging from adequate in the Ubangi basin to very good in the Niger basin (**Fig. 2**). The model for the Ubangi catchment has distinct insecurities in high and low flows but mean discharge show adequate results during the validation period. The Blue Nile shows better results with adequate representation of high and low flows and good simulation of mean discharge. For the Limpopo the validation shows a slight underestimation of high and low flows, but the total efficiency of the model is good. The model was able to reproduce high and low flows for the Niger well, and in regard of means the results are very good.

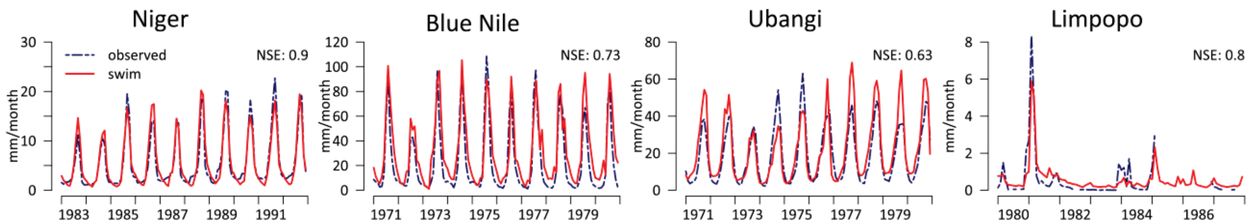

Figure 2 Validation of SWIM at the outlets of four basins. Monthly runoff rate in validation period with Nash-Sutcliffe Efficiency.

4.2 Impact on mean discharge and seasonality

For the base period the agreement between the discharge of the models driven by the inputs from WATCH and five climate models is mostly good (**Fig. 3**). For the Niger, the model outputs driven by the climate projections agree very well with the model output generated with WATCH input data during the base period (1971-2000). This holds also for the Ubangi, yet there are differences. But for the Limpopo and Blue Nile basins the results differ distinctly and especially in the Limpopo catchment only the simulation driven by climate input of one model, HadGEM2-ES, revealed results comparable to that driven by the WATCH input.

Regarding the changes in river discharge in the scenario period (2021-2050) compared to the base period (**Fig. 3**), the spread between the simulations driven by different climate models is high for all basins, ranging from strong increase to small or moderate decrease, depending on basin and climate model. Among all four basins the majority of the models show an increase in discharge, for some cases even up to 100% and higher. For the Niger, Blue Nile and Ubangi one of the climate models produces an output that differs from the other outputs, but never the same one. For the Niger, MIROC-driven results show an increase in discharge of about 100%, for the Blue Nile the IPSL model driven output has an increase of over 50% during the rainy season, and for the Limpopo the Hadley model driven simulation (which performs best during the base period), shows an increase of over 150%. In the Ubangi basin changes are rather small, all not exceeding 10%: two models show an increase during the rainy season, two models a decrease and one model almost no change. Differences between the emission pathways (rcps) until 2050 are small compared to these variations.

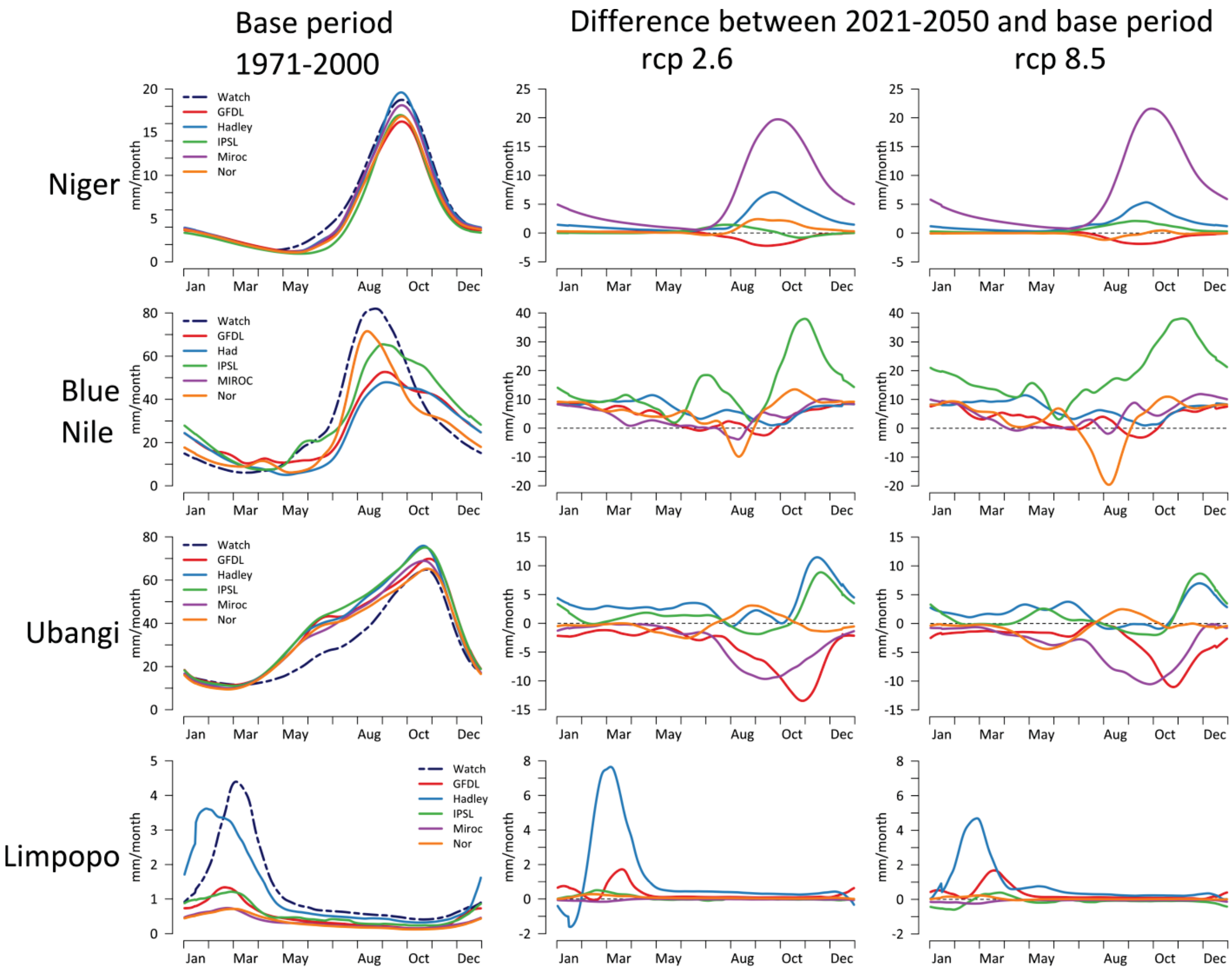

Figure 3 Left column: seasonality of monthly discharge for the reference period, middle and left column: differences in discharge between the scenario and reference periods for rcp2.6 and rcp 8.5.

4.3 Changes in extremes

The direction of changes identified for the mean discharge hold mostly also for the extremes. The Q10 value is a robust indicator for floods and designates a value which is only exceeded in 10% of the time. In the catchments of Niger, Limpopo and Blue Nile it increases for the simulations driven by the majority of the climate models (**Fig. 4**). In the Niger basin the MIROC-driven results again show the strongest increase of over 100%. Others but GDFL-driven results show a smaller increase but still of over 20%. In the Limpopo basin, GFDL and Hadley-driven simulations show a strong increase but those driven by IPSL and MIROC - a decrease. For the Blue Nile even simulations driven by all models agree in a higher Q10 value with an increase of less than 50%. In the Ubangi basin high flows are projected to stay on the same or slightly reduced level under climate change.

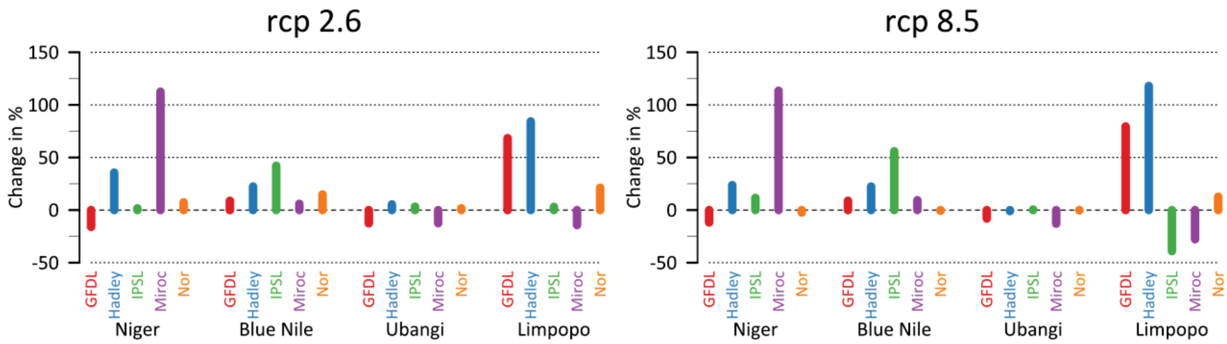

Figure 4 Change of Q10 between 2021-2050 and 1971-2000 for rcp 2.6 (left) and rcp 8.5 (right).

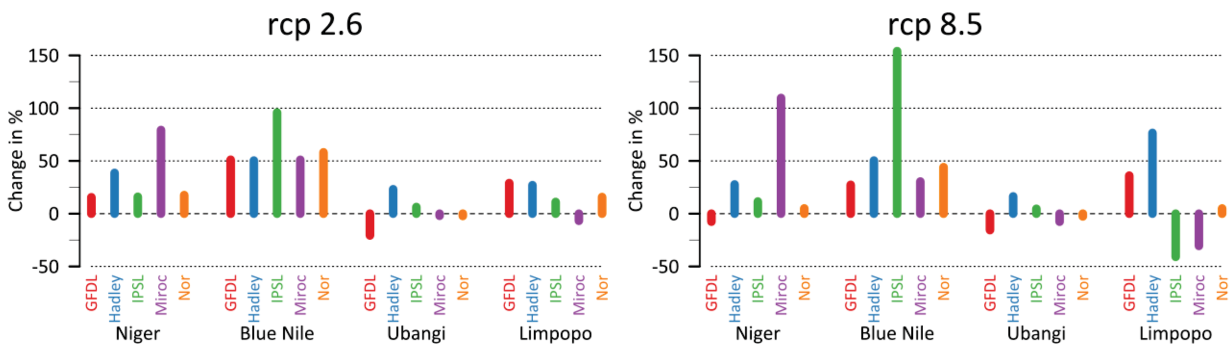

Figure 5 Change of Q90 between 2021-2050 and 1971-2000 for rcp 2.6 (left) and rcp 8.5 (right).

For identifying projections in low flows, the Q90 value was used, indicating that 90% of the time that value is exceeded. In all four basins and for almost all simulations the direction of the Q10 trends hold also for Q90 (**Fig. 5**). For the Niger, MIROC-driven output shows the level of low flows increased to over 100%, which holds for the Blue Nile for the IPSL-driven results. In the Blue Nile, the simulations driven by other climate models show also an increase of over 50%. In the Ubangi basin, low flows stay almost on the same level. The differences between the rcps until 2050 are minor, and there is no agreement whether more emissions would lead to a rise or decline of the extremes in all regions. Still most trends are stronger in the rcp 8.5 when compared to the rcp 2.6.

5 Discussion

The broad range of changes in discharge in each basin according to simulations driven by five ESMs and the associated uncertainties are striking. This holds for means as well as for extremes and makes the interpretation difficult. Noticeable is the fact that most extreme results are produced by simulations driven by different climate models. For the Niger it is MIROC, for the Limpopo basin it is Hadley and for the Blue Nile the IPSL-driven results exceed others very distinctly. Only in the Ubangi basin all projections agree in rather moderate changes in discharge.

As the performance of the SWIM model for all basins is adequate compared to the observed discharge, the share of the hydrological model in this uncertainty is probably minor. This assumption is supported by the small differences between river discharge simulated with WATCH input and with the inputs produced by climate models during the reference period. Especially in areas with very low discharge rates as in the Limpopo basin, the model is very sensitive to climate input and the requirements for reliable climate input are very high.

6 Conclusions

The study confirmed that good reproduction of the observed discharge depends strongly on availability and quality of data. The requirement on data increases with the size of a basin and more direct with its heterogeneity and complexity in terms of hydrology and water management. However, an improvement of the regional hydrological model performance will not diminish uncertainties in discharge changes under climate scenarios, as a major share of this uncertainty comes from the climate model projections. These high uncertainties are problematic to communicate to decision makers, and the needs of regional impact modeling should be communicated more intensively to climate modelers in order to better assess the main sources of uncertainty. Additionally, the efforts on the bias correction of climate projections should be stepped up as done in the ISIMIP. For communicating the differences between rcps and therewith the human influence, several runs of bias-corrected climate projections should be provided. Considering a larger set of regional climate model outputs may help to better quantify the inherent uncertainty but also to detect some robust trends.

Due to the remarkably high uncertainties in all four basins and almost all climate projections, the increasing discharges have to be interpreted with caution. Additionally, the needs and efforts on basin development and in intensification of water management in Africa are already high and growing fast. This water demand will have an impact on water availability and quality. However, the agreement of many models in the basins of the Niger, Limpopo and Blue Nile on increasing high flows agrees with observations of the past decade of an increase in flood frequency and amplitude (Di Baldassarre et al. 2010). Adaptation efforts on climate change in Africa should not neglect this thread even if water scarcity is still the main challenge in most of the African regions.

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Evaluation of the Use of SWAT for Land Use Change and Climate Change Predictions: a Multi-basin Comparison

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Abstract- The Soil and Water Assessment Tool (SWAT) has become popular tool for land use and climate change impact studies because the model is both physically based and processed-oriented, hence accounts for the various hydrological processes within a catchment. Of course, the model's prediction capability, which is crucial for impact investigations, relies on a proper representation of the distributed parameters and input data quality. One of the important changes on water resources under land use change scenarios are due to changed evapotranspiration (ET). Thus, we evaluate the SWAT ET estimates and their spatial representations by comparing with ET estimates from remote sensing techniques within three case studies. The findings from the cases considered in these studies were not conclusive. However, they highlighted the potential uses of independently derived remote sensing ET to improve hydrological models performance.

Index Terms- Evapotranspiration, Remote sensing, SWAT

1. Introduction

Evapotranspiration (ET) is on average the main hydrological component, as around 60% of precipitation leaves as ET flux over land surfaces (Brutsaert 1986). Changes in land surface characteristics due to human activities have a direct effect on hydrological processes through their link with ET processes. Of course, climatic variations are also important factors in governing ET variability in a large river basin. Therefore, during the investigations of the impacts of both climate and land use changes on hydrology using hydrological models sufficient attention should be given to this component of the water balance.

Most often distributed hydrological models are calibrated against the observed discharge time series from one or more gauging stations. Apparently, these models show reasonable skills to simulate discharges based on the calibrated parameters; however, this does not guaranty a good performance on the simulated ET (Muthuwatta et al. 2009). A River basin surface characteristics, by its very nature, varies spatially and their combination with a large number of model parameters inhabits the identification of one set of parameters describing the natural system (Immerzeel & Droogers 2008). Consequently, more than one parameter combination could provide the same result. The problem of equifinality has been widely discussed in literatures (Seibert & McDonnell 2002; Beven 2006; Immerzeel & Droogers 2008). Hence, the question if our models can represent the hydrological processes in a proper way so that they are able to do what they are aimed for remains as a key issue.

The objectives of this paper are twofold: i) to evaluate the ET estimates of physically based Soil and Water Assessment Tool (SWAT) using ET derived from remote sensing images and ii) to highlight the areas where spatially and temporally distributed remote sensing information could be used as a complementary data in distributed hydrological models using studies from different locations.

2. Methodology

The overall methodology consists of the comparison of ET estimations between a hydrological model SWAT, and surface energy balance models such as Surface Energy Balance Algorithm for Land (SEBAL)(Bastiaanssen et al. 1998) and Surface Energy Balance System (SEBS)(Su 2002). Besides, ET data from Moderate Resolution Imaging Spectroradiometer (MODIS) were used for the comparisons.

2.1 SWAT model

The SWAT (Arnold et al. 1998) is a semi-distributed physically based hydrological model that simulates flow and nutrient transport and transformations at river basin or catchment scale. To this purpose, it uses a GIS based interface that allows to use topography maps (DEM), land use maps and soil maps to create sub-basins which are further subdivided in hydrological response units (HRUs). HRUs are areas with similar land use, soil and slope classes in the sub-basin. For each HRU, hydrological, soil, crop and chemical processes are computed on a daily time step to provide the inputs into the river network. A very interesting feature of SWAT is that it enables to compute crop growth processes and land use management practices and their effects on the hydrology and water balance.

2.2 ET estimations using remote sensing surface energy balance

The surface energy balance algorithms (SEBS, Su 2002; SEBAL, Bastiaanssen et al. 1998) are used to estimate spatially and temporally distributed ET. Land surface characteristics such as albedo, vegetation indexes and surface temperature are retrieved from radiances measured by remote sensors. By coupling land surface characteristics and routinely collected meteorological data, ET is computed as a residual term by solving the surface energy balance equation.

In this study, the SEBS and SEBAL algorithms were applied to the Don and Mara basin, respectively to compute ET. The input remote sensing data were derived from Landsat 5 and MODIS images covering the Don and Mara basin, respectively. For the Don basin the reference ET was also computed based on FAO penman-Monteith method using local climatic data.

2.3 MODIS ET product

Global MODIS evapotranspiration product (MOD16A2) provides ET, hereafter MODIS ET, for vegetated surface at a regular 1 km^2 spatial resolution (http://www.ntsg.umt.edu/project/mod16). This ET product is computed based on the Penman–Monteith logic using MODIS global data (MODIS land cover and FPAR/LAI data) and global surface meteorology data from the Global Modeling and Assimilation Office (Mu et al. 2011). In this study, the SWAT model ET estimates for the Rib and Gumara catchments were evaluated using the MODIS ET.

3. Case studies and model description

3.1 Gumara and Rib (Ethiopia)

The Rib and Gumara Rivers are located on the headwaters of the Upper Blue Nile River with combined basin area of 2986 km^2 (Fig.1). The climate of the area is largely controlled by altitude and the movement of the inter-tropical convergence zone. In these catchments agriculture, which accounts for about 70 % of the catchment area, is the dominant land use/cover type followed by shrubland. Using ArcSWAT the Rib and Gumara watershed was delineated and divided into 7 sub-basin and 101 HRUs.

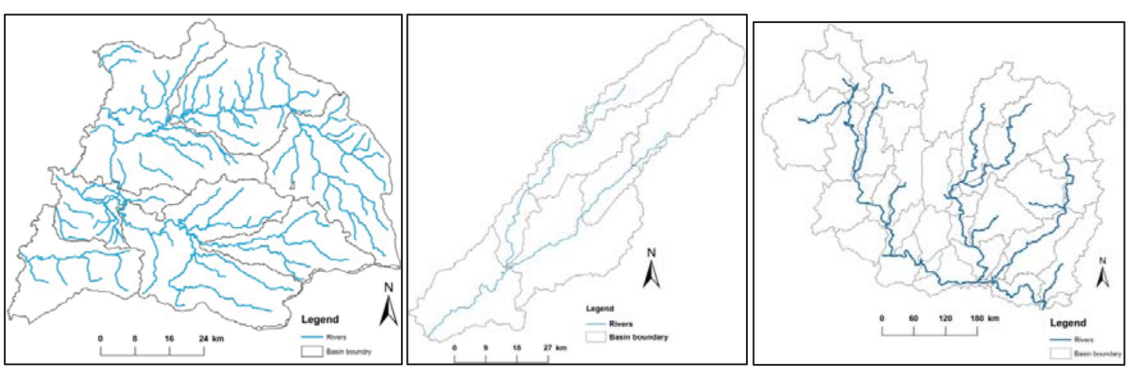


Fig.1 Map of the three case study basins: Rib-Gumara, Mara and Don (left to right)

3.2 Mara (Kenya)

The 395 km long Mara River, which discharges into the Lake Victoria and is thus part of the Nile Basin, is transboundary and drains an area of about 13,750 km^2 across the Kenya -Tanzania border (Mango et al. 2011). The Upper Mara River catchment with total area of about 3,000 km^2 forms the recharge area for the Mara River basin and our study focus on this region (Fig.1). This part of the basin is drained by two main rivers originating in the Mao forest-the Amala and the Nyangores, which merge at the midsection to form the Mara River.

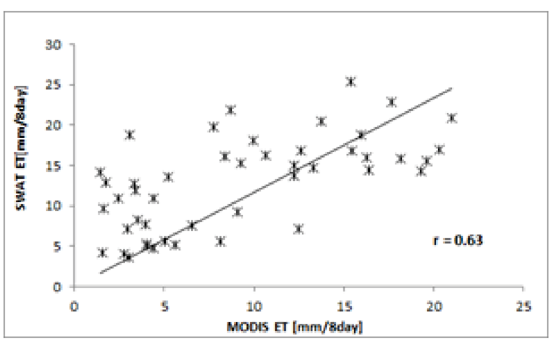
3.3 Don (Russia)

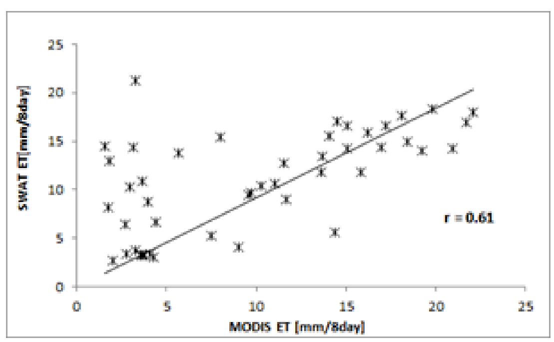
The Don River is one of the main tributaries, which brings the major part of freshwater, to the Azov Sea. The Upper Don River subcatchment encompasses more than 50% of the total Don basin area and consists mainly cultivated land and the Tsimlyansk reservoir, the largest freshwater body in the basin.

4. Results and Discussion

Spatial variability

The SWAT simulated ET variability at finer spatial resolution (i.e.HRU level) were not significant whilst the ET computed using the SEBS and SEBAL revealed higher spatial variability for the Mara, Don and Rib-Gumara basins. Fig.2 shows the fair comparisons between the SWAT simulated ET and the MODIS ET averaged over a watershed for the Rib-Gumara basin. This is attributed to the averaging effects at coarser spatial resolution. Besides, we observed further improvements on the correlation of these estimates when averaged over monthly time scale. Senay et al.(2011) mentioned also a good agreement in ET estimates from Simplified Surface Balance (SSEB) model and basin water balance approach at a basin scale due to the lumping effect.

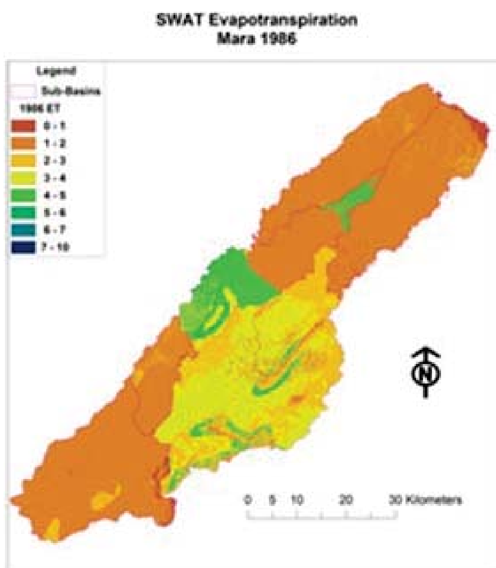


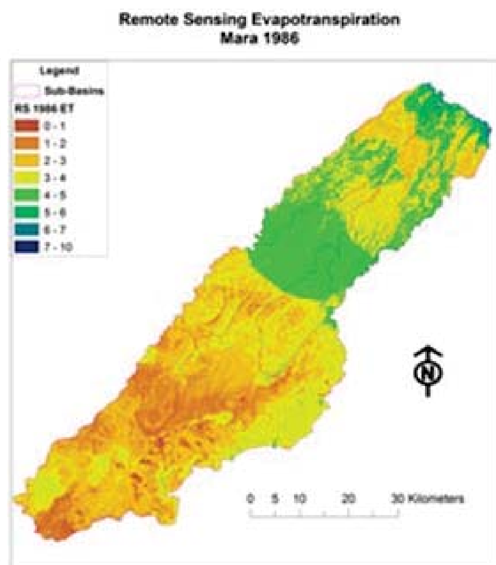


(a) (b)

Fig.2 Comparison of 8 day aggregated ET for the Rib (a) and Gumara (b) watersheds for year 2006. The solid line is 1:1 relationship.

Since agriculture is the predominant land use/cover in the Rib-Gumara basin, the simulated ET spatial variability is less from both approaches. However, for the Mara basin a clear spatial pattern were observed depending on the different land use classes (Fig.3). As it turns out from the simulations, the SWAT ET for forested areas are lower compared to other land use types which intuitively supposed to be higher. On the contrary, the SEBAL estimated ET is higher for forest land cover type compared to the other land cover types in this basin. As noted in the sensitivity analysis, land surface parameters in the SWAT model (viz. EPCO, Canmx, and Blai), which could control ET estimation in forested areas, are found to be less sensitive and thereby resulted in lower ET values.





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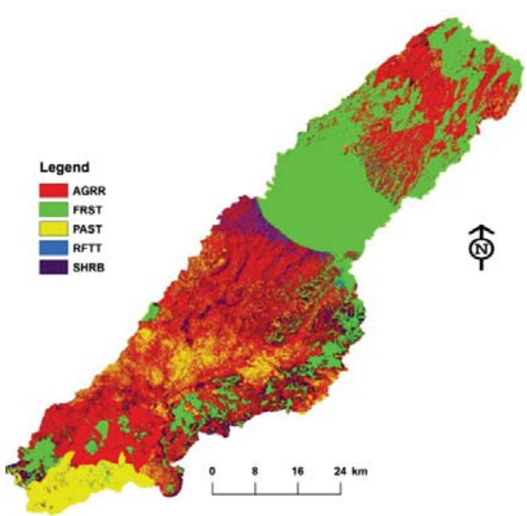
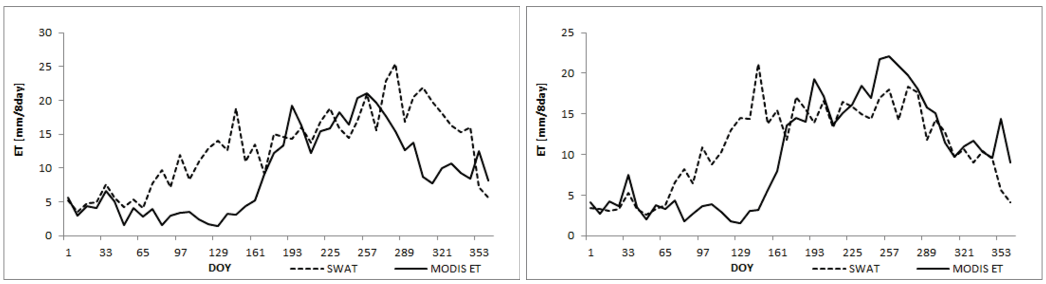


c)

Fig.3 Spatial variability of ET estimated using the SWAT (a) and the SEBAL (b) averaged over various land use /cover types (c) in the Mara basin. AGRR, FRST, PAST, RFTT and SHRB represents agriculture, forest, pasture, Tea Plantation and shrub land use/cover classes, respectively.

Time dynamics

Fig.4 presents the temporal dynamics of 8 day aggregated ET averaged over the Rib-Gumara basin. Overall, both methods captured well the seasonal ET dynamics; nevertheless, the SWAT model estimated a higher ET during March– May, 2006. One of the major factors for ET variation is the rainfall events. Thus, the observed measured rainfall events, though sporadic, at a few upstream meteorological stations located in this basin from March-May, 2006 could be one of the likely reasons for the higher ET values (compared to MODIS ET) because precipitation is one of the major forcing data for this model. Given the dominance of rainfed agriculture in these catchments, there is less crop cover (hence very low Leaf area Index) so that the MODIS ET is low regardless of the likely ET from soil following the rainfall events.



a) (b)

Fig.4 Temporal dynamics of ET averaged over the Rib (a) and Gumara (b) catchments

For the Don basin, the correspondence between the ET results obtained by the SEBS algorithm and the SWAT result is still not very good, but there seems to be a good correspondence between the SEBS and FAO-PM calculations (Fig.5).

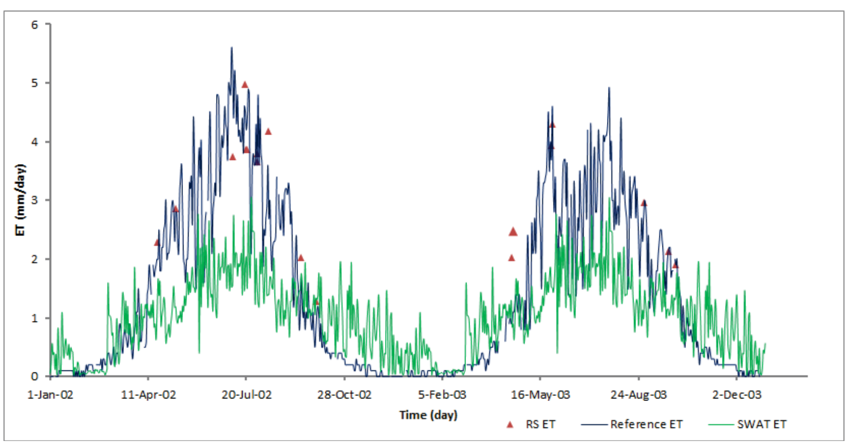


Fig.5 Temporal dynamics of ET averaged over the Don Basin

Without having in-situ measured ET, it is difficult to underpin the accuracy of ET estimates from both methods. However, the relation shown in Fig.6 could be considered as one proxy on the reasonable performance of the SWAT model to estimate ET at a coarser temporal and spatial scale. For instance, Loukas et al. (2005) shows the potential of utilizing Normalized Difference Vegetation Index (NDVI) values for the estimation of basin-wide actual evapotranspiration.

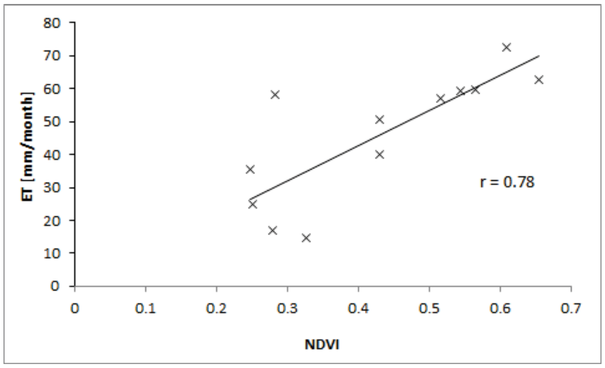


Fig.6 The relationship of monthly NDVI and ET averaged over the Rib-Gumara catchment. The solid line represents the 1:1 relation.

5. Conclusions

From the analysis it became clear that the performance of SWAT model to estimate spatially distributed ET at higher spatial resolution (i.e. HRU level) is less reliable. This is partly associated with the fact that in the SWAT models climatic input data are prepared at sub-basin level and hence results insignificant spatial variability of ET in HRUs. The ET from remote sensing approaches showed a better spatial variability and a fair consistency with the land uses /cover types.

The results showed in this paper are not conclusive; however it highlighted some of the practical shortfalls during the application of SWAT for hydrological processes modeling. Such gaps could be partly addressed by using ET retrieved from thermal images as a “soft “data. Furthermore, we noticed the benefits to consider spatially distributed ET during the application of hydrological models to evaluate of the impacts of climate and land use changes.

Potential of use of remote sensing (RS) information:

- RS can show areas with higher ET among the various land cover classes (eg. Forested areas)
- RS can help in justifying or falsifying differences in mass balance obtained from model and/or data
- Spatially consistent and distribute ET from RS can help to parameterize SWAT model together with the conventional data.

Although there are a number of potential opportunities to use remote sensing, there are still limitations on the use of RS information due to the inherent noise with the sensors as well as the ET computations.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Climate change impacts on forest ecosystem services at local and landscape scales: the challenge of creating representative regional projections

Che Elkin, Maxime Cailleret, Harald Bugmann

Abstract— Process-based vegetation models are essential tools for projecting the impacts of climate change on ecosystem functioning and ecosystem services (ES). The challenges associated with accurately projecting these impacts are accentuated in heterogeneous environments, where impacts may differ depending on the biophysical environment at a specific locale, and on its disturbance and management history. In particular, projecting if and when ecosystem thresholds will be reached under a future climate can depend on site-specific characteristics. This renders the task of linking regional with global assessment studies daunting. In a series of case study landscapes in central Europe, we examined how landscape heterogeneity influences projections of forest ES. We simulated forest dynamics using a stand-scale and a landscape-scale model. We evaluated the role that landscape heterogeneity and environmental gradients play in projecting how a range of forest ecosystem services will respond to climate change. Our simulations show that climate change will induce non-linear shifts in forests, with most forests exhibiting a threshold response around the middle of the century. However, the timing of these shifts, and their impact on forest ecosystems services, depends heavily on the topographic situation of the forest stand (elevation, aspect) and its current structure. At lower elevations our simulations indicate that many forest ES will be negatively impacted by climate change, while at higher elevations many ES will be resilient, or positively influenced, by climate change. As a consequence of these divergent results along regional elevation gradients, the projected magnitude, and sometimes direction, of climate impacts on forest ES will depend on whether the evaluation is done at a local or a regional scale. We discuss the challenges this presents for developing robust and representative regional projections of forest ES.

Index Terms— Process-based vegetation models, landscape heterogeneity, forest ecosystem services

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1 Introduction

Projecting future changes in ecosystem services at a regional or local scale often requires an examination of how local species composition and vegetation structure will change (Bugmann et al., 2005, Ojea et al., 2010, Nelson et al., 2009). For example, forests are instrumental for provisioning services such as timber production (Kirilenko and Sedjo, 2007, Hanewinkel et al., 2012), regulatory services such carbon sequestration (Stoy et al., 2008, Fahey et al., 2010) and water regulation (Ford et al., 2011, Zierl et al., 2007), and cultural services such as recreation (MEA, 2005, EEA, 2010). Process-based forest models have proven to be valuable tools for projecting future impacts on vegetation as they allow forest responses to novel conditions to be examined (Bugmann, 2003), and often allow for the interactive impacts of climate change and changes in land use and management to be evaluated (Fontes et al., 2010, Seidl et al., 2011b, Temperli et al., 2012, Wolf et al., 2012, Briner et al., 2012). The capacity of these models to effectively project future vegetation dynamics is contingent on the models capturing the impact of important drivers at a relevant ecological grain, such as how temperature and precipitation changes will alter the recruitment, growth, and mortality of different species. As a result, these models often focus on a relatively fine ecological scale such as individuals (Manusch et al., 2012, Smith et al., 2001, Seidl et al., 2010), age or size cohorts (Bugmann, 1996, Elkin et al., 2012, Rasche et al., 2012), or functionally homogeneous land units such as forest stands (Pretzsch et al., 2008, Porté and Bartelink, 2002).

The fine ecological grain of process based vegetation models poses two related challenges with respect to projecting how vegetation based ES will change at a regional scale. First, accurately simulating vegetation response to future conditions will often require a consideration of landscape heterogeneity and how site-specific characteristics influences forest development. Heterogeneity within a landscape can result from biophysical properties such as elevation or nutrient gradients, or can reflect site specific disturbance and management histories (Kulakowski et al., 2011, Seidl et al., 2011a, Temperli et al., 2013). Each of these factors can influence current vegetation structure, and importantly, how vegetation will respond to future changes. Process based vegetation models vary in their approach to incorporating heterogeneity when projecting future change. One common approach is to identify the site features, such as elevation, that have the largest impact on vegetation development and then perform simulations that incorporate relevant gradients (Bugmann, 1996, Didion et al., 2011). Conversely, landscape heterogeneity can be considered explicitly by using spatial landscape vegetation models that incarnate a range of site characteristics (Elkin et al., 2012, Scheller and Mladenoff, 2005). However, these models are often constrained by computing limitations, and by the availability of sufficiently fine grain empirical data that is needed to initialize these spatial models (Temperli et al., 2013). The second challenge that needs to be addressed when using process based vegetation models is how to suitably aggregate fine scale ES response projections, that incorporates some degree of landscape heterogeneity, at landscape or regional scales.

Here we examine the ramifications of these two challenges with respect to developing robust projections of future changes in forest ES at local and regional scales. Using two process based forest models we assess how landscape heterogeneity and environmental gradients influences forest ES response to climate change, and the impact that these factors have on ES evaluation at local and regional scales. We also focus on when ecosystem thresholds that result in rapid changes in ES service provision will be reached. We simulate the impact of three future climate scenarios at three central European case study sites that represent different ecotypes and different degrees of landscape heterogeneity.

2 Methods

2.1 Case study regions

We simulated three case study regions: the Saas valley a dry inner-alpine valley (elevation range 600 to 4390 m a.s.l., mean annual temperature 8.2°C and precipitation 640 mm at 640 m a.s.l.), the Bavarian Forest National Park a cool-wet region at intermediate elevation (elevation range to 600 and 1,453 m a.s.l., mean annual temperature 6.5°C and precipitation 1400 mm at 600 m a.s.l.), and the Dischma valley a cool-wet high alpine valley (elevation range 1500 to 2800 m a.s.l., mean annual temperature 3.2°C and precipitation 990 mm at 1500 m a.s.l.). Each of the three regions is dominated by forests which contain a strong *Picea abies* (Norway spruce) component, but differ in their degree of landscape heterogeneity due to topographical differences as well as differences in their management and disturbance history. In particular, between 1995 and 2005 a large European bark beetle (*Ips typographus*) disturbance occurred in the Bavarian Forest National Park and increased landscape heterogeneity. In our simulations this heterogeneity was characterized by differences in stand composition and structure.

2.2 Climate scenarios

Regionally downscaled climate data, based on monthly observed climate data between 1900-2000 obtained from the Climatic Research Unit (CRU) of the University of East Anglia, Norwich, UK (Mitchell et al., 2004), was used to represent historic and current climate conditions. We analyzed three climate scenarios (2001-2100) from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007: scenario A1B, A2, B1). Regionally downscaled monthly temperature means and precipitation sums (Fischer et al., 2011, van der Linden et al., 2009), derived from ECHAM5 climate model, were used.

2.3 Process based vegetation models

The forest model ForClim (Bugmann, 1996, Rasche et al., 2012) was used to simulate the impacts of climate change on tree recruitment, growth and mortality, and the resulting impacts on forest composition and structure at the forest stand scale, while the landscape model LandClim (Elkin et al., 2012, Schumacher et al., 2004) was used evaluate the impact of climate change on forests at the landscape scale.

2.4 Simulation experiments and assessment of ES sensitivity

In Saas and Dischma valleys we simulated vegetation development from bare ground for an initial 300 year spin-up period followed by a second 200 year spin-up period during which current forest management practices were simulated. Climate data from the 1900-2000 period was used during the spin-up simulations. In the Bavarian Forest National Park, forest dynamics was simulated from current state of the forest by distinguishing 19 strata with different forest properties. Following the spin-up the period 2001-2100 was simulated using the projected climate data.

In Saas and Dischma valleys we performed both stand and landscape level simulations, while in the Bavarian Forest National Park only stand level simulations were done. Stand level simulations were conducted along elevation gradients in each region, and beetle disturbed vs. non-disturbed stands were simulated in the Bavarian Forest National Park. In addition to examining the impact of climate change on forest structure we also considered the impact on three forest ES; timber production, protection forests provide against rockfall, and carbons storage. This framework allowed us to examine the projected impact of climate change on forest ES at the plot, stand, elevation band, and landscape resolutions.

3 Results

3.1 Threshold responses of forest and forest ES to climate change

The projected impact of climate change on forests differed among the three case study regions, and depended heavily on elevation and initial climatic conditions. At sites that are currently warm and dry, such as areas below 1500m a.s.l. in the Saas valley, an increase in temperature and decrease in summer precipitation is projected to further increase drought and facilitate a shift towards more drought tolerant species. At sites that are currently more mesic, such as intermediate elevation sites in the Saas valley and regions of the Bavarian Forest National Park, drought is projected to become much more important and have a strong negative impact on non-drought tolerant species, such as Norway spruce, that currently dominate these areas. At sites that are currently cool and wet, such as the Dischma valley and the higher elevations in the Saas valley and the Bavarian Forest National Park, increased temperatures are projected to improve growing conditions and to initially favor forest development.

Importantly, the negative impacts associated with increased drought at low and intermediate elevation sites are projected to result in strong non-linear shifts in forest composition. These abrupt changes in forest biomass and species composition, which can occur within a decade, reflect threshold responses from species as their tolerance to drought is exceeded under future climate conditions.

Changes in forest structure are projected to also influence forest ES. At lower and intermediate elevations, drought induced reductions in forest biomass, and high mortality in drought intolerant species, that are projected to have strong negative impacts on forest ES such as timber production, potential carbon storage and the protection that forests provide against rockfall. In contrast, at higher elevations, and in areas that are currently cool and wet, climate dependent increases in forest growth are projected to have a positive impact on forest dependent ES.

3.2 Spatial grain of ES response

The large elevation gradient in the Saas valley resulted in forest properties and forest ES projections being different for plots and stands at high elevation compared to those at low elevation (Fig. 1). In contrast, the smaller elevation gradient and cool-wet initial conditions in the Dischma valley and the Bavarian Forest National Park, resulted in projected changes being smaller and comparatively homogeneous across the landscape. High elevation stands in the Dischma valley and the Bavarian Forest National Park did differ from low elevation stands, but the magnitude of difference was much smaller than in the Saas valley (Fig. 1).

Projected variability in forests response to climate change was largest at the smallest spatial grains we analyzed (plot, stand). The magnitude and direction of climate impact on forest ES, and the timing of non-linear changes, often differed between plots. This variability was reduced considerably when results were aggregated at the stand level, and even more when results were aggregated by elevation band.

When forest ES were aggregated at the landscape level, variability was further reduced and the projected impact of climate change was dampened compared to smaller spatial grains that incorporate elevation and aspect differences. The dampening effect of landscape aggregation was largest for forest ES that exhibit strong differences along the elevation gradient, such as timber and rockfall protection.

Aggregating results at larger spatial grains not only dampened the projected magnitude of climate impacts, but also altered the projections of when forest ES would exhibit threshold responses. Sharp reductions in timber production and rockfall protection are projected to occur earlier at lower elevations where drought stress is more sever. When results are aggregated at the landscape scale the timing of the non-linear changes in forest ES are represented as occurring later, and the duration of the change is more protracted.

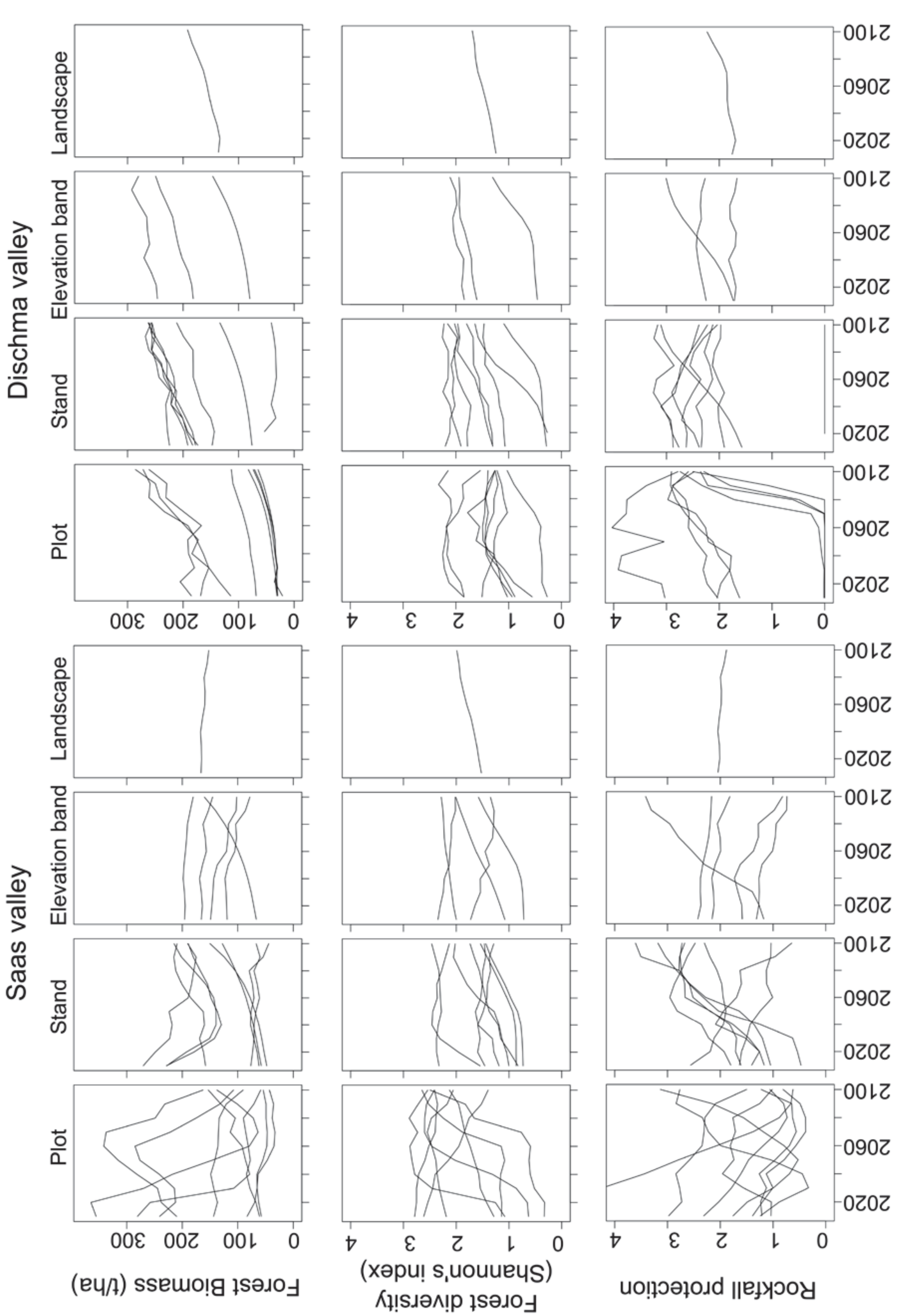

Fig. 1 ES responses to climate change (A1B) at four spatial grains in the Saas and Dischma valleys

4 Discussion

Our results suggest that the impact of climate change on forest ES can vary greatly within a region due landscape heterogeneity and the presence of strong environmental gradients. We focused on mountainous case study regions where elevation results in strong temperature and precipitation gradients that dictate both forest composition and potentially how the forest will respond to future climate change. While each case study region encompassed a relatively broad elevation range, the importance of the associated temperature and ecological gradients for making robust assessments of changes in forest ES at a regional scale also depended on the sensitivity of the region to changes in temperature and precipitation. Of our three case study regions, the cool-wet Dischma valley and the Bavarian Forest National Park were projected to be the least sensitive to climate change and to exhibit the most uniform response with respect to ES impacts. In contrast, forests in the Saas valley were projected to exhibit strong within region heterogeneity as a result of the divergent impacts that climate change is projected to have on forests at low and high elevations. Our projections of site specific climate impacts correspond with past studies that have documented local increases in mortality (Bigler et al., 2006, Dobbertin et al., 2005) and reductions in tree growth (Eilmann et al., 2011, Rigling et al., 2013) at the most drought prone sites in the Saas valley.

In regions that exhibit a heterogeneous response to climate change efforts to up-scale fine grain climate impact projections to the landscape or regional scale risk misrepresenting climate impacts. Our results highlight two specific challenges, first, if net ES impacts at a regional scale are compiled in a non-thoughtful way, negative local impacts in some areas will be masked by positive impacts in other areas. In such cases regional evaluations of climate impacts must either explicitly take into account site specific difference, or if a single ES metric for the region is needed, it must reflect directional changes in ES provision or evaluate absolute changes. The second problem associated with up scaling ES impacts to the regional scale is that the timing of ES threshold responses, and the rate at which ES change, can be incorrectly assessed. Misleading projections regarding when ecological and associated ES thresholds are projected to be reached can be particularly detrimental when trying to efficiently implement adaptive land use and land management plans (Lindner, 2000, Hans Rudolf, 2010).

The importance of accurately projecting the impact of landscape heterogeneity, and effectively up scaling local projections to the regional scale, will depend on the ES in question, the spatial grain at which the ES is relevant (Eigenbrod et al., 2010, Bennett et al., 2009), and on the spatial grain at which the ES is managed (Anderson et al., 2009). For example, projections of future changes in carbon sequestration are often made at a catchment or regional scale. Even though carbon fluctuations may differ greatly within regional environmental gradients (Tupek et al., 2010), the spatial grain at which the ES is functionally evaluated is large, and accounting can be done by calculating the projected net change in carbon storage within a region. In contrast, other ES, such as the protection that forests provide against gravitational hazards (Bebi et al., 2001, Bigot et al., 2009), are used and managed at a much smaller grain. For this type of ES, an evaluation of the net flux in the ES at a regional level isn't relevant because potential gains in one part of the landscape do no negate losses in other areas. For this type of ES, more thought needs to be put into how local changes can be summarized at landscape and regions scales, and reporting may need to explicitly account for different responses along relevant gradients.

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Impact of Future Climate Changes on the Structure and Function of the Alpine Ecosystem on the Tibetan Plateau

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Abstract: The Tibetan Plateau is one of the most sensitive areas to climate change and its climatic and ecological conditions are important for Asia and the world. In this research, we have modified the LPJ model (Lund-Potsdam-Jena Dynamic Global Vegetation Model) to make it applicable to simulate in the Tibetan Plateau, then used the Representative Concentration Pathways (RCP)4.5 and RCP8.5 climate change scenarios to drive the modified LPJ model, simulating vegetation distribution and net primary productivity patterns on the Tibetan Plateau in the future. The results showed that the distributions of forests (both broadleaf and coniferous) and shrubs have increasing trends while alpine meadows decreased and were mainly replaced by shrubs in the future. Alpine grassland expanded to the northwest and occupied a large area of the western and northern plateau. Net primary productivity increased 78.8% under the RCP4.5 scenario, comparing the Baseline period (1961-1990) to the future period (2071-2100). Under RCP8.5, the increase in net primary production was 133.6%. Productivity generally increased in most parts of the plateau to 200 $gC \cdot m^{-2} \cdot a^{-1}$ and showed the gradual rise from the eastern to western region of the Tibetan Plateau at the end of this century.

Key Words: Vegetation distribution, Net primary productivity (NPP), The Representative Concentration Pathways (RCP), Dynamic Global Vegetation Model, Tibetan Plateau

1. Introduction

As one of the "most sensitive areas" to global climate change (Liu et al., 2000), the Tibetan Plateau, exhibits changes that exceed those in the rest of the Northern Hemisphere and even the world (Feng et al., 1998; Liu et al., 2002), especially showing a clear warming trend and greater precipitation (Niu et al., 2004; Wu and Yin, 2007). The Tibetan Plateau has extremely harsh and variable weather conditions and has ecosystems that are relatively unstable. Thus, external disturbance can easily cause changes in ecosystem pattern, processes and function. Therefore, it is urgently necessary to evaluate the comprehensive impacts of climate change on alpine ecosystem structure and function, to understand the influence of climate change on the alpine ecosystem of the Tibetan Plateau, and to provide a scientific basis for sustainable development and adaptation to climate change on Tibetan Plateau.

The objectives of this study are 1) to modify climate, vegetation and plant physio-ecological parameters of the LPJ (Lund-Potsdam-Jena Dynamic Global Vegetation Model) model based on field observations and other works and 2) to predict the influence of future climate change on alpine ecosystem structure (vegetation distribution) and function (NPP) of the Tibetan Plateau with the Representative Concentration Pathways (RCP) recommended by the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Results will provide a theoretical basis for future climate change adaptation in the alpine ecosystem on Tibetan Plateau.

2. Material and Methodology

2.1 Study area

The Tibetan Plateau exceeds 4000 m in average altitude (Figure 1), is the largest high-altitude area on the Earth and is called "Third Pole of the Earth” with following the Antarctic and the Arctic (Yao and Wang, 1997; Wu and Yin, 2007). The Tibetan Plateau is the headstreams of the Yangtze, Yellow, Salween, Mekong and other major rivers, and its amount of ice is next only to the Antarctic and the Arctic (ECENRTR, 2002). The Tibetan Plateau is covered with a large area of alpine grassland and alpine meadows, and shrubs are mainly distributed in the southeast, whereas coniferous and broadleaf forests are mainly in the south and the southeast of the plateau, and a large area of bare land exists in the northwest.

2.2 Data sources and processing

2.2.1 Spatial interpolation of historical meteorological data

Historical monthly precipitation, temperature and sunshine rate data of the 187 meteorological stations which are all stations in the Tibetan Plateau plus the neighboring stations from 1961 to 1990 were extracted from the "Monthly Value Data Sets of Surface Climate Data" of the National Meteorological Information Center of China Meteorological Administration. The spatial database of monthly meteorological elements in the IPCC Baseline period (1961-1990) was obtained through spatial interpolation.

2.2.2 Generation of the future climate change scenarios

The future climate scenario data were provided by the National Climate Center of China Meteorological Administration. In this database, the global model BCC-CSM1.1 was used to drive the regional model RegCM4.1 and to obtain the CO_2 concentration, monthly mean temperature, monthly precipitation and other estimated climate data in the Tibetan Plateau under the RCP4.5 (Stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100) – the best estimate emissions reduction scenario and RCP8.5 (Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100) – the business as usual emissions scenario (Moss et al., 2010). The simulation periods were divided into (i) the Baseline Period: 1961-1990, (ii) Future Period I: 2011-2040, (iii) Future Period II: 2041-2070, and (iv) Future Period III: 2071-2100.

2.2.3 Collection and processing of other data

The soil type maps (with 0.5° × 0.5° spatial resolution) , the DEM (with 1 km^2 resolution) and the Vegetation Map (scale 1:1,000,000) of the Tibetan Plateau were collected and used in this study.

2.3 Model modifications

The LPJ model (Lund-Potsdam-Jena Dynamic Global Vegetation Model) can predict the distribution of regional vegetation types and other structural characteristics, and estimate the net primary productivity (NPP) of vegetation and other functional characteristics under the impact of climate change (Sitch et al., 2003). The LPJ model is a dynamic global vegetation model, and the 10 plant functional types (PFTs) in its original parameters are applicable to simulations at global scale. But it is necessary to modify the LPJ model parameters and add PFTs for the area of the Tibetan Plateau where major grasslands are alpine meadow and alpine grassland. By consulting the relevant literature and research results (Wong and Zhou, 2005; Zhao *et al*., 2011), the number of PFTs for this model was increased to 19, and then categorized into vegetation types as Broadleaf forest, Coniferous forest, Shrub, Alpine meadow, Alpine steppe, and Bare land (Table S1). The modifications were made to the bioclimatic limit parameters and physiological and ecological parameters of the PFTs by the observed data (Tables S2 and S3).

3. Results

3.1 Vegetation distribution pattern in the future climate change scenarios

Under the RCP4.5 scenario, coniferous and broadleaf forests showed significant expansion, and were mainly distributed in the southeast of the Plateau in the future (Figure 2). The distribution of shrubs extended from the eastern fringe to the hinterland of the Plateau, occupying part of the region where alpine meadows grew in the Baseline Period, and the area of shrubs rose from 6% in the Baseline Period (1961-1990) to 17.3% in Future Period III (2071-2100). The area of alpine meadows was decreasing, down from 21.9% in the Baseline Period (1961-1990) to 9% in Future Period III (2071-2100) mainly in the central Plateau, and was intermingled with shrubs (Figure 2, Table 1). The alpine grassland expanded northwestwards and occupied 61.5% of the area of the whole Tibetan Plateau in the future (2071-2100). The region of bare land reduced gradually in the northwest region of the plateau, down from 18.6% to 3.3% (Figure 2, Table 1). Under the RCP8.5 scenario, the overall trend of the distribution and composition of vegetation types on the Tibetan Plateau was basically the same as that in the RCP4.5 scenario, but the responses of individual vegetation types differed slightly (Figure 2, Table 1).

3.2 NPP patterns in future climate change scenarios

With changes in the hydrothermal conditions caused by climate change, the NPP of the Tibetan Plateau showed an increasing trend, but the range differed under varied scenarios (Figure 3). Under the RCP4.5 scenario, the annual average NPP was 493.3 $gC\cdot m^{-2}\cdot a^{-1}$, 571.7 $gC\cdot m^{-2}\cdot a^{-1}$, and 606.8 $gC\cdot m^{-2}\cdot a^{-1}$ respectively in the whole region of the Tibetan Plateau from Future Period I (2011-2040) to Future Period III (2071-2100). That is an increased of 45.3%, 15.9%, and 6.1% respectively over the previous period, and a total increase of about 78.8% from the Baseline to Future Period III (Figure 3). Under the RCP8.5 scenario, the annual average NPP of the Tibetan Plateau in Future Period I (2011-2040) was 502 $gC\cdot m^{-2}\cdot a^{-1}$, up 47.9% over that in the Baseline Period (1961-1990), followed by a 29.8% rise to 651.7 $gC \cdot m^{-2} \cdot a^{-1}$ in Future Period II (2041-2070). NPP was 792.9 $gC \cdot m^{-2} \cdot a^{-1}$ in Future Period III (2071-2100), increasing by 21.7% over the previous period and by 133.6% over the Baseline Period (Figure 3).

The trends in the distributions and range of NPP also differed significantly (Figure 4). The areas of relatively low NPP (i.e., 0-200 $gC \cdot m^{-2} \cdot a^{-1}$ and 200-400 $gC \cdot m^{-2} \cdot a^{-1}$) were reduced while the area with NPP of above 400 $gC \cdot m^{-2} \cdot a^{-1}$ increased significantly. Under the RCP8.5 scenario, the area of NPP production at 800-1000 $gC \cdot m^{-2} \cdot a^{-1}$ even occupied the entire eastern plateau in the late Future Period (2071-2100). The spatial changes of NPP in different periods varied under future climate change scenarios. NPP in all the regions of the Tibetan Plateau continued to increase, and the increasing trend showed the gradual rise from east to west, but gradually reduced over time. At the end of this century, our modeling suggests that NPP will increase in most parts of the plateau by about 200 $gC \cdot m^{-2} \cdot a^{-1}$(Figure 4). The region of bare land in the northwest had no significant change, and the area of coniferous and broadleaf forests in the southeastern plateau showed an overall decline.

4. Discussion

Under the RCP4.5 and RCP8.5 scenarios, the CO_2 concentration, temperature, precipitation, and radiation intensity increased and led to changes in the distribution of the hydrothermal conditions on the Tibetan Plateau, and hence changes in the structure and function of ecosystems. The areas of alpine grassland and shrubs increased greatly and showed the same expansion from southeast to northwest under both scenarios. Ding *et al*. (2010) indicated that the grasslands, meadows and shrubs were sensitive to changes in temperature and precipitation changes on the Tibetan Plateau, which is consistent with our simulation results. The changes in vegetation distribution under the RCP8.5 were more rapid than under the RCP4.5 scenario, and forests and shrubs expanded greatly in the northern plateau. The effect of rising temperature on vegetation growth in the high latitude also played a role (Zhou and Zhang, 1995; Nemani *et al*., 2003).

NPP increased significantly in simulations of future change, due to rising precipitation, temperature and CO_2 concentration on Tibetan Plateau, especially under the RCP8.5 scenario. Temperature rise played an important role in increasing local ecosystem productivity according to related research results, especially in temperature-restricted areas (Nemani *et al*., 2003). The increase in temperature, precipitation or both had either positive or negative influences on the NPP in different regions of

China, but the NPP of the Tibetan Plateau consistently showed an increasing trend (Huang, 2011). This suggests that improvement in the hydrothermal conditions brought by future climate change will play a positive role in increasing ecosystem productivity in the Tibetan Plateau. The increased CO_2 concentration and solar radiation have positive effects on plant-produced energy and material resources, and hence on NPP. These effects work in a synergistic way to with improved hydro-thermic condition to further increase NPP.

5. Conclusions

Under future climate change scenarios, broadleaf forests on the Tibetan Plateau further expanded to the southeast. The coniferous forest showed an increasing trend and extended gradually to the hinterland of the plateau; the shrubs were had the most obvious increasing trend, gradually becoming the main vegetation type on the eastern plateau. Alpine meadows decreased and were mainly replaced by shrubs under future climate change. Alpine grasslands expanded to the northwest and increased significantly, occupying a large area of the western and northern plateau. Bare land continued to decline in area because of the westward extension of the alpine grassland.

The change of vegetation NPP in the Tibetan Plateau was an increasing trend under future climate change scenarios with 78.8% and 133.6% more productivity in the future period (2071-2100) as compared to that in the Baseline Period (1961-1990) for RCP4.5 and RCP8.5 scenario, respectively. Areas with productivity of blow 400 $gC \cdot m^{-2} \cdot a^{-1}$ declined, mainly in the northwestern plateau. The area with NPP of above 400 $gC \cdot m^{-2} \cdot a^{-1}$ increased significantly. The NPP in all the regions of the Tibetan Plateau continued to increase, and the increasing trend showed the gradual rise from east to west, but gradually reduced over time. At the end of this century, our modeling suggests that NPP will increase in most parts of the plateau by about 200 $gC \cdot m^{-2} \cdot a^{-1}$.

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Table 1 Cover percentages of various vegetation types in the Tibetan Plateau under climate change scenarios. Columns with labeled periods show percent cover, and columns spanning two periods show the percent change in cover.

RCP4.5 Scenario								
Periods	Baseline period 1961-1990	1961-1990 To 2011-2040	Future period I 2011-2040	2011-2040 To 2041-2070	Future period II 2041-2070	2041-2070 To 2071-2100	Future period III 2071-2100	1961-1990 To 2071-2100
Broadleaf forest	0.21%	+0.43%	0.64%	+0.00%	0.64%	+0.32%	0.96%	+0.75%
Coniferous forest	3.84%	+1.71%	5.54%	+2.03%	7.57%	+0.32%	7.89%	+4.05%
Shrub	5.97%	+5.54%	11.51%	+4.16%	15.67%	+1.60%	17.27%	+11.30%
Alpine meadow	21.86%	-4.48%	17.38%	-3.20%	14.18%	-5.12%	9.06%	-12.79%
Alpine steppe	49.57%	+8.42%	58.00%	-0.96%	57.04%	+4.48%	61.51%	+11.94%
Bare land	18.55%	-11.62%	6.93%	-2.03%	4.90%	-1.60%	3.30%	-15.25%
RCP8.5 Scenario								
Periods	Baseline period 1961-1990	1961-1990 To 2011-2040	Future period I 2011-2040	2011-2040 To 2041-2070	Future period II 2041-2070	2041-2070 To 2071-2100	Future period III 2071-2100	1961-1990 To 2071-2100
Broadleaf forest	0.21%	+0.53%	0.75%	+0.11%	0.85%	+0.43%	1.28%	+1.07%
Coniferous forest	3.84%	+0.53%	4.37%	+4.90%	9.28%	+8.96%	18.23%	+14.39%
Shrub	5.97%	+8.96%	14.93%	+1.81%	16.74%	+2.24%	18.98%	+13.01%
Alpine meadow	21.86%	-6.18%	15.67%	-2.67%	13.01%	-7.36%	5.65%	-16.20%
Alpine steppe	49.57%	+8.42%	58.00%	-0.11%	57.89%	-2.24%	55.65%	+6.08%
Bare land	18.55%	-12.26%	6.29%	-4.05%	2.24%	-2.03%	0.21%	-18.34%

Figure captions

Figure 1 Projected change of annual mean temperature and annual total precipitation on Tibetan Plateau under RCP4.5 and RCP8.5 scenarios

In this figure, RCP4.5T is the annual mean temperature under RCP4.5 scenario, RCP4.5P is the annual total precipitation under RCP4.5 scenario, RCP8.5T is the annual mean temperature under RCP8.5 scenario, RCP8.5P is the annual total precipitation under RCP8.5 scenario, BP is the baseline period, FP I is the future period I, FP II is the future period II, FP III is the future period III.

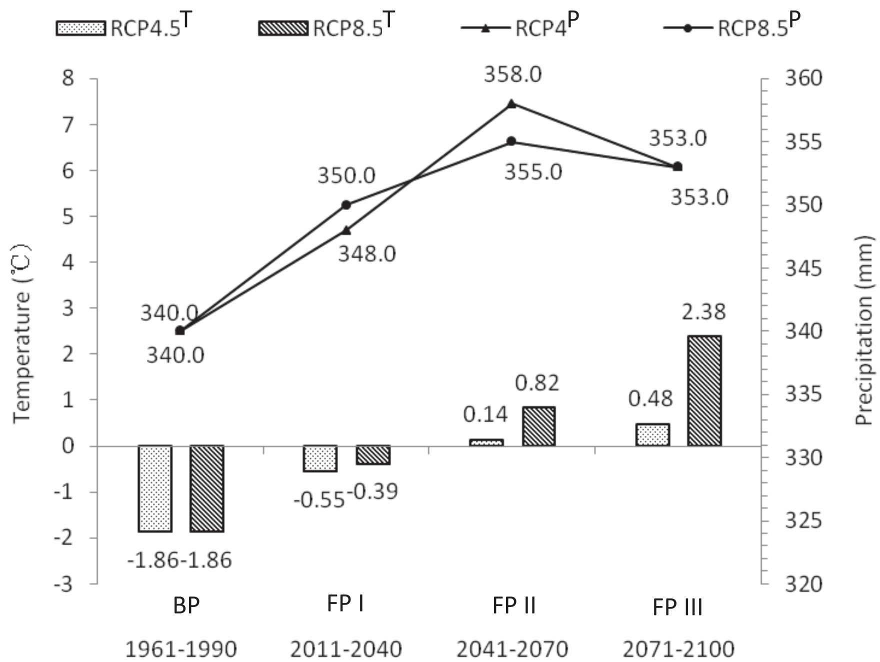
Figure 2 Distribution of vegetation on Tibetan Plateau under RCP4.5 and RCP8.5 scenarios

In this figure, a is the vegetation distribution in baseline period (1961-1990), b is the vegetation distribution in future period I (2011-2040) under RCP4.5 scenario, c is the vegetation distribution in future period II (2041-2070) under RCP4.5 scenario, d is the vegetation distribution in future period III (2071-2100) under RCP4.5 scenario, e is the vegetation distribution in future period I (2011-2040) under RCP8.5 scenario; f is the vegetation distribution in future period II (2041-2070) under RCP8.5 scenario, g is the vegetation distribution in future period III (2071-2100) under RCP8.5 scenario; the vegetation type BL is the bare land, BF is the broadleaf forest, CF is the coniferous forest, SH is the shrub, AM is the alpine meadow, and AS is the alpine steppe.

Figure 3 Predicted change of annual mean NPP in Tibetan Plateau under climate change scenarios

Figure 4 Distribution of NPP on Tibetan Plateau under RCP4.5 and RCP8.5 scenarios

In this figure, a is the distribution of NPP in baseline period (1961-1990), b is the distribution of NPP in future period I (2011-2040) under RCP4.5 scenario, c is the distribution of NPP in future period II (2041-2070) under RCP4.5 scenario, d is the distribution of NPP in future period III (2071-2100) under RCP4.5 scenario, e is the distribution of NPP in future period I (2011-2040) under RCP8.5 scenario; f is the distribution of NPP in future period II (2041-2070) under RCP8.5 scenario, g is the distribution of NPP in future period III (2071-2100) under RCP8.5 scenario



In this figure, RCP4.5T is the annual mean temperature under RCP4.5 scenario, RCP4.5P is the annual total precipitation under RCP4.5 scenario, RCP8.5T is the annual mean temperature under RCP8.5 scenario, RCP8.5P is the annual total precipitation under RCP8.5 scenario, BP is the baseline period, FP I is the future period I, FP II is the future period II, FP III is the future period III

Figure 1 Projected change of annual mean temperature and precipitation under RCP4.5 and RCP8.5 scenarios in Tibetan Plateau

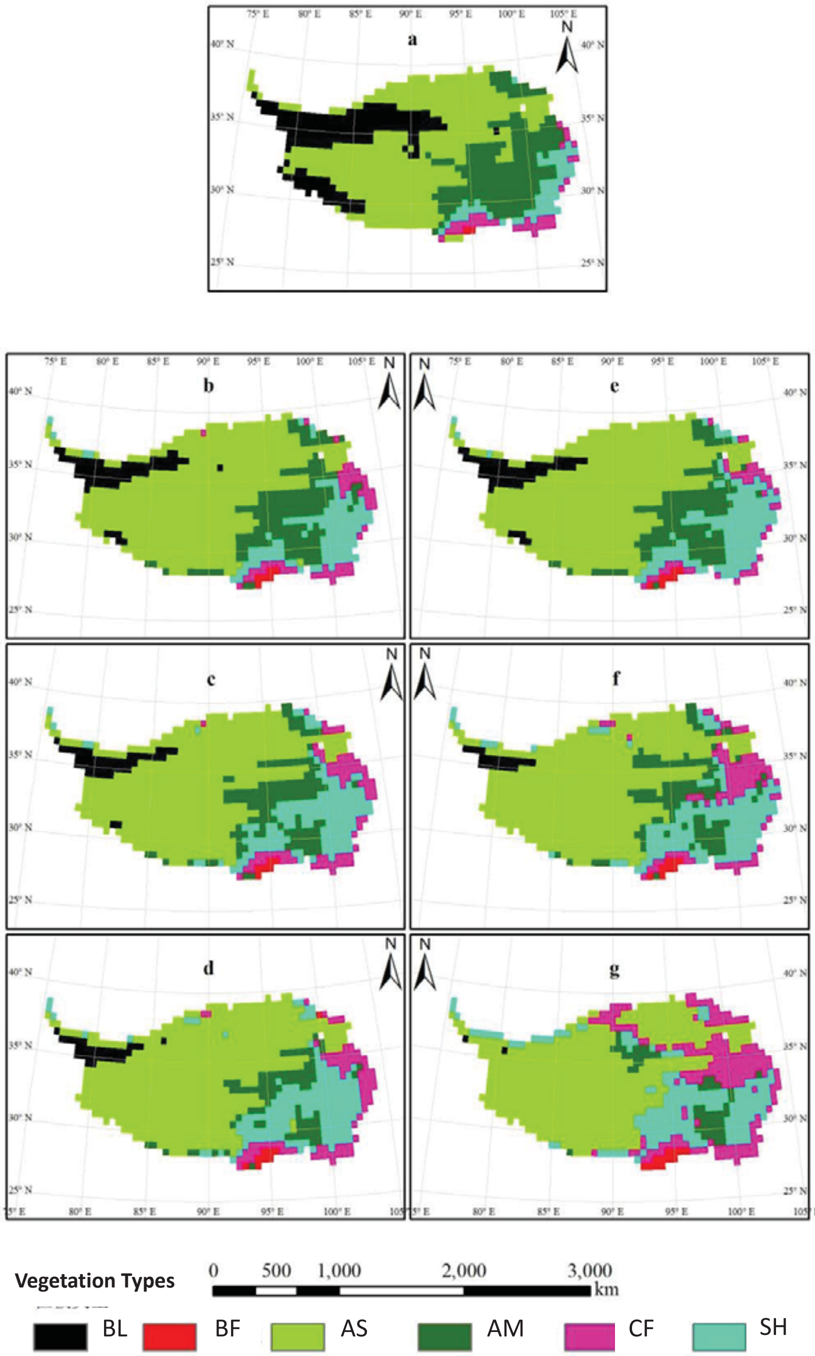


Figure 2 Distribution of vegetation under future climate scenarios in Tibetan Plateau

(In this figure, a is the vegetation distribution in baseline period (1961-1990), b is the vegetation distribution in future period I (2011-2040) under RCP4.5 scenario, c is the vegetation distribution in future period II (2041-2070) under RCP4.5 scenario, d is the vegetation distribution in future period III (2071-2100) under RCP4.5 scenario, e is the vegetation distribution in future period I (2011-2040) under RCP8.5 scenario; f is the vegetation distribution in future period II (2041-2070) under RCP8.5 scenario, g is the vegetation distribution in future period III (2071-2100) under RCP8.5 scenario; the vegetation type BL is the bare land, BF is the broadleaf forest, CF is the coniferous forest, SH is the shrub, AM is the alpine meadow, and AS is the alpine steppe.)

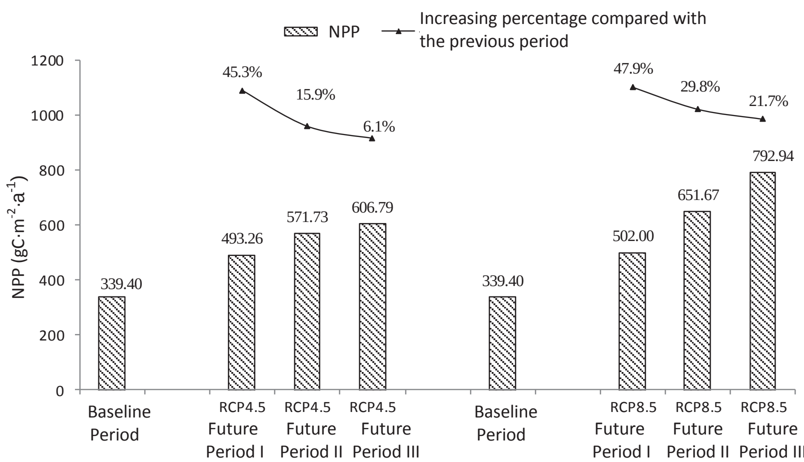


Figure 3 Predicted change of annual mean NPP in Tibetan Plateau under climate change scenarios

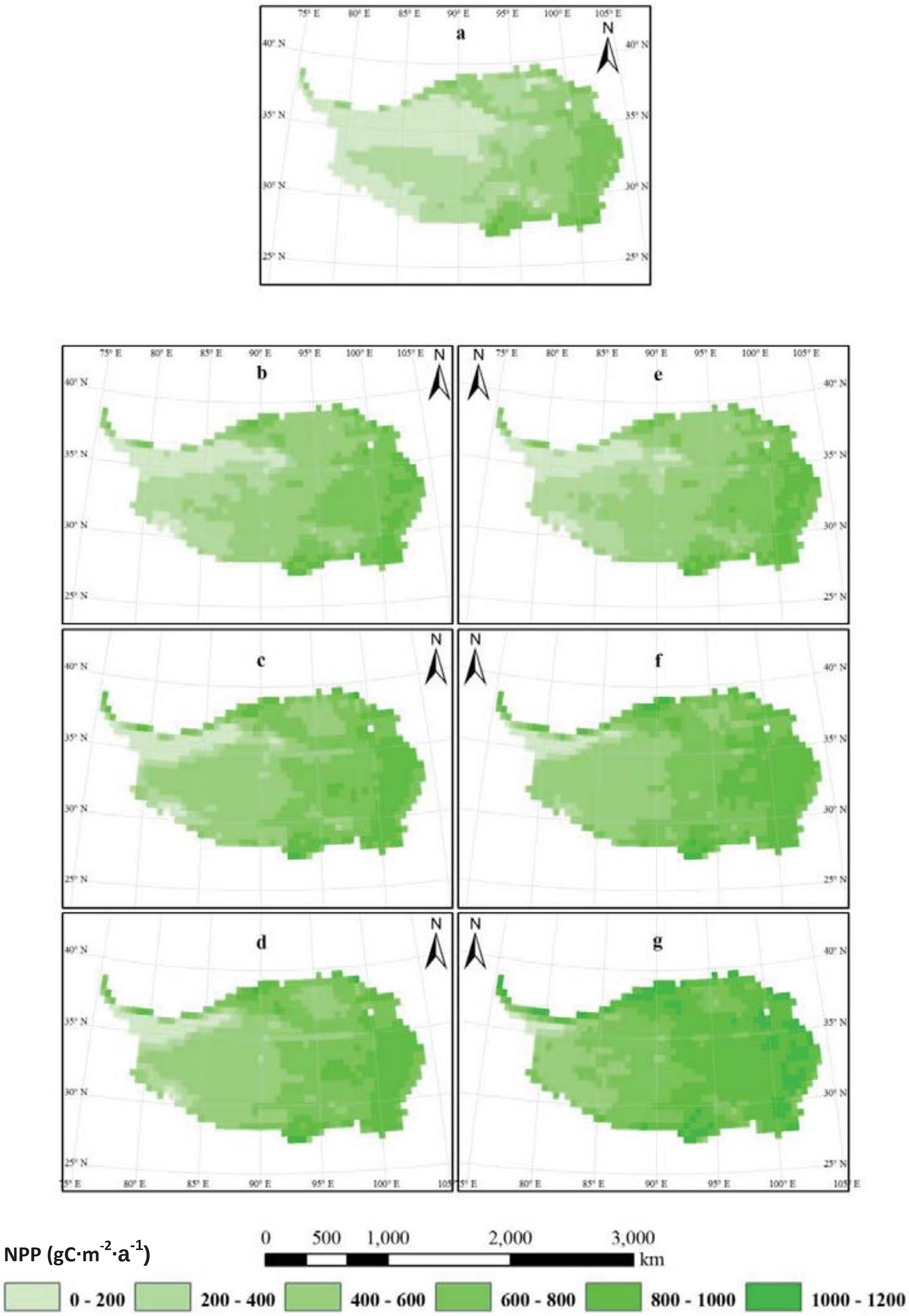


Figure 4 Distribution of NPP under RCP4.5 & RCP8.5 scenarios in Tibetan Plateau
(In this figure, a is the distribution of NPP in baseline period (1961-1990), b is the distribution of NPP in future period I (2011-2040) under RCP4.5 scenario, c is the distribution of NPP in future period II (2041-2070) under RCP4.5 scenario, d is the distribution of NPP in future period III (2071-2100) under RCP4.5 scenario, e is the distribution of NPP in future period I (2011-2040) under RCP8.5 scenario; f is the distribution of NPP in future period II (2041-2070) under RCP8.5 scenario, g is the distribution of NPP in future period III (2071-2100) under RCP8.5 scenario)

Supplementary materials

Table S1 PFTs in modified LPJ model

No	Abbreviations	Plant Functional Types (PFTs)	Life Form	Vegetation Types
1	TrBE	Tropical Broad-leaved Evergreen	Woody	Broadleaf forest
2	TrBR	Tropical Broad-leaved Raingreen	Woody	Broadleaf forest
3	TeNE	Temperate Needle-leaved Evergreen	Woody	Coniferous forest
4	TeBE	Sub-tropical Broad-leaved Evergreen	Woody	Broadleaf forest
5	TeBS	Temperate Broad-leaved Summergreen	Woody	Broadleaf forest
6	BNE	Boreal Needle-leaved Evergreen	Woody	Coniferous forest
7	BNS	Boreal Needle-leaved Summergreen	Woody	Coniferous forest
8	BBS	Boreal Broad-leaved Summergreen	Woody	Broadleaf forest
9	TeSS	Temperate Summergreen Shrubs	Woody	Broadleaf forest
10	TeDS	Temperate Desert Shrubs	Woody	Shrub
11	MES	Mountainous Evergreen Shrubs	Woody	Shrub
12	AlSS	Alpine Summergreen Shrubs	Woody	Shrub
13	AlDS	Alpine Desert Shrubs	Woody	Shrub
14	C4G	Warm Grasses	Herbaceous	Shrub
15	TeMG	Temperate Meadow Grasses	Herbaceous	Alpine meadow
16	TeSG	Temperate Steppe Grasses	Herbaceous	Alpine steppe
17	AlMG	Alpine Meadow Grasses	Herbaceous	Alpine meadow
18	AlSG	Alpine Steppe Grasses	Herbaceous	Alpine steppe
19	Bare	Barren land	--	Bare land

Table S2 Threshold values of herbaceous PFTs' partial bioclimatic and eco-physiology parameters in modified LPJ model

Parameters \ PFTs	C4G	TeMG	TeSG	AlMG	AlSG
rootdist	0.9 0.1	0.9 0.1	0.9 0.1	0.95 0.05	0.95 0.05
Gmin ($mm \cdot s^{-1}$)	0.5	0.5	0.5	0.5	0.5
Emax ($mm \cdot d^{-1}$)	7	6	6	5	5
pstemp_min (℃)	6	-4	-4	-4	-4
pstemp_low (℃)	20	20	20	15	15
pstemp_high (℃)	45	30	30	30	30
pstemp_max (℃)	55	45	45	40	40
fireresist	1	1	1	1	1
tcmin_est (℃)	15.5				
tcmax_est (℃)		-8	-8	-12	-12
twmin_est (℃)	22				
gdd5max_est (℃)			4000	1600	1350
gdd5min_est (℃)	0	900	900	500	400
dtymax_est (℃)				30	30
premin_est (mm)				350	120

In this table, C4G is the Warm Grasses, TeMG is the Temperate Meadow Grasses, TeSG is the Temperate Steppe Grasses, AlMG is the Alpine Meadow Grasses, AlSG is the Alpine Steppe Grasses, and rootdist is the distribution proportion of fine roots in the upper and lower soil layer, gmin is the minimum canopy conductance, emax is the maximum transpiration rate, pstemp_min is the approximate low temperature limit for photosynthesis (deg C), pstemp_low is the approximate lower range of temperature optimum for photosynthesis (deg C), pstemp_high is the approximate upper range of temperature optimum for photosynthesis (deg C), pstemp_max is the maximum temperature limit for photosynthesis (deg C), fireresist is the fire resistance (0-1), tcmin_est is the minimum coldest month mean temperature for the last 20 years, tcmax_est is the maximum coldest month mean temperature for the last 20 years, twmin_est is the minimum warmest month mean temperature, gdd5max_est is the maximum growing degree day sum on 5 deg C base, gdd5min_est is the minimum growing degree day sum on 5 deg C base, dtymax_est is the maximum difference between the warmest month mean temperature and the coldest month mean temperature, premin_est is the minimum annual precipitation for successful sapling establishment.

Table S3 Threshold values of woody PFTs' partial bioclimatic and eco-physiology parameters in modified LPJ model

Parameters \ PsPFTs	TrBE	TrBR	TeBE	TeBS	BBS	TeNE	BNE	BNS	TeSS	TeDS	MES	AlSS	AlDS
rootdist	0.85 0.15	0.7 0.3	0.7 0.3	0.65 0.35	0.9 0.1	0.6 0.4	0.9 0.1	0.9 0.1	0.7 0.3	0.6 0.4	0.9 0.1	0.8 0.2	0.75 0.25
Gmin ($mm\cdot s^{-1}$)	0.5	0.5	0.5	0.5	0.3	0.3	0.3	0.3	0.3	0.5	0.3	0.5	0.5
Emax ($mm\cdot d^{-1}$)	7.0	7.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
turnover_leaf (yr^{-1})	0.5	1.0	1.0	1.0	1.0	0.5	0.5	1.0	1.0	2.0	1.0	1.0	2.0
turnover_root (yr^{-1})	0.5	1.0	1.0	1.0	1.0	0.5	0.5	1.0	1.0	1.0	0.5	1.0	1.0
Leaflong (yr)	2	0.5	1	0.5	0.5	2	2	0.5	0.5	1	1	0.5	0.5
fireresist	0.12	0.5	0.5	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
phengdd5ramp				200	200			100	200	200		200	200
tcmin_est (℃)	15.5	12	3	-17		-2	-32.5		-17	-17	-32.5		
tcmax_est (℃)			18.8	0	-2	22	-2	-2	-5	-5	-2	-2	-2
twmin_est (℃)	10		10			10				10			
gdd5max_est (℃)											1600	1600	1350
gdd5min_est (℃)	0	0	1200	1200	350	900	600	350	900	1350	300	300	350
dtymax_est (℃)											20	25	30
dtymin_est (℃)				30		20		20	30	30			

In this table, TrBE is the Tropical Broad-leaved Evergreen, TrBR is the Tropical Broad-leaved Raingreen, TeNE is the Temperate Needle-leaved Evergreen, TeBE is the Sub-tropical Broad-leaved Evergreen, TeBS is the Temperate Broad-leaved Summergreen, BNE is the Boreal Needle-leaved Evergreen, BNS is the Boreal Needle-leaved Summergreen, BBSis the Boreal Broad-leaved Summergreen, TeSS is the Temperate Summergreen Shrubs, TeDS is the Temperate Desert Shrubs, MES is the Mountainous Evergreen Shrubs, AlSS is the Alpine Summergreen Shrubs, AlDS is the Alpine Desert Shrubs, and rootdist is the distribution proportion of fine roots in the upper and lower soil layer, gmin is the minimum canopy conductance, emax is the maximum transpiration rate, turnover_leaf is the leaf turnover time, turnover_root is the fine root turnover time, leaflong is the leaf longevity, fireresist is the fire resistance (0-1), phengdd5ramp is the growing degree day requirement to grow full leaf coverage, tcmin_est is the minimum coldest month mean temperature for the last 20 years, tcmax_est is the maximum coldest month mean temperature for the last 20 years, twmin_est is the minimum warmest month mean temperature, gdd5max_est is the maximum growing degree day sum on 5 deg C base, gdd5min_est is the minimum growing degree day sum on 5 deg C base, dtymax_est is the maximum difference between the warmest month mean temperature and the coldest month mean temperature, dtymin_est is the minimum difference between the warmest month mean temperature and the coldest month mean temperature.

Up-scaling from plot level to country level: estimating forest carbon balance based on process-based modeling, National Forest Inventory data and satellite images

Härkönen, S., Lehtonen, A., Manninen, T., Muukkonen, P., Mäkelä, A., Peltoniemi, M.

Abstract

Climate-sensitive process-based models are essential for predicting forest growth and carbon balance in changing environmental conditions, but they are often difficult to apply with the input data from basic forest inventories. Climforisk LIFE+ project has improved the data availability in Finland by producing raster maps of stand-level variables such as leaf area index (LAI), fraction of photosynthetically active radiation (fAPAR), mean stand height, stand basal area and biomasses covering the whole country with 100m resolution. In addition, areas with high drought risk were mapped based on digital elevation model and other map resources.

The raster maps were produced based on the National Forest Inventory (NFI) data from years 2004-2008 and k-nearest-neighbor (kNN) imputation using on 18 Landsat 5 TM satellite images (bands 1-5 and 7) from years 2004-2007. The generalized maps were evaluated by comparing the field-measured and imputed basal area estimates, the results showing similar accuracy (RMSE% of 45.8-64.4%) as those in the previous studies. Further, the LAI maps were compared with the MODIS LAI (500 m resolution) products, the results showing that the estimated LAIs were on average at the similar level, even though there were regional differences between the estimates.

The testing database is currently being applied in modeling studies with process-based growth models, such as HIFI-MS (Helsinki Integrated Forest Impact Model System), for predicting the carbon balance in different climate scenarios. Further information and the map products of LAI and fAPAR can be found in the Climforisk web site: http://www.metla.fi/life/climforisk/

1 Introduction

Climate-sensitive process-based models are essential for predicting forest growth and carbon balance in changing environmental conditions. However, they are often difficult to apply with basic forest inventory data and require complex parameterization. In addition, gathering and processing of input data for testing the models is very laborious.

In order to facilitate developing and testing of process-based growth models, Climforisk project at the Finnish Forest Research Institute has produced a data-model platform, which contains country-wise maps of the common forest characteristics, which can be directly applied to the process-based growth modeling and carbon balance estimation.

The maps were produced based on the National Forest Inventory (NFI) data from years 2004-2008 and k-nearest-neighbor (kNN) imputation using 18 Landsat 5 TM satellite images from years 2004-2007, and they cover all the forested areas of Finland with 100 m resolution.

2 Material and methods

The estimates of the target variables (e.g. biomasses, leaf area index and fraction of photosynthetically active radiation) were first estimated for the Finnish National Forest Inventory (NFI) sample plots using the tree- and stand-level inventory data. These estimates were generalized for all the forested areas in Finland using k-nearest-neighbour imputation based on similarity in the Landsat 5 TM image bands (see Härkönen et al. 2011).

The NFI data were from 2004-2008 consisting the whole Finland (excluding the north-most part in the Lapland). Only the NFI plots, which consisted of only a single stand and where the productivity was >1 m^3 ha^{-1} $year^{-1}$, were selected to the analysis (in total 29 319 sample plots, out of which 21 572 were of heath forests and the rest peat land forests).

The NFI data contained the diameter and tree species for the tally trees, and tree heights and crown base heights for the sample trees. Tree heights and crown base heights for all the tally trees were estimated using a multivariate linear mixed-effects model with species-specific parameters designed for multi-response NFI data (Eerikäinen 2009). Other NFI data used in the study contained stand basal area (BA, m^2 ha^{-1}), stand crown coverage (%), site type (Cajander 1925) and tree species.

Tree-wise needle, stem, branch, stump and coarse root biomasses for conifers were estimated using multivariate biomass equations of Scots pine (Repola 2009), Norway spruce (Repola 2009) and for deciduous trees with birch models by Repola (2008). The fine root biomasses were estimated using site-type specific needle to fine root biomass ratios (see Härkönen et al. 2011). Leaf area indices were calculated based on the stand-level leaf biomass estimates and the specific leaf areas (Scots pine: Stenberg et al. 2001, Palmroth et al. 1999; Norway spruce: Stenberg et al. 1999; birches: Lintunen et al. 2011, Sellin et al. 2006, Parviainen et al. 1999). Fraction of photosynthetically active radiation, f_{APAR}, was calculated for the NFI sample plots utilizing the Lambert-Beer formula based on the effective extinction coefficient k_{Eff} (Duursma & Mäkelä 2007) and the all-sided leaf area index (Härkönen et al. 2010).

Imputations of the plot-wise data to the regional level were run based on a teaching data set, which was created by linking the NFI-based estimates with the Landsat 5 TM pixel values (bands 1-5 and 7) at those plots. In the imputation all the forested pixels were assigned with the most similar neighbor's (k=1) value in the teaching data set. The imputations were evaluated by comparing the field-measured and imputed basal area estimates (leave-one-out cross validation).

3 Results

The data platform contains raster maps of several stand-level variables: leaf area index (Fig. 1), fraction of photosynthetically active radiation (Fig. 2), mean stand height, stand basal area and tree biomasses with 100m resolution. In addition the database contains map of the areas with high drought risk, which were recognized using digital elevation model, digital topographic maps and other GIS resources.

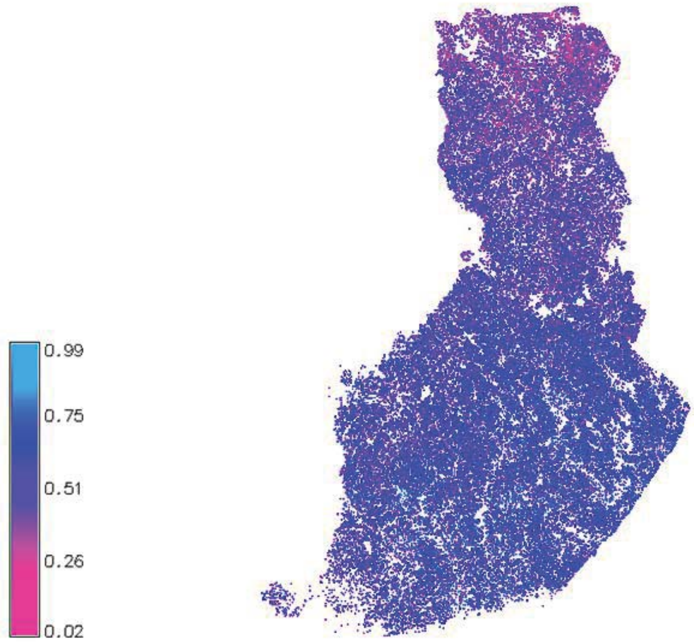


Fig. 1. Fraction of photosynthetically active radiation with 100m resolution.

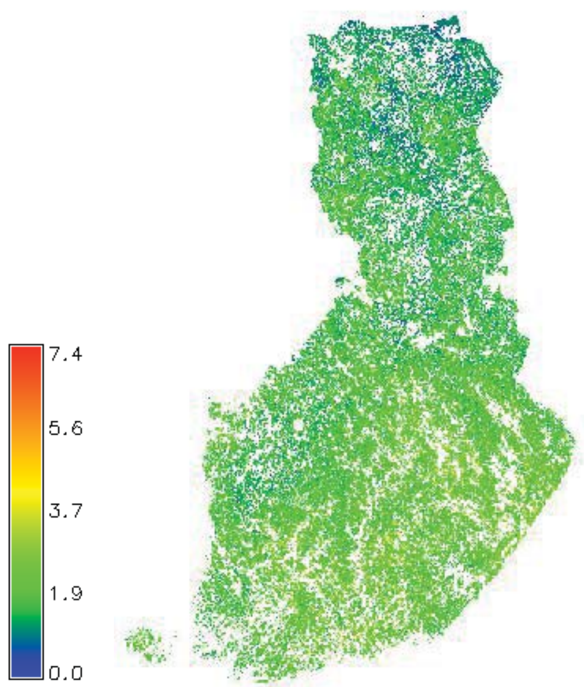


Fig. 2. Effective LAI (m^2 m^{-2}) with 100m resolution.

The imputations were evaluated by comparing the field-measured and imputed basal area estimates, the results showing similar accuracy (RMSE% of 45.8-64.4%) as those in the previous studies (e.g. Tuominen 2007). Further, the LAI maps were compared with the MODIS LAI (500 m resolution) products. The estimates were on average at the same level, but there was a lot of scatter between them. One of the main differences between these products is that our LAI is calculated based on only the forested pixels and the estimates are not mixed with other land use types or water, which is the case with the original MODIS LAI estimates.

4 Conclusions

The produced database contains raster maps of variables applicable directly for estimating carbon balance and forest growth with process-based models. The database contains also maps expressing the areas with high drought risk. These data can be easily applied with the current climate data available from Finnish Meteorological Institute (10 x 10 km resolution) in order to produce up-to-date estimates of e.g. carbon balance in the country level (see Härkönen et al. 2011).

The data-model platform is currently being applied with process-based growth models, such as HIFI-MS (Helsinki Integrated Forest Impact Model System; unpublished), to predict the carbon balance with different climate scenarios. Future goals include appending the LAI estimates with the ground vegetation LAI and linking the Yasso07 soil carbon model (Tuomi et al. 2011) to the calculation process in order estimate the net ecosystem exchange of the forests. Reliability of all the produced estimates, e.g fAPAR and drought risk, should be evaluated further in the future.

Climforisk project is currently producing a web site, where the contents of the database will become freely available for examination and downloading. Further information can be found in the Climforisk web site: http://www.metla.fi/life/climforisk/.

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Impacts World 2013, International Conference on Climate Change Effects,
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Bridging the global and regional scales in climate impact assessment: an example for selected river basins

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Abstract— Policy relevant information on climate change impacts is available from global and regional impact assessments. The global model results are used by policy makers for the global-scale assessments and could be considerd as the boundary conditions for the regional modelling studies, while information from the regional scale, which is applicable for creating regional adaptation strategies, can help to improve global simulations. Ideally, the results from both scales should agree in trend direction and strength of impacts. However, this implies that the sensitivity of impact models from both scales to climate variability and change is comparable. In this study we compare hydrological results simulated by global (LPJmL and WaterGAP) and regional (SWIM) impact models for the water sector in two regions under reference and scenario conditions. The aim is to start the discussion on how to bridge the global and regional scales for impact assessment in order to provide more reliable information on future projections for the global and regional decision makers.

Index Terms— Climate impact models, global and regional scale, ISI-MIP, Rhine, Niger.

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1 Introduction

Climate change is a global phenomenon, but the impacts manifest at the regional scale (IPCC 2007). The regional scale is also the scale, where most adaptation measures can be planned and implemented (Hattermann et al. 2008). However, a global view on climate change impacts is important because certain developments in a distant region or at the global scale can influence driving forces in the region under study, for example when looking at changes in crop distribution and crop yield having possibly a global impact via the global food market. The interplay of global and regional drivers requires bridging the scales in impact assessment. Thereby, it is desirable that results from the regional and global scales are in line for the same sectors.

Impact models for the global and regional scales of assessment often implement common processes, with regional models typically having finer resolution in temporal and spatial scales as well as in process representation. Besides, calibration and validation of regional models usually include data of with fine spatial and temporal resolution leading to higher reliability of results for planning of adaptation measures, whereas calibration and validation of global models is either not possible or is substituted by testing for selected regions considering aggregated variables . On the other hand, global models are designed to supply consistent impact assessment for larger regions and whole continents and allow for direct comparisons between regions.

In this study we investigate the consistency of climate change impact assessments on hydrological processes in two selected river basins, one in Europe and one in Africa, using mainly two global models (LPJmL and WaterGAP) and one regional impact model (SWIM). Though climate change impacts are often reported as relative change rates, we investigate differences in both absolute values (runoff, discharge) as well as their relative changes under climate change scenarios.

We analyze reasons for disagreement in impact projections by harmonizing inputs and comparing model assumptions. To minimize the differences in projections, we run the regional model SWIM with the coarse-resolution climate input data as used in the global models. The results of the comparison of model outputs for two river basins in Africa and Europe are presented.

2 Methods and Data

2.1 Models

The eco-hydrological model SWIM integrates the relevant hydrological and plant processes like evapotranspiration, percolation, surface runoff, interflow, groundwater recharge, plant water uptake, vegetation dynamics and river routing (Krysanova et al. 1998, Hattermann et al. 2005) at the regional scale. A three-level scheme of spatial disaggregation from basin to subbasins and finally to hydrotopes is used in SWIM. A hydrotope is a set of elementary units in the sub-basin, which have the same geographical features like land use, soil type, and average water table depth. Water fluxes, plant growth and nutrient dynamics are calculated for every hydrotope, where up to 10 vertical soil layers can be considered, on a daily time step. The outputs from the hydrotopes are aggregated at the subbasin scale, taking water and nutrient retention into account. The lateral fluxes are routed over the river network, considering transmission losses e.g. in wetlands. SWIM is usually calibrated using observed runoff by adjusting a few parameters for river routing, evapotranspiration and soil properties.

The Dynamic Global Vegetation and Hydrology Model LPJmL (Sitch et al., 2003; Gerten et al., 2004) computes establishment, abundance, vegetation dynamics, growth and productivity of the world's major plant functional types, as well as the associated carbon and water fluxes. The model is typically applied on a grid of 0.5°×0.5° longitude/latitude and at daily time steps. Carbon fluxes and vegetation dynamics are directly coupled to water fluxes. Modeled soil moisture, runoff and evapotranspiration were found to reproduce observed patterns for most of the test regions well and the model's quality is comparable to that of the stand-alone global hydrological models (Gerten et al., 2004, 2008). The version used in this study considers feedbacks of CO_2 increase on biomass production and stomata processes. In the river routing module of LPJmL (described by Rost et al., 2008) each grid cell is considered to have a surface water storage pool representing the water storage and retention in reservoirs and lakes. River routing is implemented as a cascade of linear storage functions. LPJmL is applied without calibration of the hydrological processes.

The large scale hydrological model WaterGAP (Water – Global Assessment and Prognosis) was developed to provide a basis both for assessment of the current state of water resources and water use, and for gaining an integrated perspective of impacts of global change on the water sector (Döll et al. 2012, Flörke et al. 2013). WaterGAP3 consists of two main components: a global water use model and a global hydrology model. The aim of the hydrological model is to simulate the characteristic macro-scale behaviour of the terrestrial water cycle in order to estimate renewable water resources. Based on daily meteorological fields, the model calculates the daily water balance for each grid cell, taking into account physiographic characteristics like soil type, vegetation, slope and aquifer type. Cell runoff is routed to the catchment outlet based on a global drainage direction map, taking into account the hydrological impact of lakes, wetlands, reservoirs, and dams. The model is calibrated by adjusting one free parameter controlling the fraction of total runoff from effective precipitation in order to minimize the error in simulated long-term annual discharge. WaterGAP was applied in this study on a 0.5°×0.5° grid.

These three models have been chosen for our study because they represent typical state-of-the-art models currently applied in impact studies: uncalibrated global impact models, global impact models calibrated for the variables under study, and calibrated regional impact models considering processes with finer resolution and some additional regional features not implemented in global models.

The results of these three models are compared against the results of a set of global hydrological models applied in the framework of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; Warszawski et al., 2013) comprising a set of nine global hydrological models, one global land-surface model and one dynamic global vegetation model, among them LPJmL and WaterGAP (see also Schewe et al. 2013).

2.2 Climate data

Important for the impact model intercomparison is that the models are driven by the same scenario data, whereby this study focuses on sensitivity to climate change. The climate data used have been provided by ISI-MIP. Five Earth System Models (HadGEM2-ES, IPSL-5 CM5A-LR, MIROC-ESM-CHEM, GFDL-

ESM2M, NorESM1-M) which have been bias corrected using a trend-preserving method and the WATCH data (Weedon et al. 2011) as reference are stored on a 0.5°x0.5° grid with the daily temporal resolution (Hempel et al. 2013). The “Representative Concentration Pathways” (rcp) cover different emissions and land-use change projections. In this study only the high end scenario 8.5 was used.

Other data important to set-up the impact models at both scales are soil and land cover information, the elevation and hydrological information such as the river network and were taken from global data sources.

The observed runoff data for the gauges Rees (Rhine) and Dire (Niger) have been provided by the Global Runoff Center (GRDC 2013).

2.3 Two river basins

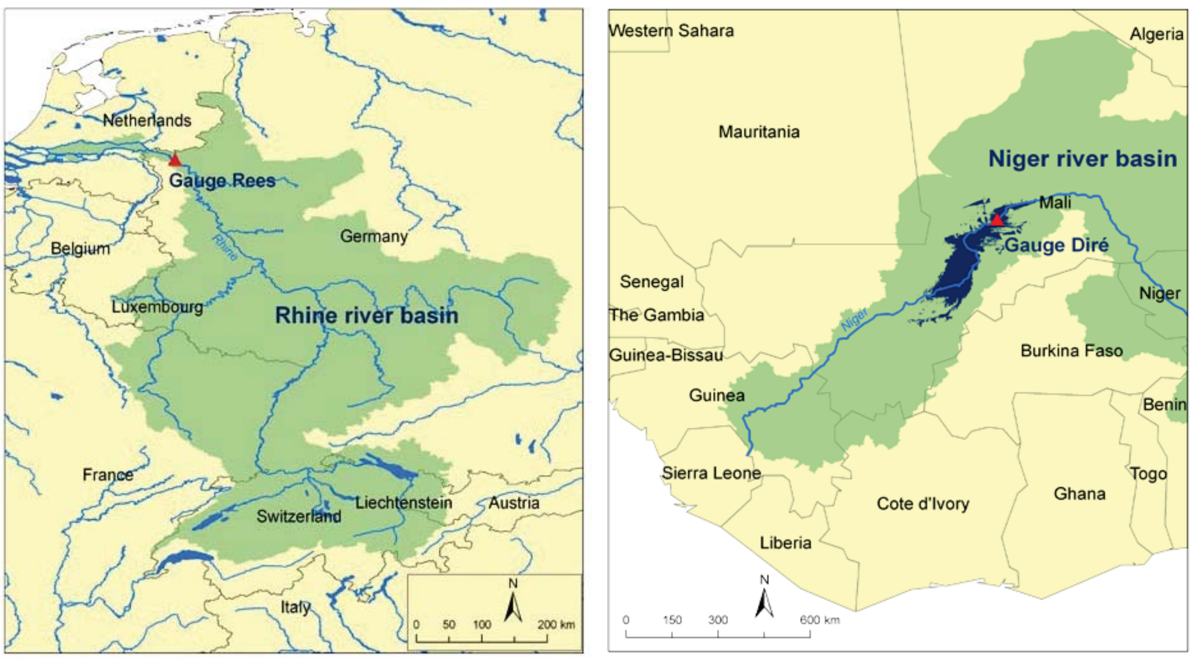


Figure 1: The basins of the Rhine and Niger rivers and the gauge stations Rees (Rhine) and Dire (Niger). The blue area in the Niger catchment indicates thearea of the Inner Niger Delta.

The Rhine river basin covers an area of 185,000 km^2 and spreads over nine countries (Table 1). The basin can be subdivided into three major hydrological areas: the Alpine area, the German Middle Mountain area and the Lowland area. In the Alpine part the annual precipitation is about 2000 mm, in the lowland between 570 and 1100 mm. The Rhine is moderately influenced by human water management like dams.

The Upper Niger Basin at the gauging station Dire covers an area of about 340,000 km^2. It spreads over the countries Guinea, Mali and a small part of the Ivory Coast. The catchment is subject to enormous seasonal and interannual variation in rainfall and river flow (Zwarts et al., 2006) and rainfall is very unequally distributed, where the headwater regions receive up to 2000 mm of rainfall during the rainy season (July–October) and the northern regions only 200–500 mm. The catchment area of the gauge Dire includes the Inner Niger Delta (IND), a seasonally inundated floodplain and network of tributaries, channels, swamps, and lakes providing vital habitats supporting livelihoods in fishing, farming, and stock farming (Zwarts et al., 2006) for 1.5 million people. In the literature, the area of the Inner Delta varies from 36,000 km^2 (Kuper et al., 2003) to 80,000 km2 (Schuol et al., 2008).

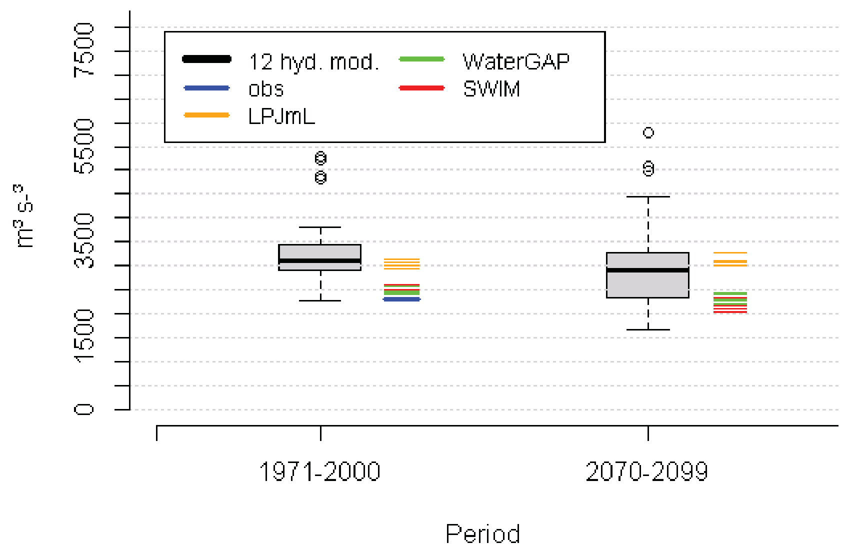
Table 1: Characteristics of the two river basins.

	Rhine until gauge Rees	Niger until gauge Dire
Area	170.000 km^2	340.000 km^2
Altitude range (mean, max, min)	495, 4725, 10	380, 1407, 220
Average temperature (1971-2000) [°C]	8.6	26.5
Annual precipitation (1971-2000) [mm]	987	1320
Dominant land use [%]	cropland 38, forest 25, grassland 9	Forest 34, savanna 30, cropland 24

3 Results

The results of the global and regional impact models are compared for the Rhine and Niger basins located in temperate humid and subtropical monsoon types of climate, respectively. Figure 2 shows the long-term average annual runoff of the reference (1971-2000) and the scenario periods (2070-2099) simulated by several global and one regional model using the five ISI-MIP scenarios as climate drivers: a) the range of results for the twelve global hydrological models, b) the respective results of the LPJmL, WaterGAP and SWIM models, and c) the observed values for the reference period. In both basins, most global models notably overestimate runoff and thus water availability and the same can be stated for the LPJmL model. While the bias is moderate for the Rhine basin representing a temperate climate, it is much more pronounced for the Niger basin. The WaterGAP model, also global but calibrated for the water balance at the outlet of the river basin, gives a very good reproduction of the Rhine water balance, however, it overestimates the runoff and consequently water availability for the Niger basin. The SWIM model, being calibrated to the specific hydrological features of the basins (see Aich et al. 2013) and considering also the wetland dynamics, gives a good reproduction of the long-term runoff, only slightly overestimating the observed values. The *relative changes* simulated by the models until 2099 are, however, comparable at both scales with a decrease in mean annual runoff simulated by the global as well as by the regional models in the Rhine basin and no clear trends in the Niger basin.

a) Rhine



b) Niger

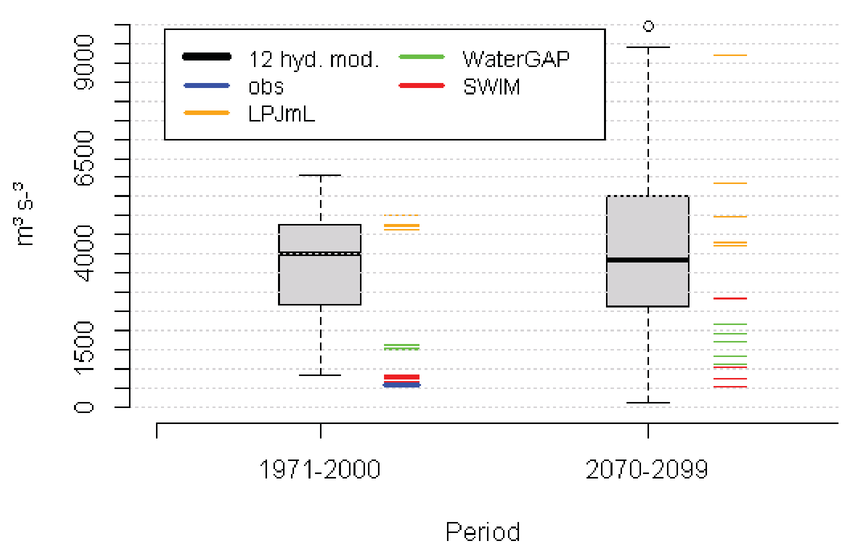


Figure 2: The boxplots summarize the long-term average daily runoff simulated by 12 global hydrological models fed by 5 ISI-MIP climate runs (reference period 1971-2000 und scenario period 2070-2099). The blue line indicates the observed value for the reference period, and the red, green and orange lines - the values simulated by the regional (SWIM) and global (LPJmL and WaterGAP) models fed by the same five

climate runs. Left: Rhine basin, gauge Rees; right: Niger basin, gauge Dire

Figure 3 gives the long-term average daily runoff observed and simulated for the Rhine and Niger basins for the period 1971-2000 driven by the GCM HadGEM2 (top), and the relative changes until end of this century as the differences between the periods 2099-2070 and 1971-2000 (bottom). The simulated values of the LPJmL model overestimate the observed values of the Rhine river at gauge Rees by approximately 35 %, which is a moderate discrepancy when considering that the model was not calibrated for hydrological processes in the basin. Smaller are the biases for the results of the WaterGAP (~11 %) and the SWIM models (~14 %).

Looking at the relative changes, one can see that all three models agree astonishingly well in the seasonal changes for the Rhine river, and a small increase in winter and early spring and a stronger decrease in the summer months can be stated.

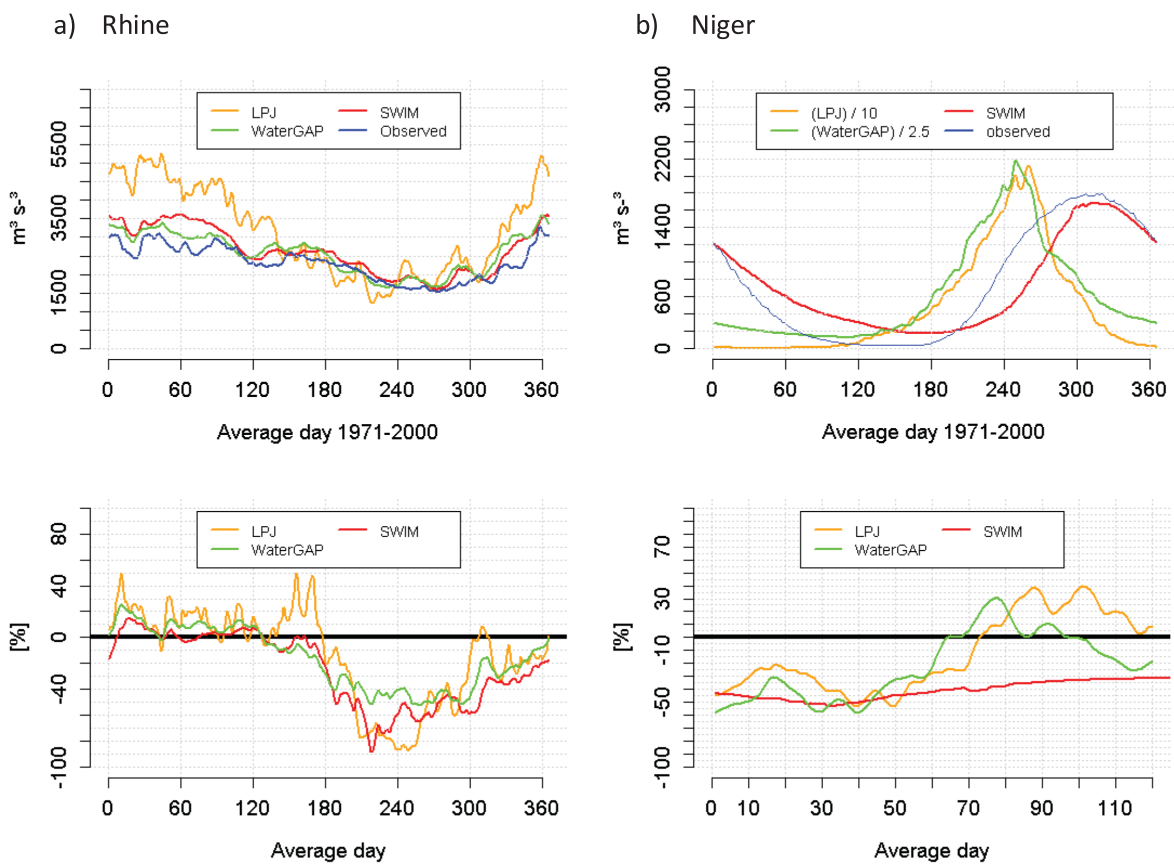


Figure 3: Top: Long-term daily runoff for the period 1971-2000 (left: Rhine at gauge Rees, right: Niger at gauge Dire). The values of LPJmL for the Niger are divided by ten, and the values of WaterGAP by 2.5. Bot-tom: The relative changes in daily runoff (difference 2070-2099 minus 1971-2000)

For the Niger river, the results of the single models show larger differences. The LPJmL model overestimates the observed runoff and therefore water availability by approximately 550 %, the WaterGAP model by ~110 % and the SWIM model underestimates the observed runoff by ~6 %. The overestimation of runoff by the LPJmL and WaterGAP models can partly be explained by the Inner Niger Delta, periodically flooded by the Niger river during the monsoon season, where about 40-50 % of the inflowing water evaporate. Also, flow velocity in the delta decreases and the hydrograph of the outflow is smoothed and the flood peak delayed by approximately two months, a feature only reproduced by SWIM with integrated inundation module.

The relative changes until 2099 are mostly negative, the ones of LPJmL and WaterGAP are in their seasonal development more comparable, possibly due to the lack of an inundation module (results only shown for days of the high flow period).

4 Discussion and Outlook

Comparing the simulation results of the LPJmL, WaterGAP and SWIM models for the Rhine and Niger basins we can see that the models agree much better for the Rhine than for the Niger, and the relative changes agree much better than the absolute values in both cases. The differences are larger for the absolute values, especially under arid and monsoon type of climate. This is a pattern also visible in other catchments worldwide for the LPJmL model (Biemanns et al. 2009). The larger differences for the LPJmL model can be explained by the fact that the model is not calibrated to the local hydrological features. The WaterGAP model, on the other hand, also running at the global scale shows a better reproduction of the water balance in both river bains discussed here. However, such specific feature as the IND in this study make internal hydrological processes more complex, and require an adaptation of impact models. Naturally, this can be easier done by a regional impact model adapted to the regional scale using specific data for the model set-up.

The largest challenge for hydrological models when simulating the long-term water balance is to estimate evapotranspiration correctly. In the Rhine basin, where the runoff coefficient (share of precipitation reaching the surface waters) is relatively high with more than 20 %, the hydrological results are not so sensitive to uncertainties in calculating the losses by evapotranspiration. However, in the Niger basin, where about 95 % of precipitation is lost to the atmosphere and only 5 % reach the rivers, small changes in evapotranspiration have a huge impact on river runoff and therefore water availability. It seems like global hydrological models have a tendency to overestimate runoff – at least, this follows from examples of these two basins. This has to be taken into account when using results of global hydrological models in follow up investigations, for example for estimating water availability for irrigation at the global scale or for analyzing the trend in per capita water availability under climate change (Schewe et al. 2013), while the relative changes can still be of use.

This study is only a first step in comparing hydrological results and impacts at the global and regional scales, and more studies including more regions and more regional models and investigating the processes in more detail have to follow.

5 Acknowledgements

We would like to thank the ISI-MIP team for providing the climate data and the data of the global hydrological models applied in this study.

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Sea-level rise damage and adaptation costs: A comparison of model costs estimates

Andries F. Hof, Chris Hope, Detlef P. van Vuuren

Abstract—One of the main challenges for comparing costs with benefits of climate change policy is that the knowledge on climate change damage is very meagre. An exception is sea-level rise, for which information on adaptation costs and damages has recently been provided on country-level by the ClimateCost project, using the DIVA model. The often-used Integrated Assessment Models (IAMs) RICE and PAGE, which have been used for cost-benefit analyses of climate change, include separate modules for sea-level rise. This paper compares the damage and adaptation costs estimates of these IAMs with the projections by the ClimateCost project. Large differences, on a regional as well as on a global level, are found. On average, RICE and PAGE project higher damages than ClimateCost. Based on our results, we suggest the following improvements in sea-level rise damage projections in IAMs: i) as damages strongly depend on the level of adaptation, IAMs should include adaptation as a decision variable; ii) as damages, measured in absolute terms, seem to depend mainly on sea-level rise and less on socio-economic variables, absolute damages could be represented simply by a function of sea-level rise and the level of adaptation in IAMs.

Index Terms— Adaptation costs, Climate change damages, Integrated Assessment Models, Sea-level rise

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1 Introduction

Assessments of the cost and benefits of climate policy have been performed since the beginning of the 1990s, with Nordhaus as one of the pioneers (Nordhaus, 1991, Nordhaus, 1992, Nordhaus, 1994, Manne et al., 1995, Hope et al., 1993, Tol, 1999). These assessments rely on Integrated Assessment Models (IAMs), that aim to describe the complex relations between environmental, social and economic factors that determine future climate change and the effectiveness of climate policy (Weyant et al., 1996, Harremoës and Turner, 2001, Hope, 2005). A major challenge of applying IAMs to compare the costs and benefits of climate policy is that literature on climate damages on a global scale – on which damage estimates in IAMs are based – is very limited (Tol, 2009). There are relatively few studies focusing on global impacts, and hardly any global damage estimates exist for global warming levels of more than 3°C relative to pre-industrial times, while a warming in the order of 3°C to 6°C at the end of this century is expected without climate policy (van Vuuren et al., 2008). As such studies form the basis of the climate damage estimates in cost-benefit studies, heroic assumptions need to be made as to the estimates of climate change damages, especially for climate change above 3°C. Related to this, Patt et al. (2010) argues that also the representation of adaptation within IAMs needs to be improved.

1

Recently, detailed estimates of the economic effects of climate change and the costs and benefits of adaptation were provided within the European FP7 ClimateCost project (Brown et al., 2011). Physical and monetary estimates were provided on country-level for different impact categories: coasts, river floods, energy, health, agriculture, ecosystems, and windstorms. Comparing such estimates with those of IAMs provides insight in the robustness of climate change damage estimates of IAMs, and thereby of the benefits of mitigation and adaptation policies. However, most IAMs that focus on cost-benefit analyses do not distinguish specific impact categories, but include more aggregated impact functions. The exception is sea level rise, for which two often used IAMs – RICE and PAGE – include separate impact functions.

The overall aim of this study is to provide more insight in the robustness of climate change damage estimates of IAMs, and thereby of the benefits of mitigation and adaptation policies. A secondary aim is to provide suggestions for improving the damage and adaptation cost estimates of sea-level rise in IAMs.

2 Scenarios

Five sets of scenarios, all taken from the ClimateCost project (Brown et al., 2011), are included in this assessment. These scenarios reflect possible sea-level rise based on academic literature, ranging from 0.28m (climate mitigation) to 1.75m in the 2080s, compared with pre-historical levels[1] (Table 1). The A1B(IMAGE) and E1 scenarios (Lowe et al., 2009, Pardaens et al., 2011) were derived following the methodology of Meehl et al. (2007) based on a patterned rise in sea level from the ENSEMBLES HadGEM-A0 model, where some oceanic areas rise at faster rates than others, based on observations. A range of sea-level rise is given due to uncertainities in ice melt contribution, based on Meehl et al. (2007) and Gregory and Huybrechts (2006). As the IPCC did not indicate an upper bound of sea-level rise, this, together with new scientific evidence, suggests that rises in excess of 1m are considered plausible, although of a lower probability during this century (Nicholls et al., 2011, Rahmstorf, 2008). These higher scenarios are important for land use and adaptation planning. Furthermore, due to the commitment to sea-level rise (i.e. a time lag between oceanic warming and sea levels rising), sea levels would be expected to continue to rise over long time scales, even if greenhouse emissions decrease and temperatures stabilise.

To determine the effect of climate change only, the damages caused by socio-economic change are subtracted from total sea-level rise damages. In this paper, damages are presented for the 2020s (2011-

[1] Note that in ClimateCost, temperature and sea-level changes were reported relative to 1961-1990 levels.

2040), 2050s (2041-2070), and 2080s (2071-2100). For this paper, results are given for the regions EU, USA, Japan, China, India and Africa.

Table 1. Overview of scenarios. Source: Based on Brown et al. (2011)

Scenario	Model / notes	Global mean temperature rise in the 2080s, relative to pre-industrial	Global mean sea-level rise in the 2080s, relative to pre-industral	Socio-economic scenario
H++	High impact rise, low probability. Globally uniform rise	n/a	1.75m	A1B
High-end	Representative of higher rise in post-IPCC AR4 scenarios. Globally uniform rise.	n/a	1.1m	A1B
A1B(IMAGE) 95%	Medium-high emission scenario of patterned sea-level rise from HadGEM-A0.	3.8°C	0.56m	A1B
A1B(IMAGE) Mid			0.47m	A1B
A1B(IMAGE) 5%			0.38m	A1B
E1 95%	Mitigation patterned sea-level rise from the HadGEM-A0.	1.85°C	0.43m	E1
E1 Mid			0.37m	E1
E1 5%			0.28m	E1
No sea-level rise	Hypothetical rise to act as a baseline to assess the effects of relative land levels and socio-economic change.	0°C	0m	Results averaged from A1B and E1 model runs

Each climate scenario was mapped to its equivalent socio-economic scenario (Table 1). In the A1B scenario, global population continues to rise until mid-century at 9.5 billion people, before declining to 7.5 billion in 2100. In the E1 scenario, population increases to 9 billion people, declining to a similar level as A1B in 2100. World GDP increase to $650 trillion (A1B) and $550 trillion (E1) in the 2090s.

3 Model and costing methodology

3.1 DIVA model

The ClimateCost project (Brown et al., 2011) used the DIVA model to determine global impacts (Hinkel and Klein, 2009, Hinkel, 2005, Hinkel et al., 2012). DIVA is driven by climate and socio-economic scenarios, combined with adaptation options, through a number of modules to determine bio-geophysical impacts and associated costs. To undertake this, DIVA breaks the world's coastline into approximately

12,000 linear segments (average length 85km) and associates each segment with around 100 pieces of socio- and geophysical data. The sea-level rise scenarios are downscaled to these segments and combined with local natural changes in land level (uplift / subsidence) (Peltier, 2000a, Peltier, 2000b), except in 76 of the world's deltas where actual levels of subsidence are applied, following work of Ericson et al. (2006). Impacts resulting from extreme events are assessed by raising mean sea levels so that the return period of an extreme event is reduced. No changes to storminess were assumed.

A full description of the methodology for assessing damages can be found in Brown et al. (2011). Damages include the cost of sea floods, coastal river floods, land loss through flooding and submergence, salinisation and those forced to move due to frequent flooding. Impacts and damage depend on the level of protection, and sea and coastal river dikes were modelled in the base year 1995, based on a demand for safety (no dikes where population density is less than 1 person/km^2. Above this threshold, there in an increasing proportion for demand up to the 90% threshold at 200 person/km^2). Two routes were taken assuming: a) No upgrade to adaptation measures as sea levels rise and population density increases; and b) Adaptation was upgraded through raising dike height (to reduce flooding) and by nourishing beaches (to counteract erosion), again based on a demand for safety. Only capital costs are reported. It is assumed that all adaptation is undertaken, and there is no adaptation deficit.

3.2 RICE method

The sea-level rise module of RICE, 2010 version (Nordhaus, 2010), projects sea-level rise and the damages caused by it. For sea-level rise, we use the ClimateCost projections (Table 1), since our aim is to compare damages for the same level of sea rise (in fact, the sea-level rise projections of RICE use the same method as used in the ClimateCost project). The regional damage estimates of RICE were calculated based on the model version which was downloaded from http://nordhaus.econ.yale.edu/.

The damage estimates of RICE are based on the assumption that an estimate of 0.1% of income is a reasonable willingness to pay estimate for preventing a 2.5 °C warming for the coastal sector of the United States (Nordhaus and Boyer, 2000). This assumption is mainly derived from average damages from major tropical storms over the period 1987-1995, which amounted to 0.083% of GDP. For other regions, an index is used that takes into account the share of coastal area in total land area. Furthermore, an income elasticity of 0.2 is used to reflect the rising urbanization and rising land values with higher per capita incomes. For more details see Nordhaus and Boyer (2000).

No distinction is made between damages and adaptation costs in RICE and the projections should be interpreted as estimates including adaptation costs at an “optimal” level (de Bruin et al., 2009).

3.3 PAGE method

As the calculation of sea-level rise is embedded in the PAGE model, the rise in sea level on which the damages are based slightly differs with the ClimateCost scenarios. In the A1B scenario, the difference of the mean levels is negligible up to the 2050s, but amounts to 6cm (with PAGE projecting a higher rise) in the 2080s. In the E1 scenario, PAGE has a 2cm higher projection by the 2050s and 9cm by the 2080s. The uncertainty range in sea-level rise of PAGE is also higher than ClimateCost projections.

In PAGE09 (Hope, 2011), sea level impacts before adaptation are a polynomial function of sea level rise. This function is calibrated for the EU based on a mean estimate of damages of 1% of GDP for a 0.5m sea-level rise – with an uncertainty range of 0.5 - 1.5% of GDP. For other world regions, weight factors ranging from 0.4 to 0.8 relative to the EU are used. In contrast to ClimateCost and RICE, damages in PAGE are probabilistic. In this paper, the mean values, as well as the 10^{th}-90^{th} percentile uncertainty range, are given.

The reduction in impacts due to adaptation is represented by the start date, the number of years it takes to have full effect and the maximum sea level rise for which adaptation can be bought; beyond this, impact adaptation is ineffective. This paper only reports global damage projections from PAGE, assuming effective adaptation.

4 Comparison of results

4.1 Global comparison

Fig. 1 shows how estimates of the sum of sea-level rise damages and adaptation costs compare between the models. The uncertainty ranges of Brown et al. and RICE include uncertainties due to sea-level rise only; PAGE also accounts for uncertainty in damages for a certain rise in sea level. This could explain the larger uncertainty ranges found by PAGE compared to RICE and Brown et al.

The damage estimates of RICE and PAGE are substantially higher than the Brown et al. projections: in the A1B scenario, the mean projections of PAGE are about five times the level of Brown et al. without adaptation and 9 (2020s) to 70 times (2080s) the level of Brown et al. with adaptation. The damage function of RICE lead to even larger differences of 7-10 times the level of Brown et al. without adaptation and 15 to more than 100 times the level of Brown et al. with adaptation. So even though the RICE and PAGE estimates assume that adaptation takes place, their damage projections are even (much) higher than the estimates of Brown et al *without* adaptation. Another interesting finding is that the sum of damages and adaptation as share of GDP in the scenarios with adaptation decrease over time in the Brown et al. projections, whereas they increase in the RICE and PAGE projections. The increasing damage projections of RICE can be explained by the positive income elasticity applied to the damage functions – which lead to increasing damages as share of GDP over time even for constant sea levels. In PAGE, a negative income elasticity is assumed for damages, but still damages are increasing over time as the effect of sea-level rise more than compensates the negative income elasticity.

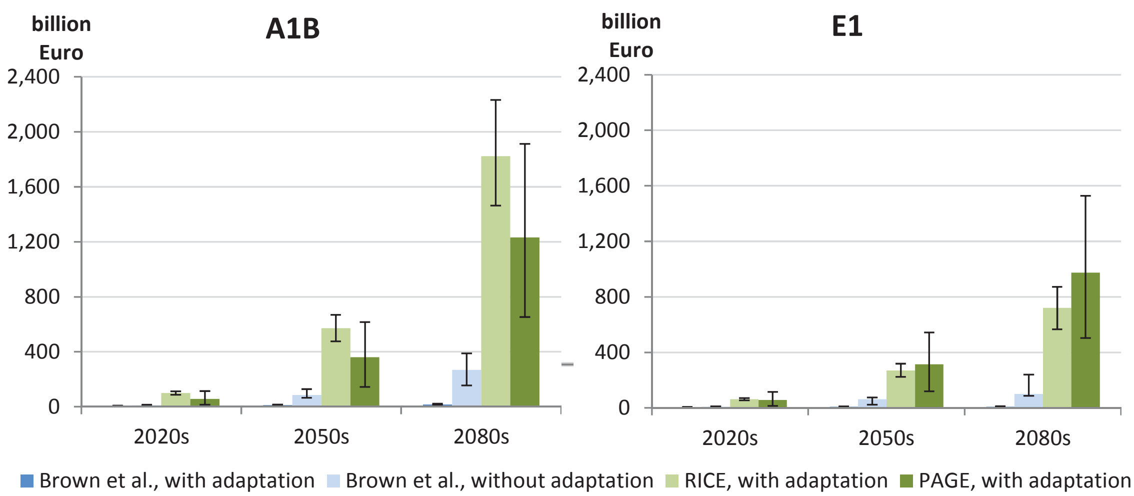

Figure 1. Sum of global sea-level rise damage and adaptation costs under the A1B and E1 scenario (for ClimateCost and RICE, the error bars indicate uncertainty in sea-level rise only, with a 5%-95% confidence interval. For PAGE, the error bars indicate uncertainty in sea-level rise as well as damage projections, with a 10%-90% confidence interval)

4.2 Regional comparison

A regional comparison between the Brown et al. and RICE results (no regional estimates are yet available for PAGE) shows that for the USA, both models show similar projections (Fig. 2). Only at the the end of the century, RICE projections are significantly higher than the ones of Brown et al. with adaptation – but still lower than the ones of Brown et al. without adaptation. This is interesting, as the US damage projections form the basis of the damage projections of all other world regions (Section 3.2).
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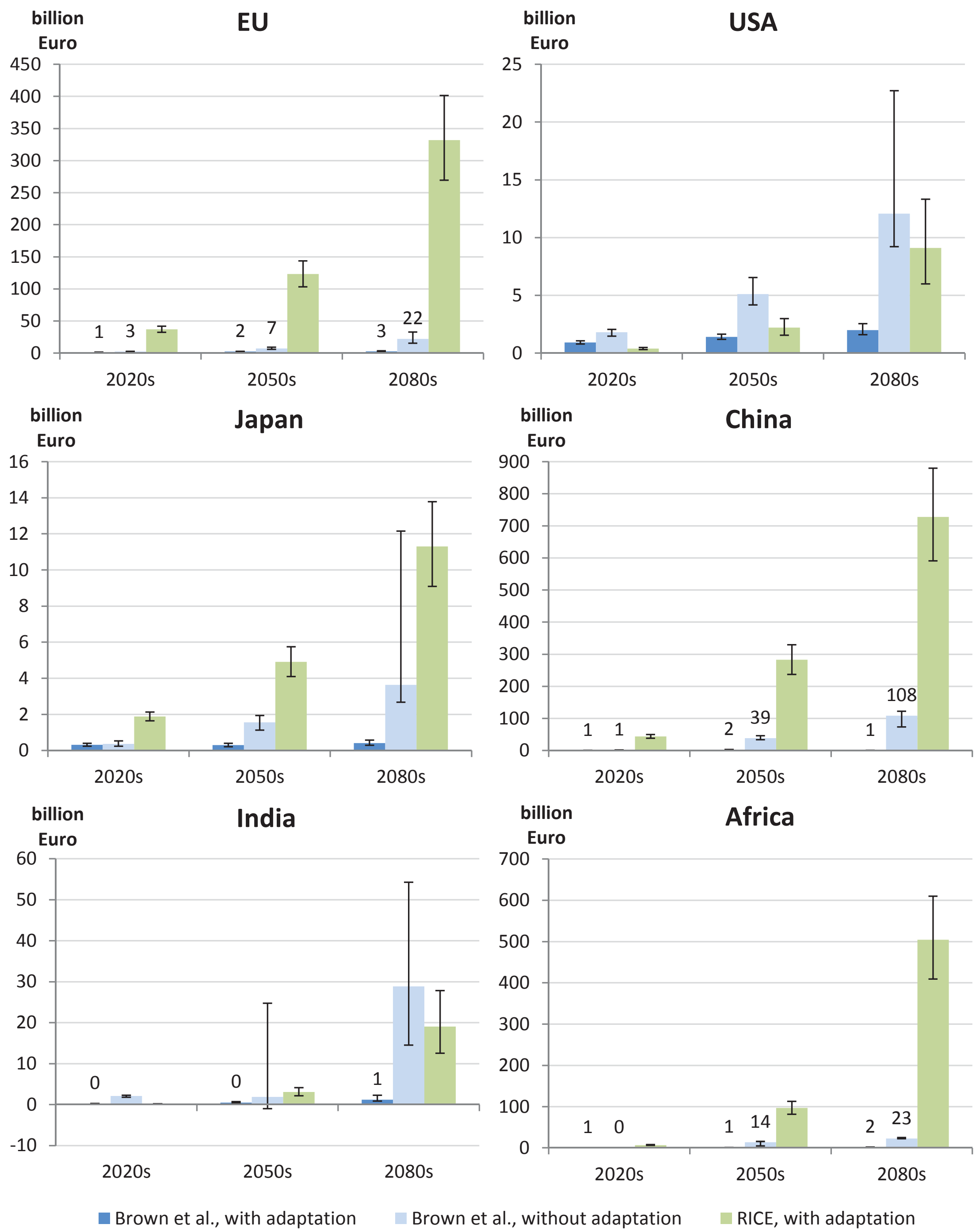

Figure 2. Sum of regional sea-level rise damage and adaptation costs under the A1B scenario (the error bars indicate uncertainty in sea-level rise only, with a 5%-95% confidence interval)

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The results from Brown et al. show that small differences in sea-level rise could have large impacts on damages if no adaptation is undertaken. For Japan, for instance, an average rise in sea level of 47 cm in the 2080s (which is the median estimate in the A1B scenario) results in damages equal to 0.02% of GDP. Would sea-level rise be 56 cm in the same period, damages are projected to be more than 3 times as high. Damages in the USA and India are also very sensitive to small changes in sea-level rise, again assuming no adaptation.

4.3 Comparison of extreme scenarios

For more extreme sea-level rise, the findings are similar to the A1B scenario, although the absolute costs are much higher (Fig. 3). For the USA, Japan, and India, the RICE damage projections are of a similar order of magnitude as the Brown et al. projections without adaptation – but much higher than the Brown et al. projections with adaptation. For the other three regions, the damage estimates of RICE are (much) higher than Brown et al. Another interesting finding is that damages in the H++ scenario by the 2080s are not always higher than damages in the High-end scenario. The reason for this is that some regions face relatively high damages earlier in the century in the H++ scenario, as most of the damages occur at sea-level rise up to 1 meter where most of the infrastructure is located. This implies that the dynamics of sea-level rise damages is much different in Brown et al. projections than in IAMs, the latter of which generally assume gradually increasing damages over time and over higher increases in sea levels.

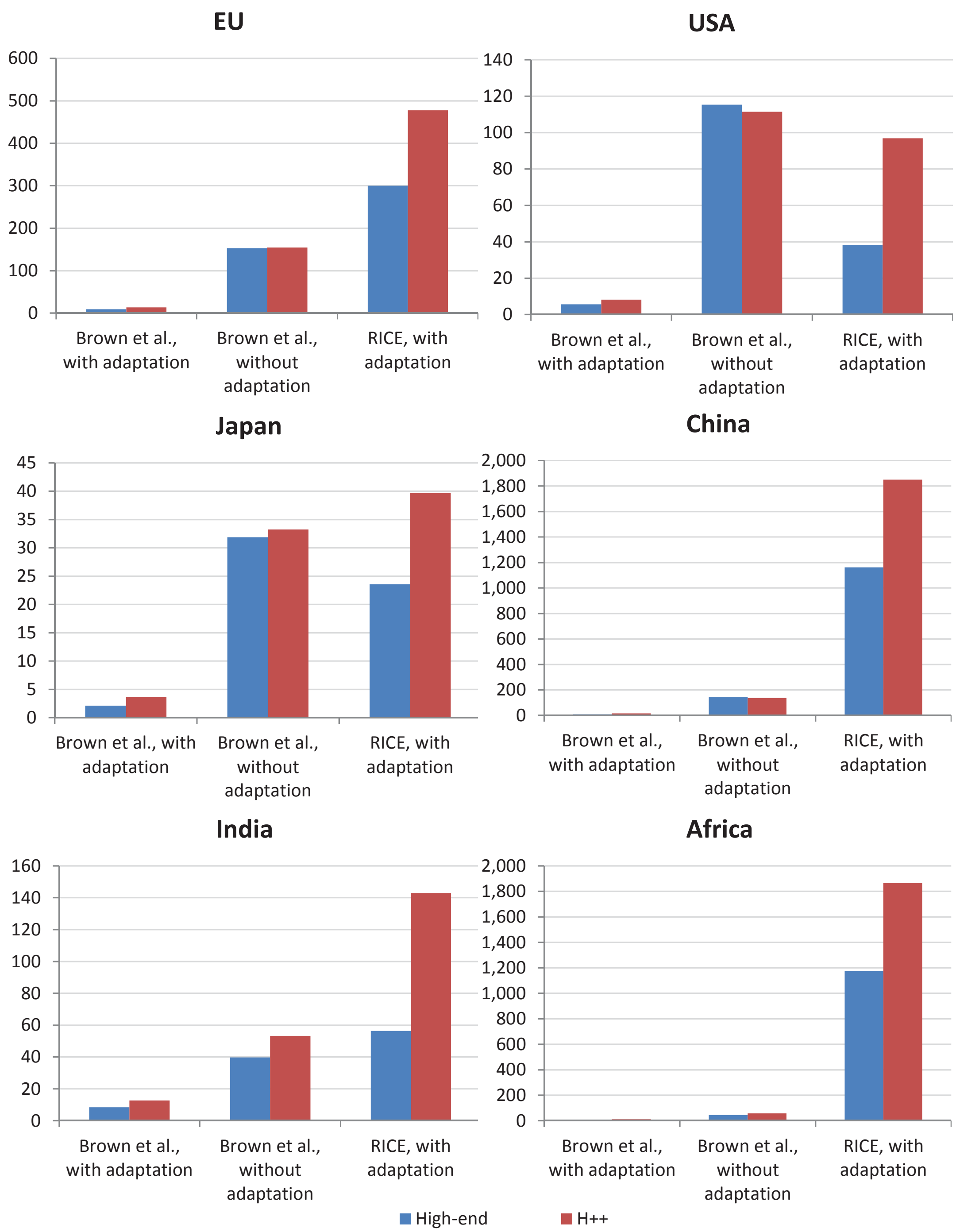

Figure 3. Sum of sea-level rise damage and adaptation costs in the 2080s under extreme sea-level rise scenarios

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4.4 Relationship between sea-level rise and damages

IAMs typically use relatively simple equations or sets of equations to simulate the behaviour of the socio-economic and environmental systems. In RICE and PAGE, damages are a function of sea-level rise and income level relative to the base year (2005 in RICE; 2008 in PAGE). To test whether simple equations can simulate the damages of sea-level rise, Fig. 4 plots annual sea-level rise damages and adaptation costs from Brown et al. as function of sea-level rise. The results of all A1B and E1 scenarios and for all time periods are all plotted in one graph. The left-hand side figures plot adaptation costs or damages in absolute numbers; the right-hand side figures as share of GDP. In order to clearly show the relationship between sea-level rise and damage and adaptation cost estimates, the results of the High-end H++ scenarios have been omitted from the figures.

Fig. 4 shows that there is not a strong relationship between annual adaptation costs and sea-level rise: for sea-level rise of about 0.28 meter, for instance, annual global adaptation costs are projected at 2 to 6 billion Euro, dependent on the scenario (more specifically, 2 billion Euro for the E1 5% scenario in the 2080s and 6 billion Euro for the A1B 5% scenario in the 2050s). Most likely, the reason is that the adaptation level in the DIVA model depends more on future sea-level rise than the current sea level. In all scenarios, adaptation costs as share of GDP decrease over time. Absolute adaptation costs increase over time in the A1B scenarios, but decrease slightly in the E1 scenarios.

In the scenarios with adaptation, absolute annual damages seem to be relatively independent on socio-economic assumptions. This implies that on a global level, absolute annual damage projections can be reasonably well approximated by sea-level rise only, without taking into account factors such as income levels. The relationship is almost perfect linearly, from about 1 billion Euro for a sea-level rise of 0.17m relative to pre-industrial levels to about 12 billion Euro for a sea-level rise of 0.56m. For higher sea-level rise, the relationship is not linear: annual damages are projected at 39 billion Euro for 1.1m, whereas a linear relationship derived from the A1B and E1 scenarios would imply 26 billion Euro. For a 1.75m sea-level rise annual damages are projected at 73 billion– whereas a linear relationship would imply 43 billion Euro.

Absolute annual damage projections without adaptation are relatively independent on socio-economic assumptions as well, but here the relationship is not linear: for sea-level rises from about 0.25 meter, annual damages start to increase rapidly to almost 400 billion for 0.56m sea-level rise.

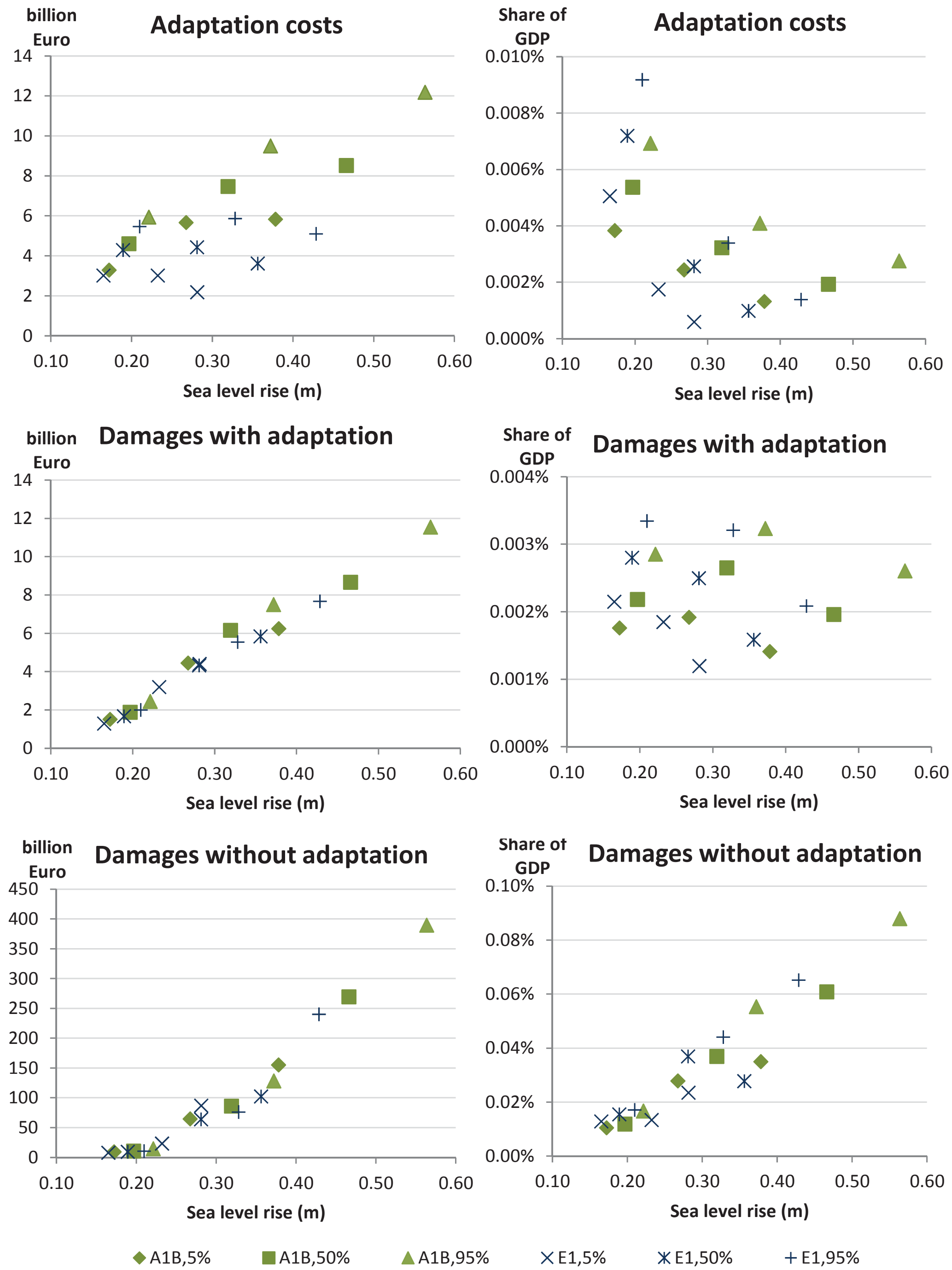

Figure 4. Annual sea-level rise damage and adaptation costs from Brown et al. as function of sea-level rise

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5 Conclusions

The main conclusions from the comparison of damage and adaptation costs of sea-level rise between different models are:

- Even in the case of sea-level rise, for which relatively large literature on damages is available, there are very large differences in damage projections between IAMs and models which are based on detailed information on sea-level rise patterns and coastline data. This implies a recommendation for IAMs to better take into account global damage estimates for impact categories for which such estimates are available.
- IAMs should explicitly take into account the possibility to adapt, since this strongly determines total costs. PAGE already includes adaptation as a policy option, but RICE does not.
- On a global level, RICE and PAGE project (much) higher damages than Brown et al. On regional level, RICE damage projections of especially the EU, China, and Africa are much higher than those of Brown et al.
- The results of ClimateCost indicate that absolute annual sea-level rise damages – at least on a global level –are relatively scenario-independent and are mainly a function of sea-level rise. This implies that damages are better calculated as absolute numbers and could be a function of sea-level rise only (currently, they are calculated as share of GDP and depend on GDP growth). This does not hold for adaptation costs.

***Acknowledgements*:** This paper has been written as part of the RESPONSES project (www.responsesproject.eu), funded by the European Commission within the Seventh Framework Programme. The ClimateCost data was generated as part of the Seventh Framework Programme project ClimateCost (www.climatecost.eu). The Met Office Hadley Centre generated the sea-level rise scenarios for ClimateCost.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

How to include water management in regional scale impact assessment for large river basins using freely available data

Hagen Koch, Stefan Liersch, Valentin Aich, Shaochun Huang, Fred F. Hattermann

Abstract— Today there are very few large river basins not affected by human intervention and regulation, i.e. water management. Beside natural processes affecting river discharge, water management has to be considered in impact studies for large river basins. Without that, a reasonable calibration and validation of impact models for the historical period is hardly possible, and impact assessment at the regional scale is usually done after testing of the model for current conditions. In some basins unsustainable water withdrawals may lead to zero discharge in some seasons, while in other basins reservoir management essentially changes the timing and volume of water discharge. Furthermore, reservoir management is a topic often discussed when designing adaptation strategies considering improved water supply and reliable electricity production.

The basic data on water management used in our impact studies for large river basins are available from literature or internet presentations of national agencies and local companies. They can be used to simulate reservoir management and water withdrawals from the river reaches when the model is set-up, calibrated and validated for the historical period.

Examples from studies on the Nile, Niger, Limpopo (Africa) and São Francisco (South America) river basins are presented. In these basins the effect of water management on water discharge is significant. Without consideration of water management it is not possible to reach satisfactory calibration and validation results in these large scale simulations - unless parameter sets are used to force the model into states out of physical boundaries. This fact means that a reliable simulation of land use or climate change scenarios is only possible by the inclusion of water management in the models.

Index Terms—Data availability, Impact assessment, River basin, Water management

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1 Introduction

The assessment of possible changes in eco-hydrological systems due to climate change or land-use changes is of high interest. This assessment is needed, for instance, to develop adaptation strategies to these changing conditions. To simulate the changes the most important natural processes governing the eco-hydrological system, e.g. plant growth or river discharge, must be included.

Anthropogenic land and water management can magnify or reduce the effects of climate and land-use change. Inasmuch as most large river basins are managed, these anthropogenic impacts should also be integrated in assessment studies that rely on simulations. A number of river basins all over the world are already under high stress due to overexploitation of water resources. This anthropogenic pressure results from population growth, increasing living standards accompanied by growing demand for agricultural, industrial and potable water as well as non-sustainable water use. Therefore, measured time series contain, beside natural effects, impacts of anthropogenic management. Using measured time series from highly managed river basins for the calibration and validation of models can lead to extreme parameters settings, e.g. the evapotranspiration is increased drastically to reproduce agricultural water withdrawals. This in turn will lead to erroneous simulation results in climate and land-use changes studies. The inclusion of anthropogenic land and water management, however, is often constrained by lacking model capacity and/or data availability. While the models capacity can be expanded to allow for the consideration of management processes, data availability, depending on the region or country, can bring about problems that can not be solved by modelers.

In the following of this paper it is shown how water management and water use data, available from literature or internet are used to calibrate and validate an eco-hydrological model.

2 The Soil and Water Integrated Model SWIM

The model Soil and Water Integrated Model (SWIM; Krysanova et al. 1998, 2000) is a continuous-time spatially semi-distributed eco-hydrological model. It was developed for climate and land use change impact assessment. It combines approaches developed for the models SWAT (version '93, Arnold et al. 1993) and MATSALU (Krysanova et al. 1989). Using SWIM hydrological processes, vegetation growth, erosion, and nutrient dynamics at the river basin scale can be simulated. It is a process-based model, combining physics-based processes and empirical approaches.

3 Data sources used in the studies

3.1 Data for setting up a SWIM model

The setting up of a model for a river basin using SWIM requires a number of input data sets. Hydrotopes or hydrological response units (HRUs) are the core elements in the model. These elements are generated by overlaying GIS-maps of land use/cover, soil, and sub-basins. The latter are derived from digital elevation models (DEM). The hydrotopes are considered as units with the same properties regarding bio-physical processes. Lateral connections between hydrotopes are not included in the model. All processes are calculated at the hydrotope level using daily time-steps. The eco-hydrological model SWIM requires spatial and temporal input data that are described in the following. A daily climate dataset providing precipitation, air temperature, radiation, and humidity is required. Unless stated otherwise, for the results presented climate datasets produced within in the EU FP6 WATCH project (http://eu-watch.org/) are used (Weedon et al. 2011). These datasets are based on monthly CRU, GPCC, and sub-daily reanalysis data (ERA40). For the computation of the sub-basins digital elevation data from the Shuttle Radar Topography Missions' (SRTM) with a 90 m resolution were used. Depending on the size of the basin these were changed to lower resolutions. Soil parameters were derived from the Digital Soil Map of the World (FAO) while land use (cover) data were reclassified from Global Land Cover (GLC2000).

3.2 Discharge and water management data

For a large number of gauging stations world wide river discharge data can be obtained on request from the Global Runoff Data Centre (GRDC). However, for some regions or river basins little or no data is available or the time series are rather short. In the internet different sources for discharge measurements are available. Often these data are provided freely by basin authorithies or other institutions. In any case for an internet search it is favourable to have some basic knowledge of the countries language. For instance discharge measurement data for South Africa, in this study used for the Limpopo River basin, can be downloaded from the homepage of the Department of Water Affairs (http://www.dwaf.gov.za/Hydrology/hymain.aspx). For Brazil discharge measurement data, here used for the São Francisco River basin, can be obtained from Agência Nacional de Águas (http://portalsnirh.ana.gov.br/).

Beside discharge measurements data on water management, i.e. reservoirs, water transfers, withdrawals and return flow are needed in highly managed river basins. For South Africa documents with regard to these topics can be downloaded from the homepage of the Department of Water Affairs (http://www.dwaf.gov.za/documents/), some of which are listed in the references. From the Department of Water Affairs and Forestry (2011) also measured mean monthly reservoir volumes are available.

Data about the main reservoirs and main water withdrawals in the Mozambiquian part of the Limpopo River basin can be found under http://www.waternetonline.ihe.nl/workingpapers/WP11%20Limpopo%20Basin%20in%20Mozambique.pdf.

For the Nile River basin data about reservoir management can be found in Sutcliffe and Parks (1999). For instance the so called "agreed curve" for water release from the Lake Victoria depending on the water level is given there. Also measured water levels for Lake Victoria are presented.

Data about water use and reservoir management for the Niger River basin are provided by Zwarts et al. (2005). Measured mean monthly reservoir volumes for selected reservoirs are available from this source.

For Brazil from Operador Nacional do Sistema Elétrico (http://www.ons.org.br/) volumes for large reservoirs can be downloaded. In the São Francisco basin these are the reservoirs Itaparica, Sobradinho and Tres Marias. On this homepage also water level-volume-surface area relationships for these reservoirs are available. Furthermore, water use data from 2002-2012 can be obtained from Agência Nacional de Águas (http://www2.ana.gov.br/Paginas/institucional/SobreaAna/uorgs/sof/geout.aspx). Data regarding reservoir management in the São Francisco basin can be found, e.g., in do Nascimento (2006).

4 SWIM application to river basins

4.1.1 General description

A general overview about the main characteristics of the basins presented is given in Table 1. For all basins the reservoir module described in Koch et al. (2013) is applied. If the required data are available also water withdrawals, e.g. for agricultural irrigation or domestic/industrial demand, are included.

Table 1 Overview on river basins

Name	Catchment area [km^2]	Mean discharge [m^3/s]
Limpopo	410.000	180
Nile Up to Lake Victoria (outlet)	3.000.000 193.000	2.660 1.112
São Francisco Up to Reservoir Tres Marias (outlet)	631.000 50.600	2.756 688
Niger Up to Reservoir Sélingué (outlet)	2.260.000 31.200	6.000 242

4.1.2 Limpopo River basin

Using the measured inflow data and data about the volume and management of the Blyderivierpoort reservoir the SWIM-reservoir module was applied. In Figure 1 observed and simulated volumes, inflow and outflow for this reservoir are displayed (observed inflow is used as input in this simulation).

The results of two different simulation runs for the whole Limpopo River are compared to measured discharges in Figure 2. In the first simulation run a reasonable calibration result was only achieved by setting the evaporation parameter to an unreasonably high value (ecal = 4.5). A value of 4.5 means that the potential evaporation is increased by the factor 4.5. In this simulation run, water management, reservoirs and water withdrawals, were not included. Losses due to withdrawals and reservoir evaporation are compensated by increasing the potential evaporation drastically. In the second simulation run (ecal 1.5) the ecal-parameter is set to a value of 1.5. Furthermore, a number of reservoirs and water withdrawals are included in the model. In this simulation run the potential evaporation is increased to a much lower degree. However, due to missing data about water use in some parts of the river basin, e.g. Botswana, and unaccounted for withdrawals in South Africa, the ecal-parameter can not be set to unity.

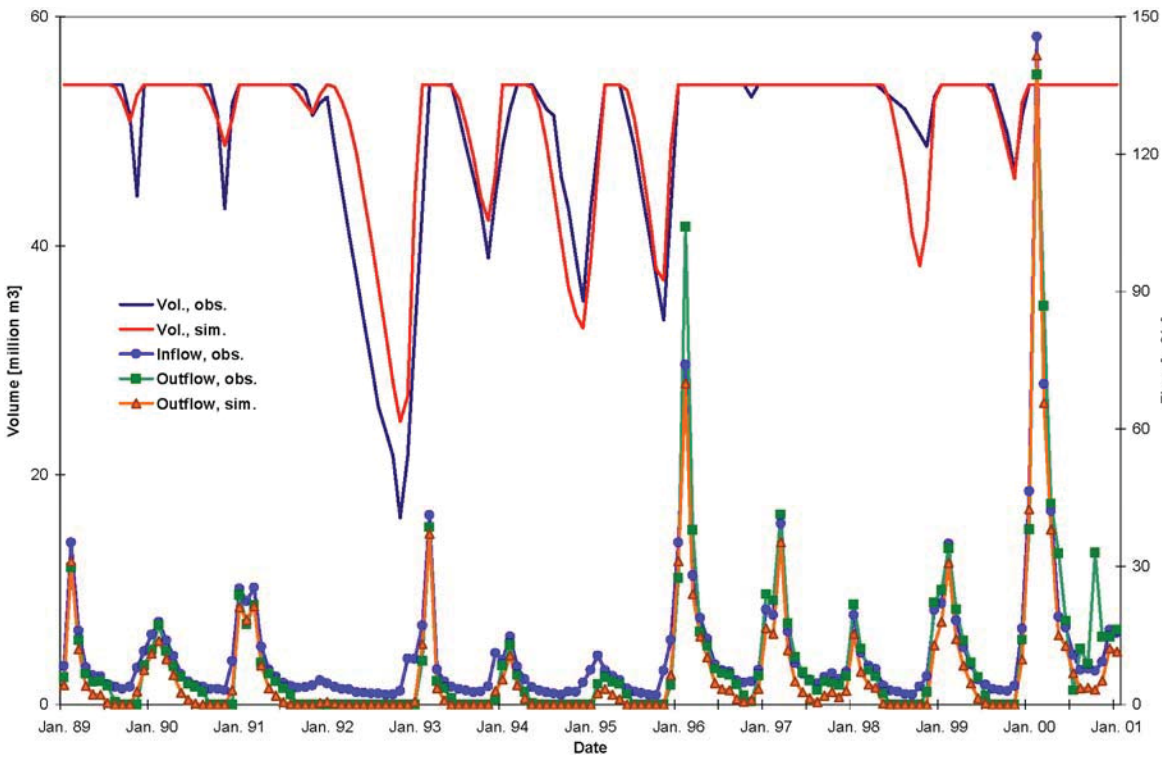

Figure 1 Observed and simulated volumes, inflow and outflow from Blyderivierpoort reservoir (Limpopo basin)

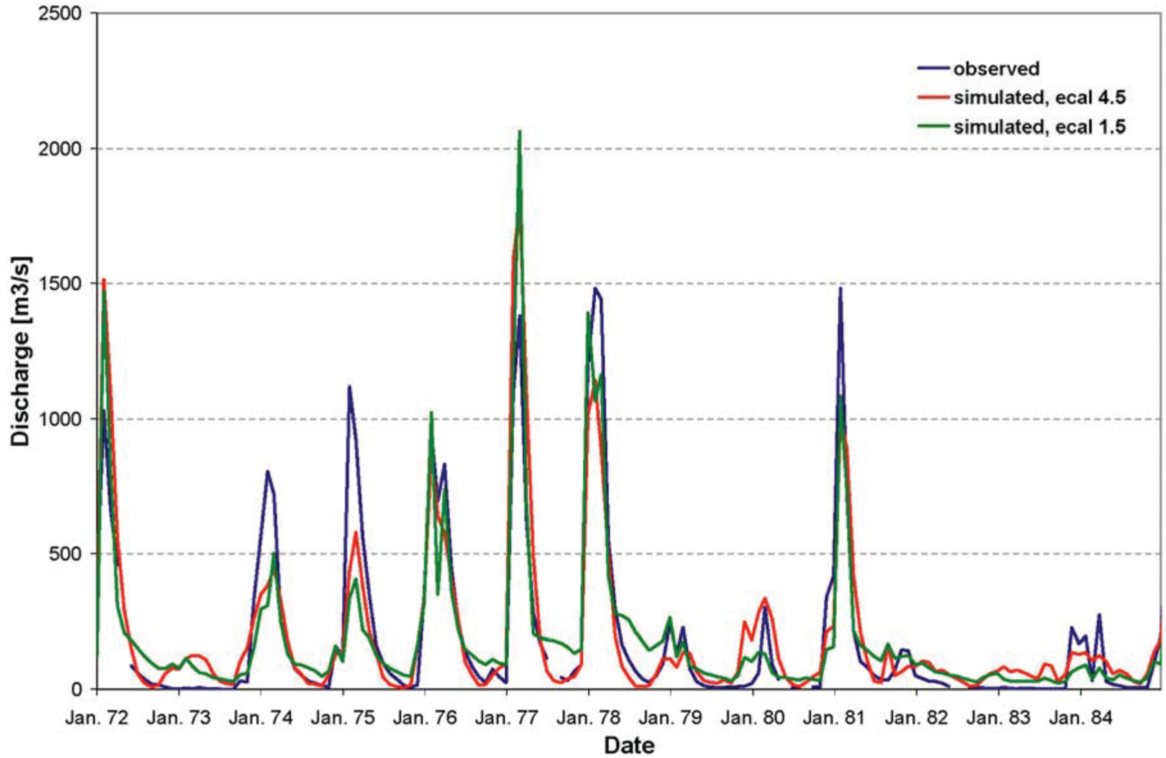

Figure 2 Observed and simulated discharge for Limpopo River basin (simulations with different settings), calibration period 1972 – 1979, validation period 1980 - 1985

4.1.3 Nile River basin – Lake Victoria

The results displayed in Figure 3 were obtained by applying pplying the so called "agreed curve" for water release from the Lake Victoria (White Nile) depending on the water level in the SWIM-reservoir module. In our simulation the "agreed curve" with a maximum water level at gauging station Jinja of 13 m (approximately 1136.3 m a.s.l.) is used. In case the water level is higher than this all water is released. In the simulation observed inflow is used as input. Beside river inflow rainfall is an important part of the water balance of Lake Victoria (lake surface approximately 60,000 km^2). Measurements from a few rainfall gauges in the lake are interpolated to the whole lake area and used as input in the simulation. Therefore, heavy rainfall events measured at one or a few rainfall gauges are transferred to large areas and can have a strong impact on simulation results (e.g. extremely high simulated discharges in the 1960s).

While the general management of the lake can be reproduced, i.e. high outflows for high water levels, some deviations between observation and simulation are visible. As shown in Figure 4, the real management is not always according to the agreed curve, which is strictly kept in the simulation run. Up to a water level of 1136.3 m a.s.l. the simulated outflow follows the agreed curve. If this water level is reached the outflow can not be controlled and all water is discharged (strong increase of outflow if water level reaches 1136.3 m a.s.l.).

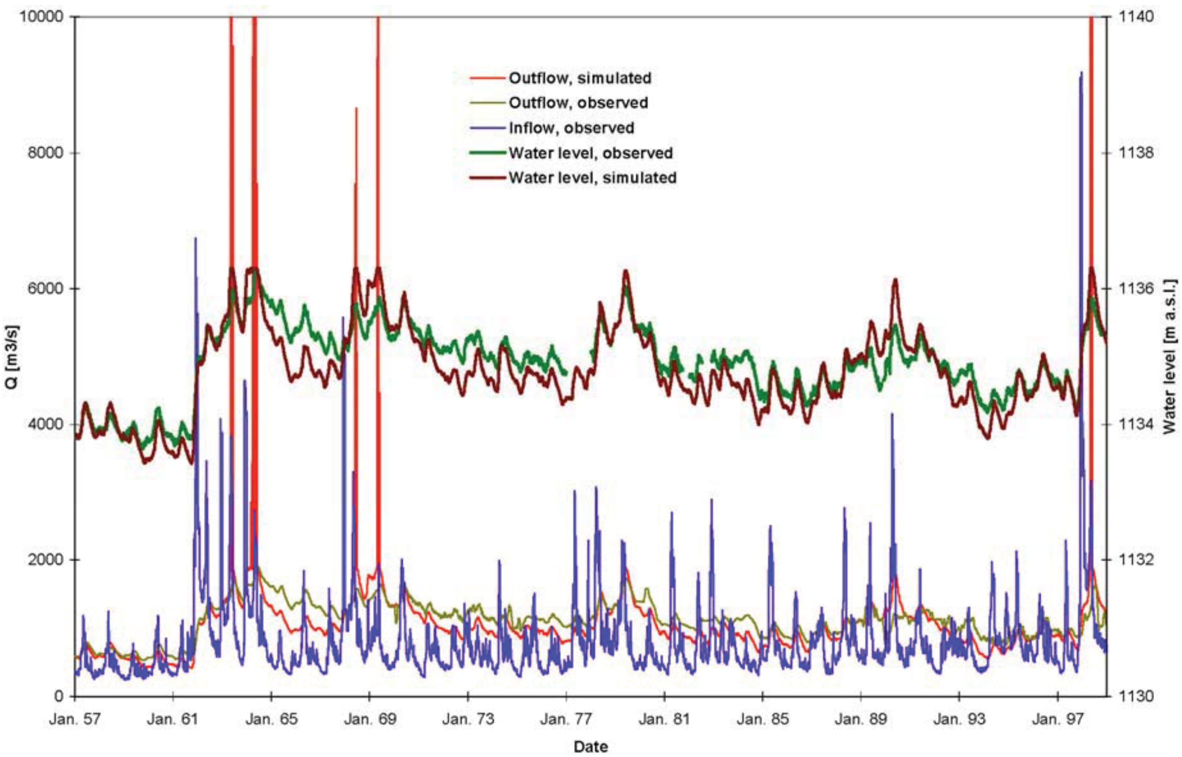

Figure 3 Observed inflow, outflow and water level, and simulated outflow and water level for Lake Victoria

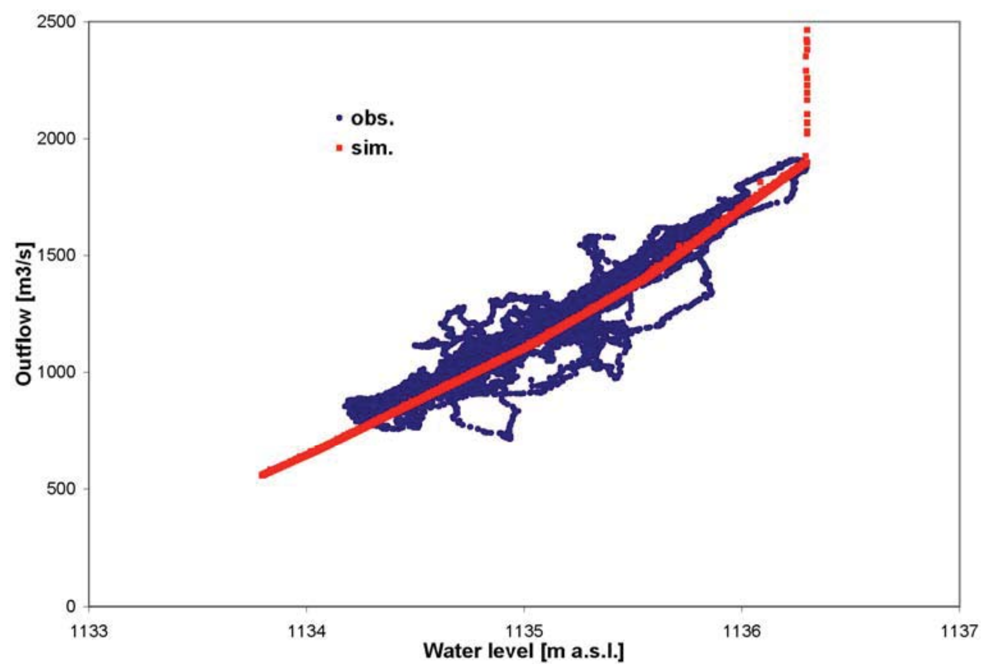

Figure 4 Observed and simulated water level-outflow-relation for Lake Victoria

4.1.4 São Francisco River basin

Another example for the use of freely available data and the application of the SWIM-reservoir module is given in Figure 5. In the simulation observed inflow is used as input. The observed and simulated volumes and outflows from Tres Marias reservoir are in good agreement. The filling of the reservoir, months January to April, and the emptying from May on as well as the reduction of high flows and the increase of low flows is simulated quite well. However, deviations between observation and simulation may arise because of short-term adaptation of real reservoir management unaccounted for in the simulations.

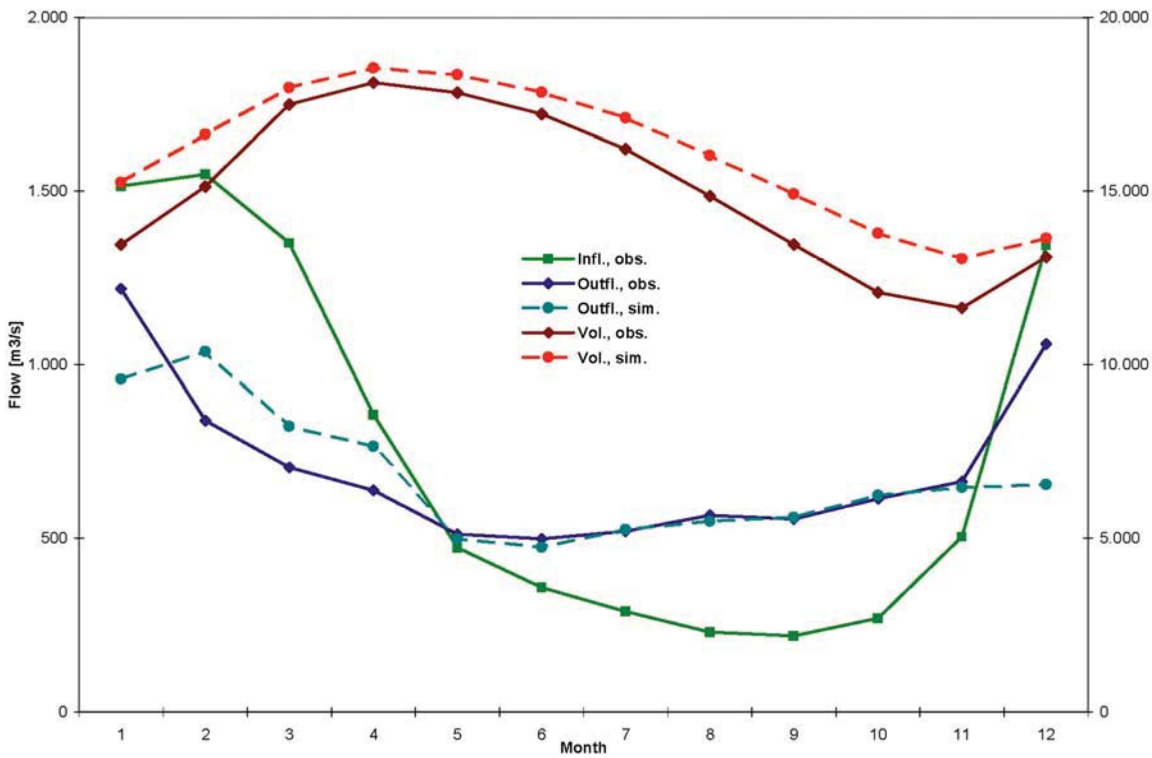

Figure 5 Observed and simulated volumes, inflow and outflow from Tres Marias reservoir (Upper São Francisco basin)

4.1.5 Niger River basin

For the Sélingué reservoir in the Upper Niger basin in Figure 6 results from a climate impact study are displayed (see Liersch et al. 2012). In this study a climate warming of approximately 2°C by 2050 is assumed. For both time periods, 2010 and 2050, the effect of the Sélingué reservoir on the discharge downstream is clearly visible. While in the first half of the year (drought period) the discharge is increased significantly, the discharge is decreased especially in the first part of the rainy season when the high flows are used to refill the reservoir.

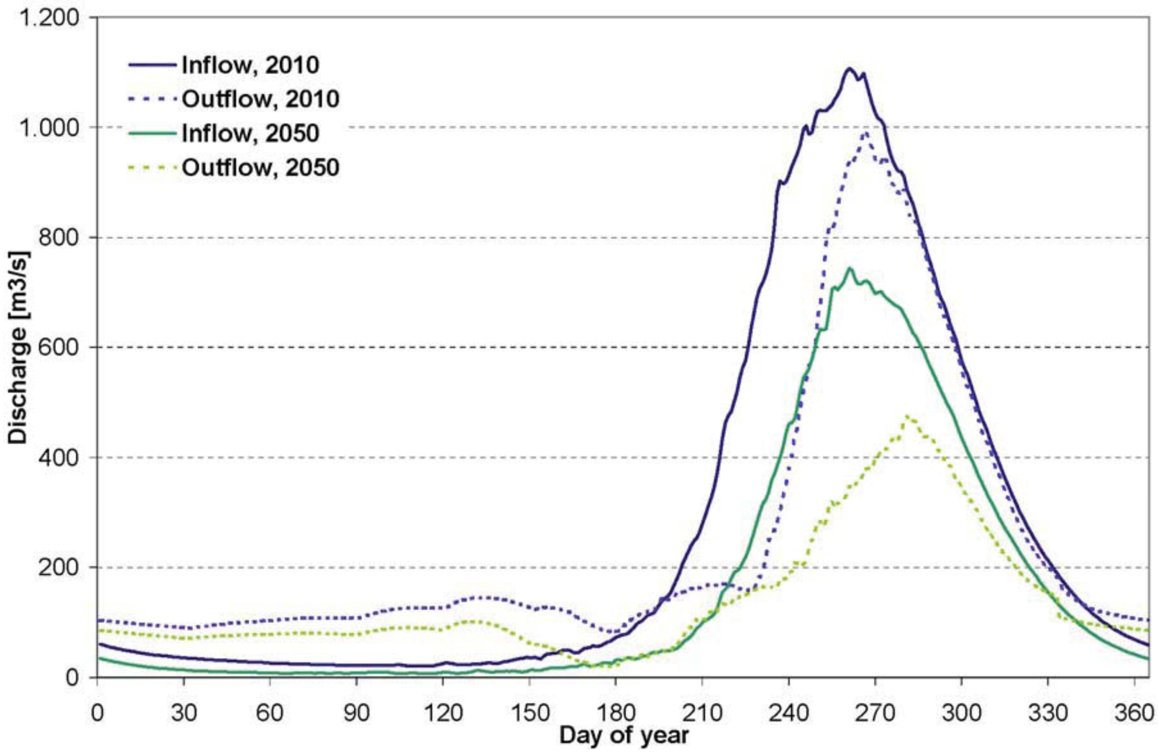

Figure 6 Simulated mean inflow and mean outflow from Sélingué reservoir under recent (2010) and climate scenario (2050) conditions (Upper Niger basin)

5 Discussion and conclusion

This paper shows that for different river basins world wide the required data to include water management in simulation studies are freely available from the internet and other sources. The data can be used to increase the reliability of simulation results. However, the search for these data is time consuming and often time series have large gaps. Also the real management of reservoirs, due to short term adaptation to current conditions, and the quantities withdrawn for agricultural irrigation or domestic/industrial uses may differ markedly from available data, e.g. planning data.

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Analysing Urban Heat Island Patterns and simulating potential future changes

Eric Koomen, Jesse Hettema, Sem Oxenaar, Vasco Diogo

Abstract— This paper analyses the strength of the urban heat island effect in a temperate climate, explains local variation in the observed temperatures and quantifies how this urban heat island effect may develop in the coming 30 years due to projected climatic and socio-economic changes.

Index Terms— climate change, land-use change, UHI

1 Introduction

Various studies measure the urban heat island (UHI) effect using different data sources such as satellite images (Nichol and Wong, 2009; Döpp, 2011), weather stations (Steeneveld et al., 2011) and mobile devices (Heusinkveld et al., 2010). Yet, few studies exist that explain spatial variation in observed urban temperatures from local urban conditions. This paper analyses the strength of the urban heat island effect in a temperate climate (Amsterdam, the Netherlands) and attempts to explain local variation in the observed temperatures. Based on that, a quantitatitve assessment is made of the potential changes in the magnitude and spatial pattern of the urban heat island effect in the coming 30 years as a result of projected climatic and socio-economic changes. The analysis is based on our own measurement of the UHI effect that we define as UHImax: the maximum temperature difference between local urban temperatures and a rural reference station observed during a 24 hour period (Van Hove et al., 2011). To assess potential future changes we build on existing scenario studies and a land-use simulation model. Using observed relations between average maximum daily temperatures and observed UHI values we are able to assess the impact of global climate change on local UHI values. The land-use change model allows the translation of macro-level socio-economic changes into potential future urbanisation patterns and thus the assessment of increased urbanisation on UHI.

In section 2 the selected methods for this study are discussed. Section 3 then presents the main results, and the final section (4) summarises them.

2 Methodology

2.1 Analysing Current Urban Heat Island Patterns

We describe current urban heat island patterns based on two separate analyses. *Spatial variation* in urban temperatures is measured along a route using mobile measurement devices and then explained using regression analsyis and spatially explicit explanatory variables, while *temporal variation* is described based on local temperature measurements derived from amateur weather stations.

2.1.1 Spatial Variation in Urban Temperatures

Urban temperatures were measured using a GPS Logger and a USB-thermometer fixed to a bicylce while travelling along a circular tour around the city of Amsterdam that passed open areas outside the city, various neighbourhoods with different densities and the historic centre. Measurements were taken every minute during a two-hour period after sunset on an average-temperature summer day. This particular day (June 17 2012) an average maximum daily temperature of 19.7°C was measured at the nearby Dutch Royal Meteorological Institute's weather station (Schiphol Airport) that was considered as the rural reference station in this study. The observed maximum daily temperature corresponds very well to the 30-year average maximum daily temperature of 19.8°C for the same station. The late evening period was chosen because maximum UHI values are known to be highest after sunset when the heat stored in artificial surfaces is slowly released (Van Hoven et al., 2011). The Urban Heat Island-effect was described by comparing the collected urban temperatures with those measured at 10-minute intervals at the Schiphol Airport reference station. The observed variation in Urban Heat Island-effect was explained from local spatial conditions using linear regression. With a geographical information system various explanatory variables (presence of different types of land use, degree of sealed surface, number of houses) were made available for differently sized neighbourhoods surrounding the temperature observation locations. The amount of urban volume in a 500x500 metres neighbourhood turned out to best explain variation in Urban Heat Island-effect (R^2 = 0.569, constant and coefficient significant at 1% level). Additional explanatory variables (e.g. proximity to water and green spaces, local degree of sealed surface) were also incorporated in the regression analysis, but this did not improve the explained amount of variance (R^2). This leads us to believe that urban volume is able to capture similar spatial characteristics as the other variables. As a simple explanatory model allows us to assess potential future changes in a more straightforward way (without requiring too many additional assumptions) we preferred to keep this model for subsequent analysis.

2.1.2 Temporal Variation in Urban Temperatures

Hourly records of air temperature were collected from five amateur weather stations in Amsterdam for a 30-day period in the summer of 2010 (June 15 and July 15). This period was chosen because of the occurrence of relatively high temperatures, calm wind and clear sky conditions, which enhance UHI effects (Arnefield, 2003). Although amateur stations are not fully compliant with the standards of the World Meteorology Organization, they offer the possibility to study long-term temporal weather data in urban areas (Steeneveld et al., 2011). Again, the weather station at Schiphol Airport was considered as reference station. All amateur stations showed a consistent relation between between daily UHI_{max} and daily maximum temperatures in the observed period. For our analysis we selected the Watergraafsmeer station (Fig. 1) because of its proximity to the location where spatial variation in temperatures was analysed.

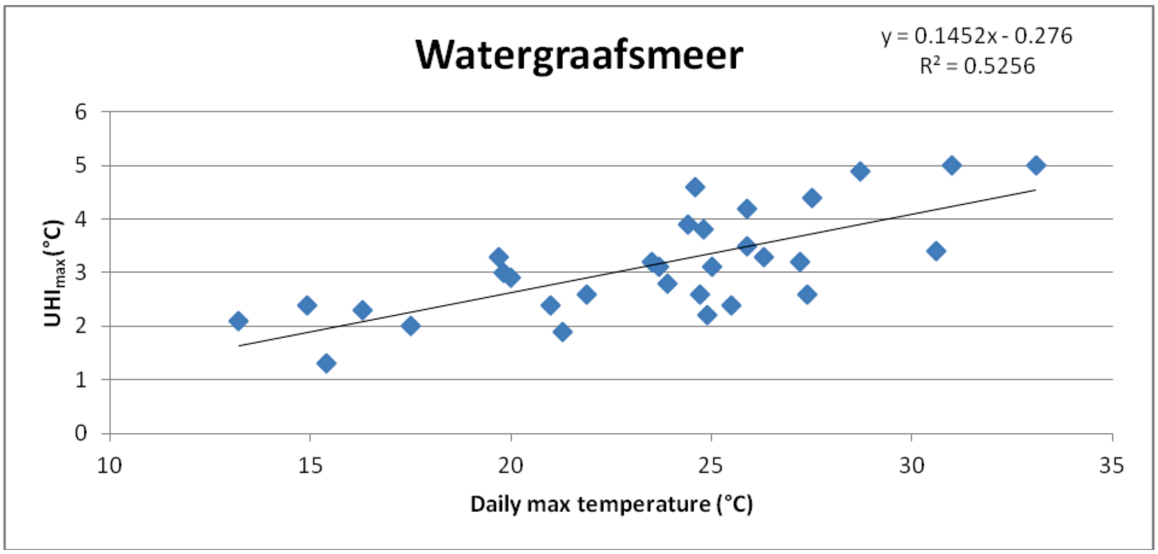

Figure 1: Relation between UHI_{max} and daily maximum temperature at Watergraafsmeer weather station

2.2 Simulating Future Urban Heat Island Patterns

The UHI effect is likely to become stronger in the future as both temperature and amount of urban area are expected to increase. Dutch climate change scenarios indicate an increase of either 1°C or 2°C in the average yearly temperature for 2050 (Van den Hurk et al., 2006). This increase can be translated into a likely UHI increase with the observed relation between daily UHI_{max} and daily maximum temperatures described above: for each degree increase in daily maximum temperature the UHI_{max} is expected to increase by about 0.15°C. This impact is expected to be present within the urban area of Amsterdam (close to the amateur station on which it was based) and will decrease to 0 near the reference station. This relation is used to create a climate change correction factor that can be applied to update the map depicting spatial variation in UHI effect.

To provide an outlook on future urban patterns we apply a land-use simulation model that is well-established in spatial planning and climate adaptation research in the Netherlands and beyond: Land

Use Scanner (Kuhlman et al., 2012; Koomen and Borsboom-van Beurden, 2011; Te Linde et al., 2011). This GIS-based model is rooted in economic theory and integrates sector-specific inputs (e.g. regional demand for residential land) from other, dedicated models. It is based on a demand-supply interaction for land, with sectors competing within suitability and policy constraints. To reflect the inherent uncertainty in future socio-economic changes we have selected the two most diverging scenarios from an existing Dutch scenario study (CPB et al., 2006). The Global Economy scenario is part of the A1-scenario family in the SRES terminology and shows a substantial population growth and strong economic growth. In the Regional Communities scenario (based on the B2-scenario family of SRES) the population remains more or less stable, with modest economic growth and a higher unemployment rate.

Based on the simulated land-use patterns for 2040 we created two updated versions of the 2006 urban volume data set; one for each scenario. These were created according to the following rules: 1) for locations where land use did not change between 2008 (base year for simulation) and 2040, the urban volume values for 2006 were maintained; 2) for locations where land use changed the urban volume value was updated to the average 2006 urban volume value of the corresponding new land-use type. This approach is an obvious simplification of potential future developments, but allows for inclusion of changes in the urban fabric. The updated uban volume values were then used to create a new set of maps depicting spatial variation in UHI effect.

3 Results

Using the statistical relations obtained in our explanatory analysis of local measurements of spatial variation in UHI effect and a data set describing urban volume in Amsterdam we mapped spatial variation in the UHI effect for the entire city (Fig. 2). The results indicate how the UHI effect is thought to be distributed over the greater Amsterdam area on an average June day corresponding to the moment of our measurements.The inner city is clearly distinguishable with values up to 2.9° C. Moving outwards the temperature shows a gradual decrease. In the areas surrounding the old centre, with lower urban density, the UHI effect is found to be between 1.5° C and 2.5° C. Still further from the city the UHI pattern becomes more heterogeneous; with several areas with low UHI values representing open areas and areas with moderate UHI values following the suburban lobes of Amsterdam. A second area with high UHI values represents a dense commercial district. It is interesting to note that the outskirts of Amsterdam still show an UHI effect of around 0,95 °C, which is probably due to the fact that we did not travel out of the uban sphere of influence.

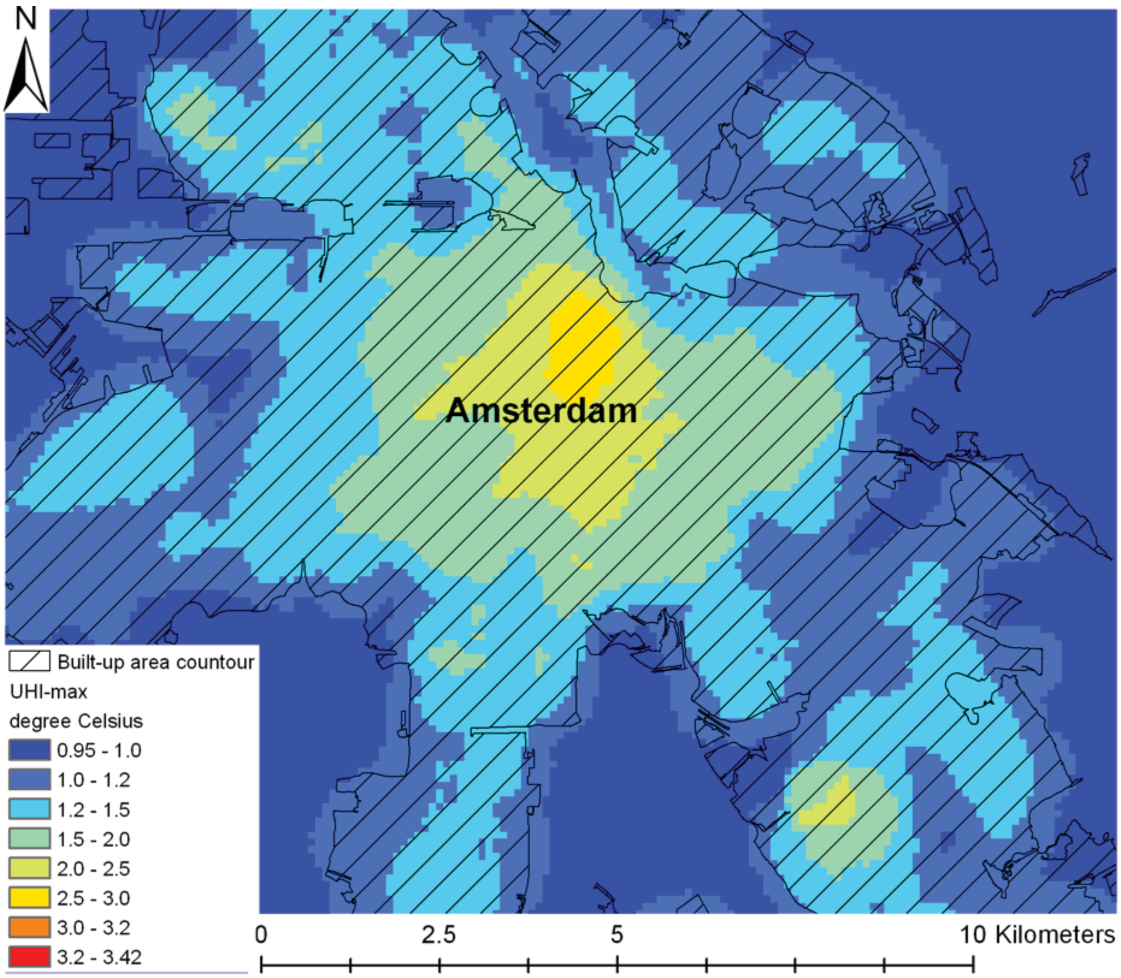

Figure 2: Spatial variation in UHI values the greater Amsterdam area

The simulated future UHI patterns are shown in Fig. 3-8. The legends for these maps are the same as in Fig. 2. From these maps it can be observed that the UHI effect increases in both scenarios. This is because of the increase in urban volume in both scenarios compared to the situation in 2006. The RC scenario shows a concentrated UHI increase in areas with high urban volume values in the centre, whereas the GE scnenario shows a more dispersed spread of the UHI. This follows from the stronger focus on concentration of activity in the RC scenario, while the GE scenario allows more urban development at the edges of town. The increases in temperature following the climate scenarios result in more extreme UHI values with maximum UHI valus in the centre rising to about 3.4° C.This may not seem much, but one has to consider that we base our depictions on an average June night. On hot summer days the UHI will be much larger.

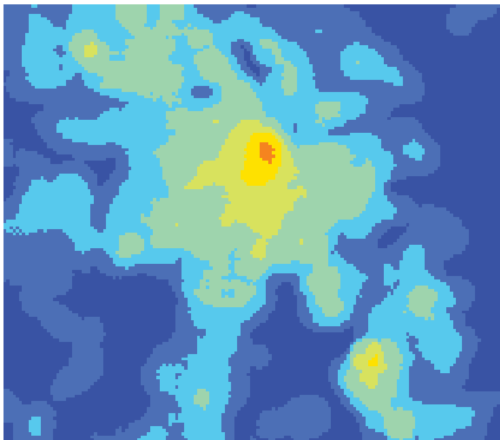

Figure 3: scenario RC with current temperature

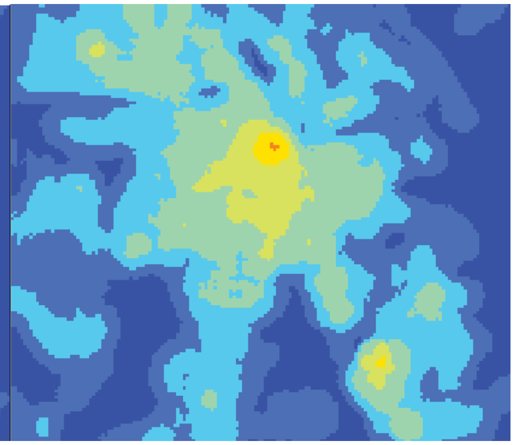

Figure 4: scenario GE with current temperature

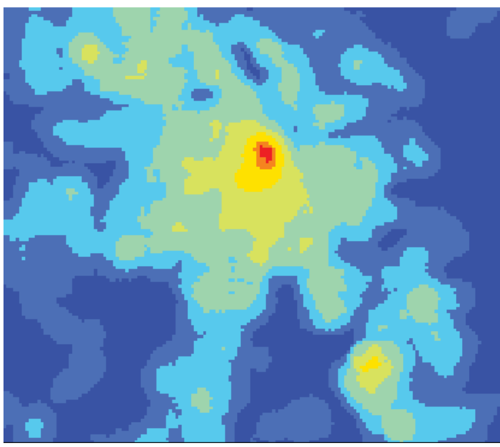

Figure 5: scenario RC with 1C° increase

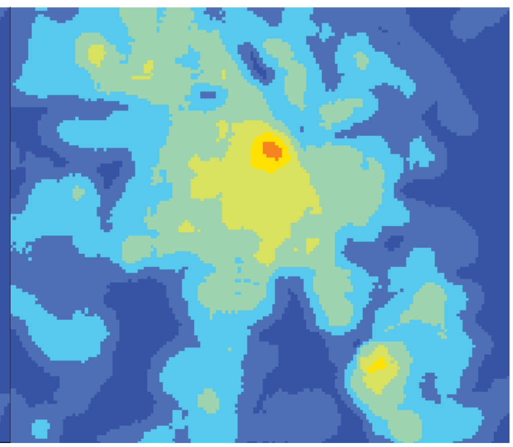

Figure 6: scenario GE with 1C° increase

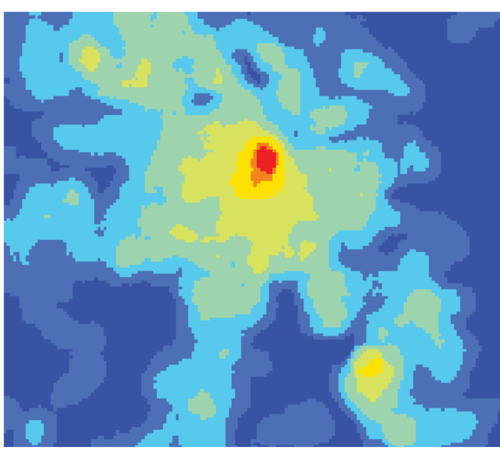

Figure 7: scenario RC with 2 C° increase

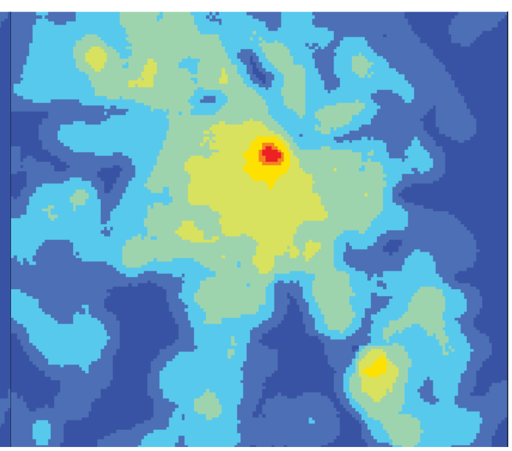

Figure 8: scenario GE with 2 C° increase

4 Conclusion

Our measurements for the Amsterdam region in the Netherlands show that the urban heat island effect induces maximum temperature differences with the surrounding countryside of over 3° C on moderately warm summer days with a maximum daytime temperature of 20° C. The observed temperature difference between urban and rural areas increases by about 0.15° C for each degree increase in maximum daytime temperature. The simulations of potential future changes in urban heat island patterns indicate that strong local temperature increases are likely due to urban development. Climate change will, on average, have a limited impact on these changes. Large impacts can, however, be expected from the combination of urban development and potentially more frequent occurrences of extreme climatic events such as heat waves.

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Impacts World 2013, International Conference on Climate Change Effects,
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Some methodological issues for impact models intercomparison at the regional scale (water sector)

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Abstract— Bridging the scales between global and regional impact research is needed. It can be done as a top-down or bottom-up approach. For that, projections of climate impacts must be provided at the regional scale more systematically, and intercomparison of regional impact models is important to assure the robustness of results. Many questions arise on methodology of the regional model intercomparison. They will be shortly discussed below in relation mainly to the regional-scale model intercomparison for the water sector.

Index Terms— Hydrological model, model intercomparison, regional scale, river basin.

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1 Introduction

Setting adequate climate stabilization goals and designing appropriate adaptation policies should rely on a sound quantitative understanding of the anticipated impacts of climate change under different emission scenarios and levels of global warming. In particular, a comprehensive assessment of climate impacts is urgently needed within the IPCC process. However, the scientific knowledge about the impacts of climate change still remains fragmentary. Many studies have been undertaken to investigate climate change impacts for specific sectors and regions as well as globally. Though these studies are of value in their own right, a quantitative synthesis of climate impacts, including consistent estimation of uncertainties, is missing.

Assessment of climate change impacts using global-scale models is necessary to provide a global overview and information for the global policy makers. However, it is not sufficient for decision makers at the regional scale, where impacts occur and adaptation strategies are designed, as the global-scale modelling results are often not reliable at the regional scale. Therefore, bridging the scales between global and regional impact research is needed, and could be realised via extension of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) to the regional scale. It can be done as a top-down approach, if hot spots are identified at the global or continental level, and then investigated further by "zooming in" with the regional models. It can also follow a bottom-up approach, if the outputs of regional models are aggregated and compared with the global results either to increase the reliability of global analysis, or to identify problematic areas that need further research.

Therefore, projections of climate impacts must be provided at the regional scale more systematically, and intercomparison of regional impact models is important to assure the robustness of results which could be used later for exploring the adaptation strategies. The objectives of the impact models intercomparison could be as follows:

(1) to compare impacts and uncertainty ranges produced by global and regional impact models for the hot spot or representative regions, or

(2) to compare impacts and quantify uncertainties from different sources in a systematical way at the regional scale: by using a set of climate scenarios from several driving climate models and a set of regional-scale impact models.

Besides, the intercomparison of the regional-scale impact models for one sector (e.g. water) can contribute to the cross-sectoral integration of impacts for selected regions, when impact studies for different sectors are combined. In this paper some important methodological questions in relation to study objectives (1) and (2) and mainly related to the intercomparison of regional-scale hydrological impact models will be discussed.

2 Discussion of methodological questions

Many questions arise on methodology of the regional model intercomparison related to the choice of representative regions, datasets, metrics for the intercomparison, methods of uncertainty estimations, etc. Of course, it is not feasible to discuss all these questions in detail in a short paper. Therefore, only some important hints based on the own experience (see e.g. Aich et al., Hattermann et al., Huang et al., Vetter et al. on this webpage) will be suggested for the following nine questions:

1) What is the appropriate scale for the regional impact assessment?
2) How to choose a set of representative regions on different continents?
3) How to apply spatially distributed and point models for the same region doing intersectoral assessments?
4) Which datasets should be used?
5) Which common criteria should be used for the models validation prior to impact assessment?
6) What are appropriate metrics to be used for model performance and comparison of impacts?
7) How to account for human management, which could influence the modelling results?
8) How to quantify and compare uncertainties from different sources?

9) How could the results of impact assessment be linked most effectively to the development of adaptation strategies?

2.1 Appropriate scale for the regional intercomparison and choice of regions

<u>Which criteria to use for choosing the focus regions?</u> For the global-scale modelling there are less specific modelling restrictions, as most of such models are not adjusted or validated for specific regions in advance. Therefore, the choice of focus regions could be based on such criteria as "maximum diversity": covering different climatic zones and geomorphological conditions on all continents, or "maximum threat": including most vulnerable for human society regions. However, the regional modelling usually involves adjustment to specific regional conditions and verifying how the model represents observed variables, such as river discharge or crop yield, and the same procedure is also used by some global models. This provides higher reliability and closer connection to adaptation strategies, but requires more efforts for the model validation. Besides, the input data requirements for the regional scale are usually higher. Therefore, the choice of focus regions for the regional-scale modellers depends on data availability to a larger extent, and is not as free as for the global scale modellers.

<u>Appropriate scale: how large should the regions be?</u> For the impact assessment considering water sector the river basin represents a natural spatial unit for the analysis. Basins of different scales could be considered, for example:

River basin scale	*Drainage area*	*Examples*
the largest	above 1.000.000 km^2	Niger, Amazon, Lena, Mackenzie, Volga
very large	500.000 - 1.000.000 km^2	Danube, Ganges, Yukon, Mekong
large	100.000 - 500.000 km^2	Rhine, Blue Nile, Upper Mississippi
medium to large	20.000 - 100.000 km^2	subbasins of the above basins

The basins which were recently suggested by regional modellers (water sector) invited to participate in the ISI-MIP and which could be potentially included in the intercomparison are presented in **Fig. 1**. For the global-scale impact study providing results for the largest basins like Amazon is not a problem (though the results quality is another question). However, for the regional modellers the model validation for a basin with the drainage area of about 500.000 km^2 is a challenge. In this case the modelling results should be verified not only for the total area and the river outlet, but also for intermediate gauges. The regional-scale models are often scale-specific, and their applicability depends also on the modeller's experience.

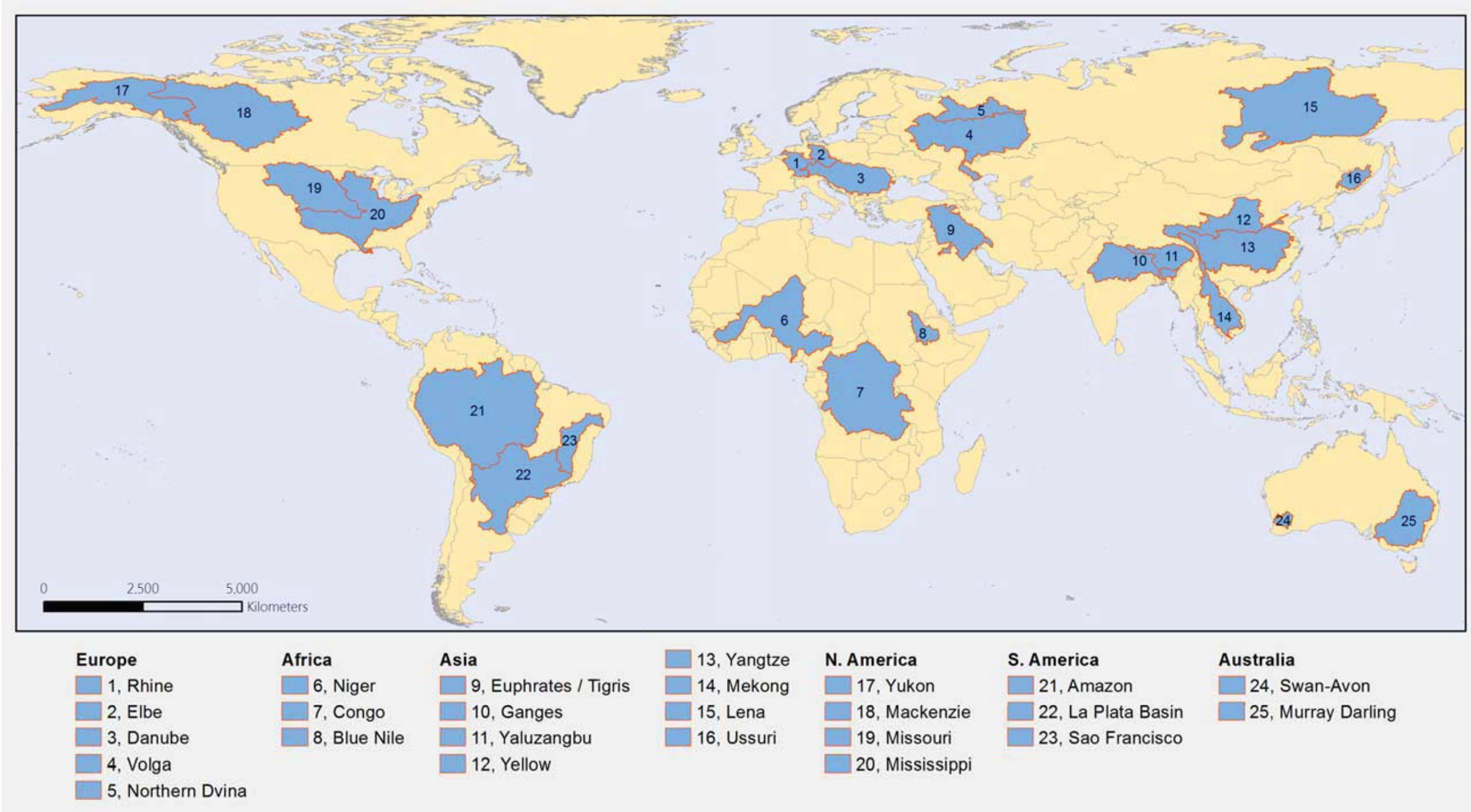


Fig. 1. River basins that could potentially be included in the model intercomparison at the regional scale

Therefore, if the idea is to intercompare both global and regional-scale models, the focus regions should be chosen considering climatic and geomorphological conditions, data availability, and putting attention on regions or river basins where the regional-scale models have already been validated and applied (following a pragmatic choice). Both large and medium-scale regions could be covered in the study.

How to apply both spatially distributed and point models for the same region? This question arises when the regional-scale study involves several sectors, e.g. forestry and agriculture along with the water sector. Then the spatially distributed or semi-distributed hydrological models could be applied at the river basin scale, and the lumped point models (crop models, vegetation models) could be applied for selected representative points within these river basins. It is important to take into account diversity of climate conditions within the region when choosing the points.

2.2 Datasets to be used

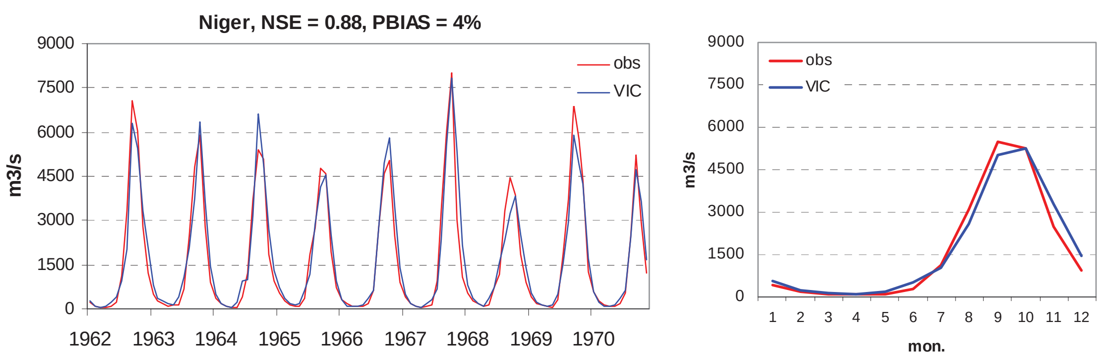
For the model intercomparison necessary input data could be taken from national sources or available global datasets. If the study is planned to be done for river basins on all continents, data from global datasets, such as topography, soils, vegetation, land use, climate and discharge should be preferred. For the model validation observed climate data for the historical period or data from the WATCH project could be used. Regarding regional climate scenario data, CORDEX is now producing an improved generation of regional climate change projections (http://www.meteo.unican.es/en/projects/CORDEX) worldwide for impact studies within the AR5 and beyond. CORDEX simulations for Europe and Africa are ready. For example, the following data from the global datasets could be considered for the water sector:

Variable	Source/Name	Description
Climate	WATCH	Daily precipitation, temperature (mean, min, max), humidity and solar radiation reanalysis data at 0.5 arc degree grid global dataset, 1957-2001.
Climate scenarios	CORDEX	Main climate parameters with a 50 km grid spacing.
Topography	SRTM	Global digital elevation model constructed from the Shuttle Radar Topography Mission (SRTM) in decimal degrees at 3 arc seconds resolution (~90 m).
Land use/cover	GLC2000	Global Land Cover (GLC) 2000 map by the EC Joint Research Centre with 22 land cover types.
	Corine 2000	Corine Land Cover 2000 by the European Environmental Agency with 44 land cover types.
Soil	HWSD	The Harmonised World Soil Database (HWSD) from the FAO.
Soil	ESDB	European soil data base (JRC).
Water discharge	GRDC	Daily/monthly discharge data from the Global Runoff Data Center (GRDC).

Checking important input data, such as climate, may be also necessary in advance. For example, solar radiation is an important input parameter defining to a large extent the simulated evapotranspiration. Therefore, in case the reanalysis data (e.g. the meteorological forcing dataset from the WATCH project) is used, the radiation data should be compared with the available observed data where possible.

2.3 Model validation and metrics to be used for intercomparison of impacts

The model validation is a usual procedure for the regional-scale hydrological models. Common criteria of fit should be used for all models and regions such as the Nash and Sutcliffe efficiency (NSE) and percent bias (PBIAS), see an example: river discharge for the Niger modelled with VIC (from Vetter et al.).



For larger scale hydrological studies, ideally, the validation should be done as multi-scale (at the outlet, for main tributaries, and including gauges located in different landscapes of the basin), multi-criterial (using e.g. data on groundwater dynamics or evapotranspiration in addition to river discharge) and considering different time periods for calibration and validatin. This of course puts high requirements on the datasets needed in terms of input and validation data, and compromises regarding data availability and validation strategy for certain regions could be needed. In addition, sensitivity and uncertainty studies are nowadays a standard in model studies though they are often time consuming.

If an intercomparison of global and regional models is planned, checking the quality of the global modelling results for the focus regions is also necessary.

The metrics to be used for the intercomparison will surely be sector specific. For the water sector such metrics as 30-yr average seasonal (monthly) river discharge and mapped spatial patterns of major water flow components could be used. For the comparison of impacts on hydrological extreme events such metrics as return period of 50 yr flood, deficit volume, and percentiles Q10 and Q90 could be used.

2.4 Accounting for human management or ignoring it?

The large basins usually include water management facilities, which can substantially disturb water cycle in a basin. Probably, the most important influences such as the large reservoirs, large water transfers and major irrigation schemes should be considered in the impact models. For some hydrological models, which do not include an algorithm representing water management, this could be a challenge. For that, a possible solution could be to develop the simple modules for “reservoirs” and “irrigation” (see e.g. Koch et al. on this webpage) which could be included in the models.

However the basins with very heavy water management, where water demand is approaching the water availability level and the natural river discharge is hardly biased, and data on water management is scarce, should probably be excluded from the intercomparison, because the primary purpose is to evaluate climate impact on the natural water discharge.

2.5 Quantification of uncertainties

While it is impossible to quantify the entire uncertainty range related to climate change impacts, the aim of the impact model intercomparison is to focus on the question how much uncertainty is added by the impact models in relation to the emission scenarios and climate models uncertainties. This has not yet been done in a systematic way and for different regions and sectors at the same time, and is therefore a major concern when discussing climate change impacts worldwide in the light of potential adaptation strategies that are often costly. What, for example, is the range of possible changes in river discharge or crop productivity in a certain region when comparing impacts driven by different emission scenarios, global and regional climate models, and to what extent do the impact models agree in the trends of change? Is this consistent in different regions or climate zones and for different sectors? What if the uncertainty ranges are very high, and agreement low? These questions have to be addressed by the model intercomparison studies.

2.6 Linking impact results to adaptation strategies

Quantifying the impacts is normally the logical first step when designing climate change adaptation strategies. The results of the impact model intercomparison have certainly the potential to increase the robustness of impact quantifications for certain regions and in turn also the reliability of possible adaptation strategies based on them. However, it is also possible that in some cases the uncertainty ranges will be too large, and no clear statements could be derived. Linking of the impact results to adaptation can be done in two ways: A) in regions, where climate change adaptation strategies already are being discussed or in place, the outcomes of the impact model intercomparison can be applied to cross-check the underlying assumptions e.g. on trends and strength of change; B) in other regions the impact models can be used in order to investigate effects of certain potential adaptation measures. While variant A is doable in a fast track manner, variant B would certainly imply more work and basic discussions on possible adaptation measures and associated socio-economic scenarios.

3 Summary

The discussed questions could contribute to the development of a Conceptual framework for the Impact Models Intercomparison at the regional scale in the framework of ISI-MIP. Moreover, the methodological issues raised and discussed in this paper should build a basis for preparing the modelling protocol for the model intercomparison at the regional scale.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Rapid Urban Impact Appraisal

Matthias K. B. Lüdeke & Oleksandr Kit

Abstract

Bridging the global-regional divide inclimate impact research for urban areas means to establish a comprehensive picture which covers all urban agglomeration of the world. This is different from the case of, e.g., hydrological impact modeling where coarse-scaled (spatial and functional) global models and detailed regional studies have to be brought together. Therefore we suggest a structured approach towards a full spatial and functional coverage of urban impact analyses: (1) Filtering - all urban agglomerations are identified where a specific Climate Change impact path is probably relevant or even the dominant one and (2) a targeted, fast quantitative impact assessment of the respective impact path is performed for these urban areas. Step (1) starts with the existing knowledge on potential urban impact paths and extracts through different natural, social and economic filtering steps the urban agglomerations where these impact paths have to be studied quantitatively. In step (2) this is done by applying a set of tools which are mainly based on urban remote sensing to overcome the data scarcity bottleneck. It occurs that single filtering steps and tools can be reused for different impact paths. To illustrate the approach we presenta filtering example, resulting in a global map which shows the urban agglomerations where the following impact path is relevant: pluvial flooding of slum settlements under increasing frequency of heavy rain events To exemplify step (2) we present a remote sensing based toolset for quantitative assessment.

Index Terms—climate impact assessment, urban agglomerations, remote sensing, data scarcity

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1 Introduction

Several single studies on climate change impacts on urban agglomerations are available while a global impact model for the urban agglomerations of the world does not exist. So in urban impact research the methodological challenge of bridging the global-regional divide is different from the case of, e.g., hydrological impact modeling where coarse-scaled (spatial and functional) global models and detailed regional studies have to be brought together. However, global coverage of urban impact assessments is necessary because (1) each urban area should have at least a rough estimate of climate change impacts they will encounter as a first orientation for local adaptation decisions, (2) the sum of all local urban adaptation costs/efforts has to be included into the global balance between adaptation and mitigation and (3) international (EU, UN) policies that need to strike a balance between the costs and benefits for individual member states need national quantitative estimateds of impacts on urban areas .

In this paper we suggest an approach towards a more comprehensive and systematic global urban impact assessment which identifies subsets of cities being sensitivite to specific climate change impacts and provides tools for quantitative impact assessment along these specifities. In particular these quantitative assessments are rather difficult in large urban agglomerations in developing and newly industrialized countries. Most of future urbanization will happen here but due to informality and rapidness of development the data basis is for quantitative impact assessment is often unsufficient. The assessment tools have to reflect these conditions by, e.g., using urban remote sensing techniques for data acquisition to overcome the data bottleneck. Starting from experiences gained in a comprehensive impact assessment for Hyderabd/India we propose a systematic and feasible way to obtain a global and quantitative overview on climate change impacts on cities. We furthermore show a specific example where we already applied this approach. In the following section we sketch the basic structure of the approach, in section 3 we give an example for the identification of city subsets with similar impact sensitivities and in section 4 an example for a quantitative impact assessment tool.

2 Basic Idea: a two-step procedure

We suggest a structured approach towards a full spatial and functional coverage of urban impact analyses:

(1) Filtering - all urban agglomerations are identified where a specific Climate Change impact path is probably relevant or even the dominant one and

(2) A targeted, fast quantitative impact assessment of the respective impact path is performed for these urban areas.

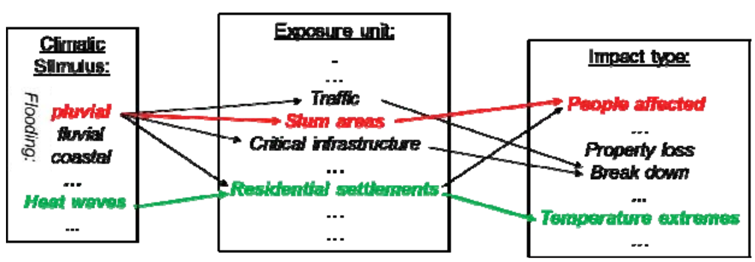

Figure 1: Subset of urban climate impact paths. The red path will be exemplarily analyszed using the suggested rapid urban impact appraisal approach (here impact paths were taken from Reckien et al. 2011)

Step (1) starts with the existing knowledge on potential urban impact paths and extracts through different natural, social and economic filtering steps the urban agglomerations where these impact paths have to be studied quantitatively. The impact paths are characterized by a specific climatic stimulus (e.g. a flood, heatwave or storm event), an exposure unit (e.g. the traffic system, settlements, the water supply system) and the type of impact (e.g. structural damage, operational deterioration or health impacts) – see Fig. 1. Sources for these impact paths are the numerous detailed case studies for single cities (for our example we used the Hyderabad case as a starting point). Once an impact path is chosen, filters can be constructed which exclude urban areas where the respective climatic stimulus or the exposure unit are irrelevant. These filters are based on global datasets characterizing climatological, physical and socio-economic properties of the urban areas from different sources. The climatic stimulus “Pluvial flooding” for instance will be only relevant for cities in climatic zones with strong rain evnts and a hilly urban orography. On the other hand, “fluvial flooding” requires a city with a large upstream basin. This stimulus is not to be expected for locations near watersheds. The benefit of this filtering step for a specific case study is the priorisation of the impact paths to be studied. Regarding the global overview already this first step results in an interesting map of urban agglomerations being sensitive towards the same specific impact path. For step (2) an urban remote sensing oriented toolbox was developed to quantify impacts along the chosen relevant impact path. In Figure 1 different urban impact paths are displayed exemplarily (see, e.g., Reckien et al., 2011). The red impact path asks for the number of slum dwellers severely affected by pluvial flooding and how this would change under climate change.

3 An example for the filtering step

In the following we will demonstrate the filtering steps for the redimpact path in Fig. 1, dealing with the climatic stimulus of pluvial flooding.

Figure 2 illustrates the filtering steps necessary to identify urban areas which are susceptible to the choosen impact path. The first filtering step excludes cities in climatic zones which typically do not experience high intensity rainfall events as given by the Koeppen-Geiger climatic zones. The second step identifies urban agglomerations which are not sensitive to fluvial flooding because they are close to a watershed (i.e. very upstream in the river basin, within a buffer zone around the watershed of 100km) and far from coasts (no estuary, at least 50 km distance from coast). Step 3 excludes cities which do not show a hilly urban landscape (small mean absolut curvature) and at least urban areas with a low probablilty of slum occurrence (less then 3% urban slum population according to UN statistics) are filtered out. The red dots in Fig. 2d denote the remaining urban areas which are susceptible towards the chosen impact path. Fig. 3 zooms into the global result and shows the cities where the slum population is potentially endangered by pluvial flooding. In section 4 we will show for one of these cities how to do a fast quantitative impact assessment along this impact path.

A

B

C

D

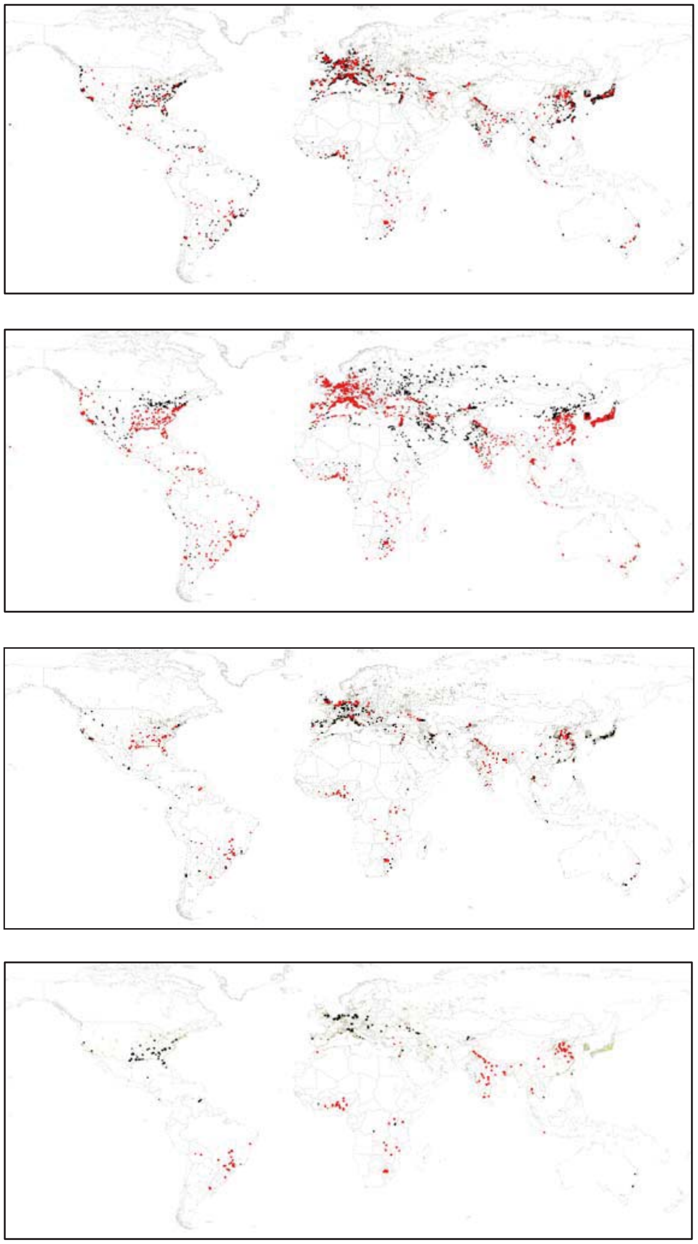

Figure 2: Large urban agglomerations (>1000km^2) filtered for the following characteristics:
a) experiencing high intensity rainfall, b) additionally close to watersheds and distant to coasts, c) additionally hilly urban landscape d) additionally high probability of urban slum settlements. Red: urban agglomerations remaining after the respective consecutive filtering steps. Black and grey: agglomerations excluded.

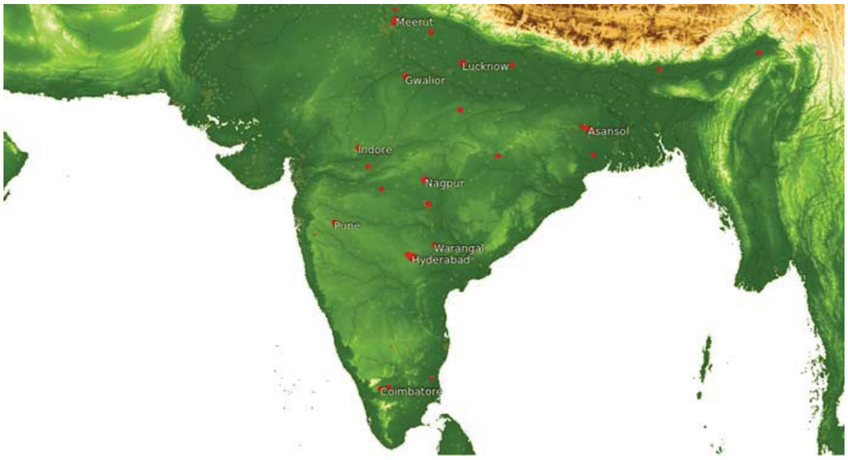

Figure 3: Large urban agglomerations in India which are susceptible for pluvial flooding of slum settlements (detail of Fig. 2d)

4 Fast quantitative impact assessment

In this section we present an example for the second step. We choose the impact path of pluvial flooding of slum settlements for which we introduced the global filtering in section 3. The identified urban agglomerations are affected by this process but the quantitative impact has still to be determined. In Figure 4 we show all steps to be performed for obtaining the quantitative impact and its uncertainty for the example of Hyderabad/India. Fig. 4a shows urban locations which are severely flooded under different projections of the “once in two year percentile” of expected daily precipation depending on different global emission scenarios (B1, A2). For the present Hyderabad climate this percentile amounts to 80mm/day and was chosen due to historical evidence of severe, city-wide impacts. If possible, for other cities affected by this impact path this threshold has to be empirically verified. The range of the projections of the considered climate variable is denoted by the hatched rectangles in Fig. 4a, top. Half of the considered global climate models (AOGCMs from the IPCC AR4 model ensemble) project values within this range after they were statistically downscaled to the Hyderabad region (Lüdeke et al., 2012). To identify which additional areas will be affected by severe flooding in the future a flow-accumulation analysis was performed (DEM taken from SRTM remote sensing, see Kit et al., 2011). To identify the exposure unit, a remote sensing (QuickBird satellite) based identification of slum areas was developed. Here we use the relation of the urban texture (measured by lacunarity) with the probability of slum occurrence because slum areas show a typical settlement structure (Kit et al., 2012). Applied to different QuickBird time slices it allows to identify spatially explicit trends in slum development during 2003 to 2010 (Kit et al., 2013) as shown in Fig. 4b. This current trend (roughly: reduced slum population in the central part of the city, mostly due to slum upgrade and newly occurring slum areas at the fringe of the inner city) was used together with projections of the total population to produce plausible scenarios of future slum development up to 2050. In Fig 4c the impact on slum dwellers is quantified. It shows the ward-wise evaluation of additional slum dwellers severly affected by future pluvial flooding in 2050 under the A2 scenario, the extrapolated current slum development and the assumption of exponential population growth within the city. Clear spatial hotspots can be identified which imply prioritization of e.g. storm drainage improvement activities. The total number amounts to about 78000 dwellers additionally affected, the uncertainty range of [20000, 193000] takes into account the whole range of climate projections by the ensemble of the AOGCMs, including the outliers. Assuming the average climate projection and changing between exponential and linear population growth generates an uncertainty range of the same order of magnitude.

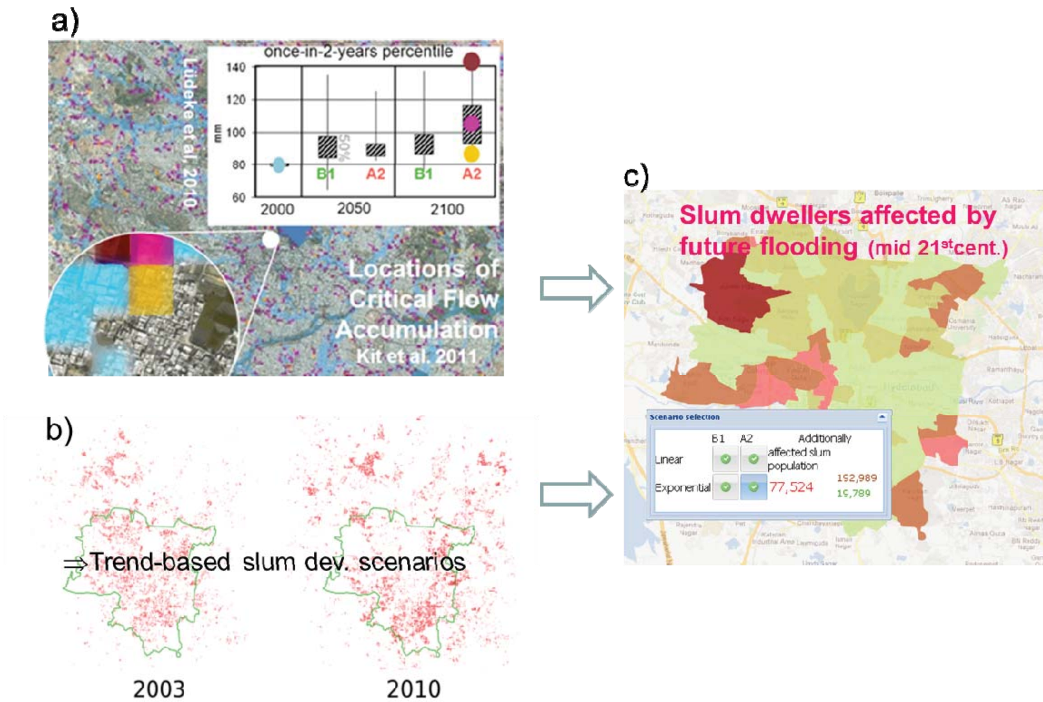

Fig. 4: Fast quantitative climate change impact assement for Hyderabad/India with regard to the expected number of slum dwellers severely affected by pluvial flooding under climate change. a) Driver: once in two year percentile of expected daily precipation under different global emission scenarios (B1, A2, for details see text). Flow-accumulation based identification of areas severely affected by the resulting pluvial flooding (Kit et al., 2011). b) Remote sensing based identification of slum areas (Kit et al., 2012). c) Ward-wise evaluation of the number of slum dwellers additionally severly affected under future pluvial flooding (for details see text) under the A2 scenario and the assumption of exponential population growth within the city.

5 Conclusions

The presented examples for the filtering of cities affected by specific impact paths showed how comparable subsets of cities can be identified and then, in a second step, be further investigated with similar analysis tools to obtain quantitative impacts. The example from section 4 for such a toolset maily depends on remotely sensed and globally available input data sets, i.e.global data availability would allow to apply it to all filtered cities resulting in a worldwide quantitative evaluation of the "severe pluvial flooding of slum dwellers" impact path, relying on a minimum of ground based data, including some calibration data for the slum identification algorithm, at least exemplarily for larger world regions like India, Souith-America, Africa.

Slight modifications and recombination of the filtering steps in section 3 yield different but also very relevant paths so that an increasing collection of such partial filters will cover a very large number of relevant climate impact paths. These filters rely on aggregated, structural indicators for urban areas which are related to the sensitivity towards climate change. Further research to discover such relations is a prerequisite for achieving a more comprehensive overview on climate impacts on cities. The proposed approach provides a framework to integrate this kind of partial knowledge in a systematic manner - possibly leading to a well founded global picture of urban climate change impacts.

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Preparing for Climate Change: Canadian Agriculture Adapting and Innovating

R.J. MacGregor[1], T. Colwill[1], A. Zhang[2]

Abstract

Weather dependent sectors such as agriculture are highly vulnerable to weather and climate change. Governments invest considerable dollars and have multiple policies to improve productivity, enhance competitiveness, support innovation and help manage risks. The Canadian agricultural sector competes in the global market thus understanding how regional challenges could impact Canada's ability to compete in global markets will be critical to developing appropriate policy responses. Employing an integrated assessment framework, General Circulation Model (GCM) scenarios will be downscaled to provide regional climate data to run crop models to ascertain how crop yields will be impacted. Uncertainty will be assessed by comparing results from various GCM. A number of crop models could also be employed but for this research only Environmental Policy Integrated Climate (EPIC) model is employed. This data will feed into a partial equilibrium, regional, sector model for Canada. This will provide the basis to initiate analysis of various adaptation policies covering agronomic decisions and business risk management programs (crop insurance). The objective is to provide policy relevant analysis to help define the range of plausible outcomes that could challenge Canadian farmers in the future (2040-2069) and reflect this back into the strategic policy direction for the sector to determine how robust and resilient current policy is and if the current investment in technological development is sufficient.

1 Introduction

Impacts consistent with climate change are being felt throughout the world, including in Canada (Lemmen eds, 2007, U.S. 2013, Nelson et al, 2009). Some may dispute the causal link between increasing greenhouse gas (GHG) concentrations in the atmosphere and these impacts, but the weight of scientific evidence strongly supports that a link exists and the impacts are increasing in magnitude, sometimes in positive ways, but also with emerging negative consequences (Nelson et al 2009) in particular due to an increase in the occurrence and severity of extreme events (Lemmen

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eds, 2007). Canada is not immune and already we see significant changes from historic weather patterns including summer temperatures consistently above long term averages, increases in frost free days and earlier on-set of spring, changes in precipitation patterns and worrisome trends in extreme events – droughts and summer flooding (Wheaton et al, 2010). To prepare for this emerging reality, the Canadian government has been investing in research and foresight activities to better understand the range of possible impacts and by sharing these with stakeholders and holding discussions to formulate a strategic direction for policy to support adaptation to meet the future challenges and take advantage of emerging opportunities. Using an integrated assessment modeling framework, this research provides a quantitative analysis of what the future might hold for the Canadian agricultural sector to support the evolution of robust policies that will support the sector.

2 Objective

For the Prairie region of Canada, estimate how climate change could start to impact the cropping sector through changes to mean yields and variability, how producers would start to adapt their cropping system to reflect changing temperature and precipitation patterns, and how crop insurance programs might be impacted. Output from climate models and crop models (Zhang et al, forthcoming) will be incorporated into a regional economic agricultural model to produce a range of possible outcomes.

3 Methodology

i) Daily weather data for the 1951 to 2001 period provided the base data for the crop model. Climate data for the 2040-69 period are obtained from the Canadian GCM (CGCM1 for 2.0-4.5^{0}C change) and the Hadley GCM (HADCM3 for 1.5-3.0^0 C change) for the A2 SRES (Special Report on Emission Scenarios) from the Inter-governmental Panel on Climate Change (IPCC) Forth Assessment Report (AR4). Weather patterns for 2040-69 were based on overlaying the changes from the GCM's onto the historic data series. Neither model showed a significant decrease in precipitation during the growing season but both exhibited higher temperature stress and water stress in the eastern Prairies with climate change. Weather data was downscaled through an interpolation process based on historical observation sites to the Soil Landscapes of Canada (SLC) polygons, the lowest spatial aggregation for regional analysis. There are some 5,000 SLC polygons in the agriculture area of Canada (AAFC, 2007).

ii) The crop model used for this analysis is EPIC as it could reflect management systems (historic planting and harvesting dates, tillage and fertilizer) for each crop at the SLC polygon level in terms of a 10 year crop rotation. Daily weather, soils and management data were assembled and EPIC was calibrated and run at the SLC polygon level for the historic climate and the future period based on the output from the GCM's. Adjustment to crop growth was made for increasing CO_2 concentrations and to account for wind. EPIC calibration and validation ensure a high level of precision between the model results and the actual yields over the historic period, including annual variability for the Canadian Prairies. Extensive statistical testing was carried out to confirm performance with SLC data upscaled to Census of Agricultural Regions (CAR) for this aspect (Zhang et al, forthcoming).

iii) EPIC produced data on mean harvested yields and yield variability for the historic period and the future periods. These were the key inputs into CRAM, the Canadian Regional Agriculture Model (Gill et al, 2013), with a spatial disaggregation at the level of the CAR. For this analysis risk related to weather and its impact on yields are directly incorporated into a risk term in the objective function to capture producer response to changes in expect output as well as to the riskiness of that output. Crop Insurance reflective of the Canadian program is also incorporated into the objective function and pays out once a farms actual yield for a crop falls below 70% of the long term average yield.

4 Adapting Cropping Patterns

The key to this analysis is developing new time series projections of yields that reflect changing weather patterns resulting from climate change. As shown in Figure 1 for spring wheat (largest seeded area in the Prairies) the average yields projected at the CAR level will change significantly relative to the historic yields and this depends on the GCM and whether CO_2 fertilization is taken into account. Starting in Manitoba on the eastern edge of the Prairies, the impacts are generally negative for both GCM models but as you travel west, yield improvement can actually be seen for Alberta when CO2 fertilization is taken into account. Figure 2 provides a better view of the spatial impact. On close inspection of the data, an increase in heat stress resulting in higher evapotranspiration rates and water stress in the Eastern Prairies is the key driving force.

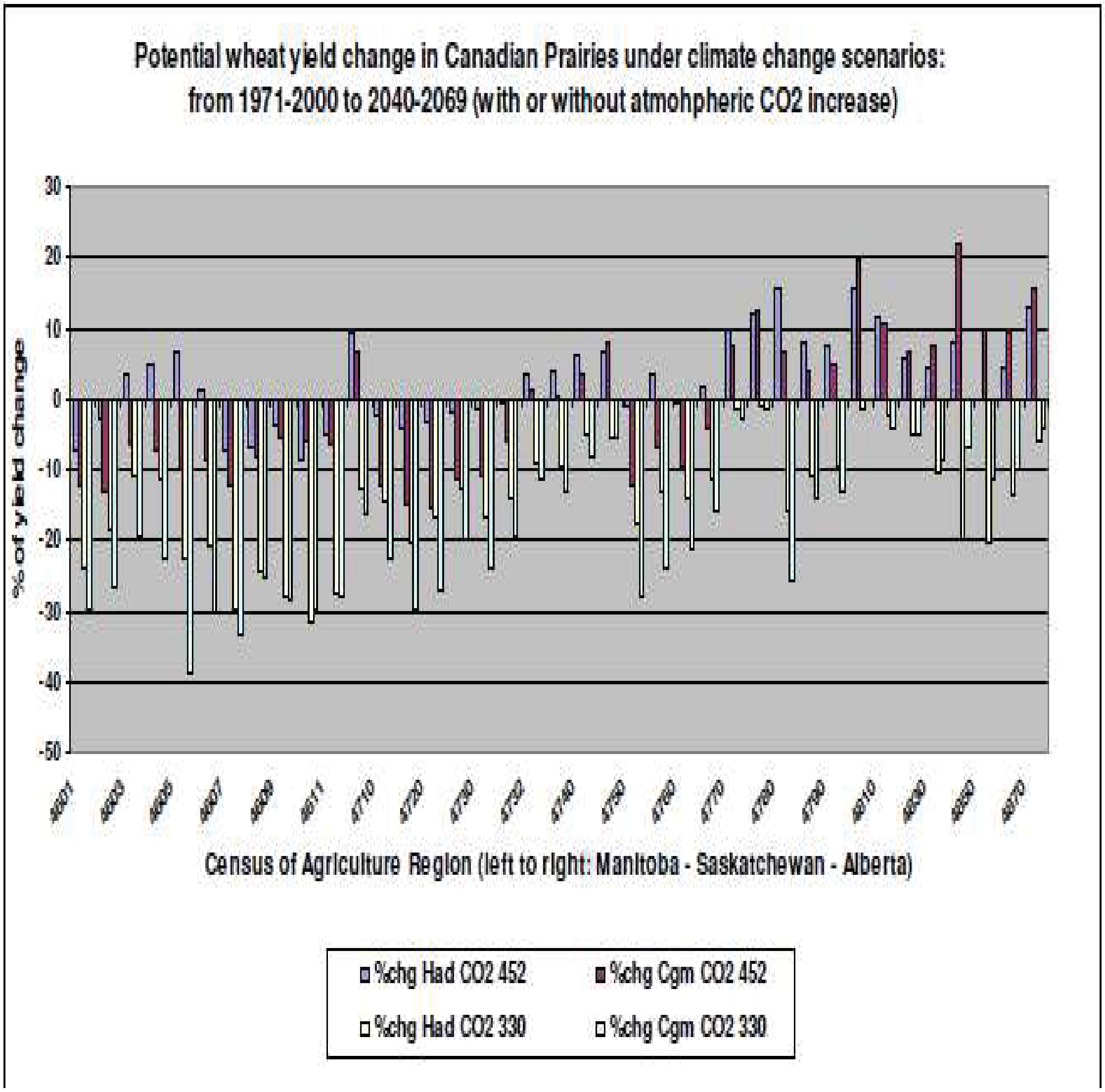

Figure 1: Average yield changes by crop district 1971-2000 compared to 2040-2069 (Zhang et al, 2011)

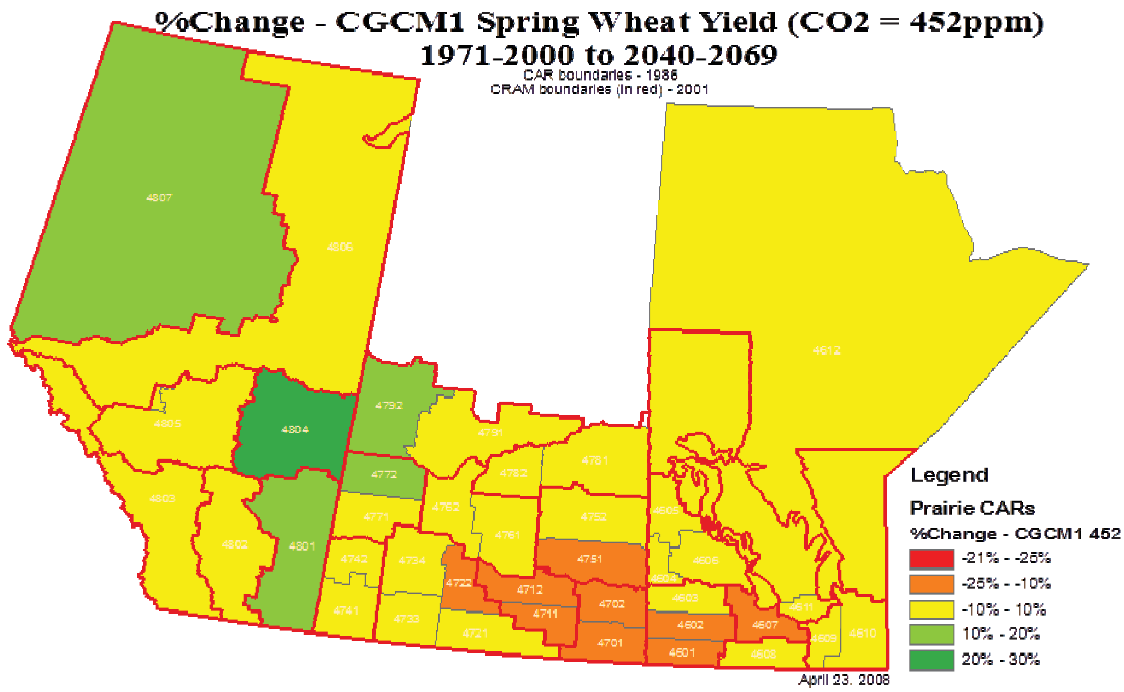

Figure 2: EPIC: Spring wheat scenario assuming CO2 increase over time (Zhang et al 2011)

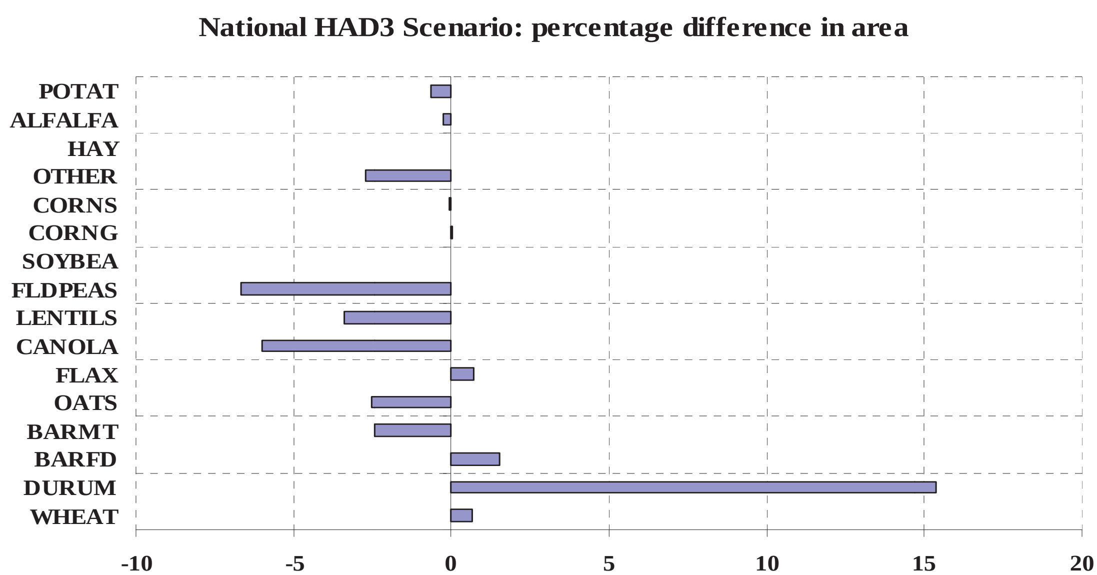

Figure 3: Climate Change Scenario: CRAM Results with HAD3 without CO2 fertilization

The CRAM model estimates how crop selection would adjust to climate change. Figure 3 demonstrates how producers would adjust their crop selection across the Prairies as a result of climate change. This would be the first level of adaptation by producer to changing expected yields and the variability in those yields. Given warmer weather with an increase in heat stress, durum area increases substantially while canola, lentils and field peas decline. This analysis assumes that the same cultivars available in the historic period are those available in the future, something that would change as a result of future innovation (Malcolm et al 2012). In terms of income with adaptation for crop selection, some crop districts (see Figure 2) benefit from this degree of climate change while others are impacted negatively. This analysis is preliminary but the implications for policy are quite clear. If the types of weather changes projected by the GCM's are realized in Canada, significant adjustment and adaptation will result at the farm level. This would likely be accentuated by the impacts arising from international markets where the impacts could be much larger (Nelson et al, 2009) which are not accounted for in this analysis.

A significant feature of this analysis is that changes in riskiness related to expected yields is taken directly into account by specifying an objective function that optimizes cropping activities taking into account expect yields and the underlying risk to the expected yields through a variance-covariance matrix of yields over the simulated periods, 1970-2000 for the historic period and 2040-2069 for the future. The EPIC model provided the data for the future period and the risk term is incorporated using a standard formulation assuming producers are risk adverse with a greater risk penalty incurred as risk increases as measured by the variance-covariance term for each CAR. In the version of the CRAM model used for the analysis market risk related to price is not included.

5 Risk Management

One of the principle and long standing risk management tools available to Canadian farmers is crop insurance (CI). This is co-funded between producers (40%) and the government (60%) with premiums set so that the program is actuarially sound over the longer term. For principle crops on the Prairies roughly 70 to 80% of the crop is insured. Crop insurance (Beach et al, 2010) is proposed as one of the key risk management tools that will help producers adapt to climate change as it will allow them to adjust production processes as they incorporate a changing climate into their decisions. Producers historically have considered weather as a given in making production decisions but with climate change the new reality is that in the future weather will become another variable in their production function in terms of input and output decisions.

Weather will continue to evolve over this century as GHG concentrations in the atmosphere continue to increase. The following equation tries to demonstrate this paradigm shift as all future decisions become a function of weather (ω) which in turn is a function of CO2 concentrations in the atmosphere (g). Historically output (Y) is determined by own price (p) and production based on inputs (x) the cost of inputs (c) and technology (τ) with weather (ω) taken as constant.

$$Y(p|\omega) = f(x, c, \tau|\omega) \;\rightarrow\; Y\big(p\ (\omega(g)\big) = f\big(x\big(\omega(g)\big), c(\omega(g), \tau(\omega(g)\big)$$

To test whether the CI program would continue to perform within current design features with climate change, CI was included directly into the objective function of CRAM providing a payout if realized crop yield fell below 70% of the expect yield. Monte Carlo simulations are run with draws from the probability distributions for yield for the historic and future periods. Given the regional disaggregation in the model, a method was developed for any given draw (a year) to link the weather for adjacent CAR given that weather patterns would impact several CAR and therefore we could not treat each CAR independently. This is one area which has been identified for additional research to bring in the greater understanding of climate and weather patterns that is being developed by climate scientists.

The metric used to assess the relative robustness of CI is the average annual surplus or deficit resulting over the 10K simulation runs for both historic climate and future climate. Table 1 provides the results and based on this metric indicates that CI as designed performs as well under either climate regime, the future having a somewhat smaller average annual deficit due to slightly lower average yields. The size of the annual deficit is not considered significant as it represents a relative small percentage of annual premiums (around 10%).

Table 1: Cumulative Result from Monte Carlo Simulation for Crop Insurance for the Canadian Prairies, 1970-2000 and 2040-2069

Scenario	Average Annual Surplus (Deficit)	Iterations
Historic	**($99 Million)**	**10,140**
Future (CGCM)	**($86 Million)**	**10,140**
Future (Had3)	**($92 Million)**	**10,140**

6 Concluding Comments and Future Research

The various streams of bio-physical and economic research underway provide the building blocks to support the development of an integrated assessment modeling system that can produce policy relevant analysis which must deal not only with future climate impacts, but also address global food security, poverty reduction, economic growth, protecting the environment (including avoiding climate change) and using resources sustainably. This analysis has demonstrated that it is possible to undertake this type of analysis and opens the way to bringing in additional science and economic research to deepen it and address a wider array of issues. It does show, at least for Canada, that there could be regional winners and losers arising from climate change, but to remain competitive all producers will have to adapt and innovate. This is consistent with results from other modeling exercises that indicate northern temperate countries may not be impacted as great, at least under moderate climate change (Nelson et al, 2009). Governments will need to continue to invest, as will the private sector. Concern has been expressed as to whether some of the key risk management tools we use now will still be relevant, such as CI, and this preliminary analysis indicates they may. Future research can address a much broader array of policy issues such as will the increasing incidence of extreme events challenge the sector in unexpected ways and what types of investment in research will provide producers of the future with the tools and production processes that will allow them to prosper. It would also allow us to estimate what the benefits to mitigation might be in terms of future avoided costs.

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Potsdam, May 27-30

A modular method for predicting forest growth responses to environmental change

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Abstract—The HIFI-MS (Helsinki Integrated Forest Impact Model System) approach combines forest models of different scale and objective in a modular system for estimating climate change impacts in the regional scale. Here, the system is illustrated with an example on adaptation of forest management alternatives under climate change in southern Finland. We used physiologically-based models of daily GPP and respiration to predict NPP, and models of daily soil processes to predict C and N release as a function of environmental drivers. The results of these were inserted as parameter changes in the PipeQual stand growth model and further translated into changes in site index, which were used as input to an empirical growth model to estimate regional forest growth changes. Economically optimal forest management schemes were calculated on the basis of the scenario results. Our models predict a 16-40% growth increase in southern Finland under climate change scenarios (A2,A1B, B1). No single thinning regime showed to be optimal in the transient climate. The initial age distribution of stands largely determined the total growth in the region until 2050, after which different climate scenarios and management options started to influence the outcome.

Index Terms—boreal forest productivity, climate scenarios, management scenarios, modular model

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1 Introduction

Prediction of forest growth under climate change involves quantification of a multitude of impacts at different spatial and temporal scales. Few ecosystem models incorporate all the essential impacts at a time, and furthermore, single models easily become too complex to parameterise for larger areas or longer time spans. On the other hand, a lot of information and theoretical understanding of different aspects of forest ecosystem functioning and growth has already been gained and quantified in different models. The HIFI-MS (Helsinki Integrated Forest Impact Model System) approach is to combine such models in a modular system for estimating climate change impacts in the regional scale.

2 The model system

The model system consists of physiologically-based models of daily GPP and respiration to predict NPP (SPP: Mäkelä et al. 2006; PreLes: Mäkelä et al. 2008, Peltoniemi et al. 2012), and a model of daily soil processes to predict C and N release as a function of environmental drivers (ROMUL: Chertov et al.

2001). The results of these simulations are expressed as aggregated parameters for process-based stand growth models. These parameters typically describe potential rates of processes under a changed climate, while the growth model simulations introduce feedbacks between the different processes and the changing state of the stand. In this report, we use the PipeQual model (Mäkelä and Mäkinen 2003, Kantola et al. 2007) for stand growth simulations under climate scenarios. In our forthcoming work we will apply the OptiPipe model (Valentine and Mäkelä 2012) with optimal C:N allocation to derive a response-surface relating the climate-sensitive parameters to carbon allocation. Changes in carbon allocation are further translated into changes in site index, which is used as input to an empirical growth model to estimate regional forest growth changes (Fig. 1). Changes in site index also infer changes in the ground vegetation and therefore in the need of site preparation. The results from the empirical model allow us to assess the economical returns from different management options and to calculate economically optimal forest management schemes (Mäkipää et al. 2011).

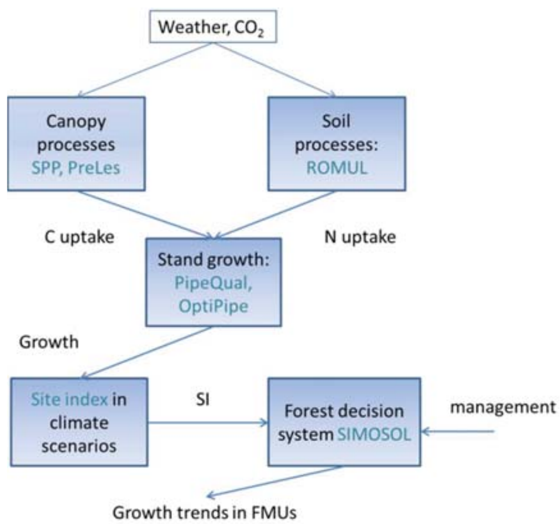

Fig. 1. Modular model system in HIFI-MS. FMU = Forest Management Unit

3 Material and methods

3.1 Climate scenarios

We used three climate scenarios based on SRESB1, SRESA1B and SRESA2 emission scenarios. Changes of daily temperature, precipitation, vapour pressure deficit and solar radiation were calculated separately for periods 2011-2040, 2041-2070 and 2071-2100 by using a climate model that represented the median temperature change among 10 climate models (CSIRO). The results were calculated (1) across Finland on a 10 km x 10 km grid, and specifically (2) over a circular region of radius 25 km around the SMEAR II ecological research station (61º 50' 50.685'', 24º 17' 41.206'').

3.2 Forestry data

National multisource forest inventory data were available for the circular forest area at 20 m x 20 m resolution (*ca.* 140 000 ha). Variables measured included land use class, stand age, basal area, total volume and volume by species (*Picea abies*, *Pinus sylvestris*, *Betula pendula* and other deciduous).

3.3 Forest management decisions

Simulations were carried out using the SIMO model platform in the forest area. The initial state was based on the inventory data. Forests were grown as even-aged stands with a dominant species. The management decisions concerned timing and intensity of thinnings, timing of clearcut and the choice of species (pine, spruce, birch) for the next generation. In addition, removal of ground vegetation was carried out when needed and its cost depended on the biomass of the vegetation to be removed, which in turn was related to the current site index. Two management strategies were compared: (1) current recommendations which are based on basal area and height (Tapio 2006) and (2) adaptive management which was defined so as to harvest when the current rate of value growth goes below the current interest rate (taken to be 3%).

4 Results

4.1 Productivity changes

Changes in potential productivity were estimated for the whole of Finland, while subsequent analyses were only carried out for a selected region. The simulations predict that by 2100, the potential productivity (GPP) will increase approximately by 20, 30 or 50% in the B1, A1B and A2 scenarios, respectively (Fig. 2). This represents the maximum change in productivity provided that N availability would also increase respectively. Preliminary results indicate that N availability may not increase in pace with the increased potential for GPP, if the potential is estimated as a function of CO_2 increase and changes in meteorological variables. In our simulations, changes in CO_2 and meteorological variables are each responsible for about 50% of the increase. The availability of N is dependent on soil temperature and humidity, while the increase in atmospheric CO_2 concentration may not contribute to an increase in N availability.

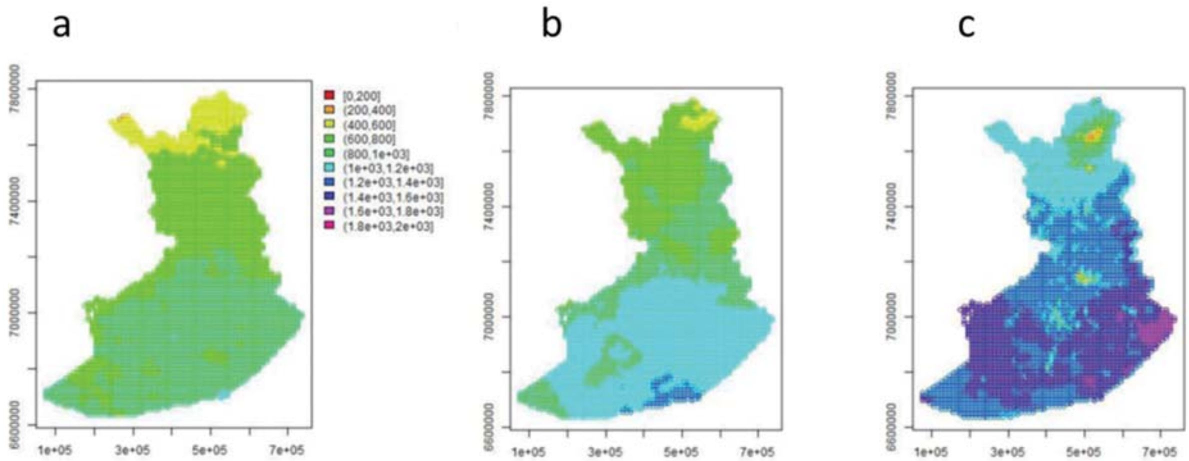

Fig. 2. Distribution of reference GPP in Finland in current climate (a), 2050 (b) and 2100 (c) according to the A1B scenario as simulated by a climate model representing the median temperature increase for 2010-2100 in Finland among 10 climate models (CSIRO).

4.2 Changes in site index

We predicted the changes in site index (dominant height at age 100 yrs) for the SMEAR II region using the PipeQual model with changes in parameters relating to potential GPP, specific rate of respiration and N uptake rate for the period 2000-2100. The predicted change was 4 – 6 m depending on the current growth site, with poorer sites showing larger increases in site index (Fig. 3).

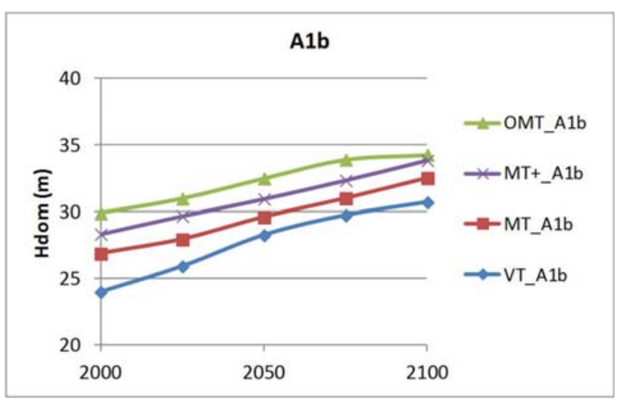

Fig. 3. Development of site index in four site types during 2000 – 2100. Site type refers to dominant ground vegetation type: VT = Vaccinium type, MT = V. myrtillus type, OMT = Oxalis-myrtillus type

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4.3 Changes in productivity in the sample region

The mean annual increment (m^3/yr) increased in the forest area as a function of the climate scenario used, but was much less than the increase in potential productivity (Fig. 4a). However, the harvests were less intensive in the adaptive scenario, resulting in less total volume removed (Fig. 4b). At the same time, the net present value of the forest area was greater with the adaptive management method than using the conventional harvest (Fig. 4c). The initial age distribution of stands largely determined the total growth in the region until 2050, after which different climate scenarios and management options started to influence the outcome.

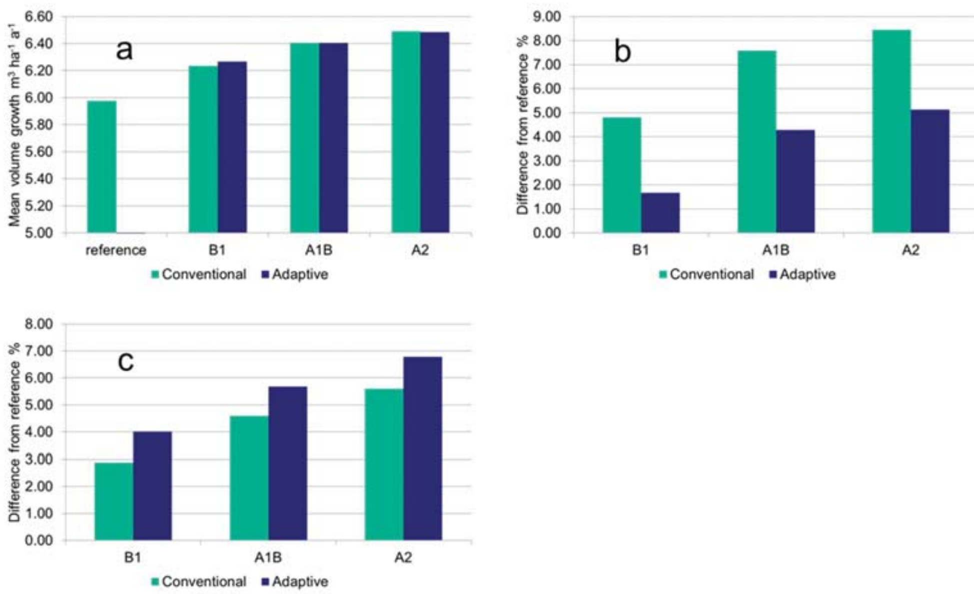

Fig. 4. Forest productivity and economic value in different climate scenarios and management strategies in a sample region in Finland during 2000-2100. a) mean annual increment (m^3/yr), b) total harvests, % of reference (current climate and current management), c) net present value, % of reference.

5 Discussion

Here, we presented preliminary results from simulations using HIFI-MS, a modular model system for combining eco-physiological and empirical growth models with economic assessment of management options. So far, the results indicate that while climate drives total productivity, management methods are crucial for determining stand structure and revenue from harvests. Because of increasing growth potential, the changing climate moves harvests earlier. Partly because of this, the impacts of climate change appear less at the FMU scale than at stand scale.

Risk of damage was not included in this study (wind, fire, insects, dry spells). Previous studies show that the optimum rotation length is shorter under a risk of damage (Reed, 1984 and later studies), and also that the adaptive management would be even more preferred when risks increase (e.g., Gong, 1998).

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Globally consistent adaptation policy assessment for agricultural sector in Eastern Asia

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Abstract—Achieving food security in the face of climate change is considered to be a major challenge for humanity in the 21st century. The science of farm level climate adaptation measures is well established, while more comprehensive analysis including global market feedbacks are lacking. In a context of uneven impacts of climate change across interconnected regions through trade, climate change impact and adaptation policies in one region need to be assessed in a global framework. In this study we investigate how pressure on the food system in Eastern Asia can be mitigated by a consumer-sided adaptation policy. We find that the costs of implemented adaptation policy vary greatly across climate projections representing between 2 billion USD and 30 billion USD per year in 2050 for the Eastern Asian region. The costs of a policy that would be implemented only at the regional level would be greatly reduced. However, market price leakage of a regional only adaptation policy exacerbates pressure on food systems in other world regions. These findings point to the need to coordinate the implementation of adaptation policies internationally to avoid negative climate change impact falling on the poor.

Index Terms—food security, adaptation, trade, Eastern Asia, integrated modeling

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1 Introduction

Eastern Asia is one of the most populated regions of the world with 1.5 billion inhabitants. Around half of the food consumption comes from domestic production in Japan and South Korea and two-thirds in Mongolia while China is close to food self-sufficiency level. This indicates that local agriculture has an important role to ensure food security in the region (Piao et al. 2010). However, food and feed imports have continuously increased during the last decades reinforcing food interdependency between Eastern Asian countries and the rest of the world. Most staple food is imported in Japan and South Korea (McMichael 2000) and livestock sector in China relies more and more on soybean imports (Nepstad, Stickler, and Almeida 2006). Currently, Eastern Asia sources its imports mainly from North America, Latin America, Australia and South Asia. When the impact of climate change on food consumption in Eastern Asia will likely result from the combination of climate change impacts on domestic production potential and on trading partners' production potential, existing studies have focused on the impact on domestic agriculture only (Wang et al. 2009; Wei et al. 2009).

With future climate change, higher temperatures could reduce crop yields while increased atmospheric CO2 concentrations might improve plant growth conditions (Lobell, Schlenker, and Costa-Roberts 2011; Kaufmann et al. 2008; Erda et al. 2005). It will also lead to a shift in suitable growing areas inside a country and across countries (Iizumi, Yokozawa, and Nishimori 2011; Olesen and Bindi 2002). While the global impact of climate change is supposed to be small, regional impacts are projected to be important with for instance serious droughts problems in China and Mongolia (S. Liu and Wang 2012). Most of the climate change adaptation literature has focused on producer-side measures (Howden et al. 2007; Smit and Skinner 2002). However, consumer-oriented adaptation strategies could be more efficient to target food security (Nelson et al. 2010). Since it could exploit gains in relative competitiveness in production by allowing geographical production flexibilities of relocation through international trade, the financial burden of the food security adaptation policy could be lower.

2 Methodology

We use an integrated modeling framework to investigate both biophysical and economic impacts of climate change and the effects of a consumer side adaptation policy (Fig. 1).

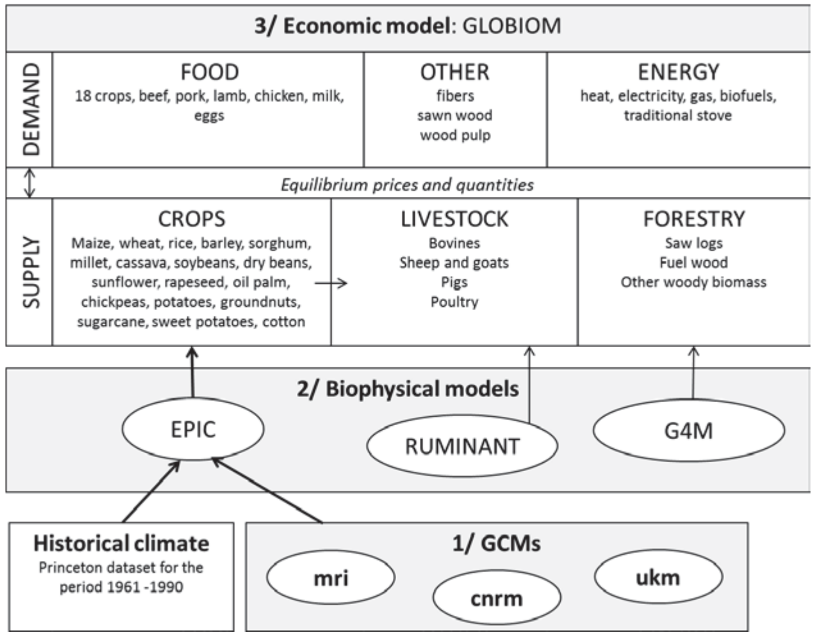

Figure 1. Overview of the IIASA-ESM integrated modeling cluster to assess climate impacts and climate adaptation policy

Climate projections have been taken from 3 General Circulation Models focusing on the A2 SRES story-line whichy represent contrasted climate projections and consequently give an idea of the uncertainty range of global climate change among GCMs. They have been selected among 17 GCMs according to the changes in the Climate Moisture Index (CMIs) between 2046 - 2055 and the baseline period 1961-1990 which is an indicator of aridity depending on annual precipitation (P) and average annual potential evap-otranspiration (PET):

$$CMI = \frac{P}{PET} - 1, \quad \forall \quad PET > P$$

$$CMI = 1 - \frac{PET}{P}, \quad \forall \quad P > PET$$

Mri.cgcm2.3.2a represents a global wet climate, *ukmo.hadgem1* a mid-range climate and *cnrm.cm3* a global dry scenario. However, *cnrm.cm3* is the driest of the three GCMs for Northeast Asia while both *mri.cgcm2.3.2a* and *ukmo.hadgem1* are wetter climate scenarios for the region (Fig. 2).

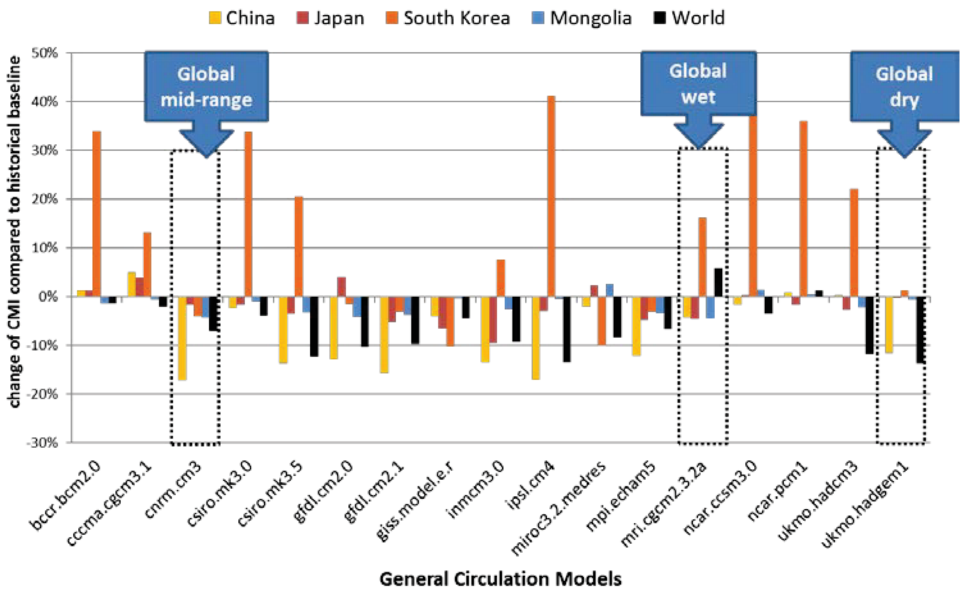

Figure 2. Changes in the Climate Moisture Index (CMI) compared to historical climate (2046-2055 vs. 1961-1990, A2 emissions scenario) show positive values for wetter climates and negative values of drier climates. The numbers are the spatial averages for the global and Northeast Asian country.

The Environmental Policy Integrated Climate (EPIC) model is used to compute the effect of climate change on 18 major crops' yields and input requirements globally, including carbon fertilization effect (Williams 1990). The biophysical impacts are computed by applying change in potential crop yields on current crop areas. The potential yields and related input requirements are then included in GLOBIOM (Havlík et al. 2011), a global economic model, where the supply side draws on detailed land information on soil types, climate, topography, land cover, and crop management. Countries are assigned to 1 of 31 regions among them Northeast Asian countries -China, Mongolia, Japan and South Korea- have been singled out as individual countries. Principal exogenous drivers are gross domestic product (GDP) and population change as well as bioenergy demand. The model is recursive dynamic. It runs over the period 2000-2050 and is solved by 10 year-steps. Autonomous adaptation is possible through trade, reallocation of crop production, and changes in crop management.

The adaptation policy is introduced as a constraint to reach at least the same calorie intake level from crops and animal origin as with historical climate over 2000-2050. The amount of the required monetary transfer to consumers to reach such a level is endogenously computed and is referred as the cost of adaptation. We first introduce the constraint at the country level in Northeast Asia and then to all the other regions.

3 Results

3.1 Biophysical impacts

Despite heterogeneous climate projections globally, we observe some common regional patterns in the estimates of biophysical impacts of climate change (Fig. 3). Our results always show a negative impact of climate change on total crop calorie production in the North Plain which is very densely populated and where most of the grains are produced. A positive impact is observed on total crop calorie production in South Korea, in most of Japan, in the Sichuan Basin and above the Xi Jiang River in China by 2050. Among the main trading partners of Eastern Asia we consistently observe a negative impact of climate change on crop production in North America and a positive impact on Australia in 2050 across all three GCMs while there is more uncertainty about the climate change impact in Latin America and in South Asia. Combined external and internal biophysical impacts of climate change would lead to a reduction in domestic calorie availability until 30% in Mongolia, 14% in Japan, 10% in China and 8% in South Korea in 2050.

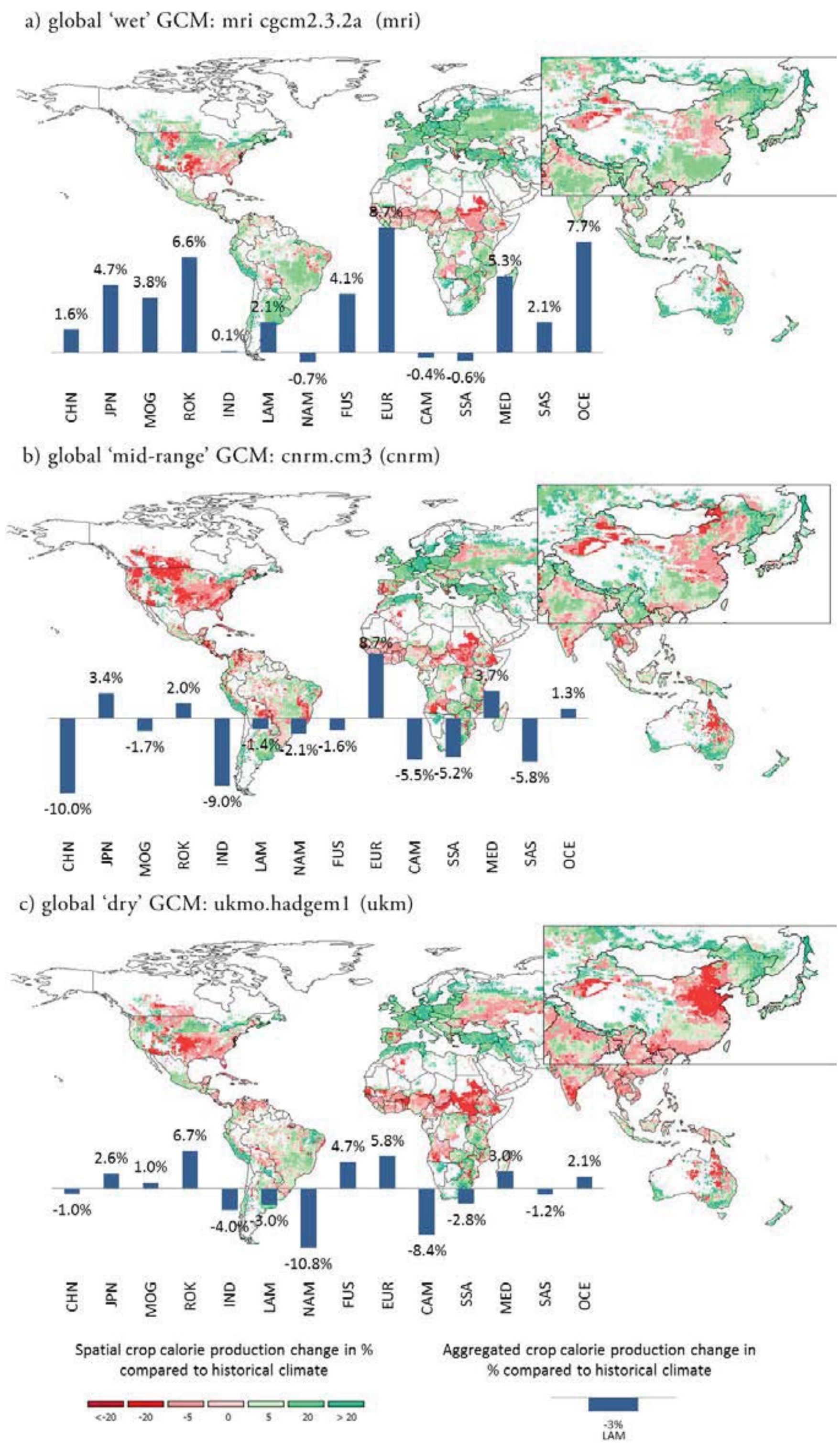

Figure 3: Biophysical impact of climate change in 2050 on current cultivated area in % change of crop calories production compared to the situation with historical climate. The results are aggregated at the following regional level: China (CHN), Japan (JPN, Mongolia (MOG), South Korea (ROK), India (IND), Latin America (LAM), North America (NAM), Former Soviet Union (FUS), Europe (EUR), Central America (CAM), Sub-Saharan Africa (SSA), Middle East and North Africa (MED), South Asia (SAS) and Oceania (OCE).

3.2 Global economic feedbacks

3.2.1 No planned adaptation

However, economic feedbacks generally lead to higher calorie production in Eastern Asia compared to the only biophysical impacts. The calorie production is still always reduced in China but the magnitude of the reduction is limited to 4% as compared to the biophysical impacts of 10%. That could be partly explained by internal shifts in area of production and in management. We observe for instance a wheat production increase in the south of China and a rice production increase in the Sichuan basin. Calorie production increases strongly in Mongolia and in South Korea. Mongolia is a landlocked country where transportation costs are high and imports are concentrated on few trading partners. It leads to high import price increase in case of negative impact of climate change in partner countries, and as a result, higher domestic production to substitute imports (Fig. 4). To the contrary, China has more flexibility to adjust trade patterns. We observe some shift from North America to Australia and Europe in Chinese imports sourcing. Improvement in rice productivity under climate change also stimulates exports from Japan and South Korea.

From our estimates, the global wet scenario would lead to the lowest impact on calorie consumption in Eastern Asia (Fig. 4). Across all climate projections, average food consumption per capita remains almost constant in Japan and South Korea because higher domestic productivity is able to compensate higher import prices. Since rice is a major component of human diet and animal feeding is mainly imported, our results show on one hand a reduction in calorie price from vegetal origin and an increase in calorie price from animal origin. China is expected to experience increases in crop and meat prices regardless of the climate scenario, leading to a reduction in food consumption. However, the average calorie consumption reduction is quite low, representing less than 1% of the daily calorie intake. In our estimates, Mongolia faces a crop price rise of 40% and a reduction of the daily average intake down to 7%. In addition to low flexibility of trade, higher price rises in Mongolia are explained by less flexibility of the demand which is concentrated on few products.

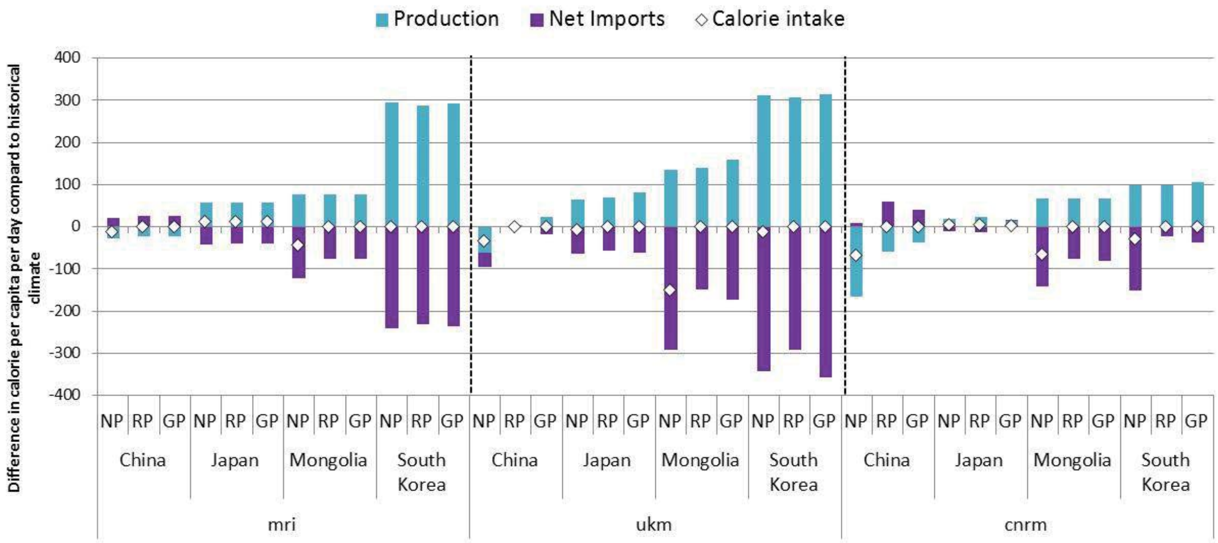

Figure 4. Impact of climate change on calorie intake (consumption), production and net trade in China, South Korea, Japan and Mongolia in 2050 with and without adaptation policy. Absolute difference with results obtained with historical climate data. To allow comparison between Northeast Asian countries, differences are expressed in average calorie per capita per day. *NP* stands for No policy, *RP* for Regional consumer adaptation policy scenario which is only implemented in Northeast Asia and *GP* for Global consumer adaptation policy scenario.

3.2.2 Regional adaptation

The consumer adaptation policy is first introduced regionally and is modeled as a financial transfer to consumers allowing them to reach the same level of calorie intake as in the case of constant climate. Between 50% and 70% of the additional consumed calories are projected to be produced domestically in China while in Mongolia more than 80% of the additional consumed calories are imported. We estimate the cost of such a regional policy to vary across GCMs from 80 million in the global wet scenario to more than 8 billion USD per year in 2050 in the global mid-range scenario which corresponds to the driest scenario regionally. However, even if Chinese calorie imports only increase by 9% maximum with the consumer support policy, it still represents large quantities on international markets. Higher exports to the Northeast Asian region lead to higher prices in Southeast Asia and Brazil where the average calorie intake per capita is further reduced in addition to the climate change impact. Thus, market leakage effects of domestic adaptation policies raise important equity and food security issues on the international level.

3.2.3 Global adaptation

When we implement a global policy that would restore calorie consumption to levels of no climate change in each region of the world we face another trade-off. Higher global demand will further increase world prices due to additional production in all the regions. Comparing to the global policy scenario to the regional one, we observe that food imports tend to be lower and domestic production higher in Eastern Asia under the global policy. The regional cost of the global adaptation policy strongly increases in Eastern Asian countries reaching a minimum of 2 billion USD and a maximum of 30 billion USD per year in 2050. We estimate the global cost of the global adaptation policy to be in the range of 12 to 119 billion USD per year in 2050 in the global wet scenario and in the global mid-range scenario respectively. This range of adaptation costs corresponds to less than a promille of global GDP.

4 Discussion and conclusion

The success and the overall cost of such an adaptation policy depend on several factors. On the one hand, technological change in crop or livestock breeding (Huang et al. 2004; Y. Liu et al. 2010) could reduce the price increase due to climate change and consequently the required financial support to consumers. If we consider crop yield growth due to technological change in line with historical observations over the period 1980-2000, we estimate that the global adaptation cost to support consumers decreases in the range of 14 to 50 billion USD per year in 2050. On the other hand, the cost could be increased by necessary investments in physical market access to allow consumers to access larger food quantities if they are ready to pay more. Reliable transportation infrastructures inside the country are an important condition to allow food transfer from food-surplus regions to food-deficit regions (Bourguignon, Pleskovič, and Bank 2008). The advantage of a consumer strategy is the possibility to rely on trade to adjust to climate shocks. However, constraints in foreign currency availability and export restrictions from large exporting countries are still obstacles to trade-based adjustments (Gilbert and Tabova 2011). Finally, instead of a universal scheme, a climate adaptation policy might favor a funding mechanism that is more targeted on the food insecure populations. Such a scheme might reduce the costs of the adaptation policy even if transaction costs of a more targeted implementation mechanism could be significant. Existing safety net programmes could be used to channel additional funding to reduce climate change impacts on vulnerable people (Grosh, Ninno, and Tesliuc 2008).

This study has illustrated that looking only at crop yield projections in one region is inadequate to derive conclusions on climate change impact on food security. The impact of climate change in the other regions should also be taken into account as it will likely be channeled through international trade. Achieving food security under climate change will require a wide range of policies. In parallel to investment in agronomic research and in rural infrastructures, policies which could reach vulnerable consumers in case of higher food prices could be an efficient way to protect against negative impacts of climate change. More generally, current negotiations should be less about funding and methods of location-specific adaptation projects and more focused on how to make the global food system more resilient.

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Impacts World 2013, International Conference on Climate Change Effects,

Potsdam, May 27-30

Is drought-induced forest dieback globally increasing?

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Abstract — Based on field observations from 88 forest and savannah regions across the world, it has recently been suggested that forest mortality has been increasing as a result of decreasing moisture availability, but it is not yet clear if these observations are representative for forests globally. We used historical climate data and a dynamic global vegetation model (LPJ-GUESS) to assess i.) if the field observations are representative for all forests, ii.) which forests are affected by drought, and iii.) if the LPJ-GUESS model can reproduce the reported mortality events.

Using two climate data sets and two drought indices, we identified a small drying trend with large variability from 1948 to 2006, but no increase in extreme drought events in forests generally. However, a weak drying trend and an increase in extreme drought events, are apparent for forests in already dry climates and savannah areas, and the locations or regions for which drought-induced mortality trends have been reported are predominantly in dry climates. Almost two thirds of the reported drought-induced forest mortality events can be reproduced by either the climatic data or tree mortality events simulated by LPJ-GUESS. But only in one third of the cases, one of the two climatic data sets indicates drying and the vegetation model simulates increased forest mortality, implying that climatic drought might not be the main driver of all these events. We conclude that an increase in drought-induced mortality in dry forest and savannah areas is indeed likely, but the general trends are not very strong and the spatial variability is large.

According to average climate change projections, many already dry forest areas are likely to become even drier in the future, but projections of the impacts of such climatic trends on forest mortality are highly uncertain because forest impact models have not been thoroughly tested against historical events of increased forest mortality. Furthermore, extreme impacts on forests are generally driven by complex interactions between direct climatic effects, disturbances, such as fire and windstorms, and forest pathogens and pests, most of which are not at all or poorly represented in impact models.

Index Terms — Tree mortality, forest dieback, drought, climate impacts on forests, Dynamic Global Vegetation model (DGVM).

1 Introduction

In a warmer climate, droughts are projected to become more severe and widespread during the next decades (Sheffield & Wood 2008b, Dai 2013), which would strongly impact agriculture, the economy, human health and forests (McMichael et al. 2006, Anderegg et al. 2013). Yet, we cannot make reliable projections of future impacts of droughts unless we understand historical impacts, and recent trends might already indicate the kind of changes to be expected in the future. Therefore, a recent meta-analysis, which identified 88 locations globally with increased forest mortality attributed to heat and drought during the 19^{th} and early 20^{th} century (Allen et al. 2010; hereafter ALLEN) received much attention (e.g. in the currently written 5^{th} assessment report by the IPCC). But it has not been assessed to what extent the field observations are representative of forests globally.

In this study, we used two climate data sets, two drought indices and a Dynamic Global Vegetation Model (DGVM) to investigate i.) if the field observations from ALLEN are representative of all forests; ii.) where it is getting dryer and wetter; iii.) if the applied DGVM can reproduce these mortality events and iv.) how strongly drought drives forest mortality.

2 Material and methods

2.1 Climate data

The two climate data sets were: a.) CRU TS 3.0 (Mitchell & Jones 2005) monthly data (hereafter CRU), at 0.5°x0.5° resolution, generating daily precipitation with a weather generator (Gerten et al. 2004), and daily temperature and sunshine hour data by linear interpolation between mean monthly values; b.) spatially downscaled daily reanalysis data at 0.5°x0.5° resolution (Sheffield et al. 2006) (hereafter SHEFFIELD). CRU covers the period 1901–2006 and SHEFFIELD 1948–2008. We used results from the overlapping period 1948–2006 for our analysis. For presentation reasons, we here focus on the results with CRU.

2.2 Drought indices

We used a.) a modified version of the Palmer Drought Severity Index (PDSI) (Palmer 1965, Alley 1984), where we make use of the LPJ-GUESS hydrology; b.) the aridity index (AI) as annual precipitation divided by annual PET (following [Priestley & Taylor 1972] as described in [Gerten et al. 2004]). The AI for the warmest 6 and 3 months, as well as the growing season were also analysed and gave comparable results. As temperature is used to calculate these indices and heat stress generally is most severe under dry conditions, we assume that these indices do not only represent drought stress, but, at least partly, also heat stress. The PDSI is calculated monthly and can have positive (wet) and negative (dry) values. The AI has a lower threshold of 0, if annual precipitation is zero and can go to infinity if annual PET is zero. For statistical evaluation, we normalized the PDSI over time for each model grid cell. The AI was log-transformed, since it is approximately log-normal distributed. With these indices, we defined three types of drought: i.) duration of 1 year with 2 standard deviations dryer than during the simulation period; ii.) duration of 3 years with 1.5 standard deviations dryer than during the simulation period; iii.) duration of 5 years with 1 standard deviation dryer than during the simulation period. The PDSI can have a memory effect concerning the conditions of previous months as well as the same month of several previous years (Guttman 1998).

A Spearman rank correlation of our calculated drought indices to growing season PDSI values of the North American Drought Atlas (NADA) with a spatial resolution on 2.5°x2.5° (Cook et al. 1999) and monthly values of the PDSI simulated by the Vegetation/Ecosystem Modeling and Analysis Project (VEMAP) at 0.5°x0.5° (Kittel et al. 2004) yielded good results (results not shown).

2.3 Field observations of increased mortality attributed to drought and heat stress

We used the locations of ALLEN where we could access the original references (54 out of 88). Many were only published as conference abstracts, with insufficient information for this study. Sometimes several drought events were reported per location, resulting in 74 reported drought-induced mortality events, spanning from one year to trends over 50 years. According to a potential natural vegetation (PNV) map (Ramankutty & Foley 1999), 43 locations are in forested ecosystems, 7 are in savannah ecosystems and 24 are in non-forested ecosystems. Based on the CRU/SHEFFIELD climate 32/36, 47/52, 32/27 locations are in arid (AI<0.65), dry(AI<1) and wet (AI≥1) regions, with the AI average over the whole period. Of the 50 forests and savannah locations, 9/14, 22/27, 28/23 are in arid (AI<0.65), dry (AI<1) and wet (AI≥1) climates with CRU/SHEFFIELD, respectively. The field observations tend to be in relatively dry regions compared to average conditions in all forests and savannahs. 10%/14%, 30%/45% and 70%/55% of the global area of forests and savannah are in arid, dry and wet climates with CRU/SHEFFIELD, respectively.

2.4 Vegetation model description

We applied the DGVM LPJ-GUESS version 2.1 (Smith et al. 2001, Ahlström et al. 2012), which combines the ecophysiological processes of the Lund-Potsdam-Jena (LPJ) DGVM (Sitch et al., 2003 with hydrological updates from Gerten et al., 2004) with more detailed representations of vegetation dynamics and forest mortality, adopting a forest gap model approach (Smith et al. 2001). In LPJ-GUESS, tree mortality occurs as a result of stochastic stand-replacing mortality (representing, e.g., windstorms and pest attacks), fire, low growth efficiency and increasing age (Smith et al. 2001). We only analysed changes in the latter two because these two are directly or indirectly driven by climatic trends and correspond best to the type of mortality events that have been reported for the field sites. Drought reduces the growth efficiency of trees (expressed as NPP per leaf area). The age-related mortality can be influenced indirectly by climate change if climate change changes the composition of trees in terms of their max. non-stressed longevity. However, in our simulation results, changes in growth-efficiency mortality dominate the total mortality change.

3 Results and Discussion

3.1 Historical changes in climatic drought in forests and savannahs

The global spatial pattern of drying and wettening trends from our drought indices (Fig. 1) corresponds well with previously published patterns (Dai 2010, Sheffield et al. 2012). Large parts of Africa have become dryer (in particular in the Sahel), as well as Alaska/western Canada, East Asia, India and eastern Australia.

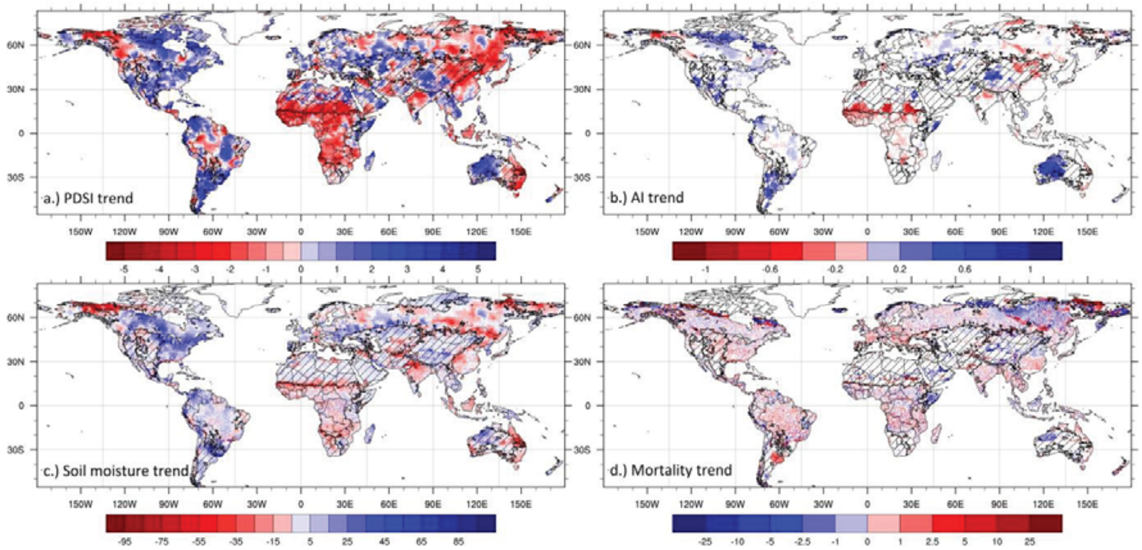

Fig. 1: CRU climate: significant (p≤0.05) trends of drought indices (a.) normalized PDSI, b.) $log_{10}(AI)$), c.) the soil moisture of the lower soil layer from the vegetation model, and d.) mortality values as change per 100 years for PDSI and AI and change in % per 100 years for soil moisture and mortality. Hashed areas are grassland/steppe, dense/open shrubland, tundra, desert and polar desert/rock/ice based on a PNV map, since trees play only marginal roles in these regions.

On average, forests and savannahs have been become slightly drier, but with large variability (-0.27±0.77 standard deviations per 50 years for PDSI; -0.0007±0.1 for $log_{10}(AI)$). In terms of areas with a significant drying or wettening trend, the PDSI gives larger areas with drying than with wettening, in particular for arid and dry areas (Fig. 2). The AI analysis yield less significant results because the sample size is much smaller (annual instead of monthly resolution), and the areas with a drying trend surpass the wettening areas only in forests and savannahs in dry or arid regions. These climatic trends indeed show a slight drying trend in forest and savannah areas, in particular in areas where forest growth is water limited. The climatic trends at the ALLEN sites have not been widely different from these general trends. For forest areas (according to the PNV map), the trends at the ALLAN locations are not significantly different from the trends over all forests, both with CRU and SHEFFIELD (Welch two sample t-test).

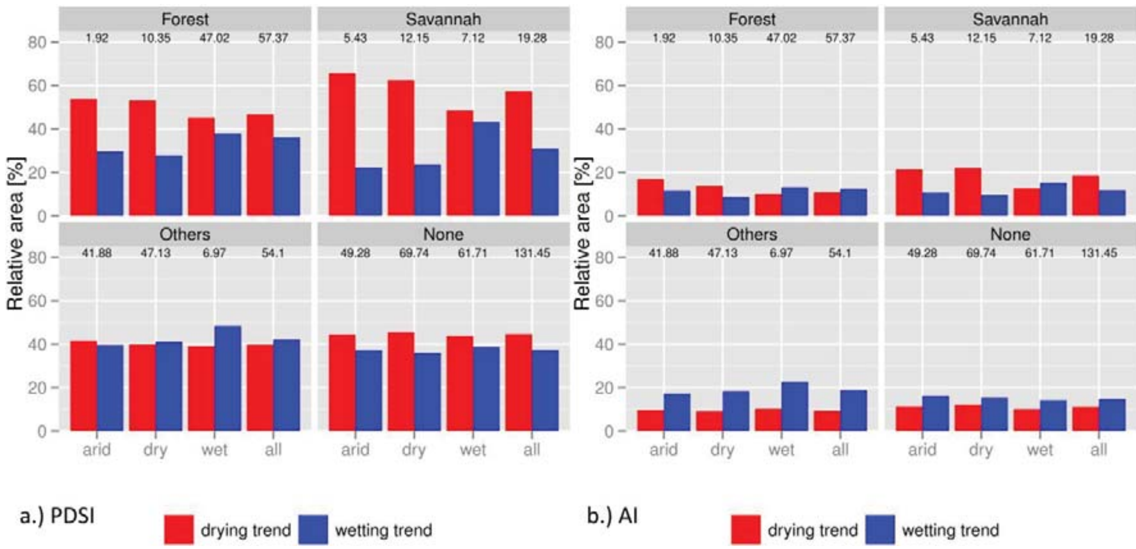

Fig. 2: Relative area in each ecosystem type and with different AI thresholds (arid: AI<0.65; dry: AI<1; wet: AI≥1) with significant drying (red) or wettening (blue) trends for a.) PDSI and b.) AI. Numbers above the columns are absolute areas in 10^6 km^2.

The areas affected by extreme drought events, irrespective of overall drying or wettening trends, have decreased over the previous decades in forests and savannahs (Fig. 3 for PDSI and Fig. 4 for AI). This overall decline in extreme drought-affected area is dominated by changes in wet locations and ecosystems in areas outside the forest or savannah biome according to the PNV map. Forests and savannahs in arid as well as in dry regions show a significant increase in the areas affected by extreme events with respect to PDSI (AI similar, but insignificant). These analysis confirm the drying in already dry areas, but not for forests and savannahs in general.

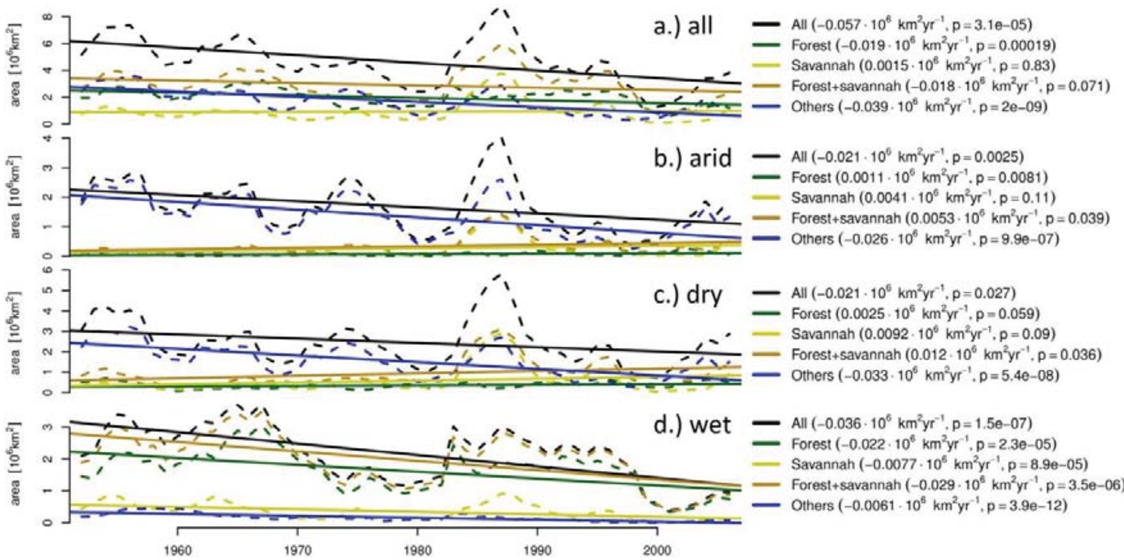

Fig. 3: Area affected by any of the 3 defined types of droughts (PDSI) each year (dashed line) and linear trend (solid line). The slope and p-value are given in the legend. a.) is without a filter, b–d are filtered by AI (arid: AI<0.65, dry: AI<1, wet: AI≥1).

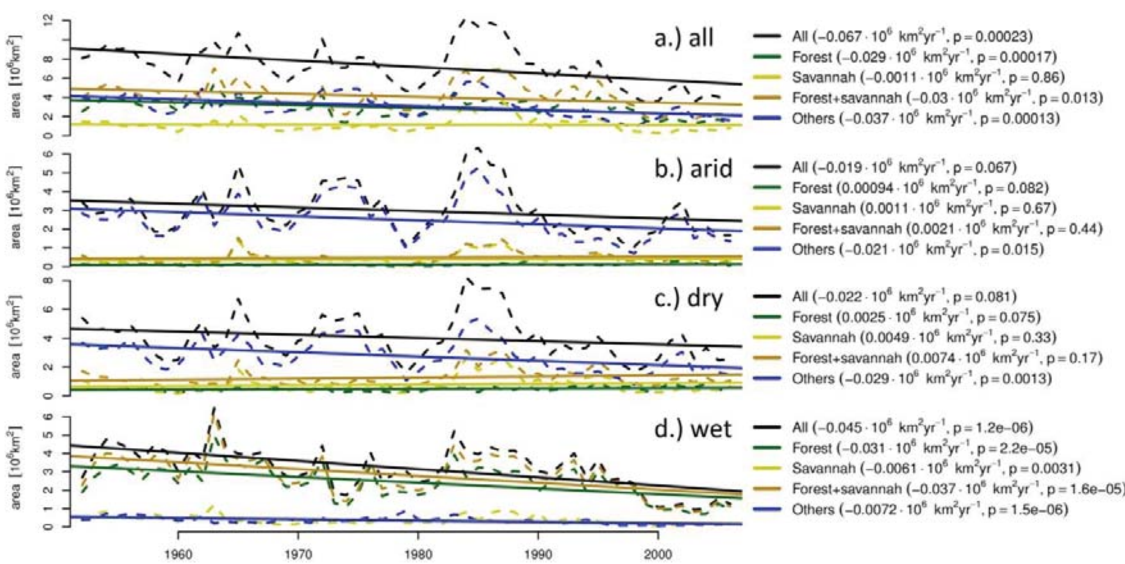

Fig. 4: Area affected by any of the 3 defined types of droughts (AI) each year (dashed line) and linear trend (solid line). The slope and p-value are given in the legend. a.) is without a filter, b–d are filtered by AI (arid: AI<0.65, dry: AI<1, wet: AI≥1).

3.2 **Climatic trends and simulated mortality at the ALLEN locations**

For each of the reported drought- and heat-induced mortality events, we checked whether one of our drought indices (with either of the two climate data sets) matches the location and reported end year ±5 years. The reported drought was apparent in the climate data for 38/41 out of 74 drought events (PDSI or AI) with CRU/SHEFFIELD, respectively, and for 48 events in CRU or SHEFFIELD. This match was better than by chance (randomly choosing a thousand times 74 locations and years in forests and savannahs) for AI, but not for PDSI. LPJ-GUESS simulates exceptional mortality for 30/29 of the reported events with CRU/SHEFFIELD, but only in 15/14 cases associated with exceptional drought. The relatively poor correspondence between the climatologies and the simulated mortality on the one hand and reported mortality events on the other casts doubt on the primary role of drought for all reported mortality events.

We looked at two well-documented large-scale mortality events in more detail. For the western U.S. (Van Mantgem et al. 2009; ALLEN Table A5: 23) the authors concluded that warming and the resulting increase of the climatic water deficit likely contributed to a strong increase of tree mortality since the 1960s . This region spans 16 model grid cells (120W–118.5W, 36.5N–38.00N). Although we calculate a significant ($p<0.05$) increase in mortality of 0.24%yr^{-1} between 1948 and 2006 in agreement with the observations, we calculate a wettening trend with the PDSI and CRU ($p<0.05$; also weak wettening in terms of the AI, but not significantly) and no significant changes with SHEFFIELD. The largest area with reported drought-induced mortality covers west to mid southern Canada (120W–60W, 49N–80N ALLEN Table A5: 20; equivalent to 1800 model grid cells) following a drought in 2001–2002 (Hogg et al. 2008). For this event, we match the exceptional increased mortality, as well as the exceptional drought with the PDSI with CRU. With the SHEFFIELD data, only the increase in mortality is reproduced.

3.3 Global simulated tree mortality changes

The spatial pattern of mortality trends varies at a much finer spatial scale (Fig. 1d). The largest changes in both directions occur at high latitudes, where temperature rather than water availability constrain forest growth. However, in rather dry areas, moisture availability is indeed a main driver of the tree mortality simulated by LPJ-GUESS, confirming that forests in these areas are sensitive to increasing droughts (Fig. 5).

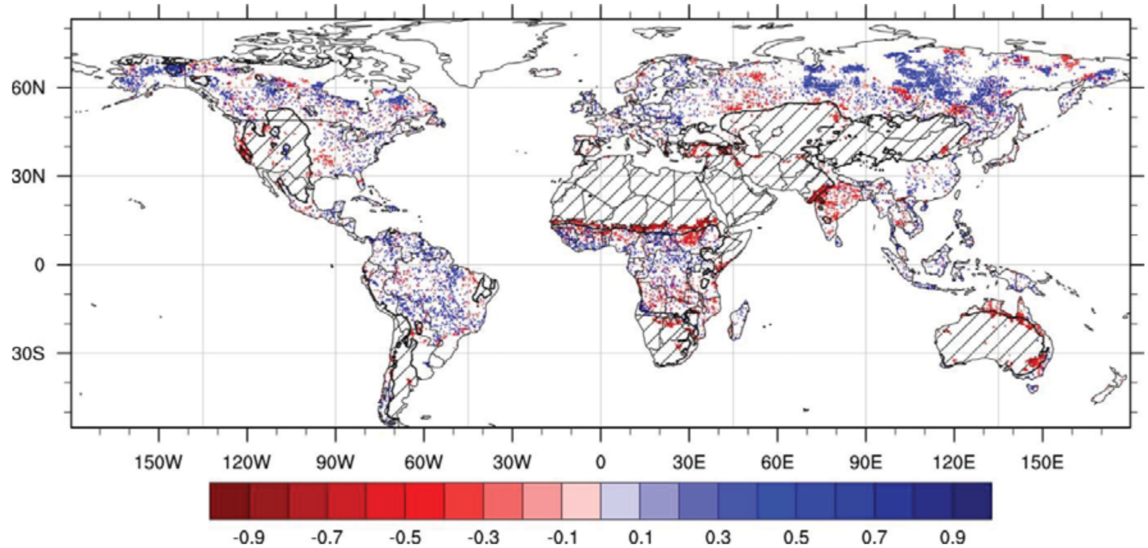

Fig. 5: Spearman rank correlation ρ between PDSI and mortality based on CRU. Hashed areas are arid (AI<0.65). Insignificant correlations (p≥0.05) as well as non-forested vegetation types are white.

4 Conclusions

According to our results, there has not been a clear general drying trend across all forest globally. This conclusion is in line with global analysis from Sheffield & Wood (2008a) and Sheffield et al. (2012), who haven't found strong changes in drought severity and extent since 1950. Even at the ALLAN locations, possibly not all reported mortality events have primarily been driven by drought and heat stress. But our results suggest increasing drought stress for forests in already dry areas, which is where increasing drought and heat also would have the strongest effects. However, estimating drought levels from climate data is challenging because different drought measures can yield quite different results (e.g. Sheffield et al. 2012). Furthermore, the gridded climate data we used may be poor in some areas, and microclimates, as well as the crucial role of soils for the drought sensitivity of forests, have not been accounted for in this study. Moreover, forest mortality is a complex process and the result of interactions between direct climatic effects, management, and disturbances, such as wind, fire, insect pests and pathogens (Franklin et al. 1987; Manion 1991; Kurz et al. 2008) are poorly or not at all represented in impact models (Allen et al. 2010). Nevertheless, more effort should be devoted to test the mortality schemes in impact models against observations from historical events. A large spatial gap in the field observations exists for Asian (especially boreal) forests, since it does not mean there were no such events, if drought-induced mortality events haven´t been reported here so far. The LPJ-GUESS model reproduces the two most widespread reported increases in forest mortality rates, but more vigorous testing with climate forcing and soil data of high quality is necessary to validate the model, and indirect climatic effects via insect pets and pathogens are not represented in the model.

Acknowledgement

We thank Dominique Bachelet and Wendy Peterman for putting the dataset on DataBasin.org, Justin Sheffield for providing his climate driver and our colleagues (Matthew Forrest, Allan Spessa, Christian Werner) for discussions. JS and TH acknowledge support from the research funding program ‘‘LOEWE-Landesoffensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz’’ of Hesse's Ministry of Higher Education.

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Intercomparison of climate impacts and evaluation of uncertainties from different sources using three regional hydrological models for three river basins on three continents

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Abstract Projections of climate impacts should be provided at the regional scale using validated regional-scale models in order to provide more reliable results for decision makers and managers. In the last decade climate impact assessment was performed for different regions and sectors using different scenarios and tools. However, the results are hardly comparable and do not allow to create a full picture of impacts and evaluate their robustness. Therefore, a systematic intercomparison of impacts should be done for representative regions, and our study was intended to do a step in this direction. The climate impact assessment was performed for three river basins on three continents: the Rhine in Europe, the Upper Niger in Africa and the Upper Yellow in Asia using scenarios from five driving global climate models and applying three hydrological impact models: HBV, SWIM and VIC. The objectives were to compare climate impacts on seasonal water discharge, and evaluate uncertainties from different sources. The obtained results are shortly discussed, and future research is outlined.

Index Terms— model intercomparison, regional scale, hydrology, uncertainties.

1. Introduction

Climate impacts occur and adaptation policies are designed at the regional level, where the global impact models may be not precise enough. To ensure that climate change impact research meets the demand for reliable information at the regional scale, projections of climate impacts must be provided at the regional scale using validated models. Many studies have been undertaken to investigate climate change impacts for a number of sectors in different regions using different models and emission scenarios. However, a quantitative synthesis of climate impacts, including consistent estimation of uncertainties, is missing. It can be achieved by a systematic intercomparison of impacts simulated by several state-of-the-art models performed for a set of representative regions on all continents using a set of up-to-date climate scenarios. Some studies on model intercomparisons are already published, but not many (Kay et al., 2009; Chen et al., 2012). As a step in this direction, our study was focused on an intercomparison of climate impacts for the water sector in three large-scale river basins on three continents using three hydrological models: SWIM, HBV and VIC. The following river basins were included: the Rhine in Europe, the upper Niger in Africa and the upper Yellow in Asia. The bias-corrected climate scenarios from five GCMs: HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, and NorESM1-M were provided for this study by the ISI-MIP project. The objectives were to compare climate impacts on seasonal water discharge and three runoff quantiles, and evaluate uncertainties from different sources, especially those from climate models providing input to hydrological models, and from the hydrological models themselves.

2. Methods and data

2.1. Study areas

2.1.1. Upper Niger

The Upper Niger Basin at the gauging station Koulikoro covers an area of about 122,000 km^2. It spreads over the countries Guinea, Mali and a small part of the Ivory Coast. The topography of the area is very heterogeneous with a network of steep-sloped tributaries in Haute Guinée that flow into the flat plane of the Niger River. The dominant land cover is forests (34 %) followed by savannah (30 %). The climate is characterized by a dry period in winter and a rainy season from June to September (see Table 1). The basin until Koulikoro is not much influenced by human management.

2.1.2. Rhine

The Rhine river basin covers an area of about 185,000 km^2 and spreads over nine countries. Two thirds of the Rhine drainage basin are situated in Germany. The altitude ranges from 4275 m.a.s.l. in Swiss Alps to zero at Rotterdam. The basin can be subdivided into three major hydrological areas: the Alpine area, the German Middle Mountain area and the Lowland area. The arable land (38 %) and forest (25 %) are

Table 1: Characteristics of the modelled river basins

	Rheine (Rees)	Upper Yellow River (Tangnaihai))	Upper Niger (Koulikoro)
Area [km^2]	170.000	110.000	122.000
Altitude range (min/mean/max) [m]	10/495/4275	2673/4256/6248	289/463/1407
Average temperature (1971-2000) [°C]	8.6	-2.0	26.5
Temp. of coldes/warmest month [°C]	0.3/17.4	-14.2/8.23	23.8/28.6
Annual precipitation (1971-2000) [mm]	987	520	1495
Prec. of driest/wettest month [mm]	69/97	0/113	3/323
Dominant land cover [%]	cropland 38 forest 25 grasland 9	grassland 90 bare soil 4 heather 3	forest 34 savanna 30 cropland 24

the two major land cover types in the Rhine basin. Maximum discharge of the Rhine in Alpine region is observed during summer due to snow melt. Downstream of Basel, a pluvial regime of the Rhine gradually becomes dominant. Rainfall dominated tributaries (Moselle, Neckar etc.) contribute to the second maximum discharge of Rhine in winter. In the middle and lower Rhine, the winter peak dominates the summer one, changing the runoff regime into a pluvio-nival type. Compared to the other two rivers the Rhine is moderately influenced by human water management.

2.1.3. Yellow River

The Upper Yellow River at the gauging station Tangnaihai belongs administratively to the Qing-Tibetan Plateau of China. With the drainage area of about 122,000 km^2 it covers approximately 15% of the entire Yellow River's drainage basin, while supplying 38 % of the River's total runoff (Chen et al., 2012). The mean altitude of the drainage area is about 4,000 m. The climate is cold and dry with 70 % of precipitation falling from July to October. The headwater part of the Yellow basin is not much influenced by human activity.

2.2. Hydrological models

Three hydrological/ecohydrological models: HBV, SWIM and VIC were used in the study.

2.2.1. HBV

The HBV model (Bergström & Forsman, 1973; Bergström et al., 1995) was developed for runoff simulation and hydrological forecasting. In this study a modified semi-distributed version of the HBV model (HBV-D) with a finer spatial disaggregation into subbasins and up to 15 land cover types (Krysanova et al., 1999) was applied. The advantages of the HBV model are that it covers most important runoff generating processes by quite simple and robust structures where topographic parameters serve as a driving force, and does not require extensive data sets. Spatial disaggregation scheme includes subbasins, 10 elevation zones within every subbasin and up to 15 land use classes. The model is used worldwide in climate impact assessment studies (Menzel et al., 2006; Yu & Wang, 2009).

2.2.2. SWIM

The ecohydrological model SWIM (Soil and Water Integrated Model) (Krysanova et al., 1998) is a continuous-time spatially semi-distributed model of intermediate complexity integrating hydrological processes, vegetation growth, nutrient cycling and erosion and sediment transport at the river basin scale. SWIM was developed based on SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989) with the aim to investigate climate and land use change impacts in large river basins. The model was validated and applied for impact assessment in many medium and large river basins in Europe, Africa and Asia (Hattermann et al., 2011; Huang et al., 2013; Liersch et al., 2012).

2.2.3. VIC

The variable infiltration capacity (VIC) model (Liang et al., 1994, 1996), is a semi-distributed macroscale hydrological model. It calculates the balances of both the water and surface energy budgets within the grid cells and its sub-grid variations are captured statistically. The runoff processes are represented through the variable infiltration curve, a parameterization of the effects of sub-grid variability in soil moisture holding capacity and a representation of the non-linear baseflow. VIC has been extensively applied in climate impact studies for a number of large river basins over the continental US and the globe (Christensen et al., 2007; Su & Xie, 2003).

The three models differ in their levels of complexity, mathematical process formulation and spatial resolution. For example, vegetation growth is simulated only in SWIM, whereas HBV and VIC use the fixed monthly plant characteristics. In this study SWIM and HBV were set up with a finer spatial representation compared to VIC. For the raster based model VIC a grid resolution of 0.5° for the Rhine and 0.125° for the other basins were used. For SWIM and HBV applications the basins were firstly subdivided into subbasins with an average area of 100-200 km^2 using SRTM digital elevation model. For example, for the Rhine 1668 subbasins were simulated. In total, for the Rhine basin 115 grid cells were simulated by VIC, 41976 hydrotopes were modelled by SWIM, and 69589 units were simulated by HBV, with the average areas of 1391

Table 2: Calibration and Validation Results. NSE = Nash-Sutcliffe efficency; VE = Volume Error

	Calibration			Validation		
Rhine	HBV	VIC	SWIM	HBV	VIC	SWIM
Period	1965-1973	1981-1990	1981-1990	1973-1983	1991-2000	1961-1980
NSE	0.75	0.83	0.89	0.71	0.87	0.89
VE [%]	0.2	-1.0	3.0	4.9	-4.0	-1.0
Upper Yellow River	HBV	VIC	SWIM	HBV	VIC	SWIM
Period	1961-1990	1961-1970	1961-1970	1991-2004	1971-1980	1971-1980
NSE	0.85	0.75	0.82	0.82	0.75	0.74
VE [%]	-9.6	-3.6	0.9	0.7	1.0	6.0
Upper Niger	HBV	VIC	SWIM	HBV	VIC	SWIM
Period	1961-1974	1961-1970	1964-1974	1975-1990	1971-1980	1983-1992
NSE	0.76	0.88	0.92	0.86	0.87	0.9
VE [%]	-4.1	4.0	5.5	13.0	-5.0	2.0

km^2, 2.8 km^2, and 1.7 km^2, correspondingly.

2.3. Input data

A digital elevation model constructed from the Shuttle Radar Topography Missions with 90 m resolution was used. Soil parameters were derived from the Digital Soil Map of the World (FAO). Land use was parameterized using the Global Land Cover data (GLCF). As climate input for model calibration the WATCH forcing data was used (Weedon et al., 2011) with the grid resolution of 0.5 degrees. Observed river discharge data from the Global Runoff Data Center was used to calibrate and validate the hydrological models. For the Rhine and the Yellow River additional national climate input data sets were used. Climate scenarios were provided by the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP). The scenarios were created by five Earth System Models (HadGEM2-ES, IPSL-5 CM5A-LR, MIROC-ESM-CHEM, GFDL-ESM2M, NorESM1-M) which have been downscaled using a trend-preserving bias-correction method with the WATCH reanalysis data and have been re-sampled on a 0.5°x0.5° grid (Hempel et al., 2013). The 'Representative Concentration Pathways' (rcp) cover different emissions and land-use change projections. In this paper only impact results from the high end scenario 8.5 are reported.

Rhine	Q10	Q50	Q90
GFDL	↓↓↓	↓↓↓	↓↓↓
Had	↓↓↓	↓↓↓	↓↓↓
IPSL	↓↓↓	↓↓↓	↓↓↓
Miroc	↓↓↓	↓↓↓	↓↓↓
Nor	↓↓↓	↓↓↓	↓↓↑

Niger	Q10	Q50	Q90
GFDL	↓↑↑	↑↑↑	↑↑↑
Had	↓↓↓	↓↓↓	↓↓↓
IPSL	↓↓↓	↓↓↓	↓↓↓
Miroc	↑↑↑	↑↑↑	↑↑↑
Nor	↓↓↑	↓↓↓	↑↓↑

Yellow	Q10	Q50	Q90
GFDL	↑↓↑	↓↓↓	↑↓↑
Had	↑↑↑	↓↓↑	↑↑↑
IPSL	↑↓↑	↓↓↑	↑↑↑
Miroc	↑↑↑	↑↑↑	↑↑↑
Nor	↑↓↑	↓↓↓	↑↓↑

Figure 1: Projected directions of trends in annual Q10, Q50 and Q90 for simulations driven by 5 GCMs and performed by 3 hydrological models (HBV-left arrow, SWIM-middle arrow, VIC-right arrow) in the Rhine, Upper Niger and Upper Yellow River basins. Statistically significant trends (α=0.05) are marked red.

3. Results

3.1. Calibration and Validation Results for hydrological models

The results of calibration of three models for three basins are presented in Table 2. With Nash & Sutcliffe model efficiency ranging between 0.71 and 0.9 in the validation period all the models perform satisfactory for all basins.

3.2. Impacts on averages and extremes: trends, magnitude of change & uncertainties

After calibration and validation of the hydrological models they were run for the period 1971-2099 using GCM scenarios. Then linear trends were calculated for the period 2010 until 2099 using a robust statistical method (Yohai, 1987) for three variables: annual median runoff (Q50), low and high annual percentiles Q10 and Q90 representing the low and high flow conditions, respectively. Significance of the trends was evaluated at the 5 % level. The results of trend analysis for the three basins for the period 2010-2099 in terms of the trend direction are presented in Fig.1.

For the Rhine basin the low flow and medium runoff driven by most of climate models (CM) and simulated by most of hydrological models (HM) show significant downward trend: 14 of 15 and 10 of 15 simulations for Q10 and Q50, respectively. Regarding the high flow (Q90) most of the results show also decreasing trend, but partly without significance. In general, a good agreement between CM-driven simulations and HM outputs can be stated.

In the Upper Niger basin for Q10 and Q50 the results driven by two CMs show an increasing trend, and by the other three CMs – a decreasing trend, demonstrating a high discrepancy between climate models for this basin. For Q90 a high discrepancy can be stated as well. Here two CMs show an increasing and three

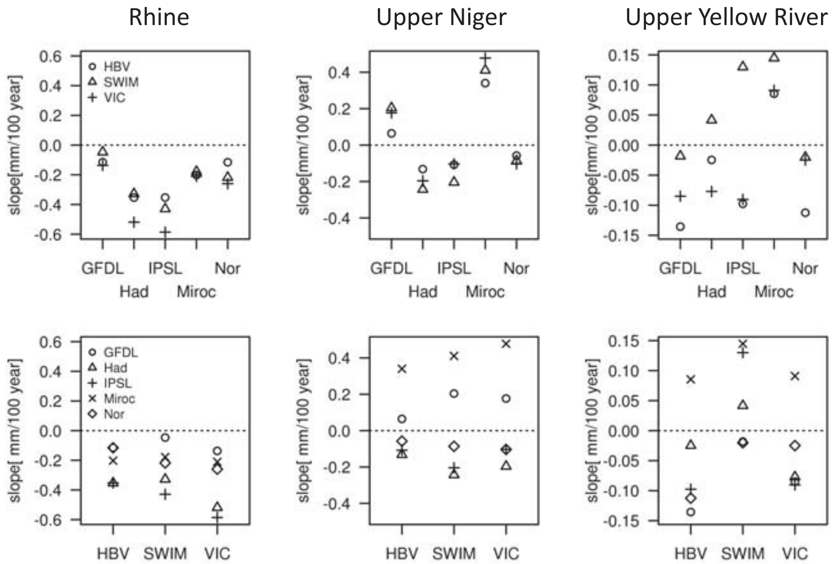

Figure 2: Estimated slopes for linear trends in annual Q50 for three basins grouped by either climate models (upper graphs) or by hydrological models (lower graphs)

CMs a decreasing trend. However, the results of HMs regarding the direction of trends agree much better: in 12 of 15 cases.

In the Upper Yellow basin the results show that the high flow discharge is mainly significantly increasing (9 of 15 cases). The results are quite uncertain for Q10 and Q50, showing a mixture of changes in both directions. Both CMs and HMs demonstrate poor agreements for this basin.

In addition to trend direction, Fig.2 shows the slopes of changes in the medium discharge (Q50). The results are grouped by CMs (upper graphs), and by HMs (lower graphs). For the Rhine all the slopes are negative and the ranges (dispersion in results) between HM (upper graph) are lower compared to CMs (lower graph). The discrepancy in the direction of change is higher between CMs (lower graphs: 6 cases of 9) compared to HMs (upper graphs: only 2 cases of 15). The outputs driven by MIROC model show the highest slopes for the Niger and Yellow.

Besides, Fig.3 presents long-term seasonal discharge for the reference period 1971-2000 (left), for the scenario period 2070-2099 (middle) and the difference between the scenario and reference periods (right). The results are averaged either by CM or HM.

For the Rhine a decrease in summer period (results driven by 4 CMs of 5), and a moderate increase in winter time are projected, which corresponds well to the previous impact assessment for this basin (Huang et al., 2010). Uncertainty related to CM is visually higher compared to that of HM. The results by SWIM and VIC agree very well.

For the Niger a high discrepancy between different CMs is visible. When the results are averaged over CMs, a small increase in the last 1/3 of the year is projected. The uncertainty related to CMs is distinctly higher than that related to HMs. A very good agreement between HMs can be stated.

For the Upper Yellow River the results driven by 2 CMs project a significant increase in summer period, whereas the results driven by three other CMs show rather moderate changes.

The results driven by the climate model MIROC for all three basins show the highest discharge in the scenario period compared to results driven by four other CMs in almost all cases. In general, notably lower uncertainty bands related to HMs compared to CMs are visible. However, the number of HMs was also lower compared to the number of the driving CMs in this study.

4. Discussion and conclusion

This study intercompared the climate impacts on runoff generation across 3 river basins in 3 continents using 3 regional hydrological models driven by climate scenarios from five global climate models. The robust results in terms of trend direction and slope could only be found for the Rhine River basin in Europe regardless which HM or CM is used. For the Niger River in Africa, scenarios from climate models are the largest uncertainty source. For the Upper Yellow River in Asia, both the hydrological models and climate models contribute to uncertainty in the impact results. In general, the uncertainty resulting from climate models is larger compared to that from the hydrological models for all three basins.

Summarizing all the results it can be concluded that the more robust climate scenarios have a higher guarantee of the robust hydrological impacts. In this study, such robust climate scenarios could only be found for the Rhine basin, and for the other two basins in Africa and Asia the scenarios differ widely. Besides, it seems like the uncertainty of HMs increases with the increase of complexity of hydrological processes. As a result, the largest uncertainty of HMs was found for the Upper Yellow river, where both snow melt and precipitation are important for the runoff generation. A minor uncertainty was found for the Niger river, where a simple rainfall-runoff process is prevailing.

However, it should be noticed that we focused only on one emission scenario in this study. The difference in impacts related to various emission scenarios have not been included in our discussion yet. In the next step, all the uncertainty sources: from CMs, HMs and emission scenarios will be analyzed more systematically to obtain a more comprehensive overview of the hydrological impacts and their uncertainties for each basin. In addition, the more consistent hydrological model setup and calibration procedures as well as climate

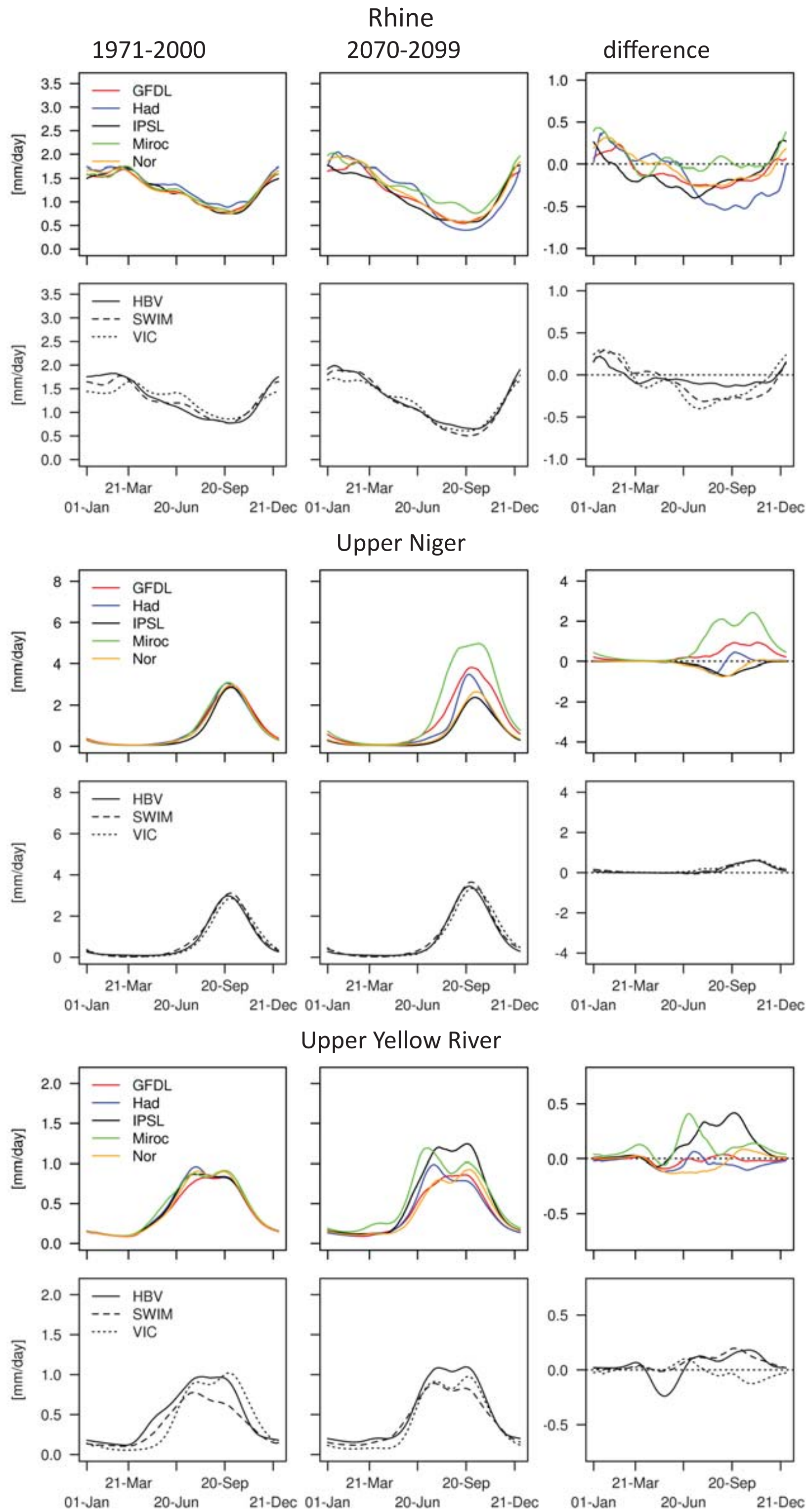

Figure 3: Long-term seasonal dynamics of water discharge for the reference period (left), for the scenario period 2070-2099 (middle) and the difference between the scenario and reference periods (right) for three basins. For every river basin the upper graphs show averages over three hydrological models and the lower graphs - over 5 climate models

scenarios from the regional climate models could minimize the avoidable uncertainties.

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Topic 5:

How do we bridge the divide between regional and global impact studies?

Framing of Climate Change News in Four National Daily Newspapers in Southern Nigeria

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Abstract

Journalists use frames to craft interesting and appealing news reports, simplify technical details and make them persuasive for audience. To frame is to select certain aspect of a situation and highlight them in the media in a way that promotes a specific definition, interpretation or evaluation of recommendation. The underlying theoretical assumption of this study is that understanding how the climate issues are framed is of vital importance to how the general public and policy makers will respond to lifestyle changes necessary to mitigate and adapt to climate predictions. The study examined the framing of climate change news in four national daily newspapers in southern Nigeria. The content analysis yielded approximately 332 climate change related articles. The results showed that greater proportion (125 out 332) of the articles used negative tone in reporting the headlines. The overall dominant frames used in all the articles, show that majority (71 articles) framed climate change in terms of “blame”, while “action” frames were used in 69 articles, among other frames. The study therefore recommends that media organizations should re-allocate some of their time and energy to explaining more of the specifics behind the mitigation and adaptive solutions to deal with global climate change, rather than devoting most of their time explaining the science behind global climate change.

Key words: Content analysis, climate change news, framing, journalists.

1.0 Introduction

Global climate change is certainly one of the most pressing concerns of the 21st century. Africa and more specifically, Nigeria is a country which scientists agree is likely to suffer dire consequences of climate change. According to Chris (2009) gas flares produced in the Niger-Delta region produces very large halos of lights affirming Oyebade (2009) that Nigeria is not only a victim but also a contributor to global climate change and its consequences.

Through media coverage of climate change, there is often a significant acceptance of political and expert voices by the public (McManus, 2000). Studies have shown that the public learns a lot about science through consuming mass media news (Wilson 1995). Moreover, the complex issue of public trust in authority figures may feed back into and influence climate policy decision-making (Lorenzoni and Pidgeon 2006). Carvalho (2007) observed that through multiple media feedback processes of communicating climate change risk over time, prominent political actors successfully frame climate risk for their purposes, and align frames with their interests and perspectives. In other words, different frames highlight different aspect of the options and bring forth different reasons and considerations that influence decision.

According to Entman (1993) to frame is to select certain aspect of a situation and highlight them in the media in a way that promotes a specific definition, interpretation or evaluation of recommendation. Not only do the media influence the perception of what topics are seen to be important by the public and policy makers, they also influence public opinion by presenting such topics within a certain frame. The way a policy maker or actor frames an issue can be a determinant in the success or failure of such issue in being placed in the public or political agendas. Specifically, frames can be utilized to suggest causes, assign blame, categorize issues, or promote certain solutions by policy makers.

The basis of framing theory is that the media focuses attention on certain events and then places them within a field of meaning. In doing this, the media brings public attention to certain topics, influences peoples' perceptions and feedback through ongoing media practices; these feedbacks shape news framing in subsequent phases, and inform ongoing policies, practices and interactions over time. Thus, framing permeates all facets of interactions between science, policy, media and the public.

It has been observed that journalists do not report climate change risk as major challenges, but they report it as news (Cramer, 2008). It is therefore argued that, it is for this reason that climate change is found presented within a certain frame. Therefore, it is believed that knowledge of how climate issue has been understood and framed is of vital importance to how the general public and policy makers will be able to respond to lifestyle changes that will aid climate protection. If the public are not adequately informed about climate change, it will be difficult for them to make demands on government, even when it is in their own interest. But how this information is interpreted and translated into decisions and potential behavioral change is complex, dynamic and contested.

This brings to the fore the importance of examining the framing of climate change in four national daily newspapers in southern Nigeria. This study was therefore designed to determine how climate change issues have been framed in the southern Nigerian newspapers.

2.0 Methodology

Four major national daily newspapers in southern Nigeria namely Guardian, Vanguard, ThisDay, and Daily Sun were purposively selected for content analysis because they were considered to be among the country's leading national newspapers. To examine the framing of climate change by print media journalists, individual articles were content analyzed. The approach of deciding on the frames used was taken from the perspective of the reader (Cramer, 2008). How would the reader be likely to delimit a story written in a particular way? Would the story result in their concluding that climate change is an environmental issue; a political issue; a scientific issue or a health issue?

3.0 Results and Discussion

3.1 Dominant Frames used in reporting Climate Change News in the Newspapers

3.1.1 Blame/ responsibility frame

Majority (71 articles) of the newspapers framed climate change in terms of "blame/ responsibility" as shown in Figure 1. This frame focused on the finger-pointing aspect of climate change outbreak. Issues like who was at fault for the occurrences, why and how it happened, and who was going to take the blame constituted the major frames. In most of the articles, the developed countries, and industries such as the oil producing companies were blamed for their high contributions to the emission of greenhouse gasses. However, several articles placed the blame on agriculture, primarily deforestation and use of high technologies (inorganic agriculture). Phrases associated with this frame included “the failure of Kyoto protocol agreement”, “attempt by the developed world to hoodwink other nations”, “China accused for Copenhagen failure”, “UN signals delay” and “top 20 major countries that flare gases”.

3.1.2 Action Frame

The “action” frames occupied 69 articles. This frames mentioned the actions that nations have to perform in mitigating and adapting to climate change effects. Such stories discussed the duties to be performed by the developed nations, developing nations, NGOs or individual citizens. This frame was the second most frequent frame in the stories. Phrases associated with this frame included “payment of ecological debts”, “reduce emissions by 50 per cent”, “green campaign” and ‘it is time to act”. The implication of this frame is that the duty to mitigate the effect of climate change is the obligation of every individual in the whole world, as no country is immune to its effect.

3.1.3 Political Frame

The political frame was also revealed in 42 articles. This frame emphasized on the aspects of government, the political side or any issue involving politicians. Words and phrases used to convey this frame included “diplomatic hackles”, “ side-line negotiating process”, “political agreement”, and “calls for signatures”. This frame implies that while the individuals are empowered to address the environmental issues, greater power for dealing with these problems is often attributed to the government.

3.1.4 Industry Frame

Industry frame was also exposed in 34 articles analyzed. This frame conveyed not only how climate change is devastating to the agricultural sector in Nigeria, but also how it has had negative implications on the agricultural sector internationally. This frame implied that climate change had devastating consequences by communicating the negative aspects of the occurrences, using key phrases like “the embattled crop sectors,” “devastating impact,” “debt-laden farmers,” “poor African farmers are losers”, “poor harvest”, “species threatened”, “farming industries in tail-spin,” and “catastrophic disruptions”. The frame was consistently characterized as disaster-causing event for the agricultural industries, which produced a negative tone throughout the articles. The implication of this industry frame is that the framing of this issue potentially could affect perceptions of agriculture in general because agricultural sector is a large industry, and trust in agricultural yield/ productivity in general could be affected by this frame.

3.1.5 Environment Frame

The “environment” frame (29 articles) focused on the predicted effect of climate change on the landscape and reliefs in Nigeria; and on several other regions. Phrase associated with this frame included “prone to drought, flooding,” “environmentally devastating,” “loss in landmass”, “cataclysmic change,” “volcanic eruption,” “desertification” “degradation of ecosystem”, and “environmental threats”. This result implies that within the articles studied, climate change was depicted very clearly as being an environmental issue, and the potential danger of such depictions lays the lack of importance placed on the environment by the average person.

3.1.6 Human Impact

“Human impact” frames was revealed in 20 articles, which attempts to bring the effect that climate change has on people. Words and phrases used to convey this frame included “changing lifestyle”, “hunger”, and “compensation”. Another important aspect from the human impact frames reviewed, exposed the negative and the positive impacts of climate change on human being; resulting in different tones resonating from the articles which led to most of the articles having a neutral tone.

3.1.7 Economic Consequences Frame

The “economic consequences” frame was revealed in 21 articles. This frame emphasized the impact of climate change on the industries outside the agricultural sector, like transportation, insurance, banks, oil producing companies, and the economies of Nigeria, Africa, and even the developed countries. This frame presented two perspectives regarding the economy. The first sub-frame was zero economic risk. Here the information presented in the articles reaffirmed that climate change can bring about major development opportunities for Africa. In most cases, this frame mentioned that climate change could be viewed as a major development opportunity for Africa, given the anticipated increase in the energy requirements as growth accelerates (Okonjo-Iwela, 2009).

Also included in the economic impact frame were the issues of amplified economic risk which climate change extends. Phrases like “long term financial risk”, “depleting our natural capital”, “falling wages”, and “diminished opportunities” portrayed the impact of climate change on several economies and other industries. Again, incorporating words like “deplete,” “falling” and “diminished” portrayed the amplified economic consequences to the readers; however, the overall tone of the amplified economic risk frame articles were negative implying that the occurrences could be worse and can be of serious economic damage if nothing is done.

3.1.8 Health Risk Frame

The “health risk” frame was the most infrequently (9 articles) used frame in all the articles analyzed. Words and phrases used to convey this frame included “danger to public health”, “health threatening” and natural disaster related death”.

3.1.9 Miscellaneous Frame

The “miscellaneous” frame, which incorporated all other frames was also among the less frequently used frames, and was revealed only in 7 out of 332 articles. Some of the more interesting and unlikely stories included a fashion story (where corporate fashions are expected to change to accommodate for warmer temperatures) and musicians stories (artistes feared for the safety of the planets).

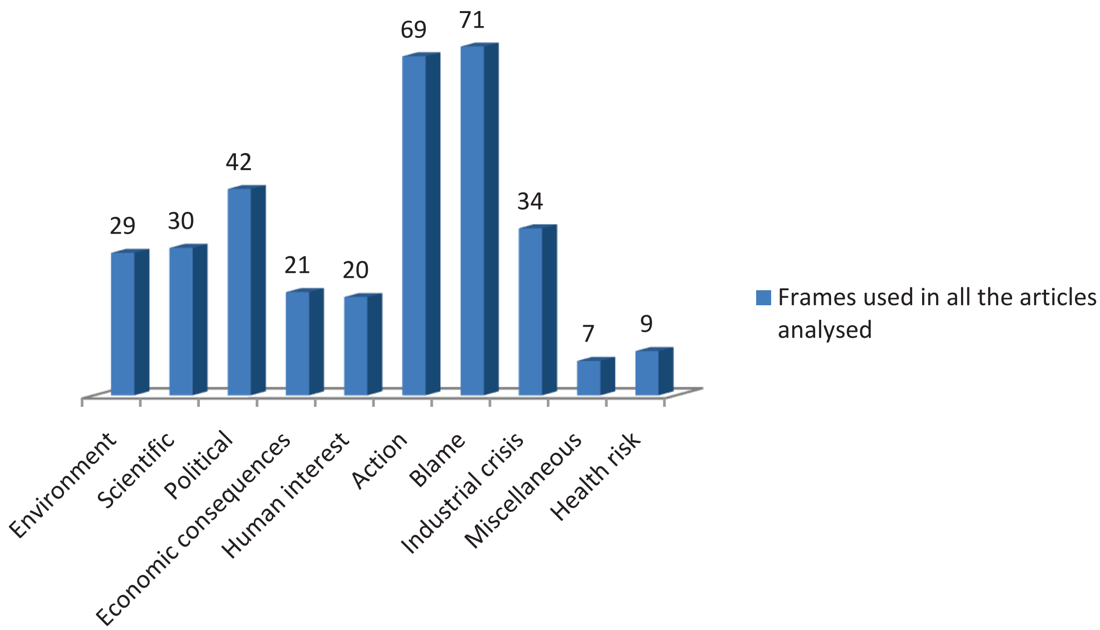

Figure 1: Dominant frames in climate change articles analyzed in four Nigeria dailies

4.0 Conclusion and Recommendation

Based on the findings, it was concluded that climate change articles are mainly portrayed using accusing or finger pointing scenario (blame) as it relates to the factors responsible for climate change occurrences. Also, the actions/strategies to be implemented were also portrayed in most of the articles. The fact that scientific frame (25 articles) dominates the environmental frame (16 articles), indicates that climate change can and should no longer be boxed into the environmental frame. Scientific research has portrayed the broadness and urgency of this threat to the world at large, but more specifically to Nigerians and in the agricultural sector. While the environment may be viewed as a softer premise which is relevant to many, climate change is an issue which goes far beyond degraded ecosystems. Water shortages, crop failures and changing weather patterns are issues which will affect all Nigerians in the near future. In other words, climate change is broader than the environment, politics and science. It is very much an economic issue, but above all in a country where poverty is prevalent, climate change is a human interest issue and it is the duty of the media to portray it as such.

Given the fact that climate change coverage tends to be increasingly blame-based, the study therefore recommends that agricultural and media organizations should re-allocate some of their time and energy away from explaining the science behind why global climate change is happening to explaining more of the specifics behind the mitigation and adaptive solutions that would help the general public deal with global climate change, and aid climate protection. Agricultural organizations should keep in mind that as they present agricultural climate change related research findings to the mass print media audience, they should provide many solutions. Otherwise, they risk falling into the trap that agricultural reporting continually fell into a decade and more ago (Cramer, 2008), when agricultural events were reported as catastrophic, isolated events that could not be predicted or avoided. Also, agricultural organizations should not be afraid to go into great detail about the policy solutions they are advocating for, explaining thoroughly what makes them good policy solutions. Finally, the media should report farmers-centered climate change stories to make the issue relevant to the public and agricultural sectors in particular.

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From assessment to service: Making knowledge usable – lessons from TEEB

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Abstract—

Events such as the Rio+20 conference demonstrate that the demand for policy relevant knowledge is growing when it comes to address the *grand challenges* such as climate change and biodiversity loss. While there is already a lot of information about causes and impacts of global change available, this information is not simply "usable" in that sense that it does not automatically meet the changing needs of decision makers. Many politicians, researchers, and government officials are calling for the creation of Climate Service that will support decision-making for adapting to a changing climate. The rational of providing service is to create and provide authoritative, credible, usable and dependable science-based information. TEEB pursues the same goals. While the establishment of climate service is pretty much in its infancy until now, TEEB has been already successful in providing "useful" knowledge. In this paper, we explore how TEEB was able to meet the challenge of providing usable knowledge. This requires to examine and readapt methods and approaches to the production, dissemination and translation of assessment outputs. TEEB turned out as "usable" when it was able to reconcile the research agendas with decision makers' information needs and to include social and political dimensions of the problems at stake. The concluding session, we ask what lessons can be learnt from TEEB to make climate services usable.

Index Terms—IPCC, TEEB, science-policy interface.

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1 Introduction

International events such as the Rio+20 UN Conference in 2012 highlight that science has been asked to be "relevant". This refers not only to define problems and provide scientific evidence for the ecological crisis, but also "provide" – or to contribute to the provision of – solutions that address these problems. There is a growing demand for "usable" information for decision-making on the "ground." But, can we take the "usability" of scientific knowledge for granted?[3]

While the IPCC was instrumental in raising public and political awareness, the knowledge produced by the IPCC and other high level programmes is seen as relevant but not directly "usable" for decision-making at the local and regional level. In other words: we cannot take the "usability" of scientific outputs

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[3] Following the SPARC definition, we understand "usable" in that sense that information meets the changing needs of decision makers. http://cstpr.colorado.edu/sparc/outreach/sparc_handbook/index.html

as given. Decision makers/ stakeholders demand information with regard to the impacts of climate change over different geographical regions and, more importantly, what types of interventions will make a difference at a given level (e.g. international, national, regional, local), over what time scales, at what costs, and to whose benefit (Beck 2011). Climate and economic models and scenarios simply cannot deliver this specific type of information (Dessai et al. 2009). The assessments of regional impacts and the evaluation of response strategies have to deal with a variety of critical uncertainties (Petersen 2012). One of the major tasks for expert bodies is to reconcile demand and supply of information (to put it in the market metaphor) and to combine and integrate political needs with the scientific supply in an effective and coherent way. Since relevance and usable are not given, it takes systematic efforts in order to make scientific knowledge relevant **and** usable. To improve its relevance, knowledge has to be "translated" and communicated into appropriate languages. The task of providing usable information also requires the integration of such information into the decision makers' existing knowledge systems so they know what the science means, and how it can help improve their decisions. "Relevant" scientific knowledge, in this sense, is situated and context-dependent. As a result, attention has also to be paid to the processes of the translation and embedding of research outputs into political decision-making and planning processes.

The paper examines how the TEEB-initiative (The Economics of Ecosystems and Biodiversity) has addressed the task to provide usable information. The initiative only started in 2007. In a short period of time a number of internationally acknowledged reports were produced (see: http://www.teebweb.org/). This success led to a growing number of national and subnational as well as local activities. TEEB combines top-down approaches with more place-based, bottom-up ones involving local and regional jurisdictions and stakeholders. TEEB has tried to reconcile the political and societal demand and scientific supply of information in order to make more people listen and act. One of the keys to TEEB's success is to focus on the demands and needs of decision makers and to integrate the social and practical dimension of the problems at stake into the assessment.

2 TEEB

Ministers at a G8 meeting in Potsdam in 2007 started an international initiative to halt ecosystem degradation and the loss of biodiversity on global scale which was perceived as being dramatic (GBO 2010; Balmford et al. 2008). Faced by this global environmental challenge, a wakening call for biodiversity was intended comparable to the Stern report on climate change (Stern 2007). The goals of TEEB were to raise awareness of the problem of biodiversity loss and to provide evidence for the opportunites and urgency to act. The basic approach for this is to recognize, demonstrate and capture values of ecosystems and biodiversity. The framing of the objective and problem had consequences. The IPCC, for instance, focused on "invisible" gases at a global scale and on "global temperature" as symbol for the problem of global-warming as well as on producing standards and standardized assessments with peer-reviewed science as the only relevant and valid source of knowledge. This approach failed to inform effective, diverse and local adaptation and mitigation policies and practices (Turnhout et al. 2012). Biodiversity, on the other hand, addresses the complex relationships between living beings and abiotic matter in different spaces and levels of organization (i.e. genes, species, eco-systems). Biodiversity has been tied to conservation issues and the ecological crisis (Reid 2004; Farnham 2007). Thus, it is necessarily linked to specific places as well as to cultural, socio-economic and political aspects. It is contextualized and situated.[4]

2.1 The Millennium Ecosystem Assessment

TEEB had not only been impacted by the climate change discourse but also by the Millennium Ecosystem Assessment (MA). The MA also shows some general similarities to IPCC.[5] It dealt, however, explicitly with the scaling issue by looking at global developments as well as sub-global ones and reflected the complexity of the nature-society interdependence. This can be seen in the MA-framework (see figure 1).
Figure 1 shows the framing of the process and objective of the MA. Two aspects are important:

- The frame distinguishes different scales of assessments (global, regional/national, local) indicating the interconnectedness and interdependence of these scales, i.e. gains on a global level might lead to losses on local levels (MA 2005; for sub-global assessments: http://www.unep.org/maweb/en/Multiscale.aspx)
- The authors of the MA process recognized that a sole science based knowledge system was no longer adequate to deal with the complexities of and that knowledge dealing with environmental management needed to be contextualized (Reid et al., 2006: 317; Willibanks 2006)

In contrast to the IPCC, the MA was rather organized as a bottom-up process driven by scientific communities and discourses with the objective to consult politics and society (Reid 2004; 2006). The aspect of scale, multilevel governance, contextuality, transdisciplinarity and the interdependence of nature and

[4] Decisions are made among a variety of competing interests and values including economic, social, political, and ethical demands, and thus the science needs to be contextual, reflecting the various constraints and opportunities of policy options (https://ams.confex.com/ams/19Applied/webprogram/Paper190530.html)
[5] For instance more than 1300 experts of 95 countrues worked on different MA reports (see: www.millenniumassessment.org).

human well-being had an impact on TEEB. Looking at conceptual and organizational aspects, the success of TEEB shall be explored further.

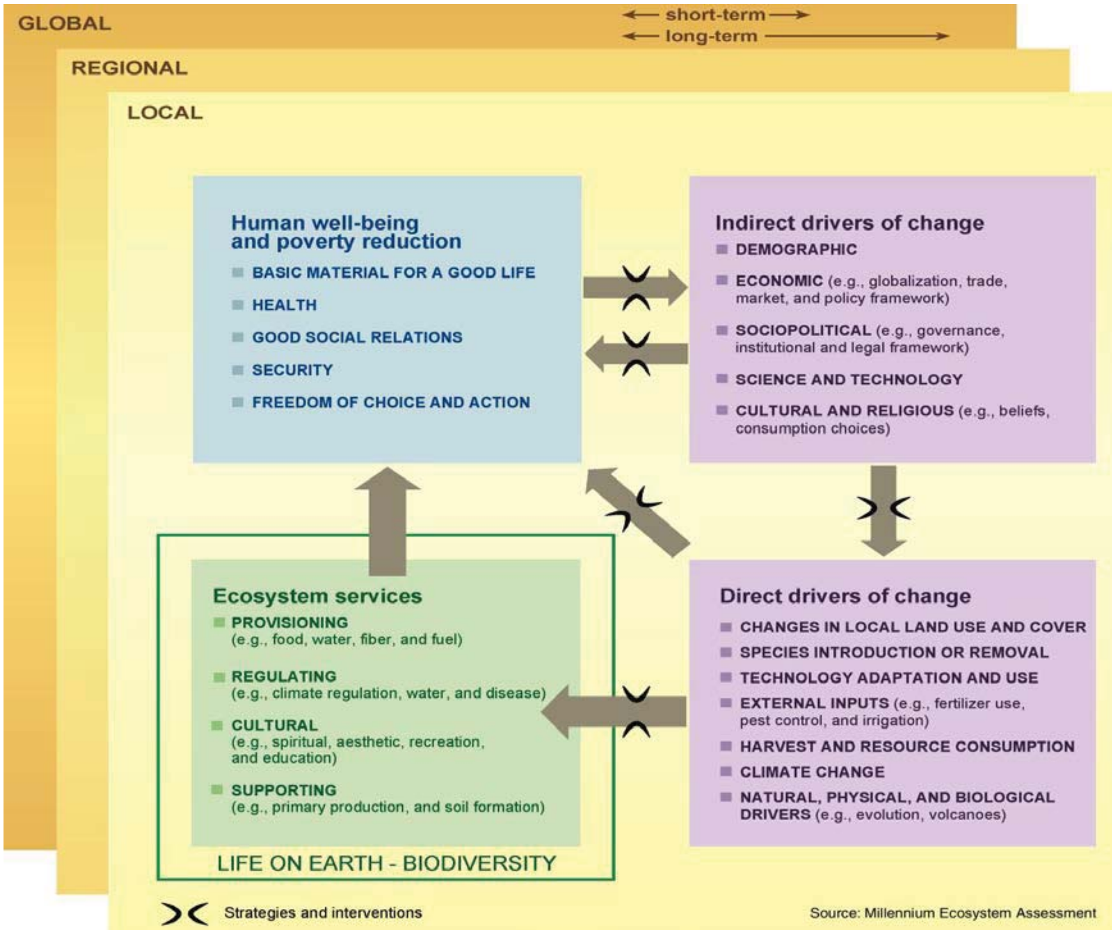

Figure 1: The framing of the Millenium Ecosystem Assessments (MA 2005: vii)

2.2 The TEEB-Approach

TEEB started with a clear political mandate and demand (Potsdam Initiative 2007). Transferring experiences from the MA process, the complex concept of ecosystem services (see figure 1; for the concept of ecosystem services: Costanza et al. 1997; Daily 1997, Potschin et al., 2011) with all its implications (see 2.1) gained importance. The central aims of TEEB can be summarized as follows (Ring et al. 2010):

- Assess, communicate and draw attention to the urgency of action to address the loss of ecosystems and biodiversity, highlighting the economic, societal and human value of the benefits of ecosystems and biodiversity, and the scale of the potential damage of losing these benefits
- Show how the value of ecosystems and biodiversity can be included in decision making

- Address the needs of policy-makers, local administrators, business and citizens

This shows the demand towards science to produce "usable" information for decision-making. Implementation and feasibility are central elements for the production of knowledge within TEEB. Highly aggregated data or a one-size-fits-all model cannot work because the most appropriate ways to address the information needs and challenges vary from case to case and are dependent on the particular context. Put in other words: An ecosystem approach dissents any universal perspective in the sense that neither the ecological dimension (i.e. the complexity of ecosystem and biodiversity) nor the culturally dependent assessments of the meaning and value of ecosystems for the human wellbeing permit unequivocal definitions or hierarchies (TEEB Foundations 2010; Görg et al. in press).

Exploring the procedural dimension, TEEB has not the status of an intergovernmental panel like the IPCC.[6] The architecture was "open". Representatives of science, business and politics were included into the advisory board. They were not nominated by governments but rather selected by a growing network itself. An international and diverse "community" of over 500 experts contributed to the assessments and review processes. They, also, had various backgrounds including natural and social scientists, practitioners, representatives of public and private institutions as well as individuals sharing their knowledge on best practices, tools, methods and experience. It should be mentioned that the majority of the authors are scientists, i.e. the knowledge production follows rules of scientific quality control (review processes). However, TEEB accepts not peer- reviewed sources. This is a prerequisite for a transdisciplinary project.[7]

The mechanism and processes to reconcile supply and demand for information are different to the IPCC due to the demand and practice oriented approach and the multi-level governance. The international initiative, for example, secured the close link to political demand by three organizational aspects:

- The Advisory Board had decision makers of governmental, public, research and business institutions
- A Coordination Group has been set up where representatives of the European Commission, governments and science regularly have discussed strategies and procedures
- Governmental institutions were directly involved in contributing to and reviewing the reports

Since 2011 the focus is rather on mainstreaming and outreaching. Following, a considerable number of

[6] TEEB is linked to UN system being hosted by UNEP.
[7] This question was intensely discussed in the Advisory Board where certain voices wanted to restrict the sources to peer-reviewed scientific articles.

national and sector studies have been initiated.[8] All of them face the challenge to translate the TEEB approach to specific demands and socio-ecological circumstances. The studies have to find their own answers to these challenges. Some are organized and financed by state institutions, others also integrate political demands through organizational structures. UNEP and the TEEB-community support the ongoing processes to secure a level of quality by providing information on best practices and by strengthening networks (e.g. guiding and training materials, TEEBrief, TEEBcase).

In the case of TEEB-Germany the environmental ministry is, for instance, part of the steering group. The Advisory Board is composed of experts also from policy (plus science, media and business) and there is an additional Project Advisory Group where representatives from several ministries, administration, NGOs, science, alliances and business meet. The produced reports are the result of an integrative process with a broad call for evidence, workshops with stakeholder consultations as well as contributing and reviewing processes where also experts from policy and administration get involved.

Table 1: The TEEB six-step approach (adopted from TEEB 2010b: 6)

Including ecosystem services (ESS) in decisions and policies step by step	Examples of guiding questions
Step 1: Specify and agree on the problem with stakeholders	Are key people on board? Are all relevant aspects being considered?
Step 2: Identify which ESS are most relevant	Which ecosystem services? Who depends on them most? How do policies affect them?
Step 3: Define information needs and select appropriate methods	What kind of information or which ESS is needed?
Including ES in decisions and policies step by step	Examples of guiding questions
Step 4: Assess ESS	What role play ESS in livelihood situation? How can ES distribution and different scenarios for changes be mapped?
Step 5: Identify and appraise policy options	How can assessment results feed into political processes?
Step 6: Assess distributional impacts	What are possible consequences of changed ESS flows (gains/ losses)?

[8] National TEEB studies: e.g. Austria, Brazil, Georgia, Germany, India, Israel, Mexico, Netherlands, Portugal, Thailand, Turkey, UK, South Africa; sub-national TEEB studies: e.g. Polish TEEB for Cities, TEEB Flanders, TEEB Reykjavík, TEEB Waikato (New Zealand); regional TEEB studies: e.g. Arab Wetland Study, TEEB Europe, Heart of Borneo, Nordic TEEB, Southeast Asia; sector TEEB studies: e.g. NL TEEB for Business, TEEB-De Germany for Business, TEEB for Business Brazil, TEEB for Business St. Lucia (personal communication with UNEP TEEB office).

Another aspect for the mentioned strong focus on the “usability” of TEEB can be demonstrated with the so called six-step approach (see table 1). This approach has been developed in response to the challenges of a demand oriented production of scientific knowledge. So far it has been applied mostly on local level. This approach indicates the aim of integrating all relevant stakeholders and to give them a voice for defining and framing the problems and conflicts with regard to the use, access and distribution of ecosystem services. Following, scientific knowledge and expertise is rather supportive in finding answers to questions and demands jointly raised by the relevant stakeholders. Thus the approach and process is open for perspectives and problem definitions by stakeholders, society or political decision-makers. It is not a deduction from universally applicable models, but a contextualization of socio-economic and ecological circumstances.

3 Conclusion

There is evidence that features and procedures of TEEB can be interesting when it comes to provide climate services. The latter have also to address information needs at the local level. TEEB’s success in visibility and replications on national and local levels allows drawing some lessons. What are the main strategies and features that have contributed to make the assessment “usable”?

- First, the TEEB focus on the application of scientific knowledge. TEEB created a conceptual framework as well as organizational and procedural strategies which make a strong case for an assessment that are *demand* driven. The social and political demands and information needs are the starting point of TEEB.
- Second, when it comes to scoping and framing processes, TEEB openly endorses the political and social dimension of ecosystem loss.
- Third, continuous interactions between experts and the potential users, target groups and audiences were additional strategies to make TEEB reports and products relevant to the changing needs of potential users. They have enabled different stakeholders to bring in their own needs and expertise. It also contributed to enhance the legitimacy and acceptance of the assessments and allows if not demands the translation and contextualization of scientific knowledge. They are also contributed to integrate TEEB findings into the decision makers' existing knowledge systems. In his way, scientific findings are rendered “usable.”
- Fourth, the “openness” in the architecture and the approach of the different TEEB assessments also

enables the demand orientation of assessment. However, there is also the risk of blurring knowledge. It is not always clear, for instance, whether or not the broad concept of recognizing, demonstrating and capturing values of ecosystems and biodiversity is really understood and applied within national or local studies. Thus, the intended TEEB approach and “spirit” might not be found in all products and processes which are labeled “TEEB”. One idea to cope with this problem is the preparation of a Guidance Manual which raises questions people responsible for organizing a TEEB process should consider and offers possibilities how things could get done.

At the same time, TEEB runs the risk to allow reducing issues at stake to a narrow economic and quantifiable core. Intrinsic cultural values and life world understandings are not easily translated into an abstract scientific language. Attempts to translate and mediate these dimensions may result in a loss of their original meaning and credibility. By opening the door for these forms of scientification, we have to keep their political and democratic implications in mind.

Making knowledge relevant to a particular user group does not directly contribute to improve the legitimacy of expertise. These questions mainly go back to a reduced understanding of relevance that is identified with strategic, utilitarian contributions to problem solving. Politically relevant information in the context is equated with a numerical evidence for decision-making. The assessments, however, cannot substitute decision making and scientific evidence is not the only authority when it comes to democratic decision. At the same time, we face real life conditions and need to be pragmatic about the limitations of such “experiments” rather than to commit us to implausible achievements and dangerous, idealized assumptions about the virtues of science and policy. This approach is doomed to fail.

Last but not least: one of the major challenges will remain how to put these insights into operational mode. How can we open up academic concepts to those who design and participate in real-life assessments and politics? The results of these experiments are open, they cannot be decided by science alone but they have to be tested and approved by active consultations and co-design processes including the voices and information of all affected by environmental change in a legitimate and balanced way.

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Adaptive water management in coastal areas: From climate impact assessment to decision making

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Abstract—Based on the results of a participatory study focusing on the adaptation of water management to climate change at the German North Sea coast, we adress the following questions: Which information is needed for adaptive water management related decision making in coastal regions? Which information from hydrologists is suitable for decision makers in such a climate adaptation process? How should we deal with the uncertainty in the climate projections? How does selective use of available information influence the characteristics of adaptation options? Discussing these questions, we infer the necessary compromise between scientific completeness of information and the requirements on straightforwardness for decision making.

Index Terms—water management; climate adaptation; participation; use of information; uncertainty.

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1 Introduction

Climate proofing the coastal water management in the North Sea region requires several subsequent actions: Providing information on expected regional hydrological change, assessing the functionality of the existing water management systems, elaborating adaptation options for future scenarios, making the decision and implementing the most suitable adaptation option. As part of this process, linking science and policy plays a crucial role (Veraart et al., 2010). Scientific projections reflecting the regional socio-ecological circumstances are required for a sound decision making, while the information provided to decision makers must be provided in a way which is suitable for non-scientists.

This contribution presents results of the EU-Interreg VIB “Climate Proof Areas” project. In the German part of the North Sea Region, water management regulates a strong seasonality in water quantity. While in winter time drainage and storage avoid flooding, in summer time watering assists guaranteeing sufficient water availability with respect to quantity and quality. In a participatory process together with representative stakeholders we analysed the efficiency of the regional water management system and developed an inventory of adaptation alternatives based on hydrological model simulations quantifying the expected impact of climate change on the regional hydrological system (Bormann et al., 2012).

During this process the question arose how different kind of information was used: experience based knowledge on the region, scientific information on climate scenarios and expected hydrological change as well as the awareness of the uncertainty inherent to all future projections.

2 Region and methodology

2.1 Regional characteristics

The Wesermarsch County (822 km²) serves as an example for many regions along the North Sea coast lying below sea level. The rural county has a population of about 92,000 people (year 2009). 95% of the area is used for agriculture (from which 90% is grassland, mainly for dairy cattle). The topography is predominantly flat (elevations between -2 m and 5 m above sea level), soils are either fine textured (marsh soils) or organic (peat). In order to safeguard the region against storm tides, dikes have been constructed for centuries and continuously heightened to reduce the risk of flooding.

The Wesermarsch County is faced with several hydrological challenges. In winter time, water has to be drained from the area to avoid flooding. In order to minimise the energy amount required for pumping, the region is drained during low tide as far as possible. Contrarily, in summer time, the region suffers from a water deficit which needs to be compensated to avoid drying out of marsh water bodies. For this purpose, fresh water from the Weser River is conveyed into the canal system of the Wesermarsch during high tide. Due to the deepening of the Weser River for shipping and the intense drainage of low-lying areas, salinisation of surface and groundwater bodies is an increasing problem. In order to regulate water surplus and deficits, a traditional water management system has been developed in the last centuries. A dense network of ditches, channels, barriers, sluices and pumping stations has been established to regulate ground- and surface water levels in the region.

2.2 Participation

Since adaptation planning on regional scale must integrate local people, an integrative and participatory bottom-up process was organised to develop and agree upon regional adaptation options for the Wesermarsch. Stakeholders from regional and local organizations were invited to take part in this process. A regional stakeholder forum was established consisting of water managers, farmers, urban and regional planners, civil servants from different administrative levels, nature conservationists and scientists. They identified water management being the common focus issue. The regional forum aimed at the development of an inventory of recent water related problems, possible solutions and the identification of actors to be further integrated in this process. The stakeholders agreed upon a time horizon of adaptation planning for the year 2050. Expert interviews were carried out individually with all stakeholders in order to ensure the consideration of their institutional and personal point of views on recent and future problems, solutions and visions without being confronted to other stakeholders with different interests. The current knowledge on regional climate change and its implications on regional hydrological processes were presented to the regional forum to provide basic information for this collaborative planning process. All members of the regional forum were invited to contribute to a joint ‘‘Wesermarsch vision 2050’’.

2.3 Climate change projections

In order to assess a possible future climate change, regional climate projections of the WETTREG model (Weather Type Based Regional Climate Model; scenarios A1B, B1, A2) were used. The model generates station based time series. WETTREG is a stochastic downscaling approach determining the frequency of specific weather types from global climate models (e.g., ECHAM) to simulate station specific weather time series.

The variations among the scenarios were relatively small compared to the differences between current conditions (=base line) and the three available scenarios. Accordingly, the results of the A1B scenario were selected as input. The A1B scenario is a rather pessimistic one and describes relatively well the development of the change in global temperature since the year 2000. The investigation of time series for four climate stations around the Wesermarsch and the nine rain gauges located in the Wesermarsch revealed consistent climate trends. For the year 2050, WETTREG projected an increase in temperature of ~1 °C and an increase in winter precipitation (+25% from December to February) while summer precipitation was expected to decrease by 15% (from June to August). Similarly, average wind speed was expected to increase in winter and decrease in summer while sunshine duration was expected to increase in summer (Spekat et al., 2007).

2.4 Simulation of hydrological change

Based on the climate projections, hydrological change can be projected by applying a hydrological model. Physically based models are expected to be suited best to reproduce future hydrological conditions. The 1-D physically based model SIMULAT (Bormann, 2008) was applied to the available climate scenarios from the WETTREG model.

3 Results

3.1 Projected hydrological change

Model simulations resulted in increasing runoff rates in winter and an increasing water deficit during summer months (Bormann et al., 2012). Changes in the simulated water balance can be interpreted as changes in water volumes to be additionally drained (winter) or watered (summer), respectively. While in winter runoff generation could be expected to increase by 10 mm per month until year 2050 (scenario A1B), water deficit during summer months might increase by approximately 10 mm per month (scenario A1B). The differences among the three investigated climate scenarios were smaller than the differences between baseline and scenarios

3.2 Participation process

The inventory of recent water management related problems revealed that already today the regional water management system works at its limit. Information on (possible) hydrological change was presented to the stakeholder forum. It was used to (1) raise awareness that the amounts of water to be drained and watered might probably change in the coming decades and to (2) be able to estimate additional volumes of water to be managed by a revised water management system.

In order to consider the different sector specific views on the future, all members of the regional forum were invited to contribute to the joint ''Wesermarsch vision 2050''. During one workshop all participants were asked to describe their personal ideas on a future development of the Wesermarsch until year 2050. They expressed their interest to achieve continuity with respect to landscape, land use (agriculture), coastal protection and working conditions. Together with the information on the expected regional climate change as well as its likely effect on the hydrological cycle, the landscape vision represented the main boundary condition for the adaptation planning process.

Two focus groups developed and discussed different adaptation options for future water management, focusing on the needs of rural and urban areas. In both cases, the focus groups favoured to compose an adaptation portfolio, consisting of a set of parallel, possible adaptation measures, instead of developing a comprehensive adaptation strategy. Most of the recommended adaptation measures were based on technical solutions (e.g., dike enforcement, extension of the canal system, modernising pumps, building barriers). The proposed adaptation options, however, complied with the currently applied water management statutes of the water boards.

4 Information related issues

Data from regional climate projections and hydrological simulations in combination with participatory planning action enable to answer to four questions being crucial with respect to future good practice in adaptive water management.

Which information is needed for adaptive water management related decision making in coastal regions?

Adaptive water management in terms of climate adaptation requires detailed regional scale information on climate change and its hydrological implications. However, such information is not necessarily available for every region. In addition, specific knowledge on recent regional challenges and problems is urgently needed in order to be able to assess the impact of changing boundary conditions on the existing water management system.

Which information from hydrologists is suitable for decision makers in a climate adaptation process focussing water management needs?

Adaptation to climate change in requires attention and action by people who have not explicitly considered climate (change) in their past decisions (Füssel, 2007). Therefore, regional projections on climate and hydrology should be translated into self-explanatory information such as changes in water balance (volumes, water levels) or sea level rise.

How should we deal with the uncertainty in the climate projections?

Dealing with uncertainty implies to synchronise the necessity to provide a band width of possible futures due to its unknown character and the tendency of stakeholders to stick to one scenario (Veraart et al., 2010), to be interpreted as a “best guess”. In our case, this problem was partly solved by the selection of a distinct time horizon (year 2050) resulting in a similar signal of all scenarios. This decision excluded considering the uncertainty as an excuse for not taking (innovative) action. However, stakeholders expected the scientists to provide fixed “numbers” describing the regional climate change and its impacts.

How does selective use of available information influence the characteristics of suggested adaptation options?

The stakeholders used the available information according to the regional water managers’ attitude to protect against design events, to implement directives, and to act according to the statutes of the water boards. Accordingly, stakeholders selectively perceived and used information which was consistent with traditional thinking (e.g., in terms of the landscape vision 2050) and opted for traditional water management solutions.

5 Conclusion

Based on the results of the “Climate Proof Areas” project we conclude that a successful climate change adaptation requires a participatory bottom-up process in order to raise awareness and acceptance. The essential knowledge on regional climate change must be linked to specific knowledge on resp. of the region and its actors. Knowledge on predictive uncertainty should be processed according to stakeholders’ way of thinking. The choice of an (adequate) time horizon thereby affects the degree of flexibility in the proposed solutions. We observed that available information is used selectively according to the stakeholders’ attitude. Therefore, stakeholders have to share their knowledge and to come to a mutual understanding which can be realised by social learning in a regional forum, as part of collaborative planning process. It became obvious that successful participation requires confidence among all participants. Hence time matters, participation should be part of the adaptation from an early stage in the adaptation process onwards.

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Reinvigorating a U.S. conversation on climate change through the lens of climate impacts

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Abstract: *The impacts and growing risks of climate change are becoming increasingly clear to the American public, especially after Hurricane Sandy. This is an opportunity to reinvigorate a national conversation about the urgent need to take action to lower global warming emissions and build resilience to climate impacts. Communicating the latest science in a way that is relevant for people's daily lives, highlighting necessary policies and actions, and engaging with local planners and experts on the frontlines of responding to climate change will be critical to realizing this opportunity.*

Introduction

The United States, along with other countries, has experienced a spate of devastating extreme weather events recently, including droughts, heat waves, and flooding. Projections of future climate change show that the risks of some types of extreme events and their impacts will continue to increase (Peterson et al. 2012, Rahmstorf et al. 2011, Min et al. 2011). Recent polling shows that Americans are increasingly recognizing the links between climate change, extreme weather and associated costs, particularly in the wake of Hurricane Sandy. [2]

We see this as an opportunity to reinvigorate a dialog on the urgent need for action in the U.S. to address the risks of climate change and limit its future magnitude.[3] Our research and advocacy in two key areas – coastal impacts caused by sea level rise along the Eastern seaboard of the U.S. and the implications of changing climate conditions on wildfire and beetle infestation risks in the forests of the Rockies – is aimed at engaging citizens, local and state leaders, and experts in development and support of ambitious climate and energy policies.

Confronting the Realities of Climate Change

Hurricane Sandy pounded ashore on the Eastern seaboard of the U.S. on October 29, 2012, dramatically changing the country's sense of vulnerability to coastal storms. The storm dealt a crippling blow to energy and wastewater infrastructure, shut down major airports and mass transit, flooded significant parts

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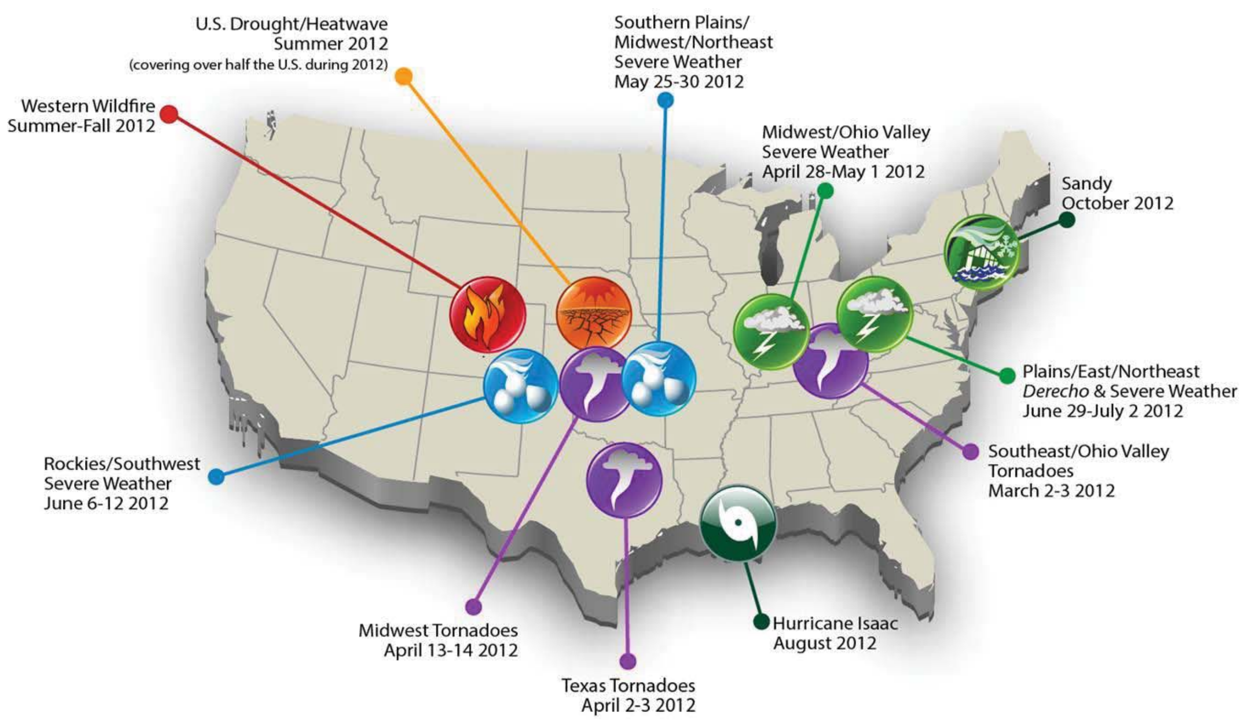
[2] For example, polling in November 2012 commissioned by Climate Nexus found that 60% of American voters agreed with the statement that "global warming made Hurricane Sandy worse," and 73% of respondents agreed with the statement: "Global warming is affecting extreme weather events in the United States." A Yale/GMU poll conducted in early September of 2012 found that 74% of Americans agreed with the statement "Global warming is affecting weather in the United States." A November 2012 Zogby Analytics poll showed that the year's extreme weather also had a dramatic effect on opinions across party lines, with 50% of Republicans, 73% of independents and 82% of Democrats saying that they are worried about the growing cost and risks of extreme weather disasters fueled by climate change.

[3] We recognize that many parts of the world are even more vulnerable to climate impacts, and that the U.S. has a unique responsibility to contribute to global efforts to mitigate and adapt to climate change. Taking action at home is a necessary, but not sufficient, condition for living up to those global obligations.

of New York, New Jersey, Connecticut and Rhode Island, and even closed Wall Street. Insurance industry estimates put the economic losses from Sandy at $65 to 70 billion across the U.S., Caribbean, Bahamas and Canada (Swiss Re 2013, Aon Benfield 2013), making it the second most expensive U.S. storm after Katrina.[4]

Vast swathes of the Midwest and Texas have suffered record-breaking drought conditions for over a year, estimated to cost $35 billion in 2012 (Aon Benfield 2013). Recent years have also brought intense heat waves, wildfires, torrential rain, flooding, low snowpack in the Western U.S., and record low water levels on the Great Lakes and the Mississippi River. In all, the U.S. experienced 11 extreme weather events that cost over $1 billion apiece in 2012 and 14 such events in 2011 (NOAA 2013a). Climate change is an important contributor to many of these events such as drought, heat waves and extreme precipitation (IPCC 2012).

U.S. 2012 Billion-dollar Weather and Climate Disasters



Source: NOAA, NCDC

Thus far, for the most part, the U.S. has dealt with these events in a reactionary way, on an emergency footing. Emergency assistance through the Federal Emergency Management Agency (FEMA), working together with local authorities, as well as taxpayer-backed insurance programs such as the Federal Crop Insurance Program (FCIP) and the National Flood Insurance Program (NFIP) have played a key role in helping with recovery and rebuilding efforts. The funding for this assistance has been the subject of much

[4] These cost estimates do not include the loss of lives (an estimated 200 people across 7 countries) or the costs of human pain and suffering. They also do not fully include costs covered by taxpayer funds such as emergency assistance and subsidized insurance coverage.

discussion and political wrangling, given the difficult economic and budgetary situation that currently confronts the U.S. Congress.[5]

But as they become increasingly common, a different approach that takes long term scientific projections about climate change and risks into account is clearly called for. The state of Texas, for example, has experienced multi-year droughts and long term water planning[6] has become an urgent issue much debated in the state legislature.[7]

In general, there has been a great reluctance on the part of U.S. government officials to draw any connection between extreme weather events and climate change. But in January 2013, President Obama, in his inaugural remarks at the start of his second term as President, said: "*We will respond to the threat of climate change, knowing that the failure to do so would betray our children and future generations*. *Some may still deny the overwhelming judgment of science, but none can avoid the devastating impact of raging fires and crippling drought and more powerful storms*." Governors Chris Christie of New Jersey and Andrew Cuomo of New York, both of whose states were hard-hit by Hurricane Sandy, have also made powerful statements about the need to recognize the risks and realities of sea level rise and climate change.

From Extreme Weather to Climate Change

It is important to be scientifically accurate and careful in discussions of climate attribution and variability. For example, in our work we always frame a single extreme weather event in the context of the longer-term observed trends and how projections of the risks of these types of events may change under future warming. For a given flood event, we talk about how heavy precipitation is generally on the rise in many parts of the U.S. and is increasing flood risk and associated health impacts (Perera, Sanford and Cleetus 2012). This trend is projected to continue under future warming. But we also acknowledge that a formal attribution study has not been carried out on this particular event. As another example, in our work on extreme heat in the Midwest, we have pointed out there are year-to-year ups and downs in the data, but the longer term trends (the climate signal) fit with what we would expect regarding the increased risk of elevated heat and heat waves with global warming (Perera et. al. 2012). We have also created an infographic based on the 2012 IPCC report on extreme weather that shows, based on data from the past 50 years, that there is strong scientific evidence linking climate change with increasing heat waves, coastal flooding, extreme precipitation and severe droughts. The evidence is much more limited for hurricanes and tornadoes (UCS, 2012). Again, we are very careful to base our work on the best available science and not overstate climate links, especially to individual events.

It has become quite common to see newspaper articles linking extreme weather events to climate change. Large scale losses, especially of lives and property, highlight the potential costs of climate change. But as time passes and immediate recovery efforts end, the event can recede from the public eye. This creates a

[5] For example, the Hurricane Sandy Relief Bill was finally passed at the end of January after being held up for weeks in the U.S. House of Representatives and becoming caught up in the so-called fiscal cliff negotiations and their fallout.
[6] Texas's most recent water plan states plainly: "In serious drought conditions, Texas does not and will not have enough water to meet the needs of its people, its businesses, and its agricultural enterprises." (Texas Water Development Board 2012).
[7] According to a recent news report, "Lt. Gov. David Dewhurst and other Republicans proposed tapping an emergency fund that is fed by taxes on oil production to finance the building of new reservoirs and other projects identified in the state's 50-year water plan, an unusual move in a state where fiscal conservatives usually push to streamline government and limit spending." (New York Times, January 12, 2013)

fundamental problem for sustained public pressure for climate action. However, there are some climate impacts such as sea level rise that are proceeding apace rather than manifesting themselves episodically. Highlighting those risks can be an entry point for raising people's awareness of what climate change could mean in their daily lives and why we urgently need to act.

Sea Level Rise and U.S. Coastal Communities

Sea level rise, driven primarily by climate change via thermal expansion of ocean waters and melting land ice, is a global problem most acutely affecting low lying nations such as the island states and Bangladesh. The United States is also uniquely at risk: Recent studies have found that the stretch of the U.S. eastern coast between Cape Cod and Cape Hatteras experienced rates of sea-level rise 3 to 4 times faster than the global average, between 1950 and 2009 (Sallenger et al. 2012, Cazenave and Llovel 2010).[8] This is partly due to local factors such as changes in the path or strength of ocean currents and local land subsidence. The stretch of Atlantic coastline between the Gulf of Mexico and Nova Scotia has also experienced among the fastest *rates* of sea level rise in the world.[9]

The American coasts, as elsewhere in the world, are among the most densely populated and developed parts of the country. Roughly a third of the nation's population—more than 100 million people—lives in coastal counties.[10] These counties account for 42 percent of the U.S. gross domestic product.[11] Coastal states with low-lying land are especially vulnerable to rising seas and coastal storm surges. Future projections of global sea level rise show that 1 meter of rise is likely to occur by the end of the century under a mid-range scenario for sea level rise[12] and that it could occur even earlier under the highest scenario (NOAA 2012), and local factors make it likely that parts of the East and Gulf coasts of the United States will experience an even faster pace of sea level rise, than this.

Amplified storm surge, coastal erosion, flooding and inundation have already cost lives and billions of dollars of damage in the U.S. and these risks are only growing with rising sea levels. Coastal communities, from Alaska to the Florida Keys, are increasingly being forced to grapple with difficult choices regarding whether to accommodate the rising seas, retreat from them, or try to defend coastal properties and infrastructure with a variety of protective measures.

Wildfire Risks Faced by Rocky Mountain Communities

The risk of wildfire in western U.S. states seems to be increasing as illustrated by recent trends in number of fires, area burned, and duration of wildfire season (Westerling et al. 2006, Climate Central. 2012). Wildfire leads to many costly societal impacts including potential for loss of life, damage to structures, and reduced air quality. The forest ecosystems are often greatly altered impacting the functions and

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[8] Sea level rise in the Northeast US has risen by approximately 30 cm since 1900—a rise that exceeds the global average by approximately 20 cm (Church et al. 2011).

[9] Since 1955, much of the eastern North American coast has experienced rates of sea-level rise exceeding the global average (Milne 2008**).**

[10] Coastal shoreline counties are defined and provided by NOAA. See *http://coastalsocioeconomics.noaa.gov/coast_defined.html*. We exclude counties bordering the Great Lakes from our population analysis (U.S. Bureau of the Census 2010).

[11] Data are available from NOAA's State of the coast website: *http://stateofthecoast.noaa.gov/coastal_economy/welcome.html*. Economic data include activity along the Great Lakes shorelines of Pennsylvania and New York but not along other Great Lakes shorelines.

[12] NOAA 2012. This comes from NOAA's Intermediate-High scenario. http://cpo.noaa.gov/sites/cpo/Reports/2012/NOAA_SLR_r3.pdf

services they provide such as improved water quality and habitat for many species. These in turn can affect local communities not only through direct impacts to life and the built environment, but also through recreation and tourism losses.

Wildfire risk presents, perhaps, a more challenging scientific issue than sea-level rise as many interacting factors may be driving the risk. Temperatures are rising throughout the Western U.S. which is leading to increasing aridity and drought, especially in the southern portion of the Rockies favoring conditions for fire. Also, increases in temperature throughout the year are increasing the length of the fire season. In the northern portions where precipitation is showing some increase overall, trends in winter precipitation are toward more coming in the form of rain as opposed to snow. This can lead to decreased snowpack and earlier snowmelt. This reduces water availability and soil moisture in later months during fire season driving increasing risk. The warming West has also lead to favorable conditions for widespread insect outbreaks and tree mortality. There is still debate whether insect killed trees are driving fire risk, but some view it as a large increase in fuel. Also, mapped onto this are non-climate factors, such as decades of fire suppression management that have forests far from their historic fire regimes.

Communicating Climate Science to Policymakers, Planners and the Public

A unique aspect of our work at the Union of Concerned Scientists (UCS) is the melding of scientific research and a robust communications initiative to get salient information to decision makers and the public. We have recently launched an initiative focused on elevating the realities of climate impacts in the U.S. and thereby motivating the public, experts and policymakers to engage in an action-oriented national conversation. Without a solid, broad-based foundation of support, attempts to enact climate legislation are likely to suffer the same fate as the Waxman-Markey bill of 2009.[13] Combining good science with a sharp political and outreach strategy will be vital to breaking through the partisan gridlock and finding both Democratic and Republican champions willing to support climate action in the U.S. at all levels from the local to the national.

As an early example from our coastal impacts project, we are convening a roundtable for city and state officials from the East Coast states of Florida, New York, New Jersey, North Carolina and Virginia to discuss their experiences in planning for and responding to coastal storms and sea level rise. This will provide an opportunity for sharing lessons and good practices, as well as setting an agenda for future changes that are necessary for increasing coastal resilience.

In the Rocky Mountain States, we hope to engage a variety of stakeholders to bring attention to climate risks there. As the scientific message around climate impacts and fire risk is a bit more complex we first are reaching out to key experts in the region, including Federal land management scientists, to determine where the most robust connections reside between regional climate change, forest impacts, and fire risks. We are also reaching out to outdoor recreation businesses, such as the ski industry, which face existential

[13] The Waxman-Markey Bill (more formally known as the American Clean Energy and Security Act) was a comprehensive climate and energy bill passed by the US House of Representatives in June 2009. However, the Senate failed to pass matching legislation before the legislative term ended in July 2010 and thus the whole effort to get legislation enacted foundered. There have been many reasons cited for this failure – from shortfalls in the bill’s provisions to the economic recession, from competition with other Obama Administration priorities (such as passage of the Health Care bill) to failed strategy from the environmental community – but it is clear that the American public was never fully convinced of the urgent need for the legislation and thus political leaders found it easy to sidestep their responsibility to address climate change.

threats from climate change.

Our work is informed by a growing body of social science research on how people perceive risks, and how their attitudes about climate change are formed and can change (Leiserowitz et. al. 2012; Myers et. al. 2012; Kahan et. al. 2011; Kahan 2008). One major theme that is emerging from this work is that Americans relate more to climate impacts in their daily lives than to a polarized discussion of the science and causes of anthropogenic climate change. The question remains: How best to use these insights to motivate action to address climate change on an urgent basis?

Through our research and advocacy we want to call attention to the opportunity to make smarter collective choices, based on the latest science, so as to begin to reduce exposure to climate risks. Even as we work to adapt to unfolding climate change, making deep reductions in global warming emissions is still the best way to reduce adaptation costs and limit the magnitude and pace of future climate impacts.

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Translating science into public knowledge: climate change and the science/practice interface

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Abstract

There is mounting evidence that global warming is producing variations in local weather patterns and water supplies, disturbing ecosystems and soil landscapes, and impacting economic production and social conditions. Climate change has been defined as a “wicked” problem for which there are no easy solutions and no simple approaches. The paper discusses climate governance and the science/practice interface in terms of improving adaptation policy making.

A significant challenge has been the limited integration between researchers and those government agencies that play a central role in the everyday management of development and natural resources. There are significant institutional and cultural barriers between researchers and policy-makers that hinder the transformation of scientific knowledge into plans and actions able to strengthen adaptive capacity. Recommendations in this paper are made, based on previous research project experience, on how to improve the communication between all parties to improve policy-making. Based on the dissemination experience of this policy-oriented project, and the political context of two other projects, the paper applies the lessons learned in these projects.

Introduction

The expected impacts of climate change will certainly increase risks, with serious repercussions for sustainability and local livelihoods, and, in some cases, new opportunities for development. There are significant unknowns about the balance of risks and opportunities at a regional and local level, but what is absolutely certain is that an effective management of both threats and opportunities requires the development of a planned and proactive strategy of adaptation and a strengthening of the determinants of adaptive capacity, which is a strategy in which governments should play a central role. A necessary step in this direction requires an increasing elaboration and systematization of scientific knowledge and local knowledge, and their integration into public policies and programs and governments’ information systems.

This paper contributes to the discussion of section 5 of the conference. It focuses on the science/policy interface in the area of climate change, an issue that is becoming highly relevant to our present research efforts. The paper is based on a process of self-reflexive evaluation of one of our interdisciplinary policy-oriented research project –the Institutional Adaptation to Climate Change Project (IACC)—and two other Latin American projects, in terms of their ability to contribute to policy development. The paper starts with a brief account of the project and its outcomes and then it moves into a discussion of the interface in the specific context of the problematic of climate change. It ends with a set of brief recommendations.

The Outcomes of the IACC project

The IACC project involved a study of governance institutions in two river basins, one in northern Chile and another in western Canada. The study involved both an assessment of governance and set of community vulnerability assessments oriented to know how vulnerable are the communities to climate and the role played by governance in reducing this vulnerability. The development of climate change scenarios for the two basins, historical studies, analysis of water conflicts, and economic evaluations of the impacts of extreme climate impacts complemented these assessments. As a scientific study, the IACC project was highly successful. There was an increased knowledge of local vulnerabilities and capacities to climate and a deeper understanding of the capacity of governance to reduce the vulnerability of rural people. Moving beyond the idea that the simple presence of an “institutional capacity” and “well developed institutional systems” (IPCC, 2001: 896-897) are conditions that ensure an adaptive capacity, it was demonstrated that even well established institutional systems have shortcomings due to the absence of proper climate policies and internal management practices that limit the proper integration and coordination of policies. The project was also able to address the complexities of organizing and implementing an interdisciplinary approach, integrating different disciplinary interests and emphases into well coherent research results. Important for this interdisciplinary success was an emphasis on vulnerability as a central focus, channelling all research efforts into the same direction. The success of the project translated into a large number of academic publications and conference presentations, as well as in new international and national research projects in related areas and the development and consolidation of a Canadian and Latin American interdisciplinary research network in the area of climate change and adaptation. New projects and academic collaborations have also resulted in the training of new scholars and significant job opportunities for research assistants.

The IACC also implemented a knowledge dissemination program to inform rural communities, practitioners, and policy-makers in both countries of its activities and results. In the case of policy makers, a special effort was made to facilitate the transfer of knowledge from the project, which included annual and final reports, participation in government workshops and conferences, and special reports for Chilean and Canadian government agencies, which included several general recommendations for changes to government programs and organizational patterns. The results were mixed. On one side, the project contributed to increasing awareness of climate change within the rural community and practitioners. Also, solid linkages were established in Canada with one of the agencies of the federal Ministry of Agriculture, a linkage that has become very fruitful for the development of new forms of research and working collaboration. In Chile, linkages were developed with the National Commission for the Environment and the Office of Agricultural Planning. On the other side, and in spite of a well-organized strategy of knowledge mobilization, the project was unable to attract the attention of those involved in the policy agenda. As expected, establishing causal links between scientific results and these changes is difficult to prove. We would like to think however, that the IACC provided additional grist for the decision making mill and that the insights provided by the project was part of the wider conversation going on in the province of Saskatchewan regarding water management. In the case of Chile, the project –through some of its researchers—provided significant inputs for the development of a National Adaptation Program and started the discussion for a climate program within some of the agencies of the Ministry of Agriculture. While it is difficult to identify how much it influenced the processes, one can nonetheless reasonably assert that it added a further substantiation to these program creations.

Evaluating the Science/Policy Interface

The science/policy interface in the area of climate change seems to be plagued by difficulties –and the failure of Kyoto is a good indicator of this. There are already significant insights about the barriers that impede a smooth flow of the information between science and policy. Some of them are related to the institutional tensions that characterize each one of the spheres. In the policy area there are issues related to the politicisation of science and reciprocal scientisation of policy (Hoppe, 1999; Weingart, 1999). Climate science is questioned, either because of the high level of uncertainty that characterize its work, or because the findings demand important redefinitions of the ideas that sustain existing political constructs (Choi et al. 2005, Sarewitz, 2011). Three areas have been identified based on our experiences and confirmed in the existing literature relevant to the analysis of the science/policy interface: the quality of the scientific evidence, the nature of the links that exist between the policy and research communities, and the political context (Jones et al. 2009; Court and Young, 2003). Using these three areas as lens to analyze the IACC's experience provides us with some relevant insights.

The dimension of **evidence** is related to the quality of the research process and has to do with issues of credibility, the methodological approach, and the degree of consensus arrived at within research teams (Court and Young, 2003: 16; see also Ingram et al, 2007; Morgenstern Brenner, 2011). Having well-known scholars in the team provided the necessary scientific credibility and legitimacy to the results. Moreover, the interdisciplinary nature of the teams and the high degree of integration reached in the projects facilitated a proper methodological approach and a comprehensive set of timely results. An issue, however, was the degree of uncertainty that characterize climate change, which affected the acceptance of many of the IACC recommendations by policy-makers. Policy makers interviewed in the governance assessment often identified as reasons for not making policy changes the uncertainty of climate change and the distrust of the community in climate change science (Hurlbert, 2011).

A clear triangular relationship between scientists, policy makers and community is essential and a strategy employed to bridge the divide between the “cultural construct” of policy makers and the “scientific construct” of scientists identified by Van Storch (2009). Often the social distrust and lack of credibility (also identified by Kasperson, 2011, p. 433) although apparent in the interviews, was not acknowledged or dealt with.

Links between scientists and policy-makers were non-existent at the beginning of the project (they certainly improved during the project) which meant that the definition of the project’s objectives and its research design were orphans of policy-makers’ advise. At the beginning of the project there was a limited recognition of the diversity of interests existing within the policy sphere, which was realized later to be naïve. Establishing these links in the formulation of the project may have allowed some of the barriers of conflicting time frames, epistemologies, goals, reward structures, process-cycles and criteria for judging the quality of knowledge (Hegger et al., 2012; Hegger and Dieperinck, 2012; Dilling and Lemos, 2011). Perhaps the epistemological differences between engaged and neutral scientists in relation to the role of scientists in the policy process (Higgins et al, 2005), the relevance of local knowledge (Liberatore and Funtowicz, 2003), or the need for specialized expertise versus the democratization of knowledge (Cash et al., 2003), could also have been bridged.

The **political context** was perhaps the most problematic issue. A clearly limitation was the team’s naïve understanding of the complexities of the policy-making process, typical of a rationalist modern discourse (Leroy et al, 2010), assuming that informing policy was an unidirectional and direct process. This limitation resulted in the absence of mechanisms to monitor the impacts of knowledge mobilization efforts and, more relevant, a limited effort to understand the political context. In Canada, we had a limited appreciation of how difficult is to influence the federal and some of the provincial governments in the area of climate change. During the period in which the project took place the federal and the provincial governments relevant to the project were controlled by conservative politicians who ignored systematically (and still do) the relevance of climate change in the public agenda. In Chile we faced a similar issue. In spite that the government in power at the time was socialist, the government’s approach assigned to economic development a priority role in relation to environmental issues. In these terms, the possibility of mainstreaming climate as a comprehensive issue in the political agenda was an impossible task.

No less relevant was our limited understanding of the government organizational structures in both countries. The IACC project was focused on the impacts of climate on rural water resources, which required a knowledge mobilization program directed to a multitude of agencies operating at different levels and areas of government. These organizational balkanizations in Canada and Chile, characterized by limited levels of inter-agency coordination and communications, made the mobilization effort easily lost in the myriad of organizational interests.

The experience on other Latin American projects has been starkly different. In Argentina, a similar project, centred around producer vulnerability, found the political context one in which the scientists facilitated the government in legitimizing the governments proposed policies in relation to climate and water. Although these policies are still regarded by the scientists as not reaching far enough, a unity of interests between the scientists and policy makers was experienced (Montana, 2013). In a very different political context in Bolivia, a more participatory governance structure in relation to water and vulnerability projects exists (Montana, 2013; Cerruto, 2013). In this political context, a vulnerability project found the scientists acting as mediators between the government and the community in relation to the development of adaptation policies (Cerruto, 2013). Consequently, the relationship between community, scientists and policymakers varies within each political context.

Conclusions

Robust climate policies could contribute certainly to improve the capacity of society to reduce the risks associated with climate change and science could contribute with its knowledge to produce these policies. There is a need, however, to pay more systematic attention to the science/policy interface, and recognize the three way relationship between scientists, policy makers and community. The experience of the IACC project indicates the need to be better informed about the specificities of the political context and the complexities of establishing robust links with a multiplicity of government actors an integrate this information into knowledge mobilization strategy that is part of the research design of the project. The experiences of other Latin American projects determine that a flexible role for scientists depending on political context may be necessary.

Given the particularities of different government contexts and organizational patterns, it is almost essential to carry out international comparative research as a way to have a better knowledge of the multiplicity of contexts and processes that characterize the science/policy interface. Specially important seems to be areas such as the impact of development ideologies on the degree of aperture of policy to scientific evidence; the roles of a diversity of intermediaries that could facilitate bridging the gap between science and the policy community, and managing better mobilization of knowledge characterized by uncertainty. Perhaps this will help to reduce what has been the wicked problem of climate change to a structured problem of managing climate risk, mitigating climate change, and capitalizing on potential adaptation

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Is agricultural sector listening to us?

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Abstract

Agriculture is susceptible to climate risk and is therefore vulnerable to climate change. So far, climate forecasts have been developed from the seasonal time scale and longer term climate change predictions with an attempt to assist decision making in sectors vulnerable to climate risk. However, it is not always clear that the end-users' needs for that information are met and there might be a large gap between information supplied and needed. The use of medium term forecasts (1 to 10 years), which are longer than seasonal but shorter than climate change, have not been investigated. Through interview surveys with apple farmers and other experts in South Africa, we found that these medium term forecasts would affect farmers' cultivar selection for the following ten year period. We suggest that the information exchange between farmers and experts is important to make forecast more useful and usable.

Index Terms

Apple production, Climate Information, Farmers' decision making, Medium term, South Africa

1. Introduction

Climate forecasts have been developed to assist decision making in sectors averse to, and affected by, climate risks (Johnston *et al*, 2004) and agriculture is one of those. Former researchers have shown that when seasonal climate forecast information was provided to farmers prior to decisions, farmers adapted by changing their choice of planting seeds and timing (Patt *et al*, 2002) or area planted (Phillips *et al*, 2002). It has been pointed out, however, that even when forecasts were available, they were often not utilized by farmers and extension services because of lack of trust in the forecast (Ziervogel *et al*, 2010) or the forecasts didn't reach to the targeted farmers (Ziervogel *et al*, 2004).

So far, many studies have focused on the use of seasonal forecasts or longer term climate change prediction, but little research has been done on the medium term, that is, 1 to 10 year future climate information (Goddard *et al*, 2012). The agriculture and food system sector is one potential user, as land use policy and cropping systems selection may fall into this time scale and may affect farmers' decision making process. Given that reliable information is provided, it might contribute to resilient farming and furthermore longer term food security.

In order to reveal farmers' strategic decision making processes and the role of medium term climate information, we focused on apple production in South Africa. Apples in South Africa are generally grown under conditions of insufficient winter chill units; this necessitates the use of chemical rest-breaking treatments to achieve satisfactory budburst, fruit set, yield, and fruit quality (Cook *et al*, 2000). In the event of a warming climate, the accumulation of chill units is expected to decrease, eventually reaching a critical threshold at which apple production would no longer be commercially sustainable (Midgley *et al*, 2011). Under this condition, what climatic and non-climatic stimuli have farmers recognized and how have they adapted to them? Would medium term climate forecasts affect farmers' decisions? Through interview surveys with experts and farmers, we explore these questions.

2. Study Site and Methods

2.1 Study Site: Elgin

South Africa is one of the world's major apple suppliers, ranked 15th in the world (FAO, 2011) with an annual production of 766,000 t in 2011 (Deciduous Fruit Producers' Trust, 2011). Elgin (34° 8' 55" S, 19° 2' 34" E) is one of the largest apple production areas, located in Western Cape (Fig 1). In 2011 about 90 % of apples in South Africa were produced in Western Cape, and about 26 % in Elgin (Deciduous Fruit Producers' Trust, 2011), where we focused our survey. There are about 130 apple farmers in the region.

For the period 1973-2009, the mean annual air temperature was 16.3 °C, and the linear trends showed an increase of +0.55 °C/ decade for mean annual ($P<0.0001$) in Elgin (Grab *et al*, 2011). Along with temperature increases, chill units decreased by 25% in the last 40 years (1967-2007) (Midgley *et al*, 2011). In the future, by 2035, this region would experience a reduction in the chill units by 19-34 % with 1.0 °C increase in temperature, which would breach a threshold level of chill units for commercial apple production of acceptable yield and quality (Midgley *et al*, 2011).

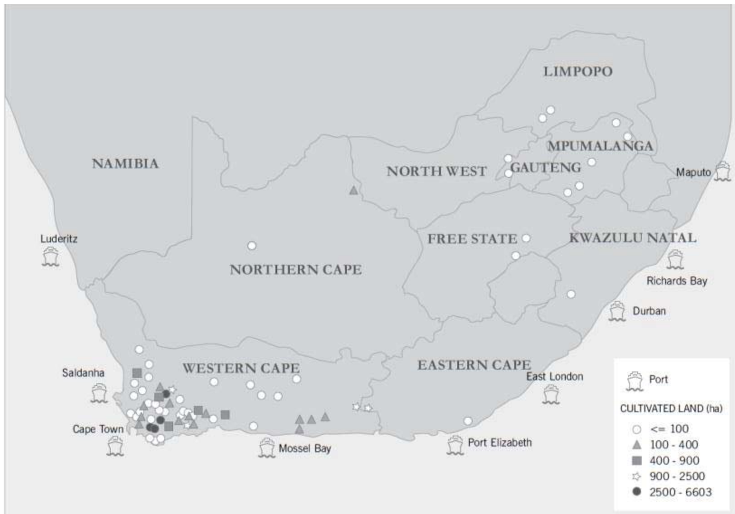

Figure 1. Geographical spread of pome fruit production in South Africa. Quoted by Deciduous Fruit Producers' Trust, 2011.

2.2 Methods

We conducted 11 semi-structured interview surveys with apple farmers and experts in November 2012. The farmers were asked basic and descriptive information. The former includes their planted area, sales channels and usage of climatic information. The latter includes their cultivation history in good years and bad years in terms of production and profitability in the last 20 years, and any actions they may have taken during bad years.

3. Results

3.1 The role of climatic information on farmers' decision making process

3.1.1 Current usage of climatic information

Farmers use updated, up to ten days in advance, weather information every day in order to schedule their practices. In the early growing stage of apples, shortly after flowering, the forecast for rainfall is especially important as the possibility of infection to fungal disease would be higher. The fungal index, calculated with the forecast of rainfall, wind and temperature, was provided to farmers by technicians at the companies through which they sell (see 3.1.2) so that farmers can adjust their schedule of pesticides spray dates. Currently it appears that farmers do not use any longer term climate information.

Apple production needs long term strategies. The life cycle of an apple tree is from 25 to 30 years; hence farmers aim to replant 4 to 5 % of their orchard every year to keep production levels constant. They order nursery trees, at least two years and up to six years, before they plant. Newly planted nursery trees bear first fruits after 4 years. In total, farmers make decisions about cultivation selection between 6 to 10 years prior to production. They are interested in medium term climate information especially for temperature in winter because chill unit information is one of the major concerns influencing cultivars selection.

3.1.2 Co-operatives and Companies: key of farmers' sales and communication channels

Farmers rely on the sales and distribution companies for the information they need. There are three main companies in Elgin who collect, pack and ship to local/ international markets. Those three companies started as farmers' cooperatives around 1950 and became private companies around 1990. Many farmers have kept supplying to the same company since they began, and the number of farms supplying the companies is stable. Of 130 apple farms, about 120 farmers supply to one of the companies above, and the remaining ten are independent or are owned by another supply company.

Each company has technical experts that specialise in cultivation. All the farmers interviewed received farming and climate information from the technical experts of the company to which they supply their product. The technical experts in the three companies also exchange information among themselves regularly, especially for planting techniques such as timing of spray and recipe of chemicals. As a result, the information different farmers receive is similar, which leads to similar farming strategies.

3.2 Farmers' strategic decision making and the factors in the past

3.2.1 Farmers' recognition of conditions that ensure a good harvest and good profit

Farmers' recognition of conditions which ensure a good harvest was closely related with climatic events. 2012 year crop was referred as a good harvest (Table 1), high yield, due to the colder winter in 2011 which brought higher chill unit and enabled apple trees to rest and produce more buds. The harvests of 2008 and 2009 were also referred as good for the same reason.

Farmers mentioned that yield and profit are closely linked and the quality of apples does not produce a huge difference in their income. However one event was mentioned as a memorably good profit year: 2009. About the half of apples produced in South Africa are for export. After 2008 the South African Rand dropped dramatically in value against Euro/ Pound which automatically increased farmers' income. The currency exchange rate changed from R 9.5 to 1 Euro in 2007 to R 13-14 to 1 Euro in December 2008. Good tonnage and currency exchange rate made this year a memorably good one for farmers.

Table 1. Farmers recognition of good harvest, profit and bad harvest, profit and the reasons

Memorable events	Years	Reason
Good harvest	2008 crop 2009 crop 2012 crop	Cold winter 2007 Cold winter 2008 Cold winter 2011
Good profit	Same as harvest 2009, 2012	Good volume Good exchange rate
Bad harvest	2010 crop 2011 crop	Warm winter 2009 Warm winter 2010 and 2011 Jan heat wave
Bad profit	Same as harvest	Low volume/ income

Table 2. The top four climatic and non-climatic events which affect farmers most

Weather/climate factors	Other factors
Lack of chill/ warm winter	Exchange rate
Heat wave/ hot summer	Trends in market
Rain in spring	Input cost (oil/ labour/ fertilizer)
Extreme events (wind/ hail)	

3.2.2 Farmers' recognition of a bad harvest, and profit and adaptation strategies

A bad production year is also related to chill units, heat waves in summer and extreme events such as hail and strong wind. Heat waves cause sunburn of apples and induce water stress in trees, which leads smaller fruit size. Sunburn increases the percentage of fruit relegated to processing/ juice, causing a substantial decrease in income. Hail damage largely depends on the location of farm and orchard, but generally hail after flowering results in loss of yield.

Low profit years were often caused by low volume. Farmers also mentioned that input cost such as oil, labour, fertilizer and shipping cost are increasing and this tightens their margins (Table 2).

Responding to the lack of chill units, farmers have changed the recipe for break dormancy, such as the mix rate of oil/ Cyanamid. From the research side, new cultivars with lower chill requirements have been introduced. The Granny Smith cultivar requires fewer chill units, but it is very prone to sunburn. The solution to protect it from sunburn is to use shade nets. However some farmers think the cost exceeds the profit and rather plan to plant other cultivars instead of replanting Granny Smith. Popular cultivars were Cripps' Pink and Fuji, mainly because they fetch higher prices at the markets. Indeed, young trees of Granny Smith (0 to 10 years) contribute much less towards the total planted area (10% of total Granny Smith) than old trees (older than 25 years) (67% of total) and the area of Cripps' Pink has increased about 30% in the last three years (Deciduous Fruit Producers' Trust. 2011).

4. Discussions

Regarding the climate forecast information, three factors are required to make information usable: user's perception of information fit: how new knowledge interplays with other kinds of knowledge that are currently used by users: and the level and quality of interaction between producers and users (Lemos *et al*. 2012). These points are discussed below.

4.1 How shall we marry impacts and adaptation research?

Through our survey we found that apple farmers' decadal decision making is affected by climatic events, and they have already started changing cultivars. Hence, the medium term climate information, particularly temperature and rainfall in the critical period for farming, may be of great use for them. It was pointed out that the current climate prediction information is not consistently or sufficiently reaching policy makers and local farmers, nor is it particularly oriented towards their needs, which has prevented farmers from using climate information to their full potential in the decision making process (Rarieya *et al*, 2010). Only by conducting this type of field research, might we be able to determine the climate information that fits the users' needs, and attempt to close the gap between information provided and that which they require (given that we could generate a reliable medium term forecast). For that, we need to better understand farmers' decision making processes and farming systems.

4.2 How can we achieve more active communication with policy makers?

Beside interaction between producers and users, we argue for the role of an intermediate institution for channelling information. It was discussed that understanding stakeholder networks is key to determining the opportunities and barriers to the flow of forecast information, which could enable more focused forecast dissemination (Ziervogel *et al*, 2004). Our research agrees with this view. Farmers rely on information exchange channels with experts in the companies, and information exchange among experts was also productive. If forecasts could be provided to farmers through those experts, the forecasts may help farmers' decision making and, at the same time, result in resilient farming in the region, which would contribute to broader food security. We need to point out that the nature of the producer-experts network largely depends on regions and crops. It would be different case by case. By accumulating these case studies, we could provide useful feedback to the agricultural sector and achieve more active communication.

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Linking impacts modeling and adaptation planning: a model for researcher-practitioner collaboration

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Abstract - This abstract addresses a number of points in the visioning document for the IMPACTS WORLD 2013 conference, primarily those in Key Challenge 3.5, Is Anyone Listening?. We present an approach for linking impacts modeling and associated research with adaptation planning undertaken by managers and policy-makers (practitioners) in the forestry sector. We base this on a number of modeling projects we have undertaken over the past five years, as well as a review and synthesis of approximately a dozen forestry case studies across Canada in which impacts modeling was used to support practitioners in developing adaptation plans. We begin with a conceptual framework that brings together climate change vulnerability assessment (comprising climate exposure, ecosystem sensitivity and forest managers' adaptive capacity) and adaptation planning undertaken by practitioners. The overriding principle in this framework is that the goal is to continue to deliver Sustainable Forest Management (SFM) in a changing environment. We find significant benefits in bringing together researchers and practitioners early in the research process, particularly in making use of practitioners' knowledge of planning and management requirements to identify and focus the research questions. Impacts modeling can then be targeted at components of ecosystem structure and function that bear directly on decision making, e.g. forest productivity (related to determining wood supply and annual allowable harvest levels), changes in fire and pest outbreaks (wood supply, fire suppression planning, integrated pest management programs) and changes in species distributions on the landscape (economics of continued forest products development). In addition, modeling can be used to examine the effects of implementing adaptation options and developing scenarios in which a variety of options are considered. Similarly, "embedding" researchers in government or industry forest management planning exercises allows researchers to obtain a first-hand understanding of the realities of forest management which can be incorporated into subsequent impacts modeling.

Index Terms – Vulnerability assessment, adaptation planning, mainstreaming, Canada, adaptive capacity, embedded science.

1 Introduction

This paper addresses a number of points in the visioning document for the IMPACTS WORLD 2013 conference, primarily those in Key challenge 3.5, Is Anyone Listening?. We present an approach for linking impacts modeling and associated research (i.e. researchers) with adaptation planning undertaken by managers and policy-makers in the forestry sector (i.e. practitioners). We base this on a number of modeling projects we have undertaken over the past five years, as well as a review and synthesis of approximately a dozen forestry vulnerability-adaptation case studies across Canada in which impacts modeling was used to support practitioners in developing adaptation plans. Much of the data reported below was based on interviews with case study leaders conducted between December 2011 and March 2012.The location of the case studies is shown in Fig 1.

Figure 1. Location of vulnerability-adaptation case studies in Canada. RAC, Regional Adaptation Collaborative Program, Natural Resources Canada; ESRD, Alberta Environment and Sustainable Resource Development. Source: Johnston and Edwards, in press.

2 Sustainable Forest Management and Climate Change

We begin by stating the principle that climate change adaptation is not an end in itself. Rather, it is a means to an end: a way in which Sustainable Forest Management (SFM) can be delivered in a changing environment. By "environment", we mean not only the biophysical environment, but also the economic, political and social environments within which SFM is practiced. Therefore forestry practitioners need to know: (*i*) something about the nature of the changing environment(s); (*ii*) how those changes may affect their local SFM activities; (*iii*) what options they may have for adapting to these changes; (*iv*) some way of choosing from among many potential adaptation options; and (*v*) a monitoring and feedback system for assessing the effectiveness of the options that were chosen. In order to characterize these elements and show how they relate to impacts modeling, we use a recent framework and a forthcoming guidebook developed in Canada and based on a four-year project under the auspices of the Canadian Council of Forest Ministers (CCFM). The CCFM represents provincial forest ministries across Canada and provided an opportunity to review several science-policy collaborations occurring across the country dealing with climate change and SFM. The CCFM framework was strongly influenced by the concept of an adaptation policy assessment as proposed by Füssel and Klein (2006). These authors characterize an adaptation policy assessment as "contribut[ing] to policy-making by recommending specific adaptation measures, thus representing a fundamental shift in the assessment purpose. They are characterized by the intensive involvement of stakeholders, by a strong emphasis on the vulnerability of a population to current climate variability, by the formulation and evaluation of response strategies that are robust against uncertain future developments, and by the integration of adaptation measures with existing policies." (Füssel and Klein 2006, p. 324).

A changing environment and its impacts on SFM is captured by a vulnerability assessment as described by Smit and Wandel (2006) and adopted by the IPCC. A vulnerability assessment as defined by Smit and Wandel (2006) comprises exposure (the nature of the changing environment); sensitivity (the responsiveness of the forest ecosystem and associated SFM system) and adaptive capacity (the ability of the SFM system to adapt to the impacts, as mediated by the system's sensitivity). We note here that in this framework adaptive capacity refers to the human system involved in SFM, rather than physiological adjustment or genetic change of the forest ecosystem (these are included in system sensitivity). Impacts modeling is applied to explore the system's sensitivity, given information about levels of exposure (e.g., output from a climate model or a socio-economic scenario). Once information about potential impacts is available, forest managers assess their adaptive capacity using a structured workshop and a guidebook (forthcoming). Information on impacts and capacity are then brought together to form the assessment of vulnerability of the SFM system.

3 Impacts Modeling

Impacts modeling is potentially a time-consuming exercise and requires relatively sophisticated expertise. Forest practitioners rarely have a sufficient amount of either time or expertise to undertake such exercises so experts (e.g. scientists) from outside the forest management organization are often consulted to do the modeling, or at least that portion that lies outside of normal modeling activity in SFM practice (e.g. wood supply analysis or harvest scheduling). Through the CCFM case studies and other experience, we find that close association between practitioners and experts is essential for successful application of impacts modeling for the Canadian forest sector. Adequate knowledge exchange needs to occur at the beginning of the assessment, so that the scientists understand the context and background to the assessment and the uses to which it will be put. Van Damme et al. (2008) used the term "embedded science" to describe the high degree of integration between the practitioners and the scientists in a forest management planning exercise that included impacts modeling. Similar projects across Canada, many involving long-term forest management planning activities, have shown similar results: strong and early integration of scientists into SFM planning is necessary for the science to be relevant and for the practitioners to communicate their objectives and the realities of their landscapes and management systems to the scientists. Often the scientists learn as much about the realities of SFM as the practitioners learn about modeling impacts to forest ecosystems.

4 Scientists and Practitioners

"Embedded science" also allows the scientists to focus on questions of direct relevance to the practitioners. The modeling can be targeted at components of ecosystem structure and function that bear directly on decision making, e.g. forest productivity (related to determining wood supply and annual allowable harvest levels), changes in forest fire occurrence and pest outbreaks (impacts on wood supply, fire suppression planning, integrated pest management programs) and changes in species distributions on the landscape (large-scale economics of continued forest products development and markets; opportunities for use of new species for new products).

An additional lesson from the case studies is that forest practitioners are often unwilling to address climate change if it is presented as something apart from day-to-day activities and decision making. Particularly since the recent downturn in the forest sector across North America, practitioners have little time or incentive to consider things seen to be "outside" of their core business. That puts the onus on the science community to help them "mainstream" (Smit and Wandel 2006) climate change considerations into business-as-usual activities. Successful examples of mainstreaming among the case studies are those in which the embedded science model was used to incorporate climate change into long-term management plans. These planning exercises are typically longer term (e.g. 20 years) and in many cases are a requirement under provincial legislation where SFM is occurs on publicly-owned land (Crown forests in Canada). In addition, the nature of these plans is strategic rather than operational, so the long-term outlook and broad-scale thinking are conducive to climate change considerations.

5 Uncertainty

Uncertainty about future conditions is always identified by practitioners and stakeholders as a barrier to coming to grips with climate change. The natural inclination is to want a clear view of the future, and then to simply develop policies and plans that take the SFM system to that new future destination. However, it is obviously impossible to accurately predict the future, so the better option is to develop policies and management systems that are robust to a variety of future conditions. One well-known approach is the no-regrets option, where, based on current understanding of SFM best practices, forest management is modified in ways that improve management regardless of the reality (or not) of climate change. Another is to assess current climate-related vulnerability and learn from actual events which adaptation options worked well and will likely be robust in the future. For example, the years 1995-2000 saw some of the worst forest fires occur across western Canada. This level of fire activity is similar to that projected by recent analyses for the latter part of this century (e.g. Balshi et al. 2009). Discussions with fire managers in this region focused on the impacts of this level of fire activity, and was based on real experience rather than asking them to imagine a hypothetical future scenario. This quickly led to a discussion of the implications of a future in which this level of fire activity becomes the norm every five or 10 years rather than once in a century. Another option that is being explored across Canada is the value of considering some type of assisted migration. There are many aspects to this, from incorporating seed from southerly locations into reforestation programs, to planting exotics. A real-world example is the use of provenance test data in British Columbia to modify the province's seed transfer guidelines in anticipated warming. This policy change was based on extensive analysis of data from a lodgepole pine provenance test established in the 1970s (O'Neill et al. 2008). This now provides practitioners with an option to move seed slightly outside the former transfer zones.

6 Adaptation Options

Once vulnerability has been assessed, adaptation options are identified. Rather than develop a long list of options with no guidance for practitioners, we have adopted the CCFM Criteria and Indicators (C&I) of SFM as a means for prioritizing options. Practitioners can test potential adaptation options against the C&I to determine whether the options will continue to deliver SFM into the future in a changing climate. Again we emphasize that adaptation is not an end in itself, but rather a way to continue to practice SFM in an uncertain and changing future. We find this approach appropriate at the national level, since forest managers are generally familiar with the system and it defines Canadian SFM at a high level. We also suggest that any additional criteria used at local levels (e.g., provincial government regulation, forest certification, individual company objectives) can also be used to screen adaptation options, as long as they contribute to SFM objectives.

7 Adaptation Modeling

Once adaptation options have been identified and chosen based on the priorities established for SFM under the C&I or other definition of SFM, further impacts modeling can be used as a preview of the effects of implementing them. Adaptation options could be implemented in the model and the impacts scenarios re-run. For example, provenance test data could be used to model future forest productivity and determine the effects of increased growth on wood supply when using different seed sources. In this way, adaptation options can be (virtually) tested, further increasing confidence in their ability to enhance SFM in the future. However, there may be circumstances in which implementing adaptation will not be sufficient to maintain SFM objectives. An example is the southern fringe of the boreal forest in central Canada. Here the forest is adjacent to the North American prairie and its boundary is determined by moisture availability (Hogg 1997). Given future projections of a warmer and drier climate in this region (Sauchyn et al. 2010), areas of forest along this boundary may not regenerate following disturbance (Hogg and Bernier 2005). For this area the objectives of SFM may have to be completely re-thought, such that maintaining forest cover may no longer be an option under future conditions. Hence the need to consider the policy implications of impacts of climate change that may overwhelm SFM objectives. This is another example of the use of impacts modeling.

8 Science and Policy-making

Linking science with policy-making has always been a challenge. We see the use of the embedded science model as one way of strengthening those linkages, particularly through the vehicle of long-term forest management plans. In addition, we encourage the review of existing SFM policies through a climate change lens. While current understanding is not perfect and uncertainty will always exist, there is enough knowledge and expertise to undertake policy reviews with respect to climate change vulnerability. It may involve qualitative analyses and depend on expert opinion, but it is certainly possible to get a general idea of vulnerability relative to forest policy now, and not wait until the science has moved further. Some Canadian jurisdictions have moved strongly in this direction and their experience provides opportunities for others to learn from. In addition, recognition by forest certification systems of the importance of climate change to achieving SFM objectives could provide an additional opportunity for helping practitioners with vulnerability assessment and adaptation planning.

9 Acknowledgements

We acknowledge funding from the Canadian Council of Forest Ministers, and the wealth of knowledge willingly shared by the many forestry professionals that were involved in the case studies across Canada.

All of the documents developed through the CCFM project are freely available at http://www.ccmf.org/english/coreproducts-cc.asp

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Climate assessment tools in communication and implementation of results of climate impact research

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Introduction

Climate change impact assessment process tries to understand and preferably to quantify the fundamental relationships between the global climate system and the human socio-economic environment. Apart from creating undisputed scientific and policy-making value, the results of the research ultimately aim to be implemented locally, translating into specific climate change adaptation measures at the local level. Such measures often seek to attract public or private funding and hence must be thoroughly justified. To do so, decision makers normally commission extensive background studies, perform cost-benefit analyses and have their plans scrutinised by public consultation processes. Climate assessment tools as described in this paper can offer great assistance and ultimately become an integral component of any climate change impact assessment process.

"Climate assessment tool" is an umbrella name for a broad spectrum of technological solutions aimed at communication and implementation of results of climate impact research. They are particularly important in the context of impact analysis targeted at rapidly growing urban agglomerations of the global South – places, where the paucity of data is often accompanied by suboptimal inter-agency communication and cooperation processes. The availability of climate-relevant information, the possibility to compare climate and socio-economic scenarios and to assess alternative futures in a coherent way are very important prerequisites for cities as focal points of global growth to align themselves with sustainable development pathways and to successfully adapt to the climate of the future.

Basically, climate assessment tools are a subtype of decision support systems – interactive computer-based systems or subsystems intended to help decision makers use communications technologies, data, documents, knowledge and/or models to identify and solve problems, complete decision process tasks, and make decisions (Power et al., 2011). Using the tools, the decision maker utilizes information technology to access the various input bases and execute the processing tasks of organizing problem elements, generating ideas, structuring the problem, simulating policies and events, and finding the best problem solution (Phillips-Wren et al., 2011). General public needs such tools to be able to act as educated citizen by controlling decision makers' actions and fostering community cooperation.

The user needs and requirements analysis performed for a climate change impact assessment tool for OECD urban areas (Cavan et al., 2010) revealed that the majority of users expect the tool to:

- Map risk and vulnerability to climate change hazards and show spatial distributions;
- Allow map overlay to enable identification of priority areas for adaptation actions;
- Identify relative patterns of risk in urban environments;
- Show the severity of the impacts;
- Generate a list of climate hazards and receptors;
- Inform preparation of planning documents to enable accounting of climate change impacts on people, property, assets and infrastructure; and,
- To be fully accessible to all stakeholders online, including residents, developers, local businesses, utilities and councils.

Development process

The development and implementation of an efficient climate assessment tool is a multi-threaded process. It involves generation of robust scientific input, development of appropriate technological solutions and establishment of suitable communication methods and feedback mechanisms. Even though the principal target audience of such tools consists of urban planners and the like, these can be efficiently used by non-professionals thanks to the possibilities offered by internet-based technologies.

The complexity of climate impact modelling algorithms and availability of computing resources either within Web-browsers (client-side) or commercial Web hosting solutions (server side) limit Web-based climate assessment tools to visualisation of pre-calculated scenarios and to simple analytical steps such as layer overlay analysis. This limitation is, however, largely offset by the advantages of Web-GIS, namely shallow learning curve, accessibility to non-professional users as well as feedback and participatory functionality. It is worth nothing, however, that JavaScript performance within a typical WebKit browser installed on a consumer-level computer is measured in tens of millions of floating point operations per second – more than IBM's 360/195 supercomputer used to run global climate models in the early 1970ies.

Hyderabad case study

This study draws upon the experience of developing an instance of Climate Assessment Tool for Hyderabad (CATHY) for use in an Indian megacity of Hyderabad, developed between 2009 and 2013.

The process of development of Climate Assessment Tool for Hyderabad consisted of the following main steps:

- study of horizontal and vertical governance structures and identification of relevant stakeholders
- assessment of existing decision making process and data availability across multiple stakeholders
- data acquisition and generation of consistent datasets
- generation of socio-economic and CO_2 emissions scenarios
- generation of quantitative and qualitative spatially explicit climate change impacts
- development of the WebGIS and dynamic scenario comparison interfaces

The impact assessment component of the tool further developed the approach of using impact nets for identification of potential adaptation points and projection of their range of influence, as outlined by section of the First Assessment Report on Climate Change and Cities which focuses on Hyderabad (Reckien et al., 2011). By visualising those nets in clear and accessible way, CATHY helps urban decision makers to better understand cause-consequence relationships of local climate change processes and to evaluate the potential of influence of planning decisions. In addition to that, the use of impact nets positively contributes to harmonization of development goals and climate change adaptation strategies at local and regional levels.

Successful science communication is always based on robust and undisputable research results. To achieve this, Luedeke et al., 2010 downscaled all the 21 IPCC AOGCMs to Hyderabad and analysed their output under A1 and B2 global emissions scenarios. The reliability of this process has been partially limited by local climate data availability in Hyderabad, with only one weather station at Begumpet airport reporting temperature and precipitation data since 1951. However, the very nature of projected climate impacts (increase in frequency of pluvial floods and extreme heat waves) made it possible to extrapolate the results to the whole of the urban agglomeration without jeopardising scientific validity of the results.

The combination of spatial and non-spatial data can enable development of new valuable spatial datasets. By combining flow accumulation model (spatial), average temperature predictions (non-spatial) and a vector-borne disease spread model (partially spatial) datasets, the user would be able to come up with a spatially explicit dataset that describes various dengue and malaria risk levels in the city under various scenarios. Such techniques can be applied to assess other urban problem areas as well.

The case study of Hyderabad also exposed multiple failures at the science-policy interface. The first one is the disagreement of planning time horizons of elected administrators and the one of the climate change process. The science-policy interface in our case also did not take into the consideration the balance of powers on the ground and the fact that it very much relies on the scarcity and exclusivity of spatial information.

Conclusions

We believe that even though a society delegates the tasks of planning and policy making to a limited set of institutions, the controllability of such decisions also depends on the accessibility of information to all members of the society. Therefore, fitness for public participation and wide accessibility of climate assessment tools are just as important part of an adequate impact assessment and efficient climate change adaptation strategy as the availability of specialised solutions.

Web-GIS applications offer the combination of simplicity and power which is difficult to achieve using other methods. They do not require any specific software or extensive setups and are instantly available at a mouse click. The exclusive use of open source technologies in CATHY meant that using and further development by the end users incurs no additional licensing costs – a strong argument given the budgetary constraints of the megacities of the global South.

Climate assessment tools can greatly facilitate achieving more active exchange of information and ideas across multiple stakeholders. The most obvious pathway is the science - decision maker one, which is well addressed through the CATHY-like concept. Nevertheless, the efficiency of this exchange very much depends on the inner motivation of the parties and willingness to exchange, and this is often far from being optimal. Therefore, only the enhancement of climate assessment tools with science - general public and general public - decision maker functionality can multiply the performance of tools and make them invaluable means and objects of communication in urban climate change impact discourse. While the technology is largely there, it the overcoming of administrative and political barriers which is often the limiting factor in successful implementation of climate assessment tools.

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Impacts World 2013, International Conference on Climate Change Effects,
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Empirically calibrating damage functions and considering stochasticity when integrated assessment models are used as decision tools

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Abstract – Benefit-cost integrated assessment models (IAMs), though developed originally for exploratory research, are now being applied as decision-making tools. This application places new demands on model calibration and capabilities. We suggest two directions for increasing the policy applicability of IAMs. First, employ recent work in the impacts community on empirical impact functions, grounded in the observed response of human systems to climate variability, to parameterize and calibrate IAM damage functions. Empirical damage functions can supplement and, in some cases, replace the often-dated damage estimates in IAMs with alternatives that can be directly compared to contemporary observations. Second, explicitly model the interactions between changes in mean climate and stochasticity in natural and human systems (e.g., weather, business cycles). Explicit stochasticity enables consideration of risk aversion with respect to episodic factors, such as extreme weather, thereby providing a natural way to examine the benefits of consumption-smoothing adaptive measures, such as insurance.

Index terms – integrated assessment models, damage functions, Earth system models, weather, stochasticity

1 Introduction

The integrated assessment models (IAMs) used for benefit-cost analysis of climate change impacts and mitigation generally trace their intellectual lineage to Nordhaus (1992) and the first version of the DICE model, presented therein. These models have employed simple functional formulas to relate physical climate changes (most typically indexed by change in global mean temperature) to their economic impacts. Most IAMs either have functional representations of or are calibrated against projections of impacts, at relatively low levels of warming, for a few discrete sectors (e.g., agriculture, energy demand, human health); interactions among these sectors and between regions are often ignored (Warren, 2011; Oppenheimer, 2013). While uncertainty in parameters such as climate sensitivity may be considered, these models generally do not explicitly treat the economic impacts of climate variance or other stochastic factors.

For example, Fig. 1 shows estimates of damages by the sectoral calibration of the damage function used by DICE (Nordhaus, 2007, 2008) and the sectoral damage estimates of FUND (Anthoff and Tol, 2012) and ENVISAGE (Roson and Mensbrugghe, 2012). In DICE and FUND, two models with long lineages of publications, most of the sectoral studies used for calibration date back more than a decade, to a time when the impact research

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community's understanding and ability to model such impacts was significantly less developed than today (see Kopp et al., 2012, for a synopsis). This lag between empirical impact research and its incorporation into IAMs is understandable: from an academic research perspective, many of the fundamental questions models like DICE and FUND were developed to address are conceptual. For example, how does the social cost of carbon change with different assumptions about discounting, equity, or socio-economic and policy scenarios? In this context, tuning or updating damage calibrations to match the latest impacts literature is not a high priority (although improving models to include unimplemented structural effects such as intersectoral interactions or stochasticity might be).

Nevertheless, the quantitative outputs of benefit-cost IAMs are currently being used to inform policy judgments. In the United States, for example, benefit-cost analyses that help set stringency of Federal regulations that reduce carbon dioxide emissions (such as energy efficiency standards and power plant carbon standards) employ estimates of the social cost of carbon derived from these models. The current range of official U.S. social cost of carbon estimates (\$5-\$70/tonne CO_2 emitted in 2013) are derived by averaging across three IAMs – DICE, PAGE (Hope, 2006) and FUND – at three different discount rates (Interagency Working Group on the Social Cost of Carbon, United States Government, 2010; Kopp and Mignone, 2012). In the context of policy analysis, the quantitative calibration of damage estimates matters greatly, as may omitted features of the climate such as stochasticity. In the remainder of this paper, we propose an approach for tackling each of these elements and illustrate their potential quantitative influence.

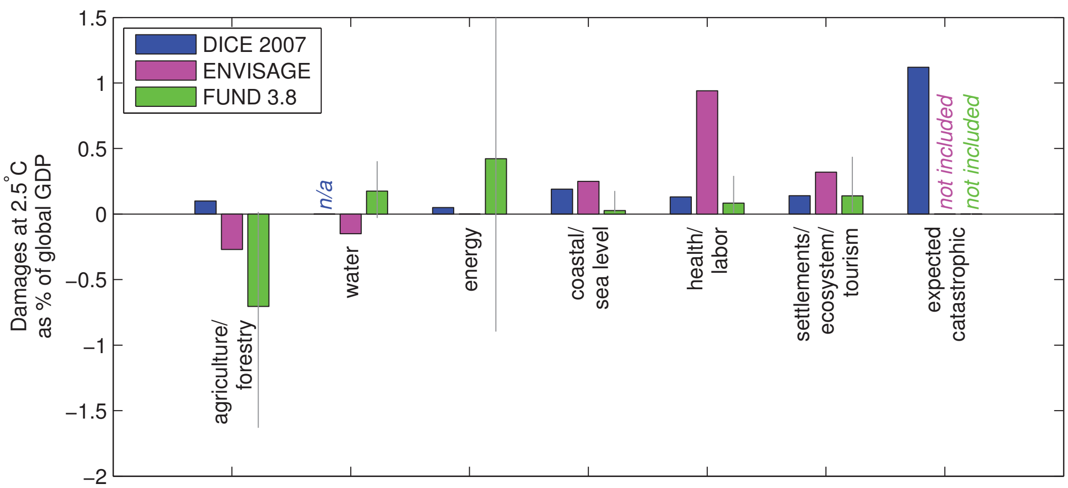

Figure 1: Monetized damage calibration (for DICE 2007) or estimates (for ENVISAGE and FUND 3.8) by sector at 2.5°C, as a percent of global GDP. Error bars for FUND reflect 5th-95th percentiles calculated off the FUND reference scenario. Modified from Kopp and Mignone (2012).

2 Empirical calibration of damage functions

Over the last decade, researchers have developed empirical estimates of climate change impacts based on observed historical relationships between environmental conditions and socioeconomic responses, such as agricultural output (e.g., Schlenker and Roberts, 2009), labor productivity (e.g. Hsiang, 2010), or energy demand (e.g.,

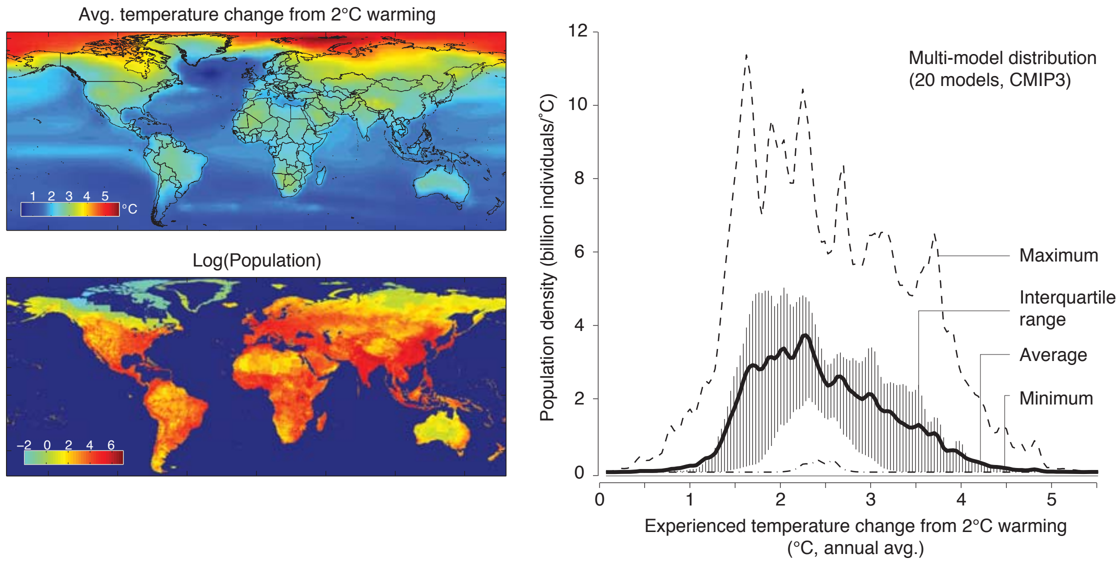

Figure 2: *Upper left:* The global distribution of surface temperature changes associated with 2° warming in global mean temperature, averaged across 20 Earth System Models in CMIP3. *Lower left:* The global distribution of the world population, from the Gridded Population of the World. *Right:* The distribution of temperature changes experienced by individuals, across models.

Auffhammer and Aroonruengsawat, 2011). Unfortunately, integrating empirical results into IAMs is a difficult task, and few authors pursue such integration. Here, we propose a procedure to streamline integration, making it easier for empirical researchers to present their results in a such a way that they are immediately applicable to IAMs. As more empirical studies are converted into IAM-ready format, we suggest developing an online database that will use Bayesian updating to continuously improve sectoral damage functions for use in IAMs. This system will provide a seamless link between the empirical impacts research community and the IAM research community, thereby ensuring that policy decisions made using IAMs are always based on the best-available empirical research.

Essentially, our approach collapses multidimensional output from global earth systems models into those statistics needed to make impact projections using statistical estimates taken from the empirical research community. Using these summary statistics, we can then project a socioeconomic response based on most empirical estimates, and aggregate these results up to the level of analysis used in IAMs. The basic flow is as follows:

1. Use Earth system model output to develop a probabilistic mapping between global mean temperature change and the distribution of social (or economic) exposure to future climatic changes based on the global distribution of primitive units, i.e. number of humans, dollars of economic production, area of agricultural crop lands, etc. (Figure 2).

2. Summarize global unit-level changes in climatic exposure based on the characteristics of units that are essential for estimating their response to climatic changes, such as the income of populations – which might influence their capacity to adapt (Figure 3).

3. Project these distributions of exposure onto empirically derived "dose-response" functions that describe

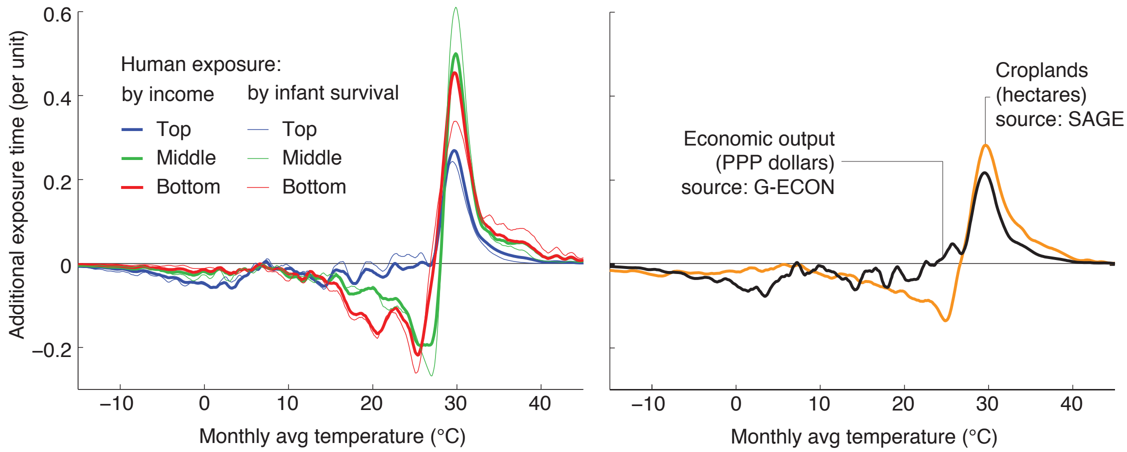

Figure 3: The amount of additional time that a randomly selected unit will be exposed to specified temperatures under 2°C warming in global mean temperature. The global population (left) is stratified into three tiers based on two metrics of vulnerability: income and infant mortality. Also shown is the distribution of economic activity and croplands (right).

how socio-economic sectors respond to a given "dose" of climatic exposure (eg. Figure 4).

4. Aggregate projected impacts, conditional on changes in global mean temperature, up to the unit of analysis used in IAMs (e.g., geographic regions).

5. Compare and, as desired, integrate (via Bayesian statistics) empirical damage estimates with process-model-based estimates, so as to overcome limits of empirical studies (for example, for out-of-sample projection).

6. Propagate impacts through a macroeconomic model, such as a computable general equilibrium (CGE) model, to translate impacts into output or welfare losses and account for compensatory or amplifying interactions between regions and sectors.

7. Integrate impact estimates across projections that use different empirical studies (via Bayesian statistics) to construct a composite damage functions that are updated in real-time and publicly available via server.

To demonstrate the importance of this calibration procedure, we project the predicted change in United States crop exposure onto the temperature response functions in Figure 4 (obtained from Hsiang et al. (2012)). We plot the projected impact of a 2°C global mean warming for all four major crops in Figure 5, along with the average response (weighted by area-planted). When we compare these responses to comparable "agricultural damage functions" used in three modern IAMs, we note that these empirical estimates suggest agricultural losses under 2°C warming will be roughly an order of magnitude larger in magnitude than the IAM functions predict. This large discrepancy indicates that systematic calibration of IAM damage functions is badly needed.

To illustrate the generalizability of our proposed calibration procedure, we demonstrate that it can easily link a "new" damage function to impacts aggregated across regions used in IAMs. In Figure 6 (upper left panel) we illustrate an empirical estimate for the loss of labor productivity observed at high temperatures Hsiang (2010).

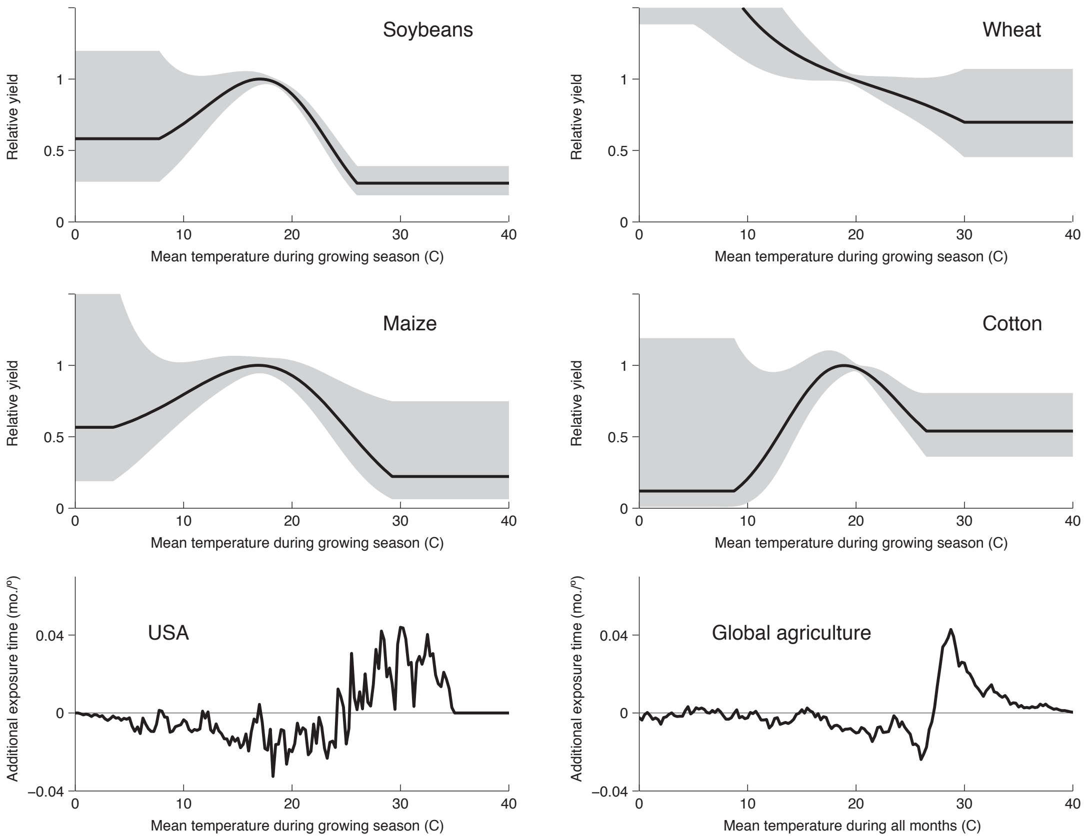

Figure 4: *Top four panels:* Empirically-derived responses of four major crops to growing season temperature in United States counties, from Hsiang et al. (2012). The estimates are based upon comparison of county-level output to county-level average growing season temperature and rainfall (1950-2010). County-level yields is modeled as a polynomial response to temperature and rainfall, accounting for unobserved differences between counties and secular trends. Outside the limits of the temperature data, we conservatively assume constant yields. *Lower panels:* The additional amount of time that croplands in the United States and the world will be exposed to these temperatures under 2°C warming in global mean temperature.

Mapping this response function onto the distribution of human exposure to temperature (lower left panel) allows us to estimate region-specific impacts (right panel) based on the regions utilized in FUND.

As parametrizations of adaptation are developed in the empirical literature, these damage function calibrations can be adjusted accordingly.

3 The role of stochasticity

Many natural and human systems are stochastic. For example, weather is the manifestation of variance around climatological means; business cycles are manifestations of variance around long-term economic growth. Although climate damages are often partially realized through shifts in climatological extremes, IAMs have generally not explicitly included year-to-year variability. IAM welfare analysis therefore implicitly assumes perfectly-functioning markets and institutions capable of spreading risk over time and thus allowing the welfare impact of

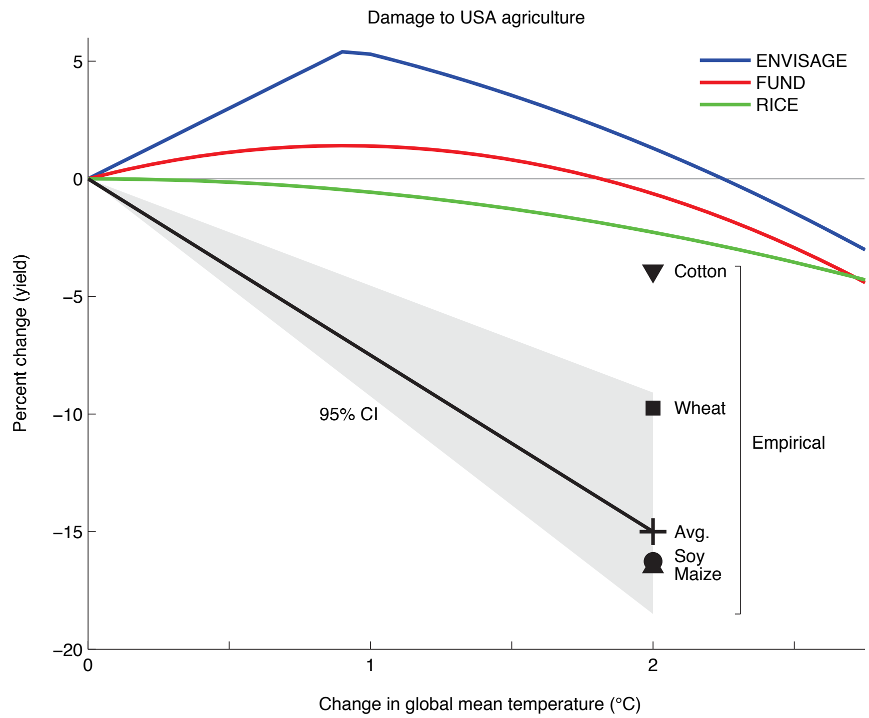

Figure 5: Black: Projected changes in yields using response functions in Figure 4 and the projected exposure of USA croplands. Average changes are averaged by cropland planted in a given crop. The shaded region is the 95% confidence intervals for the average effect across crops Comparable damage functions (in yield terms for ENVISAGE and FUND and monetized terms for RICE) from ENVISAGE, FUND and RICE are colored.

average damages to be a good substitute for the welfare impact of a sequence of actual loss realizations (which vary around this average). Without such markets or institutions, however, the absence of inter-annual variability likely leads to an underestimate of future welfare losses.

The importance of stochasticity is clearly illustrated by the example of sea level change. Most damage due to sea level rise is not due to the permanent inundation of land but to enhanced episodic flooding. Local sea surface height is the sum of long-term anthropogenic and natural trends, multi-year ocean dynamic variability, periodic tidal signals, and storm surges. The ˜20 cm of climatically-driven twentieth-century sea level rise led to acute impacts for fifty thousand additional residents of New York City when the city was hit by Superstorm Sandy (Climate Central, 2013); this impact was exacerbated because the storm surge occurred in superposition with pre-existing sea level rise (as well as high tide). IAMs, as they are currently structured, do not capture these kinds of acute impacts and instead would model the impact of a cyclone-induced surge as a small increase in average sea level spread across many years.

Natural system stochasticity is not limited to sea level and flooding; it is ubiquitous and affects most climate change impacts. As another example, consider corn yields. Employing the impact function of Schlenker and Roberts (2009) to daily temperatures from Topeka, Kansas, USA (National Climate Data Center, 2013), we find that corn yield over the interval 1973-1998 should have varied between 60% and 110% of its expected value due to the effects of temperature alone (Fig. 7). The return interval of a 20% loss event (i.e., yield of 80% of its expected value) was about 20 years. In Figs. 8 and 9 we examine the projected effect of warming on expected crop

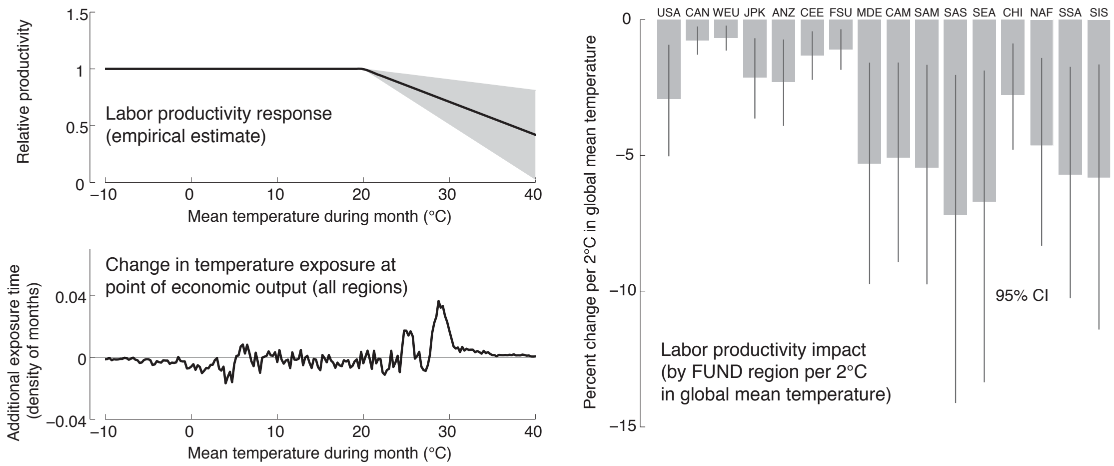

Figure 6: *Top left:* Empirical estimate of the response of labor productivity to temperature exposure with 95% confidence interval (gray) (Hsiang, 2010). The estimate is based upon analysis of the influence of annual, monthly and daily temperature variations on overall economic output (GDP) in 28 countries in the Caribbean and Central America (1970-2006) using panel data disaggregated by industry, and accounting for precipitation, hurricane exposure, unobserved constant differences between countries, secular trends and autocorrelation. *Lower left:* the projected change in temperature exposure of the global population (across all regions) under 2°C warming in global mean temperature. *Right:* the corresponding loss in labor productivity, broken down according to FUND region.

yield, the 5th-95th percentiles of crop yield, and the return intervals of crop loss events. With 1°C of warming, the return interval of a 20% loss event drops to 12 years; with 2°C of warming, to 7 years; and with 4°C of warming, it drops to 1.2 years. Estimates of welfare losses and effective adaptive measures must both take into account the increasing frequency of exceptionally low harvest years and the strain they exert on insurance and safety networks, not just the change in expected agricultural yield. With 1°C of warming, the increased frequency of the 20% loss event, not the minor drop in expected yields, may drive welfare impacts; in their present form, most IAMs can deal only with the latter, not the former.

IAMs could incorporate regional climatological variability into Monte Carlo simulations, employing as a first estimate historical estimates of variance, much as we have in this example. Earth system model estimates of changes in variance could refine this approach. Economic stochasticity has already been incorporated in some studies through the use of dynamic stochastic general equilibrium models (e.g., Gerst et al., 2013). We expect that interactions between economic variability and weather that would emerge from the inclusion of these factors would act in some cases as a dampening factor and in some cases as an amplifying factor to climate damages.

4 Conclusions and next steps

For benefit-cost IAMs to be suitable for real-world policy analysis, their damage estimates need to reflect the available impact literature. It is unreasonable to expect a handful of small research groups, motivated primarily by the pursuit of research questions of academic economics interest, to manage this task on their own. Com-

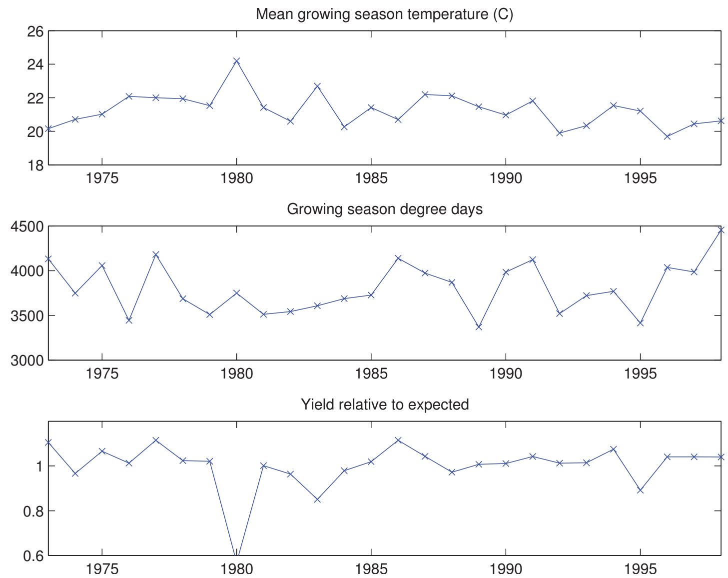

Figure 7: Mean growing season temperature, growing season degree days, and corn yield relative to expected corn yield calculated using the empirical impact function of Schlenker and Roberts (2009) for Topeka, Kansas, 1973-1998. (Data from National Climate Data Center (2013).)

munity infrastructure could therefore make a critical contribution. We propose a procedure for developing this infrastructure, so that empirical researchers will be able to easily "upload" their results so that they can be immediately and automatically integrated (in a Bayesian fashion) into subsequent IAMs.

We also note that no existing IAM takes into account natural climatic stochasticity (weather), but whether impacts are distributed smoothly through time or concentrated in extreme events will significantly affect both the nature of suitable adaptation mechanisms and, in the absence of perfect safety nets, the nature of the associated welfare impacts. An IAM drawing upon gridded estimates of climate variability would provide a more realistic picture for many categories of impacts.

Acknowledgements

REK was supported by a grant from the U.S. Department of Energy and the U.S. Climate Change Technology Program.

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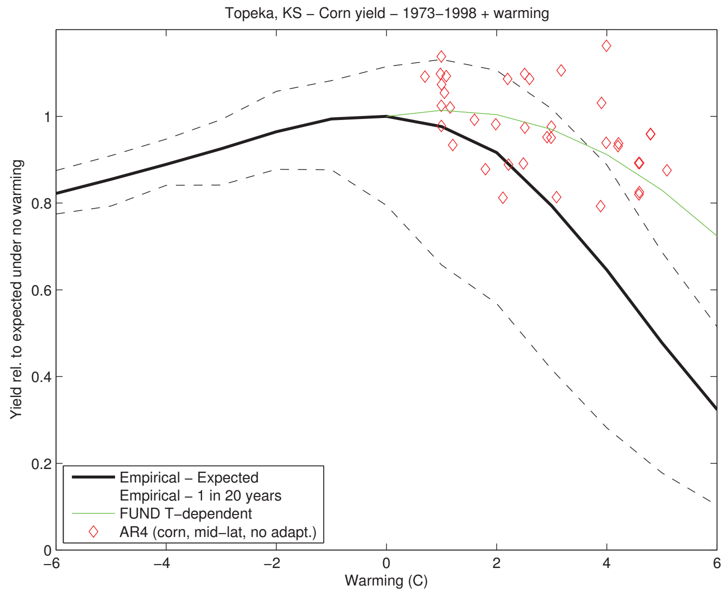

Figure 8: Expected crop yield (heavy black curve) and 5th and 95th percentiles of crop yield (dashed lines) for Topeka, Kansas, using daily temperatures from 1980-2012 incremented by different levels of warming. For comparison, crop yields from the models summarized in IPCC AR4 for mid-latitudes and no adaptation (Easterling et al., 2007) are indicated by the red diamonds and the temperature-dependent term of U.S. agricultural product change from FUND 3.6 is shown in green Anthoff and Tol (2012).

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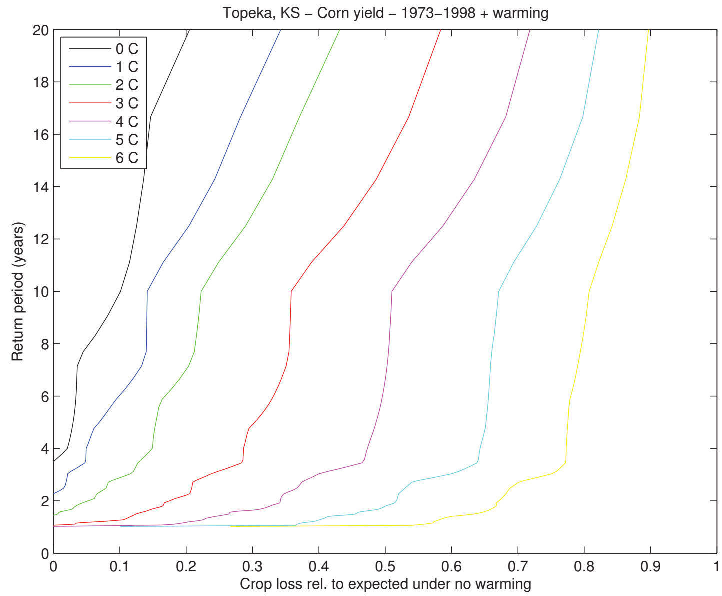

Figure 9: Return periods of corn crop loss events with different levels of warming.

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Surpassing Cognitive Barriers of Climate Communication: from citizen to policy maker

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Abstract

Individual decision making should matter for the design of climate policy. Especially responses to uncertainty will determine whether one can gain support for climate policy. Communication of its magnificence is vital to garner just this. This paper addresses the individual mind, focusing on similar cognitive barriers of both the citizen and the policy maker. Using the existing literature on behavioural decision making, two cognitive barriers that seem to get in the way of desired climate policy are highlighted: positive illusion and interpreting behaviour in a self-serving manner. For human beings, positive illusions serve as a necessary buffer in dealing with negative information about potentially disastrous future developments. In the context of climate change unrealistic optimism and the illusion of control stand in the way of climate policy. With regard to the second behavioural feature, it is in human nature to behave in a self-interested manner, more so when facing limited resources. Climate policies should be communicated in a way that does not instill such perceptions. For example, climate policies are designed to go into effect well into the future but inflict unwanted immediate self-anxieties that end up blocking such imperative policies unnecessarily. Thus communication which pays attention to words used influences expectations and information processed cognitively by a person.

The paper ends with solutions and tentative proposals on steering such biases so as to foster effective policy. Key questions from the behavioural decision making perspective are elaborated along with its contribution and important implications to the ever evolving trans-disciplinary framework in tackling barriers towards climate policies.

Keywords: Behaviour, Consensus, Climate Change, Decisions

1 Introduction

Climate change presents a novel psychological dilemma to humanity, for various reasons having to do with high levels of uncertainty that is spread out in time and space. The timing for negotiating an international climate agreement is limited while the required steps necessary for adopting appropriate climate policies are in a crucial stage.

If the assumption is that humans are rational beings, effective climate policies would already be in place on the regional, national and international level. But international climate talks have failed to reach a clear consensus. The question is why? It is essential to understand behavior and cognitive perception in relation to interpretations of and negotiations for climate change. It is a new, unique phenomenon, making it difficult for our minds to comprehend, partly because we have the tendency to not respond to it in a rational manner.

2 The role of the individual mind

Climate policy represents a complex issue that affects all regions of the world with a multi-level agreement needed across all geographical areas. It is thus important to communicate the magnitude and levels of uncertainty whilst taking into account psychological or more precisely cognitive barriers that are present in the human mind, be it of a policy maker or the wider public. Cognitive barriers in this paper are defined as heuristics used by people to simplify strategies when making choices or judgments often leading to systematic and predictable mistakes (Shu and Bazerman, 2010, Tversky and Kahneman, 1974).

The basis of behavioural decision making lies in its recognition that it is on the individual level of human-caused climate change that it can have potential influence (Clayton and Brook, 2005). Part of the problem is inadequate dissemination of information between science, policy makers and citizens (Carvalho, 2007; Johnson and Levin, 2009) Behavioural literature has robust empirical evidence to understand cognitive limitations and to a lesser extent how to surpass these limitations when designing and communicating climate policy.

2.1 Tragedy of the commons or cognition?

It is known that when a group of people share a common limited pool of resources they often act independently based on own self-interest, as a result of which they deplete the shared resources even though it is no one’s intention to do so (Hardin, 1968). It is useful to understand how this behavior arises in the first place, through the concept of cognitive limitations that drives us to behave in ways that are sometimes unintentional and is often boundedly irrational on the collective level. In terms of climate change, why are we still behaving the way we do despite knowing our actions have detrimental repercussions for the biosphere, ourselves and coming generations?

Our ancestors developed systematic biases and heuristics in daily judgments and decision making to aid basic survival choices. These biases and heuristics are *simplified* versions of cognitive processes such as guesses or assumptions that have been used before to ease decision making. However, in today's world of technology, industrial power and media, these psychological biases can lead to disasters on a large scale (Johnson and Levin, 2009). These psychological biases are inherent in the human brain and have been confirmed through experimental and economic research (Simon, 1955. Tversky and Kahneman, 1974, 1979, Camerer, Loewenstein, Rabin, 2004).

These heuristics and biases at one time served as evolutionary survival tools and reproduction needs. However, today they serve as the unnecessary immediate gratification desired at the expense of a long term projected goal, which is typical in human behaviour. This sheds light to a person's response climate policies which incurs short term costs and long term benefits.

This paper highlights two well researched cognitive limitations that seem to get in the way of misinterpreting and repelling climate policy, namely positive illusion and behaving in a self-serving manner. This is followed by recommendations on how to steer these biases towards effective policy.

2.2.1. Positive illusion

People view themselves, the world and the future in a considerably more positive way than is objective (Taylor and Lobel, 1989). Positive illusions are used to enhance and protect self-esteem, re-assert personal control in a given circumstance as well as heighten optimism about the future. Furthermore, heightened perception in threat causes increased use of positive illusions in efforts to restore or enhance such perceptions of oneself (Taylor and Lobel, 1989). For example, people generally expect one´s own future to be better than others and also are more optimistic about their future job prospects or even being featured in a newspaper. Furthermore, , studies on heart patients, cancer patients and people living with AIDS (Taylor et al 1991) show that they believed they were coping physically better than patients like themselves (self-enhancement). As climate change is seen as a negative event both to mental and physical health (APA, 2009) positive illusion can explain how people distort the truth to obtain something that does not seem threatening anymore.

Another factor essential to the inattention for climate change is perceived control over uncontrollable events. For example, AIDS patients typically exert they have control over their daily lives such as how to dress or decide about daily events. Or experienced dice players believe 'soft' throws influences the dice to roll lower numbers (Langer 1975). Additionally, positive illusions are more likely in situations of ambiguity, lack of feedback and threat. This is a perfect recipe for disaster in the setting of climate change as it represents a phenomenon that is negative, uncertain and to a certain extent, uncontrollable. As a result, unrealistic illusion will be generated by the mind and can explain certain inaction of climate issues.

The inaction of the US government under George W. Bush, one of the most influential climate skeptics, can perhaps be understood along these lines. The United States is likely to be altered by the effects of climate change with the oceanfront land of Florida becoming uninhabitable but has still failed to respond with controlling or reducing the country's heavy reliance on fossil fuels. The most threatened groups are the auto manufacturers, oil and gas companies and officials closely tied to these industries; they are the quickest to develop positive illusions (Johnson and Levin, 2009). Taylor and Lobel (1989) characterize these as efforts to reduce perceived threat with unrealistic optimism and control. Among the positive illusion used is the unrealistic optimistic belief that variances in climate change will be far less significant than the scientific community predicted. Further, the costs of prevention and abatement are amplified by politicians and industries that will be mostly affected by them.

2.2.2. Interpreting behavior in a self-serving manner

Creating climate policy in any nation or at an intergovernmental level typically depends on the benefits of reducing greenhouse emissions compared to the costs of doing so. Scrutinising how people behave in economic decision making is insightful, especially in circumstances with high uncertainty. Looking at previous climate talks, such as the Copenhagen conference, shows how different parties have varied assessments of an agreement. Emerging countries such as India and China blame the West for their past excessive consumption. Germany and much of the European Union is leading the way in effective climate policies. However, the U.S. government failed to contribute to such an agreement in turn blaming India and China for accepting little responsibility. These disagreements can partly be understood through the self-serving bias; to decide what is fair based on what benefits oneself.

Psychologists have provided robust evidence on the self-serving bias. The self-serving bias is illustrated by the fact that more than half of survey respondents typically rate themselves in an above average category regarding desirable skills, such as ethics, productivity and health (Weinstein, 1980). This bias is also generalized to a group they are affiliated with. For instance, an early study by Hastorf and Cantril (1954) carried out an experiment with students from Princeton and Dartmouth watching a football game between their two teams. The results showed how Princeton students saw Darthmouth commit twice as many fouls than their own team. It was as if the two groups of students "saw a different game". How then will individuals react to a dilemma such as climate issues and policy where interests are often different?

International climate negotiations have usually ended with deadlocks towards a consensus for a common climate framework. Moreover, the problem is worsened due to an inability to view information objectively which is not a deliberate aspiration to be unfair (Shu and Bazerman, 2010). Discerning the self-serving bias is vital in overcoming such impasse.

3 Surpassing Cognitive Barriers

It is illustrated how we have cognitive biases that strongly prevent decisions and reactions towards climate policy. Unfortunately, scant research is available on steering such biases towards positive reception of climate policies. There are few novel studies that lay steps towards the way forward.

3.1 Diminishing positive illusion

As illustrated earlier, positive illusion though vital in protecting one´s self esteem and sense of control can be detrimental when it comes to climate decision. Fortunately, positive illusion is seen to diminish when one has personally lived through a natural disaster. An example of this is seen clearly in the city of New York where climate skepticism is high. A poll published last year by Siena College in New York indicated that sixty-nine percent of New Yorkers attributed Hurricane Sandy to climate change, the highest jump in statistics than any of the preceding years (Kaplan, 2012). This suggests that positive illusions can be abandoned when personal real life disasters happen. For instance, scrutinizing the success of the Montreal Protocol which dealt with the issue of ozone depletion versus the Kyoto Protocol can shed light on communicating, designing and implementing climate policies (Kaul et al, 1999).

3.2 Reducing Self-Interests

Although the self-serving bias is a complex phenomenon, several experiments have been carried out on reducing self-serving behavior. When subjects were offered chocolates that cost 10 cents, 5 cents, 1 cent or free, findings indicated surprisingly that the number of chocolates that were taken reduced by 50 % even though it was free (Ariely, 2009). This finding suggests that when monetary value is taken out of the equation, social norms take over, hence the concern for others not being able to have a free chocolate. An assumption can be made in regards to the Cap and Trade system in the Carbon Market. Ariely (2009) states that allowing carbon tokens to be bought could indicate that they can go ahead and pollute more if they are able to afford it thus decreasing any existing social norms.

3.3 Designing choices and other biases

There are a number of other cognitive biases that have significant influence in our decisions but due to the scope of the paper shall be mentioned briefly. Among them are loss aversion, people generally dislike loosing than an equal sized gain (Kahneman and Tversky, 1979). Another is high future discounts, meaning people prefer immediate benefits compared to future ones (Ariely, 2009) which was mentioned in the opening paragraph of this paper. These biases will be discussed in the following chapter when designing climate policy.

The option of using ´choice architecture´ to avoid/employ systematic pitfalls in our decisions is promising (Thaler and Sustein, 2008). An example is utilizing human tendency to stick to the status quo. Johnson and Goldstein (2003) demonstrated the power of defaults in their investigation of organ donation behavior in the European Union. Countries with opt out policies showed an effective rate of 85.9% - 99.98% consent rate compare to opt in policies with 4.25 to 27.5%. Perhaps greener options could be set as the norm taking advantage of human behavior to avoid decisions and stick to default options. As for human tendency to avoid losses and highly discount the future, policy can be designed to portray gains more than losses while slightly delaying its implementation. This gives time for the public to accept such policies and adjust to the new status quo as it doesn’t inflict immediate sacrifice (Shu and Bazerman, 2010).

4 Conclusion

In a nutshell, an agreement to prevent no more than a 2 degree global temperature rise requires immediate climate action. The complexity of communicating a phenomenon that is non-visible but scientific and global in nature incurs certain cognitive barriers that produce environmentally destructive behaviours. These cognitive processes were evolutionary developed to aid decision making in circumstances different than global public goods. As it is present in all of us, be it a policy maker or a citizen, identifying and addressing these biases when designing climate policy will provide effective recommendations for researches, decision makers and the wider community.

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Co-designing Usable Knowledge with Stakeholders and Fostering Ownership – A Pathway through the communication problem?

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Abstract—Climate change and air pollution both have impacts across a wide range of sectors. While it is fundamental to communicate scientific findings as basis for decision making to a variety of stakeholders, it is difficult to establish long-lasting, multi-way communication and mutual learning between all parties.
Here, we report first lessons learnt from collaborative work with NGOs within the science-based "Short-Lived Climate-forcing Pollutants: Research Needs and Pathways to Policy Implementation" project (ClimPol). With ClimPol, we try to effectively utilize science through transdisciplinary work for the development of sustainable solutions that integrate climate change and air pollution mitigation. The inclusive approach of co-designing knowledge encourages all parties to take ownership in the process and solutions and thus to be more likely to act on the problem, both at their systemic, policy-driven level, and at the individual level by collectively supporting the associated structural and lifestyle developments.

Index Terms—co-production of knowledge, mutual learning, Short-Lived Climate-forcing Pollutants, transdisciplinary research

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1 Introduction

Ideally, sound climate impact science and its results form the basis for the local, regional and global contexts of policy, governance, technological and socio-economic development. Also, they ideally facilitate the implementation of climate change mitigation and adaptation measures. However, even when sufficient knowledge for decisions has been created, widely communicated and even accepted, concerted global palliative action has proven to be difficult (e.g., Esty and Moffa 2012). While many challenges have been recognized and debated, only recently have information and knowledge transfer methodologies between climate science, decision-makers, and society become an integral part in this field (e.g., Hessels and van Lente 2008, Tàbara and Chabay 2012, Cash et al. 2003, Lemos and Morehouse 2005, Dilling and Lemos 2011).

Much of science, including climate impact studies, still is conducted in the "mode 1" production of knowledge as described by Gibbons et al. (1994). In this mode, research happens in a highly academic context among disciplinary experts. Knowledge is delivered to a wider audience unidirectionally *after* the production of results, rather than incorporating stakeholders in the knowledge generation process from the beginning (e.g., Roux et al. 2006). This linear model of knowledge transfer has only limited success in bridging the gap between science, policy and society (Reid et al. 2009, McNie 2007).

Humanity faces unprecedented challenges in the Anthropocene, for example hitting the "planetary boundaries" in light of accelerated global change (Rockström et al. 2009, Crutzen 2002, IGBP 2010). Highly integrated responses are needed to address these challenges, while traditional science often delivers meticulously separated information instead (Roux et al. 2006, Tàbara and Chabay 2012). In many instances there are sufficient incentives and knowledge to act, yet there is an obvious divide between the available knowledge and actual actions (Tàbara and Chabay 2012, Cash et al. 2003, McNie 2007).

Approaches to bridging the gap include "mode 2" science, transdisciplinary research, the continuous engagement model, and the co-generation of usable knowledge (Gibbons et al. 1994, Hessels and van Lente 2008, Hirsch Hadorn et al. 2006, Dilling and Lemos 2011, Roux et al. 2006, Tàbara and Chabay 2012, KLSC 2011, Reid et al. 2009). All these aim at jointly engaging stakeholders and scientists throughout the process of knowledge generation. The collaborative effort ensures that all parties gain ownership in the solution and are thus more likely to make use of it (Hirsch Hadorn et al. 2008, Wiesmann et al. 2008).

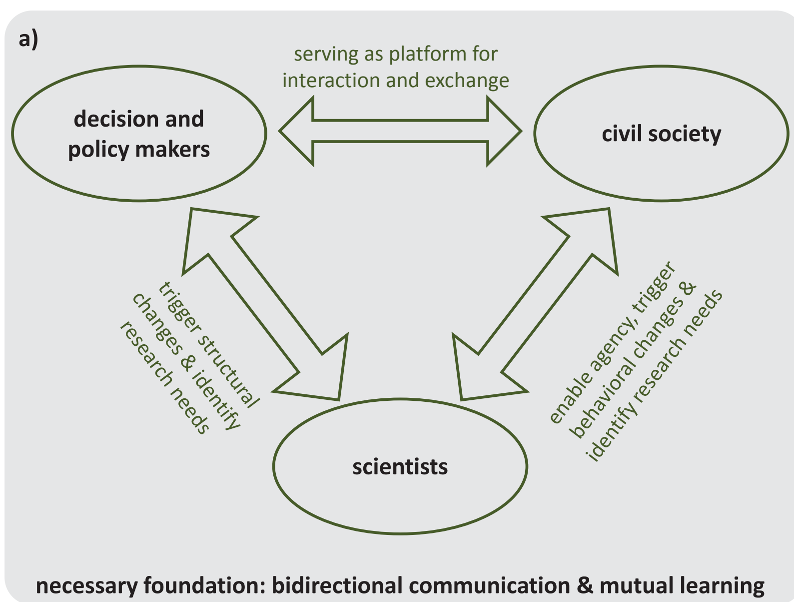
Here we present initial results of transdisciplinary research in the "Short-Lived Climate-forcing Pollutants: Research Needs and Pathways to Policy Implementation" (ClimPol) project. "Transdisciplinary" is used here to denote a collaborative research process between scientists and partners from non-scientific stakeholder communities. The main objective of this project is the co-generation of solution-oriented knowledge in collaboration with stakeholders. The focus is placed on short-lived climate-forcing pollutants (SLCPs, such as ozone, methane and particulate matter - including black carbon) with the overall objective of finding integrated solutions to the air pollution and climate change mitigation challenges. This is put into practice, for example, through joint project groups including civil servants and scientists, and close collaborations with NGOs through joint workshop and conference organization.

We stress that for the purpose of slowing global warming, there are substantial differences between mitigating SLCPs or CO_2. While CO_2 has climatic effects lasting centuries, SLCPs have short atmospheric lifetimes, and thus could result in a rapid reduction of global warming, by an estimated 0.6 (0.2-0.8) °C within decades (UNEP 2011, WMO 2011, WHO 2012, Shindell et al. 2012). They also exert immediate, direct local effects across a variety of sectors, such as public health and food security. Hence, mitigating SLCPs and CO_2 is complementary, leading to short-term improvements and long-term mitigation. The ClimPol approach works on integrated solutions for both air quality and climate change, focusing especially on SLCPs which have been so far largely neglected compared to CO_2.

1.1 The ClimPol project

The ClimPol project is intended to span the boundaries between science, policy, and society to facilitate mutual knowledge transfer triggering policy implementation (science → stakeholders) and the identification of user-oriented research needs (stakeholders → science). The science-policy interface is needed to incorporate larger policy and structural change, because long-lasting air pollution and climate change mitigation measures depend on systemic changes and adapted infrastructure, rather than exclusively implementing new technologies. The science-society bridge aims at creating knowledge for society in a way that it ultimately leads to agency and changes in individual behavior supporting societal change and sustainable development at large (see Fig.1 a).

The project's multi-level network and the influences of the network on the project are illustrated in Fig. 1b. Contacts from global to local levels were established because climate change and, to certain extent, air pollution mitigation strategies require coherent approaches across scales and levels. Between all levels, information is continuously exchanged and lessons learned are integrated through methodological adaptation. The globally oriented network ensures the involvement in up-to-date global action and science, feedback and peer-review from scientists and non-scientist partners for the improvement of the project's methodology, and attracts global capacity to be applied at local scales. At the regional (EU) and national (Germany) scale, contacts share networks and create spaces for information exchange and dialogues for facilitating the joint development of policy-supporting science. Locally, on-the-ground transdisciplinary development of mitigation measures is the focus.



b)

Level	Network	Purpose
global	global political coalition, interdisciplinary global working group, international science programs, universities	be involved in global action and science, receiving feedback and peer-review to improve the science and methodology of the project, integrate cross-discplinary perspectives
regional / national	NGOs, agencies, policy makers	share networks, create open fora for conferences and workshops, establish continuous dialogues, jointly develop policy-supporting science
local	cities, NGOs, colleagues, agencies, ministries	as for regional/national, integrate cross-disciplinary perspectives for regional, national, and case-specific development of implementation measures

Fig. 1: a) Main stakeholder communities involved in the ClimPol project, modes and directions of communication, including the main purposes. b) Sketch of the project's multi-level network and its influences on the project.

1.2 Knowledge transfer: Delivering or co-designing knowledge?

As discussed earlier, unidirectional knowledge transfer has proven to be generally unsuccessful (McNie 2007, Cash et al. 2003). The disciplinary channels of traditional science have been very successful in their own right (Aumen and Havens 1997), but lose effectiveness for implementation when they separate inherently coupled components of highly complex issues. Further, scientific information is often detached from the non-scientific knowledge systems of stakeholders (Tàbara and Chabay 2012, Roux et al. 2006). This is compounded by the poor discrimination between explicit information and tacit knowledge. In this context, it is helpful to distinguish between information and knowledge: Information is purpose-oriented, explicit, organized data which is easily transferred to others (Roux et al. 2006), while knowledge provides a framework to evaluate and incorporate new experiences based on prior experiences, values, contextual information and intuition (Davenport et al. 1997). Knowledge thus gives people their capacity for action. A significant part of knowledge exists in tacit form (Roux et al. 2006).

To address these challenges, within ClimPol we are creating new forms of knowledge, rather than deepening disciplinary knowledge. To do so, we are applying a selection of ideas stemming from practices of transdisciplinary research (Hirsch Hadorn et al. 2008), "mutual learning" in which all partners are engaged in a process of learning with and from each other (Feldman and Ingram 2009, KLSC 2011) and the "co-generation of solution-oriented knowledge" (Lemos and Morehouse 2005, Dilling and Lemos 2011) in order to help establish communities of practice (Wenger et al. 2002).

Through the process of combining the complementary knowledge systems among the partners, a common “boundary object” is created in which all parties have ownership, enhancing the salience, credibility and legitimacy of the co-designed knowledge.

2 First experiences from the ClimPol project

In the following, we will concentrate on lessons learned from the collaborations with NGOs within the first ten months of ClimPol.

Fig. 2 schematically illustrates the stages of the collaborative process between NGOs and ClimPol. In our experience, joint efforts cannot be forced, but emerge from an instance where common interests and goals are shared (“hook” in Fig. 2). Furthermore, it is important to keep in mind that the joint efforts themselves (e.g., conferences, workshops, flyers, position papers, etc.) are not the key goal, but instead a means or tool to achieving the common goals – or better yet, of co-developing common goals and approaches. Consequently, communicating and learning about the partner’s operational context is crucial to develop mutual understanding (“mutual learning” in Fig. 2). After initial trust has been built and common objectives specified, joint action can be undertaken. In our case, this was a national conference for policy-makers and civil society. In the planning and preparation process, willingness to engage continuously in mutual learning is necessary, including developing a shared working vocabulary. For example, certain statements might appear either very “unscientific” or very “ineffective” to some partners and lead to barriers to communication. Such cases were addressed by iterative framing of the issues until everyone agreed, while always respecting the partners’ key competences. In this specific case, the co-designed knowledge included scientific information on characteristics of SLCPs and the knowledge on how to feature them in a policy relevant context with appropriate language. In addition, knowledge on how to create interest among policy makers, civil society and industry representatives and scientists were combined, leading to a highly diverse conference audience with high potential for outreach. The knowledge on how to create interest among the diverse groups was shared in conversations in which each partner pointed out the driving questions and key perspectives. These points were reflected in the conference program through the choice of topics and speakers as well as in the background information document. This in turn made the conference more attractive for the various stakeholders. All partners openly shared their skills and channels of communication and networks for the organization of the conference and thereafter. The conference was successful in various ways; good attendance and high interest, and the conference created multiple hooks leading to follow-up actions (a-c in Fig. 2). It was decided that the conference will be repeated on European level, meaning that the collaboration will be carried on with additional partners while first experiences will be re-evaluated and joint actions improved (a). A variety of smaller projects emerged, strengthening the collaboration (b) while stakeholder communities had the chance to get to know each other at the event and started networking (c). A crucial factor, significantly supporting the interactions between NGOs and policy makers, was the neutral, science-based platform that the ClimPol project and the institution behind it represented. Results of this enhanced networking are invitations to support the work of other stakeholder communities as advisory board members, lecturers, event-partners etc.

At this stage, it is too early to evaluate whether this will lead to the establishment of a community of practice around joint measures for air pollution and climate change mitigation as such and climate change impacts. However, it is already evident that networks are merging, and more informal and more regular exchange between scientists, NGOs and policy makers is happening. Key lessons learned from a natural scientist's perspective of this process are:

- Humility is important to build trust and credibility.
- Willingness to share information at all stages is indispensable.
- Tacit knowledge becomes more accessible throughout the process of co-designing knowledge.
- Personal meetings, networking and sharing common experiences are important. Such processes take time and are highly dependent on the dedication of individuals.
- A primary reward is the development of long-lasting, transdisciplinary, professional relationships that grow and become more informal with time leading to short and effective communication channels.

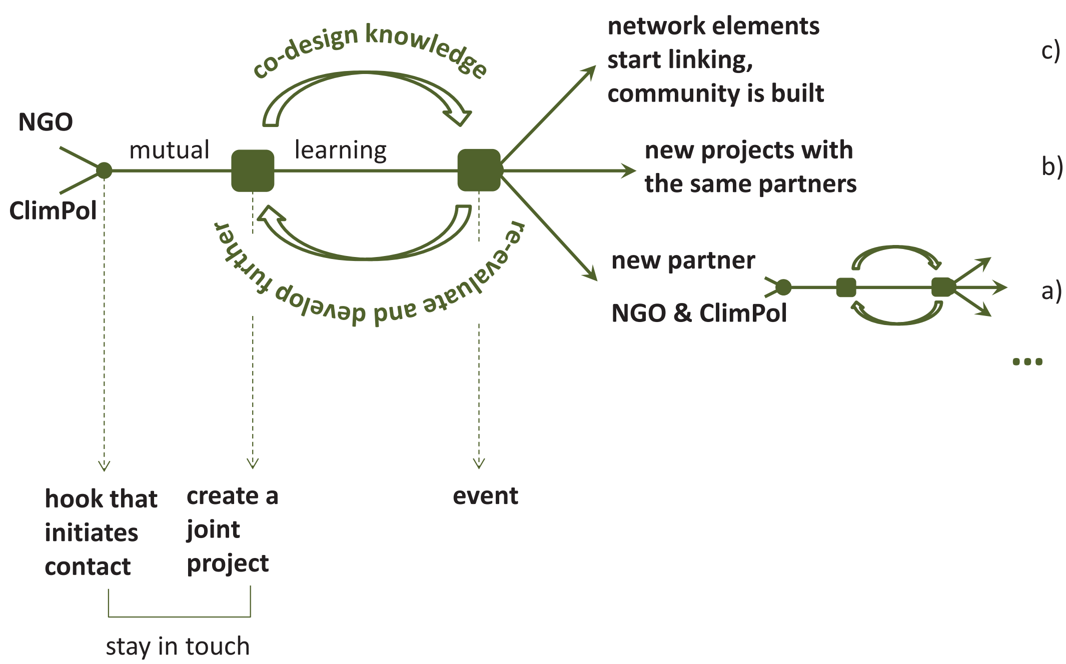


Fig. 2: Stages of collaborative actions between ClimPol and NGOs

3 Conclusions

In ClimPol, we are utilizing science through transdisciplinary work for the effective development of sustainable solutions that integrate climate change and air pollution mitigation. In our experience, SLCPs have proven as effective entry point for collaborations with stakeholders due to their immediate, direct and local effects across a multitude of sectors, making the climate change issue and its connection to other sectors much more tangible. Here, we reported on the first lessons learned from joint efforts with NGOs, one of the various project partners.

The willingness to engage in mutual learning proved to be essential in the initial phase to establish a sound basis for a long-lasting collaboration. Combining the different knowledge systems throughout the process led to co-designed knowledge in explicit and tacit form, as all collaborators were able to produce more purpose-tailored information, as well as operate comfortably and successfully in the various environments. Trust, credibility and dedication resulted in a first successful event which in turn triggered a variety of processes leading to enhanced networks, a higher degree of interconnectedness and shorter and more informal communication channels. This experience shows that the concept of co-designing knowledge can bridge the knowledge-action gap.

Such efforts, however, in the scientific context at least, rely on institutional support that values highly the solution oriented transfer of knowledge. The main priority in this case is not traditional scientific output, such as peer-reviewed papers, but the creation of long-lasting multi-way communication channels leading to policy development and supporting societal behavior changes.

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Impacts World 2013, International Conference on Climate Change Effects,
Potsdam, May 27-30

Collaborating for assessing the vulnerability to climate change in Germany – a network of science and public authorities

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Abstract— Within the frame of the German Adaptation Strategy the undertaking 'Network Vulnerability' aims at assessing the vulnerability of Germany to climate change from a national perspective. The project was deliberately framed in a way that the challenges of such an undertaking are tackled by the involvement of stakeholders (from science and public authorities) elaborating mutual and pragmatic agreements instead of using sophisticated "black box" approaches. Within the scope of this project a network of scientists and federal agencies ensures cooperation between research and decision-making realms from the start by creating a dialogue: The development of assessment and aggregation methodologies is first proposed by scientists and then discussed and agreed by the agencies. In return, the network of policy–oriented partners supports the scientists in focusing on most relevant aspects and thus reducing the work load.

Index Terms— integrated vulnerability assessment, science-policy interface, stakeholder network for decision support.

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1 Introduction – the German approach to adapt to climate change

The German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie – DAS, December 2008) sets the frame for Germany's national adaptation process. The DAS is designed as a stepwise process with the formulation of the strategy as such as first step. The second step, the Adaptation Action Plan (APA)(BMU 2012), was completed in 2011 and will be followed by the progress report in 2014. The German Environment Agency supports the German Ministry of Environment in further developing the strategy. A number of projects addressing the generation or updating of knowledge about climate change impacts, related vulnerabilities and suitable adaptation options have been initiated. These initiatives are designed in a way to support the flow of information between science, practitioners and policy by enhancing dialogues and participation, and to create networks among actors.

One of these initiatives is the 'Netzwerk Vulnerabilität', a network of 16 federal governmental agencies from 9 different federal ministries and 4 research institutions that started in 2011 and aims at assessing the vulnerability of Germany to climate change form a national perspective. It's goal is a comprehensive, Germany-wide, cross-sectorial vulnerability assessment. The sectors – such as water, human health, biodiversity, transport and others – are pre-defined by the DAS. The work of the 'Netzwerk Vulnerabilität' includes a semi-quantitative synthesis of existing regional and sectorial studies of climate change impacts and vulnerability assessments as well as the development of an consistent methodology to produce a comprehensive overview of vulnerability in Germany as the basis for the prioritization of climate threats. These assessed and prioritised climate threats will provide the basis for the second Adaptation Action Plan as part of the progress report of the DAS in 2014.

2 Rationale – the science – policy gap in climate change research

When the vulnerability to climate change is at stake science by nature aims at estimating future impacts with the highest precision possible. As a consequence a great amount of resources, effort and time is spent on the development of sophisticated methodologies and tools. The application of these tools generate outcomes such as projections of atmospheric processes, regional climate models, the analysis of potential impacts on eco-systems and societies as well as their potential to withstand such impacts.

These results provide a realm of data and information that represent important contributions to the various components of the overall vulnerability such as exposure or sensitivity. However, they are not directly useful in supporting decision making in practice. The work of decision-makers aiming at planning and implementing adaptation strategies implies a selection and assessment of the scientific output. Often the expectations of decision makers do not match the results of the scientific process: the scientific estimations of future climate change impacts are connected – especially at the local scale – with uncertainty and they are context specific, whereas the practitioners need evidence and messages that are easy to understand. Especially a cross-sectorial decision making process is a complex procedure that needs tailor-suited tangible and concise results communicated for example as the identification of sectorial or spatial vulnerability hot spots or the assessment and analysis of particular adaptation options.

This gap between scientific output and policy demand has often been described (see for example Weichselgartner & Kasperson 2010). In order to solve it the following major challenges need to be addressed:

- Reduction of data and information as well as aggregation of intermediate results in a scientific sound and transparent way.
- Communication of the complexity of underlying data sets and the uncertainty associated with

the applied methodologies and with the results.

- Fulfilment of the user requests to provide results from a rather systemic point of view. That is to take into consideration cross-sectorial interlinkages, the multiplicity of threats or adverse impacts as well as inner-systemic feedback loops.
- Agreement on the numerous normative decisions that need to be made for the selection of methodologies, the prioritisation of threats, potential impacts or sectors, the analyses of intermediate and final results etc. Hereby, justification of actions and consensus about thresholds and priorities can be understood as an appropriate way for dealing with uncertainty.
- The difference in future periods of relevance – that is the usually long-term perspective of climate change science (of ca. 100 years) needs to be brought in line with the common time horizon of political decisions, but also actions to be taken by spatial planning (about maximum 15 years).

Even though these potentially problematic aspects are not new (see e.g. Greiving et al 2012, Greiving and Fleischhauer 2012) most research activities are modest and / or late in communicating with the potential users. In order to overcome this constraint the here presented 'Netzwerk Vulnerabilität' follows a new approach to merge user needs and scientific approach from the first moment on.

3 Realisation – project design and state-of-the-art

The project 'Netzwerk Vulnerabilität' was particularly designed to address crucial shortcomings of previous projects and to close the science-policy gap as described above by not only informing stakeholders but also communicating and negotiating with them, leading to a process of science-stakeholder collaboration within the network (Cohen, 1997; Jones, 2001; de la Vega-Leinert & Schröter, 2008).

It aims at two major outcomes of different characteristic. The first main objective is the cross-sectorial and Germany-wide assessment of vulnerability to climate change as important input for the further development of the adaptation strategy. The second major goal is the generation of a platform for the exchange of information and knowledge about climate change vulnerability in Germany. The platform will foster the cooperation between government agencies and serve at the same time as basis for the development of the cross-sectorial and Germany-wide assessment of vulnerability.

The 'engine' of the project consists of a consortium of scientists and specialists in communication contracted by the German Environmental Agency for the period from 10/2011 to 09/2014. This consortium is responsible for initiating and sustaining the network of federal agencies relevant for the process of defining adaptation strategies. It ensures the continuous communication flow within the project including the organization of workshops for the exchange of the network's agencies with external experts. The scientists of the consortium develop and propose methodologies for the assessment and aggregation of the various components influencing the vulnerability to climate change. This proposal is discussed, if necessary modified and finally agreed by the agencies. In return, the network of agencies supports the scientists in focusing on most relevant aspects of the sectorial and cross-sectorial assessment. Normative decisions are formulated by the scientists and answered by the authorities to ensure transparency.

The organisation of the network activities and the communication with all partners as well as with external stakeholders are work package 1 and 6 of the project. The second work package is a synthesis of already existing studies on climate change impacts and vulnerability in Germany. The objective of this work package is a) to provide an overview on research results on vulnerability to climate change in Germany (at a local, regional or national level and with a view to various sectors), and b) to gain insight into various approaches worldwide for assessing vulnerability to climate change.

The third work package concerns on the one hand the development of a methodological approach to estimate vulnerability in Germany. On the other hand work package 3 serves to develop the new integrated vulnerability assessment itself. It is supported by work package 4 (which contributes to the identification of indicators) and work package 5 (which contains of the organisation of expert workshops to include external knowledge into the vulnerability assessment).

The following challenges encountered in advance and during the development of the research approach and were thus subject of discussions and negotiations during the dialogue process:

- Terms and definitions: Different disciplines and authorities became acquainted to a certain way of interpreting key terms and definitions. As a result the same term often has a different meaning in another discipline (need to agree on common terms for the research)
- Scientific frameworks: It became obvious that there was a main distinction line between stakeholders that were more used to the disaster-risk and others to the IPCC vulnerability framework. (need to agree on a common framework for the research)
- Complexity and range of the subject: Where do we start? Where do we stop? The identification of the range of exposure, sensitivity and impact and the complexity of interrelations often turned out in abstract discussions and diffuse results. (need to work with visualisations as a basis

for discussion)

- Sector perspective: When looking at the entirety of sectors and designing the main connections between climate change and climate impacts it was difficult to produce an in-depth view of the sectors. On the other hand, stakeholders that represented a specific sector often promoted a very detailed view of their sector. (need to balance between applicability and detail)
- Completeness: Were all relevant aspects represented from the scientific but also from the stakeholder/political perspective? (need to receive feedback from public authorities and their superior political entity.
- Acceptance and transparency: As the vulnerability assessment aims at a national and cross-sectorial approach it was important to achieve a broad acceptance among the involved scientists and stakeholders, including the transparent discussion of the methodological approach, the prioritisation of impacts and the selection of indicators. (need to inform and give opportunities to discuss approach and interim results)

These challenges were approached by the following steps within the research process: The continuous communication between project consortium and network partners is ensured by biannual network meetings, a regularly updated website, quarterly newsletters and intensive exchange via email.

In close cooperation with the network partners so-called impact chains have been developed identifying most relevant potential effects of a changing climate in the various sectors. Further, discussions have been organised in specific expert workshops covering thematic clusters of these sectors and involving relevant network partners as well as external experts nominated by the network. Within the scope of these expert workshops the scientific consortium received input concerning the impact chains as well as potential rules, models and indicators for assessing the relation between climate signals (exposure), sensitivity aspects and the resulting impact. In parallel the consortium developed in coordination with the federal agencies an overall methodological approach for the generation of spatially explicit analyses of vulnerability and its components. The next steps include a selection of the most relevant potential climate change impacts by the network partners, the result of which will guide the consortium in focusing its work. Subsequently the consortium will carry out the various assessment steps as defined in the agreed methodology relying on the cooperation and support by the network partners, namely through data provision.

4 Conclusions – lessons learnt so far

Overall the experience with the project design that closely links a scientific consortium with a network of federal agencies for assessing vulnerabilities to climate change is positive. The consortium was able to create a rapidly growing network of partners most of which participate actively in the on-going project working tasks. This success is doubtlessly supported by the fact that the planned project objectives directly support the current work of the federal agencies within their climate change related activities. Though the project is currently at mid-term of its duration the following conclusions can already been drawn:

- Climate change and climate adaptation have already become part of the work of numerous government agencies rapidly increasing the need of exchange and cooperation.
- Being a new policy area, the various stakeholders use terms and definitions in the area of climate adaptation in different ways. Thus, for any integrated approach you first need to develop a common understanding of concepts and terms.
- The willingness of the network partners to cooperate with the scientific consortium is high.
- The new approach of a closer cooperation of science and federal agencies is perceived positively by project partners from both science and administration.
- The basic rule of the project to take decision in agreement with the network partners is crowned with great acceptance of final results and an appropriate way to deal with uncertainty but is paid for with prolonged decision procedures. However, the time spent for consensus building is well invested as it lowers barriers for actions to be implemented by a manifold of actors.
- The effort to keep the large number of network partners up-to-date, to maintain their interest and motivation, to participate and to communicate and explain tasks and requirements to all partners involved should not be underestimated.
- The acceptance of the work of the consortium and the acceptance of the network itself hinges decisively on the fact that all network partners have the same rights. Though one government agency (the Federal Environment Agency) is responsible for the project, the network partners take all relevant decisions together.

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Assessing the Capacity of Local Institutions to Respond to the Gender Dimensions of Climate Change in Nigeria

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Abstract

Gender, a fundamental organizing principle in all societies, is a central factor in determining vulnerability and ability to adapt to a changing climate. Local institutions have shaped how rural residents responded to environmental challenges in the past as they play a role in determining the flow of external support to different social groups, and link local populations to national interventions. The research determined the capacity of local institutions in Nigeria to respond to the gender dimension of climate change by ascertaining their level of gender awareness and responsiveness and their awareness and knowledge level of climate change by gender, and draw the implications for climate change adaptation. Primary data used was collected using a set of close and open ended questionnaires. A variety of analytical tools were also used in analyzing the data collected in the study. This ranged from institutional analysis and characterization to descriptive presentation. Local institutions' level of awareness and knowledge of climate change issues and their understanding of key drivers of climate change/variability is commendable as majority of respondents are aware of climate change and variability in their locality. On the gender dimension of climate change, respondents generally feel that adverse climatic events will have more negative impacts on women than men. Majority however, do not have a gender mandate/policy, gender focal points, trained staff on gender issues, are gender blind, and as such, may not be able to handle gender issues in climate change hazards. There is therefore a need for policies that will support greater role for institutional partnerships in facilitating adaptation to enhance local institutional capacities and understand their articulation and access patterns before providing resource support in any climate change adaptation programme.

Key words: Capacity, Climate change , Gender, Local Institutions.

1. Introduction

Climate change as a result of global warming is a global phenomenon with widespread impacts. In climate change disasters, gender plays out in striking – and shocking – ways in terms of male and female fatalities, (IUCN 2007). Adaptation to climate change being local makes it critical to assess the capacity of local institutions in that they connect households to local resources and collective action; determine flows of external support to different social groups, and link local populations to national interventions. Agrawal (2008) posited that 'Institutional arrangements structure risks and sensitivity to climate hazards, facilitate or impede individual and collective responses, and shape the outcomes of such responses. Understanding how they function in relation to climate and its impacts is therefore a core component in designing interventions that can positively influence the adaptive capacity and adaptation practices of poor populations.

2. Purpose and Objectives

Generally, the research determined the capacity of local institutions to respond to gender issues in climate variability/change. Specific objectives included to:

(i) Characterize local institutions in the study area;

(ii) Determine local Institutions Level of Gender Awareness;

(iii) Determine respondents' perception of gender issues in climate variability/change;

(iv) Examine the climate change awareness and knowledge level of local institutions by gender.

3. Methods and Data Sources

The research was carried out in Nigeria's Niger Delta which is the largest mangrove swamp in Africa (Constitutional Right Project, 1999). Seven hundred and fifty (750) local institutions, represented by their heads, were randomly selected out of 864 registered institutions, comprising of NGOs, civil society, faith-based organisations, cooperative societies, age grades, etc, and questionnaires administered. Analytical tools used included descriptive characterization and presentation.

4. Results and Conclusions

4.1 Characterization of local institutions in the study area

Selected characteristics of local institutions in the study area are presented in table 1.

Table 1: Characterization of Local Institutions

Characteristics	Indicator	% Contribution
Age of Institution	3-5	28.00
Female headed	390	52.00
Age of head	31-50 years	79.30
Operational Hqts	City	74.00
Source of funding	Voluntary organizations	57.20
Freq. of funding	Occasionally	45.20
Ownership	Private individual	73.07

Source: Field data, 2012 Sample size: 750

Table 2: Local Institutions Level of Gender Awareness

	Level of Awareness	Yes	No	% of No in Total	% of Yes in Total
a	Institutions that are aware of the gender policy of the federal government of Nigeria	551	199	26.53	73.47
b	Institutions that mainstreamed gender policy into the thematic area of their operations	163	587	78.27	21.73
c	Institutions that have gender focal person(s)	107	643	85.73	14.27
d	Institutions that trained members of their organization on gender issues or gender related issues	142	606	80.80	19.20
e	Institutions that attest to gender inequality in their operations	85	665	88.67	11.33

Source: Field data, 2012 Sample size: 750

Table 2 shows that most institutions (73.5%) are aware of the gender policy of the federal government of Nigeria, although, only 21.7% have mainstreamed gender into the thematic area of their operation while 78.3% attested otherwise. Furthermore, only 14.3% of the local institutions have gender focal persons as against 85.7% that do not. Responses on whether the institutions trained their workers on gender issues or related issues indicated that about 80.80% of the total response agreed to “No” option.

This implies that, about 81% of the local institutions are yet to train their worker(s) on gender issues. This gives opportunity for partnership and capacity building in this area. On the other hand, only a fraction of institutions representing 19.20% trained their workers on gender related issues. The result of this response is the reflection of the fact that many local institutions in the study area are aware of the gender policy document of the federal government; but are yet to mainstream it in their operation areas. Further investigation of the gender awareness of the institutions revealed that 11% of them substantiate the existence of gender inequality in their domain; while majority (about 89%) rejected the prevalence of gender inequality in their locality. The results suggest a degree of gender blindness and insensitivity to gender issues and the differential impact of institutional policies on both men and women. This will naturally influence the ways in which the institutions address community issues.

4.2 Respondents' perception of gender issues in climate variability/change

Table 3: Perception of gender issues in climate variability/change

Activity	Responses			
	Men	Ranking	Women	Ranking
Flooding	281 (37.5)	4	469 (62.5)	8
Desertification	309 (41.2)	2	441 (58.8)	10
Lack of fuel wood	89 (11.9)	11	661 (88.1)	1
Water scarcity	108 (14.4)	10	642 (85.6)	2
Sea level rise	325 (43.3)	1	425 (56.7)	11
Destruction of farm lands	166 (22.1)	8	584 (77.9)	4
Destruction of Houses	277 (36.9)	6	473 (63.1)	6
Land Slide	308 (41.1)	3	442 (58.9)	9
Mud Slide	278 (37.1)	5	472 (62.9)	7
Food scarcity	128 (17.1)	9	622 (82.9)	3
Storms	278 (37.1)	5	472 (62.9)	7
Extreme temperature	169 (22.5)	7	581 (77.5)	5

Source: Calculated from field data, 2012. Sample size = 750. Figures in bracket are percentages.

The result presented in table 3 shows respondents all agree that climate change has impact on women and men, with fuel wood scarcity ranking first for women and sea level rise for men. Responses by the local institutions on several climatic issues concerning men and women were counted, recorded and ranked. The result reveals that in case of adverse climatic conditions, women will be mostly affected compared to their male counterpart in areas such as insufficient fuel wood (88.10%), water scarcity (85.60%) and food scarcity (82.90%). Some of the local institutions also felt that, destruction of farm lands (77.90%), extreme temperatures (77.50%) and destruction of houses (63.10%) are additional areas women would be affected more than men in case of climatic hazards in their environment. These responses are closely related to the gender roles of women both in the household and in the community. However, the analysis reveals that respondents perceived that adverse climatic condition will affect men more than women mostly through the effects generated by the sea level rise (43.30%) and increase desertification (41.20%) as well as frustration brought about by the occurrence of land slide (41.10%). In addition, the local institutions also reported that flooding (37.50%), storms (37.10%) and mud slide (37.10%) would affect men more than women in case of their occurrences. However, based on their responses, it was observed that the sampled local institutions feel that adverse climatic conditions will generally affect women more than men.

4.3 Climate Change awareness and knowledge level of local institutions by gender

The climate change awareness and knowledge index was constructed for both male and female headed institutions. The essence was to compare the climate change awareness indices for the two groups and identify which of them had more knowledge and was also more aware. The result for the male and female headed institution's climate change awareness and knowledge index are shown in Tables 4, 5, 6 and 7 respectively.

Table 4: Male Headed Institution awareness index

Index category	Frequency	Percentage
0.000 – 0.300	38	10.55^{NS}
0.301 – 0.600	73	20.28^{S}
0.601 – 0.900	140	38.89^{S}
0.901 – 1.000	109	30.28^{S}

Source: Computed from field data, 2012 **Note:** Total number of male sample is 360

Table 4 reveals that out of 360 male headed institutions, 10.55% had climate change awareness index of 0.00 – 0.30. This means that over 80% of the male headed institutions have moderate to high climate change awareness score. About 30.28% exhibited very high climate change awareness index. Given this result, the implication is that good proportion of the male headed institutions is aware of climate variability in their environments.

Table 5: Female Headed Institution awareness index

Index category	Frequency	Percentage
0.000 – 0.300	42	10.77[NS]
0.301 – 0.600	47	12.05[S]
0.601 – 0.900	62	15.90[S]
0.901 – 1.000	239	61.28[S]

Source: Computed from field data, 2012 **Note:** total number of female sample is 390

Table 5 indicates that the distribution is skewed to the left (increasing positive region), meaning that more respondents are concentrated on one side of the distribution. Only 42 respondents representing 10.77% of the total female headed institutions (390) fell in the index category of 0.00 - 0.300. This result is similar to that displayed by the male headed institutions. It implies that few female headed institutions are not really aware or have limited awareness on the climate change in their domain. Compared to data in table 4, female headed institutions are more aware of climate change than their male counterpart.

Table 6: Male Headed Institution knowledge index

Index category	Frequency	Percentage
0.000 – 0.300	37	10.28
0.301 – 0.600	87	24.17
0.601 – 0.900	169	46.94
0.901 – 1.000	67	18.61

Source: Computed from field data, 2012 **Note:** Total number of sample is 360

Comparing the knowledge gap on climate change between the two groups, table 6 gives details of the knowledge index for male headed institutions, while table 7 gives that of the female. The result shows varying levels of climate change knowledge, with only18.61 having very strong knowledge, while over 60.0% of the female headed institutions have very strong knowledge on climate change phenomenon.

Table 7: Female Headed Institution knowledge index

Index category	Frequency	Percentage
0.000 – 0.300	25	6.41
0.301 – 0.600	48	12.31
0.601 – 0.900	80	20.51
0.901 – 1.000	237	60.77

Source: Computed from field, 2012 **Note:** Total number of sample is 390

Comparing the climate change knowledge index for the two groups, it is evident that the female headed institutions have a better understanding of the climate change issues than their male counterpart.

5. Recommendations and Implications

Most surveyed local institutions have gender-blind mandates/policies, have not trained their staff on gender issues and may not be able to handle gender issues in climate change hazards. This calls for capacity development in the area of gender dimensions of climate change, sensitisation for the domestication of the national gender policy of the government and mainstreaming of gender issues into all capacity building programmes of agricultural extension and development.

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Is Anybody Listening? Yes, but . . .

Seeing Climate Change at the Local Level through Regional Radio
(Or - Hearing Climate Change Happen on the Radio - ?)

Michael Svoboda

Abstract — In response to the fifth key challenge of the Impacts World 2013 conference— Is Anybody Listening? — this paper reports on how one U.S. radio station with local, regional, national, and (via the web) international reach addressed the interrelated issues of climate change from 1999 to 2012. Through this analysis of WAMU, the National Public Radio (NPR) affiliate serving the metropolitan region that includes the U.S. capital, this study complements and qualifies previous work on media coverage of climate change, which to date has focused almost exclusively on national-level coverage by newspapers. The results suggest that this center-left source of news and opinion is slowly integrating climate change into its reporting and commentary on local, regional, and national events and issues. However, the partisan political opposition that continues to block U.S. efforts to address climate change, at the both the regional and national levels, highlights the need for further research on the media to which these groups listen.

Index Terms — climate change, media archives and databases, radio, Washington DC

Introduction

Save for a single line about “our responsibility to society,” which includes one “wider” reference (3.5), the public is missing from the background document drafted for Impacts World 2013. The “anybody” in the fifth challenge—Is anybody listening?—is not just anybody; it is the policymaker. Will policymakers heed, the drafters of this document want to know, the new and improved data, projections, scenarios, and narratives that scientists will prepare for them? But can one answer this question about the policymaker without also asking what the public will hear over these next critical years? And if not, what additional work must be done to determine what the public now hears, when it does listen, about the regional impacts of climate change?

This paper assumes that the public will determine, at least in part, what policymakers heed. And on that basis, it seeks to answer the question regarding what the public now hears, literally, about the regional impacts of climate change. This it does in three stages.

First, the results of a meta-study of over 100 studies on media coverage of climate change are quickly reviewed. These will show that, as with climate models and projections, regional and/or local data are missing or obscured. And for analogous reasons: the most widely used instruments, the media archives and databases on which most researchers rely, do not as readily collect or process data at these levels.

Second, content analyses of the national and local/regional programming of a major urban radio station in the United States—WAMU, the main National Public Radio Affiliate in Washington, DC—are conducted and compared to determine the extent to which the programs' creators have incorporated climate change into their reporting on and analysis of transportation, public health, planning, environmental, and economic issues in the DC region.

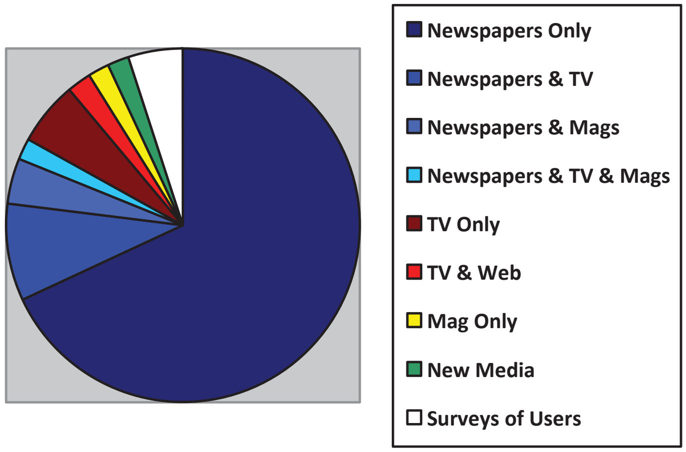
Third, the paper uses the literature on possible correlations with public opinion on climate change to evaluate the trends in the data on WAMU's coverage of climate change from 1999–2012 and to estimate the gap that will likely still exist between a public that listens and a public that acts.

Study #1 – Meta-analysis of Media Coverage of Climate Change

Researchers have reviewed media coverage of climate since the mid-1990s, but the publication of such studies increased markedly after 2000. In a meta-analysis conducted for this paper, over 100 articles from English-language journals[1] were reviewed for three foci: media, nation or region of the world, and news vs non-news. Figure 1 shows the results for the media focus. Over 68% of the studies focused solely on newspapers, typically major national newspapers. Studies that included newspapers plus some other media—television, magazines, or television and magazines—accounted for another 15% of the total. Studies that focused on media other than newspapers accounted only for 12%. (The remaining 5% examined the public's consumption of media.)

[1] The articles were found (1) by searching in library databases (Articles+, Mass Communication and Media Complete), (2) by reviewing journals devoted to climate change, environment, or science communication (*Climatic Change*, *Environmental Communication*, *Environmental Politics*, *Global Environmental Change*, *Public Understanding of Science*, *Science Communication*, etc.), and by soliciting suggestions from the subscribers to the Environmental Communication Network mailing list (now the International Environmental Communication Association mailing list). Over 35 different journals are represented in the final collection. Edited volumes (e.g. Boyce and Lewis 2009) were also included.

Figure 1. Media Analyzed in Studies of Media Coverage of Climate Change[2]



These results square with those reported in a more general meta-analysis of the media's coverage of science. And these results, the authors of the study (Schafer 2010) and a subsequent commentary (Riesch 2011) both observe, are at odds with recent trends in the public's actual consumption of news (Pew Research 2013; Media and Public Opinion Post 2013). The continued focus on newspapers, Schafer acknowledges, is "due certainly to the accessibility of databases and the relative ease of analysis," but "people use audio-visual media, such as radio broadcasting, television, and the internet on a daily basis for longer periods of time than they read newspapers" (2010, 659).

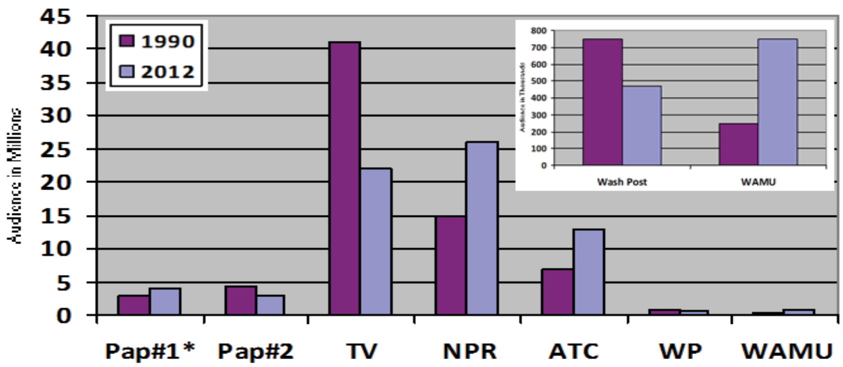
One might argue that most of what is reported about climate change on radio, television, or internet news sites originates with major national newspapers. And certainly, stories in major national newspapers like the *New York Times*, the *Wall Street Journal*, and the *Washington Post* can drive coverage by other media. However, cutbacks on science and environmental coverage at CNN, *New York Times*, *Washington Post* and elsewhere necessitate that those stories now be written elsewhere—if they are to be written at all (Brainard 2013).

[2] Note: These results are still provisional and should not be cited. Not shown here are the results for the two other foci: Roughly 70% of the studies focused on Anglo-American countries (US – 40%, UK – 22%, Canada/Australia/NZ – 8%); news coverage of climate change was the exclusive focus of over 90% of the studies.

Study #2 – What People Listen to on WAMU/NPR

While the audience and revenues for most major newspapers declined over the past two decades, the audiences and operating budgets for National Public Radio (NPR) and its major urban affiliates have increased[3]. The estimated weekly audience for NPR is now 26 million; the estimated average weekly audience for *All Things Considered*, NPR's afternoon/evening news program, is 13 million, roughly on par with the average for the three nightly network news programs and several times more than that of the average daily circulation (print and digital) for the *New York Times*.

Figure 2. Audiences for Major U.S. Newspapers, Broadcast Networks, & NPR, 1990 vs. 2012



Major National Newspapers include *New York Times* and *Wall Street Journal* (tallied together as Pap#1) and *Los Angeles Times*, *USA Today*, and *Washington Post* (Pap#2). In the TV bars are included the numbers for all three major news networks: ABC, CBS, and NBC. The insert compares, on a smaller scale, the changes in audiences for *Washington Post* and WAMU. During the same two decade period when the television networks lost almost half of their audience, NPR, *All Things Considered* (ATC), and WAMU experienced significant growth. **The New York Times* and *Wall Street Journal* increased their circulations through their websites; print numbers, and ad revenues, are down at both papers. (Sources: Csellar 2012; Giovannoni 1992; Pew Research 2010; Pew Research 2013; USA Today Timeline 2011; WAMU 2010.)

The story at the local/regional level is even more dramatic. In the spring of 2012, WAMU, the NPR affiliate licensed to American University in 1961, became the top-rated radio station in Washington, DC. Its audience now exceeds 700,000 (Csellar 2012).

Environmental issues figure in WAMU's programming at three levels. *The Diane Rehm Show* (*TDRS*) is a nationally syndicated daily two-hour talk show that alternates between topical discussions and author interviews. Starting in 2011, *TDRS* began a monthly "Environmental Outlook" series. In 2000, WAMU hired Kojo Nnamdi to host its local/regional mid-day talk show program,

[3] NPR experienced steady growth through 2010, when its audience peaked at 27.3 million (MacNichol 2011). Over this period of growth, new resources, including jobs, were provided to the news divisions. Since 2010, the NPR audience has contracted slightly, to an estimated 26 million at the end of 2012 (Pew Research 2013)

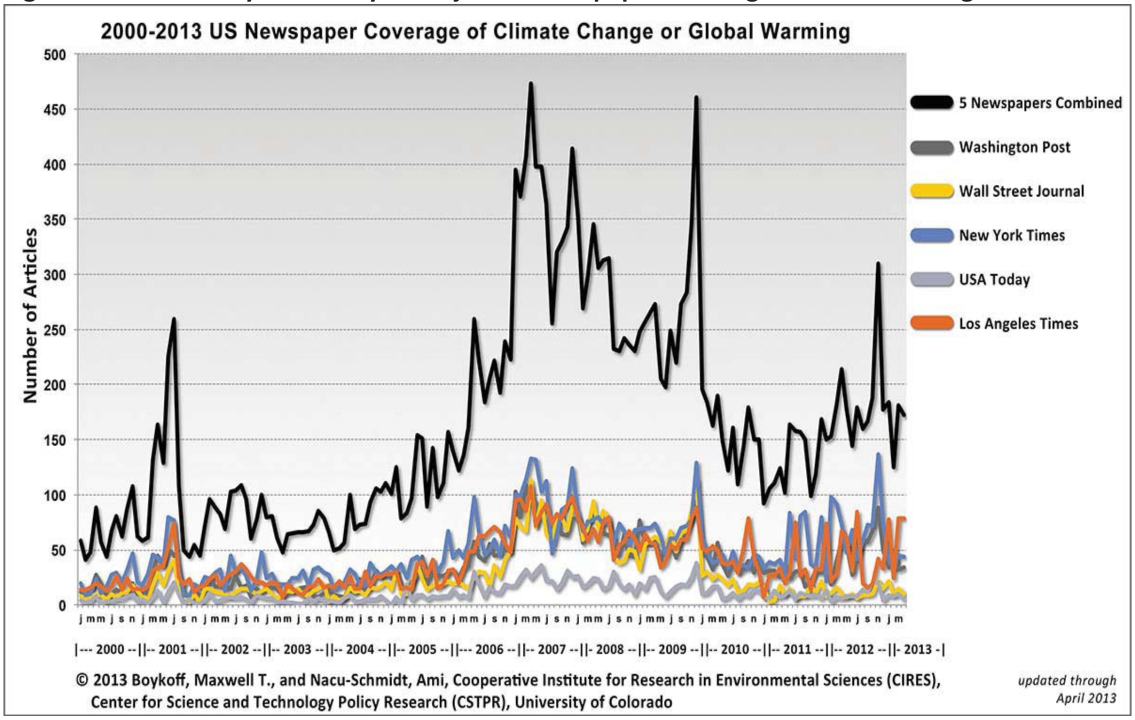
which in 2004 was redubbed *The Kojo Nnamdi Show* (*TKNS*). Then in 2007, as part of the expansion of its newsroom, WAMU hired a reporter to cover the local/regional environmental beat; these reports are included in WAMU's local "inserts" into the six hours of national news programming provided by NPR. The nine tabs that run across the top of WAMU's homepage include one for "Environment."

To determine what WAMU's listeners hear about climate change, and how often, through the two talk shows, the monthly program lists for *TDRS* and *TKNS* were examined from January 1999 to December 2012. To tally the news reports, the lists and links on the 300-plus webpages under WAMU's "Environment" tab were systematically reviewed. Counts were kept for shows/segments/reports on seven different topics: (1) global warming or climate change, (2) traditional environmental issues (e.g. biodiversity, conservation, pollution, etc.), (3) energy, (4) urban planning, (5) food and/or agriculture, (6) water issues, and (7) weather. For the news reports, the traditional environmental issues were further subdivided into the Chesapeake Bay and its watershed, the appreciation and conservation of other ecosystems, environmental health/pollution, and environmental action or policy.[4]

The topical tallies for these three different levels of programming at WAMU are provided in three separate graphs. To place these results in the context of previous work on media coverage of climate change, two other graphs are presented first. Both graphs figure prominently in annual reviews of media coverage. Boykoff and colleagues have tallied coverage by five major American newspapers since 2005. Brulle has tallied coverage by the three major news networks since 1986.

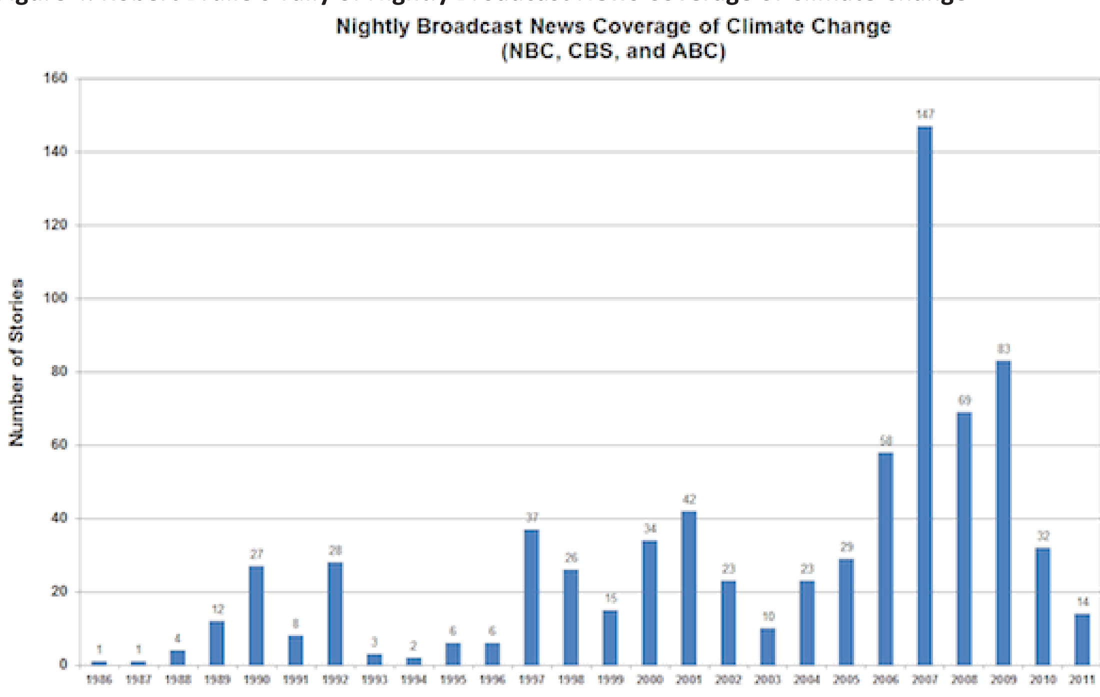
[4] WAMU maintains an exhaustive online archive of its programs. One can identify and listen to every program recorded for *TDRS* or *TKNS*, from 2013 to 1999 and beyond, by paging back through the calendars for each program. Hovering over a day of the week brings up the program or segment titles for that day, with links. The two shows cover four hours of WAMU's weekday schedule. *The Diane Rehm Show* (10AM – 12:00) is subdivided into two hour-long interviews or discussions; the two hours of *The Kojo Nnamdi Show* are now subdivided into four to six segments. Transcripts are available for all shows after January 1, 2011. The environmental news reports are archived in an ongoing list that runs in reverse chronological order (most recent first) on the "Environment" page. Each link is accompanied by a short description; the clips can be as short as 25 seconds and as long as 7 minutes.

Figure 3. Maxwell Boykoff's Tally of Major US Newspaper Coverage of Climate Change



The chart, which is updated monthly, can be found on Boykoff's webpage at Center for Science and Technology Policy Research: http://sciencepolicy.colorado.edu/media_coverage/us/index.html .

Figure 4. Robert Brulle's Tally of Nightly Broadcast News Coverage of Climate Change



In his January 2013 review of media coverage in 2012 (Fischer 2013), Fischer quotes Brulle's numbers for 2012, but no version of this graph could be found that included that data. This above graph can be found at the following site: http://thinkprogress.org/climate/2012/01/09/400795/network-news-coverage-of-climate-change-collapsed-in-2011/

Figure 5. The Diane Rehm Show, 1999–2012 (Number of Programs Devoted to Each Topic)

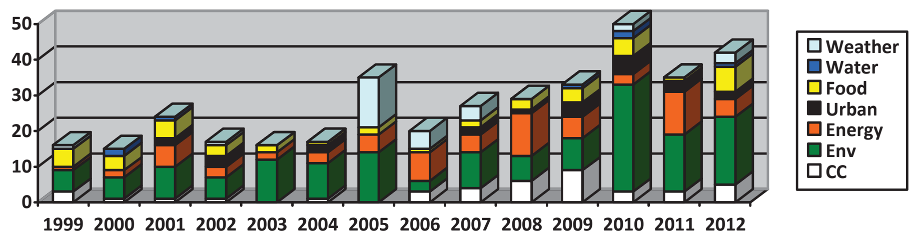


Figure 6. The Kojo Nnamdi Show, 1999–2012 (Number of Segments Devoted to Each Topic)

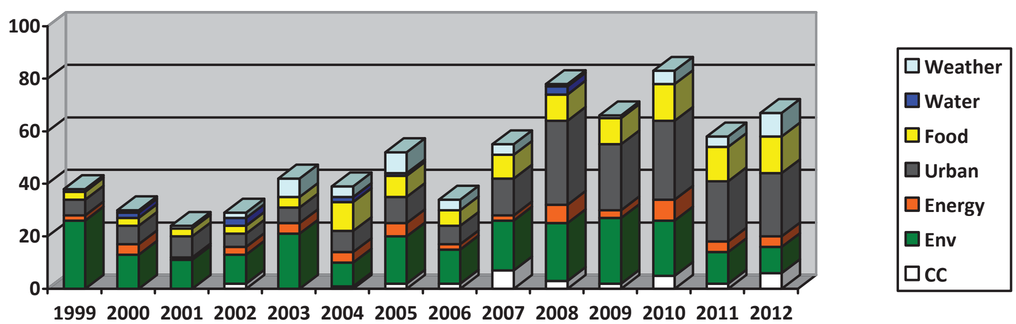
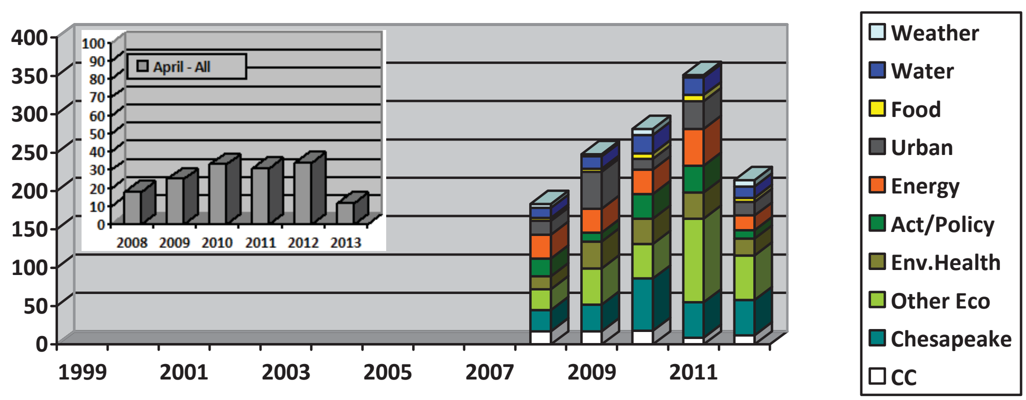


Figure 7. WAMU Env. News, 2008–2012 (Number of reports inserted into ME, ATC, or Metro Connection)



Preliminary Findings for Study #2

A comparison of the two sets of graphs yields the following basic findings:

- The peaks and valleys in WAMU's programing are less extreme and do not match the patterns of newspaper and network coverage:
  - o Environmental programs, segments and/or reports increased steadily through 2010.

  - The number of programs/segments/reports specifically focused on climate change is a small fraction of that total.[5] By contrast with the general trend in environmental coverage, coverage of climate change varies widely between *TDRS*, *TKNS*, and the news reports.
  - Coverage of climate change in the aftermath of Copenhagen varied widely. TDRS, the most national of WAMU's programs, had the most extensive coverage.

- The Kojo Nnamdi Show (*TKNS*) and the environmental news reporting show significant engagement with local issues. The many programs on urban planning, in particular, offer an opening for integrating regional modeling on climate change with area planning processes. Likewise with the extensive news coverage of the Chesapeake Bay and its watershed.
- Because parts of Maryland (a left-leaning state) and Virginia (a middle-right state) are included in its broadcast area, WAMU can report on the partisan political divide over climate change as local or regional news.[6] In its own programs, segments, and reports, WAMU has "balanced" its reporting, but to a lesser degree than Boykoff & Boykoff (2004) reported for newspapers. Climate skeptics have not been featured guests on *TDRS* or *TKNS*.
- On the whole, WAMU's commitment to environmental reporting, and to coverage of climate change in particular, seems to have held steady or increased from 2007 to 2012, in contrast to the overall decline in coverage by the five major national newspapers and the three nightly news broadcasts. But environmental news reporting at WAMU did drop off sharply in 2012. (WAMU has not yet responded the queries on this point.)

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[5] It should be noted, however, that devoting a full segment (20-30 minutes) or program (1 hour) on *TKNS* or *TDRS* is equivalent to front-page coverage in a newspaper or the lead story on a nightly news broadcast. Thus these small numbers should be weighted more heavily.

[6] Maryland has passed legislation aimed at reducing greenhouse gas emissions. In Virginia, by contrast, the state attorney journal, Ken Cuccinelli, tried to pressure the University of Virginia to release climate-science related emails in effort to find evidence of "fraud" (Kumar 2012). In the summer of 2012, groups of citizens stormed planning commission meetings in several coastal communities to protest the inclusion of climate change projections in flood zone maps (Reed 2012). WAMU has reported on these and other actions, including protests staged by activists in the capital.

Conclusion – The Gap between Listening and Acting

What can be learned from this comparison of the media coverage of climate change at different scales and in different media?

To communicate climate change effectively, researchers noted nearly a decade ago, one must surmount significant barriers and obstacles (Moser and Dilling 2004, 2007; Nisbet 2009). Global climate change can easily be perceived as an abstract, complex, seemingly remote problem about which one can directly do little or nothing. For these reasons, the same researchers advised communicators to make climate change real by making it local, tangible, and relevant—while giving their listeners ways to act. (See also Crona et al 2013.) This review of the three program streams generated by WAMU suggest that radio, the medium completely overlooked in previous studies, could be raising awareness of climate change and integrating this “environmental” issue into a broader range of local/regional concerns.

But at WAMU climate change itself remains an occasional issue, something discussed as occasions—seasonal events, others’ political actions, national disasters and emergencies, odd or extreme weather—arise. For the public’s understanding of climate change to withstand changes in fortune and/or the weather (Shanahan and Good 2000; Egan and Mullin 2012; Donner and McDaniels 2013; Mayer et al 2013), these occasions must be incorporated into a more coherent and anchored narrative. WAMU’s very active promotion of informed discussion about the capital region’s future could provide that anchor, especially if the very real concerns about sea-level rise in the Chesapeake Bay are included in the discussion.

Viewed in the context of previous studies of media coverage of climate change, this study of WAMU warrants at least the following conclusions:

- Current research on the media coverage of climate change is out of step with the public’s use of media and possibly with the media that may now be covering climate change most extensively.

- The example of WAMU offers some reasons for optimism. Albeit with significant ups and downs, coverage of environmental issues has, on the whole, increased and concern for the possible impacts of climate change is suffusing into the discussion of other topics.
- But one cannot generalize from one region to another or from one region to the nation. Other regional studies must be performed to determine the correlates between media coverage and local/regional attitudes.
- Having provided some measure of what the center-left hears about climate change in Washington, DC, it is necessary to determine what the center right hears. Talk radio is likely to figure prominently in that research, which will again require that researchers move beyond the customary, print-based databases.
- A fuller understanding of talk radio will require more than quantitative analyses. Qualitative research must be conducted to determine how the "journalistic norms" of talk radio, both left and right, differ from those of the print media (Boykoff & Boykoff 2007).

In sum, having moved beyond national newspapers, we may now know better what we do not know about what the public hears—or does not hear—about climate change at the local and/or regional level.

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Impacts World 2013, International Conference on Climate Change Effects,

Potsdam 27-30 May 2013

(Final 16 May 2013)

Title: A decision making focus for impacts research: Drawing on Australia's adaptation experience

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Abstract

In the last five years Australia has had significant growth in research and practical experience, covering climate impact, vulnerability and adaptation activities. At the same time adaptation policy has continued to evolve. The paper draws on this experience, including recent synthesis studies, to address a number of key questions relevant to the future impacts research agenda. This in particular includes how impact research might be more clearly positioned within the overall adaptation policy and decision making process. The growing maturity of adaptation efforts in Australia is making this, and the sharing of insights internationally, increasingly possible, though there also remain significant challenges.

Index Terms: adaptation, climate impacts, decision making, policy and practice

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1. Introduction

Consistent with the Visioning Paper for the IMPACTS WORLD 2013 Conference (Piontek et al. 2013), the future climate impact research agenda includes the need to improve the quality, consistency and comparability of impact assessment for a wide range of uses at global, national, regional and local levels.

This paper addresses a number of issues within one of the core questions ('Is anybody listening?') for the Conference. It focuses on the role of impact research in national, regional and local adaptation risk assessment and adaptation responses, drawing primarily on the Australian experience, and especially the practical perspective of policy and decision makers. It is therefore very much from the 'adaptation' perspective within the Vulnerability, Impacts and Adaptation (VIA) community. The Visioning Paper makes several references to the significance of this domain including the need to advance 'the development of impact studies, inter-sectoral assessments, and refined decision-support tools for local, regional, national and global stakeholders'.

2. The Australian Context – adaptation activity and emerging consolidation

Australia has significant vulnerabilities to climate change (Palutikof 2010) and evidence of climate impacts in the region from global warming is mounting (Steffen 2011, 2013).

Especially in the last five years, Australia has had considerable investment in research and practice in climate impacts, vulnerability and adaptation. This especially followed the Australian Government's Adaptation Framework (Commonwealth of Australia 2007) and related nationally funded programs especially through the Department of Climate Change and Energy Efficiency (DCCEE 2012a), including establishment of the National Climate Change Adaptation Research Facility (NCCARF 2013a), the CSIRO Climate Adaptation Flagship (CSIRO 2013a), and a number of additional project and program initiatives within and across sectors. This nationally led program has been complemented by a range of state, territory and local government programs, and in recent times growing private sector (e.g. IGCC 2013, ASBEC 2012, ICA 2012) and community sector (e.g. GCA 2013) activities. The national adaptation policy is currently under review (Productivity Commission 2012, Commonwealth of Australia 2013) and a Council of Australian Governments (COAG) Select Council on Climate Change was established in 2012 in order to, amongst other things, develop the next phase of national adaptation priorities and work plans (Commonwealth of Australia 2012).

The learning in this period has been significant. However, as assessed by practitioners, policy makers and researchers in a recent submission to the Productivity Commission (Webb 2012), translation of the above investment into strategy development and proactive response has been patchy, and the knowledge and support base is currently very fragmented (Webb and Beh 2013).

The initial steps towards a more coordinated national approach are evident in a new wave of more systematic and consistent national scenarios, modelling and analysis (DCCEE 2012b, BOM 2013, CSIRO 2013b), consolidation of the growing research knowledge base (NCCARF 2013b,c), and a number of adaptation practice and decision-making initiatives led by the Australian National University (ANU) in collaboration with DCCEE and NCCARF (see Appendix 1).

3. A decision making focus for impacts research

What does the above experience, and especially the recent investment in synthesis and consolidation, tell us about one of the core questions in the IMPACTS WORLD 2013 Conference ('Is anybody listening?') especially from the perspective of policy and decision makers? Three of the sub-questions within this conference theme are considered below.

How to ensure a systematic quantification of adaptation options including local knowledge?

Adaptation options assessment and decision making does need to be embedded in regional and local knowledge and processes, but can also better inform, and be informed by, broader (i.e. other regions, national and international) research and insights.

Developments that will enable a more systematic approach include

- a growing understanding of good adaptation principles and practices responding to common challenges and themes emerging across sectors (Prutsch et al. 2010, Webb and Beh 2013, Moser and Ekstrom 2010, Webb et al. 2013); including categorisation of decision types and better guidance on adaptation decision making (e.g. Hallegatte 2009, Stafford Smith et al. 2011, MEDIATION 2013, Webb and Beh 2013). Some of the needs are common across sectors and some highly differentiated, and in most cases the adaptation decision is embedded in a broader set of policy considerations and objectives.
- development of related knowledge portals, knowledge brokers and communities of practice, and where appropriate common and shared data and modelling infrastructure; increasingly supported (in the Australian context) by national/ regional coordinating and facilitating institutional arrangements (e.g. Webb and Beh 2013; ANDS 2013, NeCTAR 2013, AIH 2012). Decision support can include better guidance on good adaptation practices and processes; access to the most relevant and credible data and models; and knowledge sharing through case studies, communities of practice and knowledge brokers (Webb and Beh 2013).

- development of a new generation of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5)-based climate and socio-economic scenarios and assumptions drawn from global Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSP) sources (van Vuuren et al. 2012) but translated and downscaled for more consistent and comparable use in Australian regions (DCCEE 2012b, BOM 2013, Stafford Smith 2013).

With this increased emphasis on synthesising the learning from experience, and a more co-ordinated national strategic agenda emerging, there is real potential to more systematically inform both local options assessment and decision making within Australia and broader international initiatives, including more useful positioning of impacts research and modelling. However this will require sustained institutional support and continuing evidence of the value to policy and decision makers.

Specific strategies to develop a more systematic approach to adaptation assessment and decision making, and related support approaches, have been proposed in the Australian context in the nationally funded project on leading adaptation practices (Webb and Beh 2013). This project included a review of international as well as Australian adaptation practices and support, and several of the proposed strategic approaches may have relevance to other countries.

How impacts research and practical experience influences adaptation policy-making?

In the Australian context the role of the national government is critical in knowledge development and dissemination, in order to facilitate other levels of decision making in the private and public sector. This has recently been confirmed in the government's response to an inquiry commissioned as part of an adaptation policy review (Productivity Commission 2012, Commonwealth of Australia 2013), which also confirmed that the government expects all national departments and agencies to develop effective climate risk responses.

There is no doubt that at the broadest level, impacts research and understanding has influenced adaptation priorities and policy analysis (Commonwealth of Australia 2012; Productivity Commission 2012). This has been partly due to a long standing need to respond to a high level of climate variability, but more recently the progressive accumulation of climate change impacts and vulnerability knowledge, including several nationally commissioned and research institution reports for individual sectors (e.g. for water (MDBA 2012, Connell and Grafton 2011), for biodiversity and natural resources (Steffen et al. 2009, Dunlop et al. 2012), for coastal settlements and infrastructure (DCC 2009), and for agriculture (Stokes and Howden (2010)). To date this has not included either cross-sectoral integrated impact modelling incorporating biophysical and socio-economic implications, or top down comprehensive risk assessment as carried out for example in the UK (DEFRA 2012). However there is current activity building on earlier climate policy-related Integrated Assessment Modelling, and a number of national adaptation cost and benefit assessments planned across several key sectors (Commonwealth of Australia 2011, CSIRO 2013b, Stafford Smith 2013).

Whilst there is continuing national investment, impacts research is likely to be increasingly required for regional and local adaptation decision making. In this context many of the direct policy and program levers are with state and territory governments, who also have constitutional responsibility for local governments. Therefore state and regional initiatives can be especially important in brokering research into the policy and decision maker's world (e.g. NSWOEH 2012a,b, Tasmanian Government 2013, Government of South Australia 2012). However the translation of knowledge to action at the regional and local level has been far more problematic due to the sensitivity to social and political reaction, for example to local planning and development responses to sea level rise and other climate hazards. Several state governments have backed away from providing clearer policy and guidance (Norman et al. 2013) and there are also understandable local capacity issues.

Thus at the very time that policy has the potential to be increasingly informed by climate related research, the influence on policy is especially challenging at the state, regional and local level, as a result of social, political, institutional and capacity constraints.

How to achieve more active exchange and a better two-way communication with practitioners and policy makers?

The evidence from Australian experience is that research needs to be better positioned within the decision maker's world and language, including an appreciation of their multi-objective and multi-stakeholder reality, and the complex interdependencies they need to resolve across sectors and with non-climate drivers and policies. The learning from our multi-stakeholder engagement processes (e.g. Webb 2012, Webb and Beh 2013) is that where the dialogue starts from the perspective of practical policy and adaptation decision making, there can be a surprisingly high degree of consensus across public, private, community and research sector stakeholders about overall desired adaptation outcomes and higher level strategies. However the challenge is that there are limited processes to translate this shared strategic view into practical decision making and change, with institutional arrangements often not well positioned to resolve practical priorities and trade-offs.

In general there is much practitioner and decision maker uncertainty as to how to use climate and impact information and models to inform adaptation decision-making. This can be due to the need for better methodological support and guidance (Webb and Beh 2013) including how to handle different and often inconsistent underlying scenarios, assumptions and levels of uncertainty; and the difficulty in addressing complex new interdependencies and integration issues, including across sectors. Appendix 2 provides an example of the complexity and interdependencies being addressed in a typical coastal adaptation context, as part of a recent project for the southeast coastal region of Australia (Norman et al. 2013).

In practice therefore decision makers are struggling to move from impact assessment to action for a range of complexity, capacity, social, political and institutional reasons. The contribution of climate and impact modelling, including integrated cross-sector assessments, therefore needs to be positioned in this broader context. Helping decision-makers come to grips with this new and more complex world is in many ways a prerequisite, or at least a parallel issue, to incorporating more sophisticated climate and impact modelling.

Some insights on practical measures to enhance engagement with practitioners and policy makers include:

- Position climate impacts research and modelling more clearly in the overall adaptation decision making process, recognising the iterative nature of that process between impact assessment, decision making, review and learning. This is necessary both in establishing research agendas, and for individual research programs and projects.
- Build on existing stakeholder experience. For example in Australia some sectors (e.g. water, natural resource management, agriculture) have a long tradition of managing for climate variability, which can provide a strong base for considering more substantial impacts of climate change (Dovers 2009). However even in these sectors (and especially in others) decision makers are often (at least initially) happy to use qualitative and directional climate and impact data to inform preliminary risks assessment and strategy development, reducing the need for detailed impact analysis at early stages.

- Focus on regional level dialogue (in the Australian context the level between state and local governments) this being where both impact analysis and adaptation responses will often make most sense, with the potential to provide significant leverage into local decision making.
- Synthesise and translate the research findings into simpler and clearer qualitative insights at national and regional levels, and in a context relevant to policy and decision makers (e.g. NCCARF 2013c); and encourage the formation of communities of practice, knowledge brokers and networks (NCCARF 2013d, Verdon-Kidd 2012, Webb and Beh 2013). Decision makers rarely have the time or capacity to do their own synthesis and translation.
- Clarify how different methodologies and modelling approaches may be applicable at different spatial scales and for different purposes (e.g. Casaril et al. 2012 for water and ecosystems), and provide guidance on the matching of available approaches and models to context or intended use. The UNFCCC Compendium (UNFCCC 2008) is an international example of a step in this direction though currently more a catalogue than a guide.

Strategies to advance many of the above insights from the decision maker's perspective have been proposed in the Australian context (e.g. Webb and Beh 2013). A government, private and community sector sponsored project to translate these strategies into practice, initially for the coastal settlements and infrastructure segment, is currently under development.

Practitioner and policy engagement is far more than communication. An important underlying principle is to encourage the co-design and co-production of knowledge with stakeholders, which can then be significantly facilitated by the above processes. For example, at the overall research agenda level, NCCARF and the CSIRO Climate Adaptation Flagship were established with an integrated vulnerability, impact and adaptation (VIA) approach in mind, and individual research projects have to demonstrate significant engagement with adaptation decision makers.

4. Summary and conclusions

The paper has summarised some of the recent and current vulnerability, impact and adaptation (VIA) initiatives and findings in Australia from a research, practice and policy perspective. Summary conclusions are

- There has been a significant growth in VIA activity in Australia in the last five years, which is a rich source of new knowledge and learning, albeit currently fragmented, and used more for initial assessment and planning than for adaptation action.
- With an increased emphasis on synthesising and interpreting this learning, and a more co-ordinated national strategic adaptation agenda emerging, there is real potential to more systematically inform local adaptation options and decision making within Australia, as well as broader international initiatives.
- The influence of impacts research on policy in Australia is evident to some extent at all levels, but is especially challenging at the state, regional and local level, as a result of social, political, institutional and capacity constraints.
- There are however a range of practical strategies that can enhance engagement with policy and decision makers, and better integrate impacts and adaptation research, starting with climate impacts research and modelling being more strongly positioned in the overall adaptation decision making process, and recognising the iterative and adaptive nature of that process.

In this context the paper has highlighted several specific findings from the Australian experience, and points to some of the recent projects that have identified strategies to better support adaptation decision making, as well as some projects under development to translate those strategies into practical effect. Given these projects are drawing on international as well as Australian experience, the approaches may also have relevance for other countries.

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Appendix 1.

Recent adaptation synthesis projects led by the Australian National University (ANU)

In the last 2 years the ANU has collaborated with the national research body (NCCARF) and the federal Department of Climate Change and Energy Efficiency (DCCEE) to synthesise insights from the extensive range of practical adaptation experience generated in Australia, especially over the last 5 years. The collaborative projects included

- a project that has distilled and interpreted key challenges and emerging good practices from 20 significant local and regional adaptation initiatives across sectors and jurisdictions, also comparing the findings with comparable international research (Webb et al 2013),
- a project that has synthesised leading adaptation principles, and researched and proposed national adaptation strategies, products and tools to better support adaptation decision makers and policy makers (Webb and Beh 2013), and
- a workshop and follow up process leading to an *Informing Adaptation Policy* submission to the Australian Productivity Commission Inquiry into adaptation, drawing on the input of a wide range of policy makers, decision makers and practitioners across public, private and community sectors, as well as researchers (Webb 2012).

Each of these projects had its own primary focus but was carried out using collaborative and integrating mechanisms that engaged, and drew out the links between practice, policy and research (Fig.1). Whilst grounded in recent Australian experience, these studies also compared the findings with experience in other countries and the international literature.

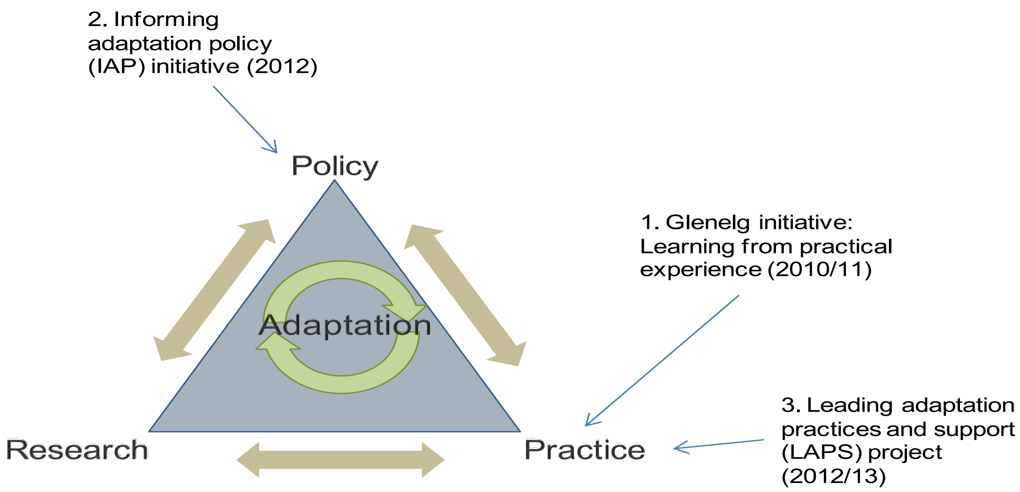


Figure 1. A broader agenda: linking practice, policy and research

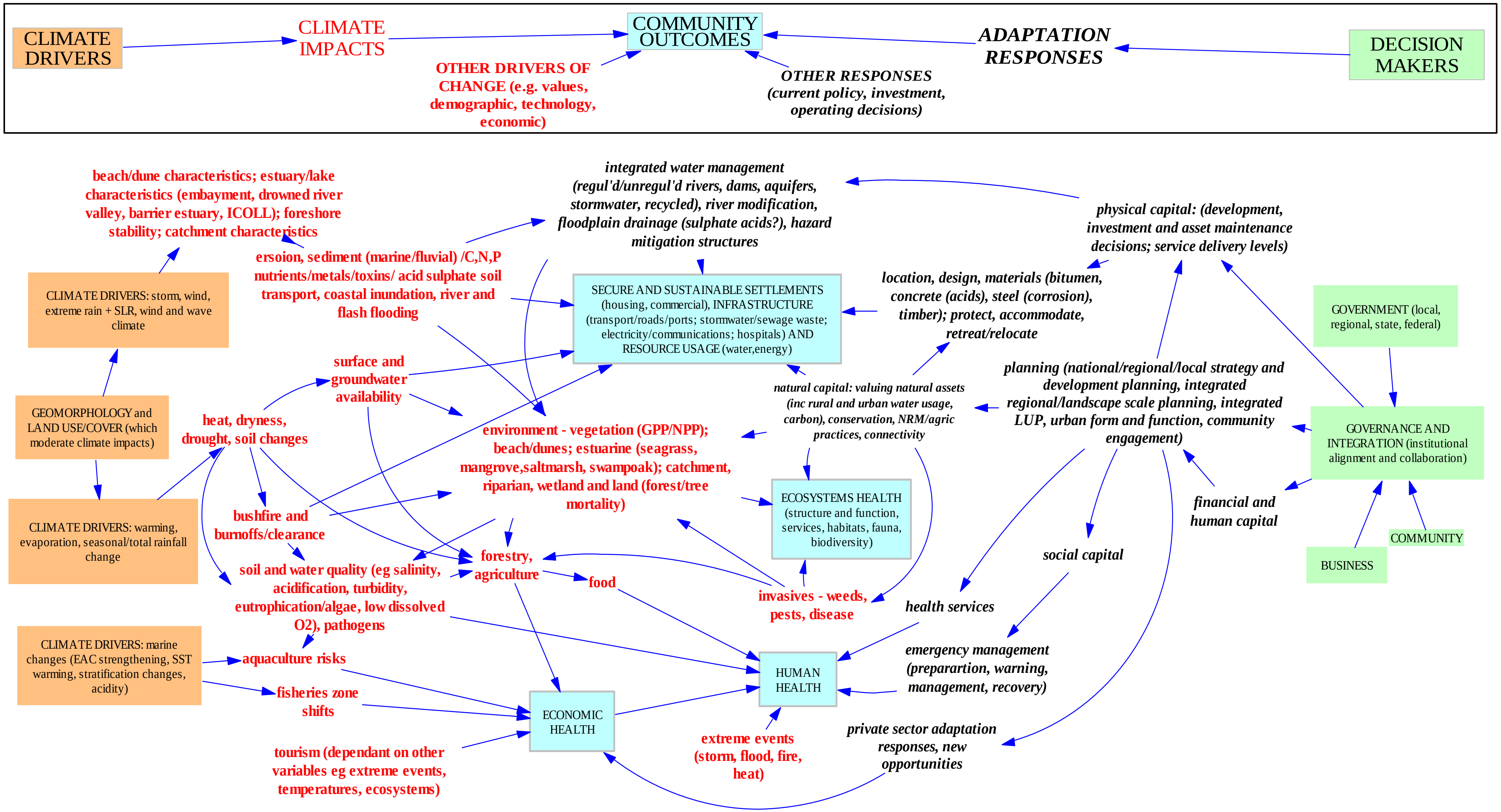
Appendix 2.

Coastal climate adaptation for Southeast Australia: an integrated systems view

A project carried out in 2012/13 jointly by the University of Canberra (lead), Australian National University (ANU) and University of Wollongong, investigated the climate related issues and desirable characteristics for a climate adapted coastal settlements in 2030, in the southern NSW and eastern Victorian region of Australia (Norman et al. 2013).

The project included sector-based literature and field research, stakeholder workshops and focus groups, and integrated analysis. One product was a mapping of some of the key issues and major interdependencies identified by both the researchers and the stakeholders as needing to be taken into account in local adaptation planning and decision making (Fig.2). This indicates the complexities faced by local and regional organisations (including local governments, regional agencies, and private and community sector organisations) and their decision makers. It is important that practitioners and researchers involved in individual sector and cross-sector impact, vulnerability and options assessments appreciate this broader context.

Figure 2. Coastal climate adaptation for Southeast Australia: an integrated systems view (Norman et al. 2013)



17

Impact of Carbon Emissions Management and Disclosure in International Supply Chains – An Example of the Food Export Industry in Latin America

Ann-Kathrin Zotz, Carolyn Robert, Alfie Ulloa

Abstract

In this paper the Latin American food export industry is used as an example to demonstrate "what is still missing" with respect to the management and disclosure of carbon emissions in international supply chains.

With a number of OECD countries entering into the post-2012 period of tightened climate change policies, low-carbon strategies of committed multinationals are expected to have international reach including suppliers and sub-contractors located in developing countries.

The following analysis shows that businesses not only benefit from carbon disclosure and management in form of reduction of energy costs, improved reputation and a decrease of their dependence on fossil fuels but also especially suppliers in developing countries can benefit from externalities as first-mover advantage, eligibility of financial assistance, technology and innovation.

Index terms

International Trade, International Supply Chains, Carbon Disclosure, Food Export Industry, Latin America and the Caribbean

1 Introduction

Although no internationally binding climate change agreement was reached during the recent Climate Change Conference in Doha, a number of OECD countries committed themselves to the post-2012 increased reduction targets for carbon emissions. With the success of these post-2012 mitigation policies, the production of carbon-embodied products will be further reduced within OECD countries.

The United Kingdom and Germany, which reached their carbon reduction targets set out in the Kyoto protocol before their deadline, did not reduce their carbon consumption and were among the top net importers of embodied emissions in 2004: Japan, the United Kingdom and France imported 3 times more kg CO2/ $ traded than it exported, Germany around 2,5 times more, Italy 2 times more and the United States 1,6 times more. Current data shows that around 25 percent of all carbon dioxide emissions related to human activity is traded through import and export of products. In particular, developed countries are net importers of carbon-embodied products, while developing countries are net exporters (Davis and Caldeira 2010).

As the consumption of carbon-embodied products is expected rather to increase than decrease due to population growth and consumer behaviour, carbon-embodied imports in OECD countries are supposed to further increase as well. Most likely, increased carbon consumption will be met by increased production of carbon-embodied products in developing countries. Thus, policymakers fear, that climate change policies in committing OECD countries could be undermined by the so-called carbon leakage effect, the increase in carbon-embodied imports from non-committing into committing countries.

Most commonly, governments opt for policies counteracting the leakage effect through border measures to reduce carbon-embodied imports. Meanwhile, consumers are worried about the devastating environmental impact of climate change and increasingly demand sustainable products. Moreover, competition is fierce, as industries increasingly advertise their efforts to make their production processes and supply chains more energy-efficient. Even investors put increasing pressure on businesses to account for and decrease their carbon emissions.

As a result of tightened mitigation policies in OECD countries and growing awareness of the risks of climate change, especially multinational companies as the main importers of carbon-embodied products are beginning to implement low-carbon strategies among their whole international supply chain including suppliers and sub-contractors located in developing countries. Thus, exporters in developing countries, which were initially exempted from the Kyoto Protocol, find themselves confronted with climate change mitigation policies of OECD countries.

Additionally to this regulatory impact, developing countries and especially their agricultural sectors face a growing physical threat of climate change. For instance, Garlati (2013) identifies floods, rainfalls, storms and landslides, which are all natural disasters impacting the agricultural sector, as being particularly frequent in recent decades in Latin America and the Caribbean. Besides, already more than 60 percent of the respondents of the recent Latin America report of the Carbon Disclosure Project (2012) perceived alterations of extreme weather events as the main risk of climate change to their businesses. Hence, a Latin American climate change response can neither be avoided nor delayed, and should have a top priority on governmental and corporate agendas.

In the following the paper focuses on the reasons for and challenges of the inclusion of Latin American food suppliers in the management and disclosure of carbon emissions within international supply chain. Finally recommendations addressing the question “what is still missing” with respect to carbon management and disclosure in international supply chains are given.

2 Carbon Emissions Disclosure and Management in the Latin American Food Export Industry

The Latin American and Caribbean food export industry was chosen as an example, as the region accounts for 11 percent of the international food production and inhabits 24 percent of the worldwide arable land (IADB 2013). Due to its counter-cyclical seasons, Latin American countries are food export leaders in many product categories (Comtrade 2013). According to De La Torre et al. (2009) the agricultural sector, including land-use change, in Latin America contributes around 70 percent to the region´s total greenhouse gas emissions compared to a global average of 55 percent.

As the global demand for food is estimated to increase by 50 percent to 85 percent until 2030, the Latin American food export sector, which is currently favoured by increased commodity prices, is expected to grow substantially in the upcoming years (Vosti et al. 2011).

As a result, the Latin American food export industry faces a threefold challenge: it has to increase agricultural output to benefit from the increased food demand while keeping carbon emissions low and adapting to the physical threat of climate change. Food exporters, in particular, are pressured and incentivized to be more energy-efficient due to regulations transmitted by international supply chains and impacts of energy markets via fertiliser and transportation prices as well as the increasing biofuel demand.

2.2 Reasons for Carbon Disclosure and Management

The OECD (2010) summarizes the general benefits of carbon disclosure and management as: reduction of energy costs, gaining independence from fossil fuels, opening of new business opportunities and improvement of reputation. Furthermore, there are a number of externalities of carbon disclosure and management from which particularly businesses in developing countries can benefit.

First of all, Bosetti and Victor (2011) argue that governments of developing countries can gain substantial international and national credibility by pre-committing to international climate change regulations, thus anticipating border carbon adjustments and speeding up investments into low-carbon technologies among businesses. In the Latin American report of the Carbon Disclosure Project (2012) the respondents ranked, besides reputation, international agreements, cap-and-trade systems, taxes and regulations on fuels and energy as well as standards and regulations for efficient products among the top five business opportunities of climate change. This result mirrors the importance of setting standards and regulations to which businesses can adhere to benefit from a first-mover advantage.

Moreover, committing small and medium-sized enterprises (SMEs) in Latin American countries are eligible for international financial support for climate change adaptation and emissions mitigation. For instance, via its Clean Technology Fund the Inter-American Development Bank invests into innovative SMEs in Latin America to improve energy efficiency and replace fossil fuel energy sources with clean energy sources (IADB 2012). The Dutch Sustainable Trade Initiative financially supports agricultural businesses in developing countries to produce sustainably and obtain certifications needed to export to “premium international markets” of OECD countries (Dutch Sustainable Trade Initiative 2012).

Furthermore, international supply chains can act as a channel for the diffusion of technology and knowledge. As the OECD (2010) points out: “multinational enterprises are the main conduit of technology transfer across borders”. For instance, the retailer Walmart incentivizes its suppliers to disclose their carbon emissions to the Carbon Disclosure Project, while offering guidelines, workshops and trainings on carbon disclosure and management (Carbon Disclosure Project 2013).

2.3 Challenges of Carbon Disclosure and Management

Before engaging in carbon emissions disclosure and management, Latin American food exporters primarily have to choose the right methodology, be trained in carbon disclosure and management and obtain the necessary technologies and financial assistance. Businesses reaching out to their respective suppliers should offer substantial support in all of these aspects.

Though a number of initiatives for the harmonization of methodologies have emerged in recent years, most of them are based in OECD countries and do not include specification about supply chains. Hence, there is a threat of misrepresentation of carbon emissions in developed countries and along international supply chains. To overcome this threat the industries in developing countries are particularly asked to proactively join existing carbon disclosure schemes and promote the integration of their industry and country specific characteristics into the respective schemes. Especially businesses with an international competitive advantage of energy efficiency should integrate themselves.

Moreover, most Latin American countries are located far away from their export destinations. Hence, emissions from transportation account for a large share of total carbon emissions in the supply chain. Furthermore, due to poor infrastructure in the region, transportation expenses are already high and range between 16 percent and 26 percent of GDP compared to around 9 percent of GDP among OECD countries (World Bank 2012). Hence, it is particularly important for Latin American countries to apply a carbon methodology, which accounts for transport specifications not add unnecessary costs.

In a World Bank Study on the effectiveness of carbon footprints for agricultural products Brenton et al. (2010) outline key aspects as land use change, carbon sequestration, and blend of products, which should be addressed when designing a carbon accounting and labelling system in developing countries.

Firstly, land use conversion for farming in developing countries increasingly takes place in order to raise agricultural output. The resulting loss of carbon captured in trees and soil accounts for the highest share of carbon emissions of the carbon footprint of agricultural products. In contrast to developing countries, developed countries such as the US or EU do not have to include carbon emissions from land use change, as land use conversions there took place decades or even centuries ago. Especially South American countries inhabiting rainforest like Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana, and Suriname as well the Central American countries Panama, Costa Rica, Honduras, and Belize as well as the southern part of Mexico, have to address the issue of land use conversion to accurately account for the carbon footprint of their agricultural products. Secondly, Latin American countries exporting agricultural products as coffee, cocoa, tea, fruits and nuts obtained from trees which capture carbon as well as the trees' soils do, cannot fully benefit from this positive effect of carbon capture, as only few carbon accounting system recognise it. Finally, some agricultural products are sold as a mix of ingredients from different countries of origin, which have to be accounted for as well.

3 Conclusion: What is still missing?

The example of the food export industry showed that compliance with climate change policies, which are transmitted through international supply chains, is necessary based on a number of arguments and the particular physical threat, which climate change poses on Latin America´s food industry. In the following some selected recommendations are presented as answers to the question "What is still missing?" with respect to management and disclosure of carbon emissions in international supply chains.

Firstly, an internationally common methodology to account for carbon emissions reaching beyond the borders of the European Union is needed to improve 1) feasibility; 2) practicability; 3) available data; and 4) to decrease the costs associated with carbon disclosure. Governments in cooperation with international organizations are urged to find an internationally binding agreement on carbon disclosure and management and to provide clear guidelines to the private sector. Finally, carbon footprint data should be made publicly available and easy to access for producers and consumers to reach greater public transparency. Furthermore an independent verification system has to be established to increase the credibility of carbon disclosure schemes.

Secondly, a customized methodology for carbon accounting in agricultural sector in developing countries has to be established. Governments and the private sector in developing countries should promote the incorporations of country characteristics as well as those of their products into carbon disclosure schemes.

Moreover, it is highly recommended, that businesses, especially those being affected by the physical impact of climate change, internalize the costs of future environmental damage in their cost and risk analysis and price determination models.

Finally, communication and cooperation on B2B and B2C levels has to be improved. Governments and those businesses, which are reaching out to their small and medium-sized suppliers, should support the affected sectors by providing training, guidelines and financial assistance to disclose and manage their carbon emissions.

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