The Inter-Sectoral Impact Model Intercomparison Project

ISIMIP2a

Simulation protocol

last updated on 22 May, 2017

Table of Contents

1 Introduction

1.1 ISIMIP: General concept

ISIMIP provides a framework for the collation of a consistent set of climate impact data across sectors and scales. This framework will serve as a basis for model evaluation and improvement, allowing for improved estimates of the biophysical and socio-economic impacts of climate change at different levels of global warming. It also provides a unique opportunity for considering interactions between climate change impacts across sectors through consistent scenarios.

ISIMIP is intended to be structured in successive rounds, each having its own focus topics (see section 2.1) and focus regions (see section 2.2) that inform the scenario design. The main components of the ISIMIP framework are:

- A common set of climate and other input data which will be distributed via a central database;
- A common modelling protocol to ensure consistency across sectors and scales in terms of data, format and scenario set-up;
- A central archive where the output data will be collected and made available to the scientific community.

1.2 General remark regarding adaptation

As in the ISIMIP Fast Track, simulations should not be designed to describe the effects of different adaptation measures. In contrast, it is the aim to describe the impacts of climate change on different sectors under "present-day" management assumptions. There are individual exceptions to this general rule (such as "naturalized" runs within the water sector). These exceptions are clearly specified in the sector-specific scenario set-up of the simulations (see Chapter 7). Wherever such an exception is not mentioned please choose the "present day" option regarding management.

In particular, the historical validation runs should be "as close to the real historic conditions as possible" (i.e. to the extent to which this can be achieved without major model improvement).

2 General Design of ISIMIP2a

2.1 Focus topic

"Extreme events and variability" was chosen as the focus topic of ISIMIP2a, reflecting the interest of the community as well as stakeholders in investigating and improving the representation of variability and extreme events, in particular in impact models and along the entire modelling chain. Therefore, the model evaluation and validation task specified in this protocol is explicitly designed to evaluate the models' ability to reproduce observed historical variability, responses to extreme climatic events such as heat waves, droughts, floods, heavy rains and storms, and representation of extreme impact events (ISIMIP2 A see section 2.3).

Based on these evaluation exercises, modelling teams will have the opportunity to adjust model parameters, and implement necessary model improvements. As a next step (see the ISIMIP2b protocol), future projections will be performed using these improved impact model settings. To this end it is also intended to implement an improved bias correction method, which better preserves variability and extreme events, and to apply this method to the RCP climate projections. This exercise will also make it possible to estimate the extent of impacts that are *not* captured, or possibly over- or underestimated, in already-available impact projections from the Fast Track using the original model settings.

Note that the emphasis on this focus topic does not exclude some other work not directly related to extreme events and variability. For example, in particular for regional models and in new sectors, it may be important to first calibrate and investigate performance for average condition.

2.2 Focus regions

While only global impact models participated in the ISIMIP Fast Track, ISIMIP2 will bring together both global and regional modelling groups. A common set of focus regions will allow for a comparison between global and regional (i.e. sub-global) models, as well as an integration of regional impacts from different sectors. It was developed together with participants prior to and during the side event of the Impacts World 2013 conference. Figure 1 shows the set of focus regions.

This first selection represents a compromise between maximising coverage of climatic, environmental and cultural zones, and keeping the associated workload feasible. The set of regions may be extended to cover new regions that are highly relevant with regard to climate change impacts but are currently under researched, or to accommodate new sectors. It may also be extended to include regions of specific interest to individual sectors, such as is already indicated by the dashed boxes in Figure 1, which are particularly relevant for the regional forest and water modellers. Participants working with (regional) marine ecosystem and fishery models are encouraged to focus on coastal regions adjacent to selected river basins (e.g. Rhine – North Sea; Mississippi – Gulf of Mexico; etc.).

All participants running regional models are asked to set up and run their models for as large a part of each focus region as possible, in order to obtain maximal spatial overlap with other models.

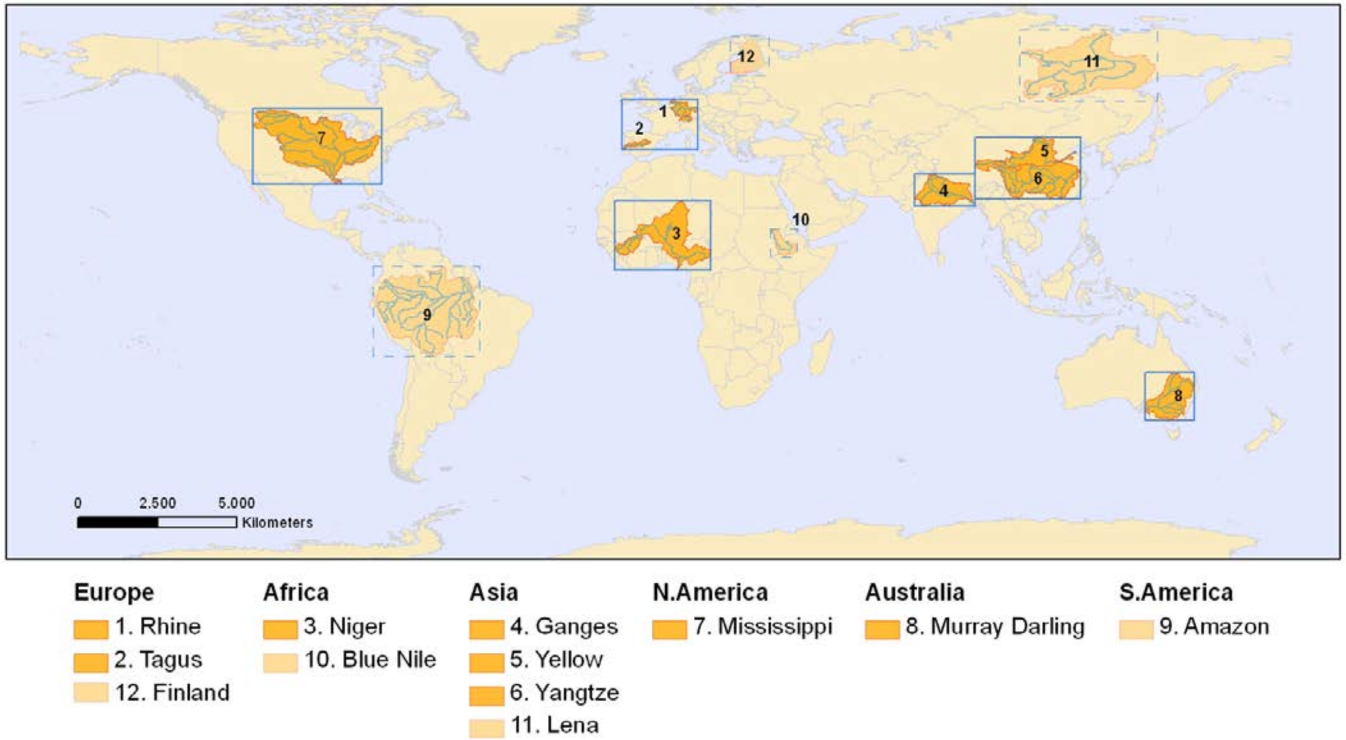

Figure 1: Focus regions of ISIMIP2. Solid boxes (centered on river basins marked in dark orange) indicate cross-sectoral focus regions. Dashed boxes and river basins/countries marked in light orange indicate possible sector-specific extensions (e.g. forests in Finland and the Amazon region, water in the Upper Amazon, Lena, and Blue Nile river basins).

Table 1: List of focus regions (as depicted in Figure 1).

Focus region (shortname)	Zonal extent	Meridional extent	River basin(s) (shortname)
		Cross-sectoral focus regions	
North America (nam)	114°0'W– 77°30'W	28°30'N–50°0'N	Mississippi (Mississippi)
Western Europe (weu)	9°30'W–12°0'E	38°30'N–52°30'N	Rhine and Tagus (rhine)
West Africa (waf)	12°0'W–16°0'E	4°0'N–24°30'N	Niger (niger)
South Asia (sas)	73°0'E–90°30'E	22°0'N–31°30'N	Ganges (ganges)
China (chi)	90°30'E–120°30'E	24°0'N–42°0'N	Yellow and Yangtze (yellow, yangtze)
Australia (aus)	138°30'E–152°30'E	38°0'S –24°30'S	Murray Darling (murrydarling)
		Sector-specific extensions	
Amazon (for forest and water sectors) (ama)	80°0'W –50°0'W	20°0'S –5°30'N	Amazon (amazon)
Finland (for forest sector) (fin)	21°0'E–32°0'E	59°30'N–79°30'N	-
Blue Nile (for water sector) (blu)	32°30'E - 40°0'E	8°0'N - 16°0'N	Blue Nile (bluenile)
Lena (for water sector) (len)	103°0'E - 141°30'E	52°0'N - 72°0'N	Lena (lena)

2.3 Structure of ISIMIP2a

Depending on whether or not a given model has already participated in the fast-track phase, ISIMIP2a will comprise the following steps:

Table 2: Simulation tasks in ISIMIP2a

	Fast-track models	**New sectors/models**
ISIMIP2a	Historical runs → validation and evaluation with focus on variability and extremes	Historical runs → validation and evaluation with focus on variability and extremes (this may, particularly for regional models, include calibration and validation for average conditions as a first step)
		Run impact models driven by ISIMIP fast-track climate data using fast track protocol ("catch-up runs"; with modifications for new sectors where necessary)

Important: New sectors/models, for "catch-up runs", please consult the Fast Track simulation protocol! See www.isimip.org > Protocol > Fast Track

3 Motivation of experiment design

This chapter provides a short description of the scientific rationale behind the design of each of the experiments in ISIMIP2a. The details of the experiments are further described in the remainder of the protocol.

The overarching objective of the historical validation experiment is to gain insight into the ability of current impact models to reproduce observed features of simulated variables, with an emphasis on (but not limited to) variability and extreme events. Simulations are designed such as to match historical conditions as closely as possible, within the limitations of e.g. availability of historical forcing data, variety of model formulations, and model development resources.

Conducting such an experiment within ISIMIP can facilitate a cross-sectoral synthesis of state-of-the-art modelling skills and help identify key opportunities for model improvement efforts. Examples of research questions that could be addressed include: How good is the current generation of impact models at reproducing the observed response to a certain climatic event (e.g. the Russian heat wave in 2010) across different sectors? What are the historic extreme events that are "extreme" across different sectors and are they reproduced by the different model types? Can yield losses in certain regions only be reproduced by accounting for the limited availability of irrigation water? In addition to the conventional, standardized validation exercises one could also look at the simultaneous effects of e.g. ENSO, as a major climatic driving force, across the various sectors, and compare with observations. One could also calculate drought indices from the water model results and test the influence of those droughts e.g. on yields. Another interesting question is the spatial and temporal coherence/concurrence of impacts in different sectors.

Four different observations-based historical climate datasets will be used to force impact models, to allow for a comparison of the different historical simulations. Each data set has its own strengths and weaknesses (e.g. regarding temporal extent, quality of particular variables, previous application within the modeling community) and generally represents a plausible reconstruction of the terrestrial climate of the past ~100 years. The different historical simulations will allow a systematic quantification of the effect of the choice of forcing data on impact model results; allow comparison to previous studies using either of these datasets; and provide an extensive data base for model evaluation and impact assessment, in particular with regard to the focus topic (e.g. a certain climatic extreme event could be better reproduced in one data set than in the other).

Note that one important criterion for the selection of climate forcing datasets was their temporal extent. Biomes models in particular need long spin-up, therefore it is crucial that the datasets cover a substantial extent of time before the start of the reporting period. Also, note that the GSWP3 (Global Soil Wetness Project 3) data set was only recently developed and a description paper is not yet available. This dataset is based on dynamical downscaling and thereby promises rather good quality in particular with regard to the resolution of the variability. A short description of the main characteristics of this dataset will be distributed by email and is also available upon request. Further details on the global dynamical downscaling method are given in ref (Yoshimura & Kanamitsu, 2008, 2013).

4 Common input data and settings for all sectors

This chapter describes climate forcing data and other input data that should be used by modelling groups in all sectors. See chapter 7 for additional, sector-specific input data and data for model validation. Note in particular that for some sectors the individual tasks (e.g. historical validation runs ISIMIP2a) may involve several different experiments with differences in input data and other settings. In this chapter we only describe the general rationale of the different tasks and list the common input data sets.

If you require additional input data that is neither specified in this chapter nor in chapter 7, please use your default data source. In case anything remains unclear please contact the coordination team or sectoral coordinators.

4.1 Historical validation runs

4.1.1 Atmospheric data

Please use the historical climate data listed in **Table 3** for the historical validation runs. The runs should start in 1971, or earlier if spin-up is needed (see below and section 6.1). All data will be available through the ISIMIP website, www.isimip.org. Separate historical simulations should be conducted with each of four different datasets, in the order indicated in the last column of **Table 3**. This is because each of the datasets has its own advantages and shortcomings, and thus by using several it will be possible to assess the influence of the choice of forcing data on the overall results. Moreover, this procedure serves the needs of the different participating sectors (e.g. data over ocean is needed for the fisheries sector), and facilitates consistency with other model intercomparison exercises (e.g. ISIMIP Fast Track; GSWP3). Modelling groups that cannot run all four datasets before the submission deadline should nonetheless begin in the order indicated, and inform the ISIMIP coordination team.

Table 3: Historical (atmospheric) climate data sets to be used in validation runs. All data sets contain the variables tas, pr, rhs, rlds, rsds, ps, wind, and partly also tasmin and tasmax. Note that simulations should be conducted with each of these datasets.

Dataset	Reanalysis	Years	Resolution, coverage	Bias target	Order of simulations; comments
PGMFD v.2 (Princeton) (Sheffield et al., 2006)	NCEP/NCAR Reanalysis 1	1901-2012	0.5° Land + Ocean	CRU, SRB, TRMM, GPCP, WMO validated against GSWP2	1
GSWP3 (Kim, n.d.)	20CR	1901-2010 (2011 and 2012 to be added soon)	0.5° Land + Ocean	GPCC, GPCP, CPC-Unified; CRU; SRB	2
WATCH (WFD) (Weedon et al., 2011)	ERA-40	1901-2001	0.5° Land	GPCC	3
WFDEI.GPCC (Weedon et al., 2014)	ERA-Interim	1901– 2012 (with 1901-1978 taken from WFD, WFDEI.GPCC data starting in 1979)	0.5° Land	GPCC	4 Combined forcing file (WFD 1901-1978, WFDEI.GPCC 1979-2012) will be provided by ISIMIP. **NOTE** a discontinuity in the data exists at the transition from WATCH to WFDEI, and results must be interpreted with caution.

Historical **CO2 concentrations** are also provided in the input data archive (historical_CO2_annual.txt). They are based on time series of global atmospheric CO2-concentrations from Meinshausen, Raper, & Wigley (2011) for 1765-2005 and Dlugokencky & Tan (2014) from 2006-2013.

Note that simulation results only need to be submitted for the reporting periods specified in section 6.1. The parts of the climate forcing data prior to the reporting period may be used for spin-up purposes and/or to facilitate further analyses. Simulation results for years outside the reporting period may still be submitted to the ISIMIP repository on a voluntary basis.

4.1.2 Oceanic data

See section 14.

4.1.3 Land-use/land-cover and soil data

We provide a time-varying historical land-use (LU) data set that should be used for the historical validation runs. The time series starts in 1700 and ends in 2012 (LandUse_DynamicMIRCA_1700-2012.nc) and should be applied for the spin-up as well as for the historical runs, as described above. This file includes constant LU at year-2000 level during the period 2000-2012. The HYDE3/ MIRCA data set does not contain any information about different types of natural vegetation. Modellers should follow their own default assumption regarding the partitioning of the area covered by natural vegetation between the different types; the coordination team will provide guidance if needed. Models that simulate their own natural vegetation should report that.

Table 4: Land-cover and soil data to be used in historical validation runs.

Dataset	Description	More info	Scale	Variables included
Mandatory:				
Historical cropland patterns "HYDE3/ MIRCA"	Combination of present-day (year 2000) crop and irrigated areas from MIRCA and trends of agricultural land from HYDE	Portmann et al. (2010) for MIRCA; Hoekstra, 1998 and Appendix of Fader et al. (2010, J Hydrol) for HYDE. Contact: LPJmL team at PIK for HYDE	Global 0.5°Annual	irrigated and rainfed crop areas for the following crop and vegetation classes: TEMPERATE_CEREALS, RICE, MAIZE, TROPICAL_CEREALS, PULSES, TEMPERATE_ROOTS, OIL_CROPS_SUNFLOWER, OIL_CROPS_SOYBEAN, OIL_CROPS_GROUNDNUT, OIL_CROPS_RAPESEED, SUGARCANE, OTHERS, PASTURES

Historical area covered by natural vegetation	Derived from “HYDE3/ MIRCA” as 1-(all agricultural area). Note that forestry is counted as natural vegetation because of lack of historical forestry data.		see above	fraction of grid cell covered by natural vegetation
Optional:				
HWSD or GSWP3 (upscaled version of HWSD)	soil map	See http://hydro.iis.u-tokyo.ac.jp/~sujan/research/gswp3/soil-texture-map.html, upscaling method A. Each model has the option to use their own soil datasets if preferred.	Global 30 arc sec (HWSD) *or* 0.5° (GSWP3) fixed	soil types: Sand, Loamy Sand, Sandy Loam, Loam, Silt Loam, Silt, Sandy Clay Loam, Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay, Clay, Ice

4.1.4 Socio-economic input

The historic population data are taken from the UN World Population Prospects 2010 revision[1]. The historic GDP data are from the World Bank World Development Indicators database[2] (see **Table 5**). Both datasets are available via www.ISIMIP.org. The reporting period for model simulations making use of this information is restricted to 1960-2010 (see section 5.1).

1 Documentation accessible at http://esa.un.org/unpd/wpp/Documentation/WPP%202010%20publications.htm

2 Accessible at http://data.worldbank.org/data-catalog/world-development-indicators

Table 5: Socio-economic data to be used for validation runs

Variable	Name	Unit	Frequency
Population (1950 - 2009), country level on 0.5°x0.5° grid	pop	number of people	annual time steps
GDP (1960 - 2010), country level	gdp	GDP PPP (can also be written as MER)	annual time steps

4.2 Catch-up runs

4.2.1 Atmospheric Data

Within the ISIMIP Fast Track bias-corrected climate data from 5 GCMs participating in the CMIP5 were provided. Data cover the time period from 1950 to 2099, i.e. the historical period, and future projections for all RCPs (RCP 2.6 (also called RCP3-PD), RCP 4.5, RCP 6.0, RCP 8.5). The same atmospheric data should be used for the Fast-Track catch-up runs.

The data have been bias corrected (see Hempel et al., 2013, ESD). They only cover the global land area (see section 4.2.2 for oceanic variables) on a 0.5°x0.5° grid, and are available via www.isimip.org.

For the catch-up runs the **CO_2 concentration** should follow the historical time series from 1951 onwards up until 2005. In 2006, switch to the RCP CO_2 concentration data.

Table 6 Climate input variables

Variable	Name	Unit (NetCDF format)	Frequency	Bias correction method[3]
Surface air temperatures T_{avg} T_{min} T_{max} (24 hour values)	tas, tasmin, tasmax	K (K)	daily & monthly	Mean and range matched to WATCH data (1960-1999)
Precipitation (sum of snowfall and rainfall)	pr	$Kg/m^2/s$ (kg m-2 s-1)	daily & monthly	Statistical distribution matched to WATCH data
Surface radiation (short- and longwave downwelling)	rsds rlds	W/m^2 (W m-2)	daily & monthly	Statistical distribution matched to WATCH data
Near-surface wind speed (east- and north-ward)	uas vas	m/s (m s-1)	daily & monthly	Statistical distribution matched to WATCH data
Near-surface wind speed (total)	wind	m/s (m s-1)	daily & monthly	Statistical distribution matched to WATCH data
Surface air pressure	ps	Pa (pa)	daily & monthly	Statistical distribution matched to WATCH data
Near-surface relative humidity	rhs	% (%)	daily & monthly	None
CO_2 concentration	co2	ppm (ppm)	annual	None

IMPORTANT: Whenever possible, monthly data should only be used for models that run with a monthly time step. Models requiring daily input data should use the daily data provided, rather than downscaling monthly data (i.e. **do not** use built-in weather generators to downscale monthly data to a daily time step unless multiple iterations are required for model processes). Models requiring sub-daily resolution should apply native downscaling methods to the provided daily data.

4.2.2 Oceanic data (Fast-track Equivalent)

See section 14.

4.2.3 Land-use/land-cover data

For the **catch-up runs,** use LU patterns as specified within the Fast Track protocol (e.g. pure crop runs for the crop models, pure natural vegetation runs for the biomes models, and "present day" or naturalized runs for the water models).

4.2.4 Future Socio-Economic Data

Socio-economic data (population and GDP; see **Table 7**) are provided and include all Shared Socio-Economic Pathways (SSPs 1-5, developed as part of the ongoing socio-economic scenario development process[4]). In ISIMIP2a, SSPs 1-5 should be used for the "catch-up runs" where applicable (see Fast Track protocol).

The parameter space of the Shared Socio-Economic Pathways (SSPs) is spanned by challenges for adaptation and challenges for mitigation. The former essentially means levels of development and the latter can be translated to degree of fossil energy and resource intensity. For each SSP there will be exactly one population and GDP scenario.

Note that there is no one-to-one connection of a given SSP with a given RCP. Instead the combination of SSPs with different climate policy and also adaptation assumptions will result in different forcing levels. More information on the SSPs can be found at http://www.isp.ucar.edu/socio-economic-pathways.

[4] See http://www.isp.ucar.edu/socio-economic-pathways for more information.

Table 7: Socio-economic variables provided via the ISIMIP database.

Variable	Name	Unit	Frequency	Spatial scale
Population	pop	number of people	5-year time steps[5]	country level (alpha-3 country code)
GDP	gdp	PPP; can also be written as MER		

4.2.5 Future fishing pressure

See section 14.

5 If annual data is required, please interpolate the data linearly.

5 General Spin-up procedures for historical and catch-up runs

5.1 Spin-up procedure for validation runs

Models requiring spin-up should make use of the portion of the respective climate forcing data set prior to the reporting period (i.e. prior to 1971. See Figure 3 for an illustration of the data to use for spin-up). For extending spin-up prior to 1901, a **spin-up data set** has been prepared by generating a “constant climate” data set of 120 years as a random combination of individual years from the 1901-1930 period of the individual data sets.

For models requiring **more than 70 years** of spin-up, we have provided a script that generates up to 2000 years of spin-up data, based on random drawings from detrended climate data from 1901-1930. After running the necessary length of spin-up data, continue with the respective climate forcing data set, starting in 1901. See section 4.1.1 for more information on the historical climate forcing data sets.

Use historical CO_2 concentration, as provided in the input data archive (use at most the years 1765-1970; filename: historical_CO2_annual.txt), for spin-up. For example, when using the extended climate spin-up data set (i.e. generated using the script provided), use CO_2 concentration for the period 1780-1900. When using a longer spin-up period that extends back further than the CO_2 concentration data, please keep CO_2 concentration constant at 1780 level until reaching the year corresponding to 1780.

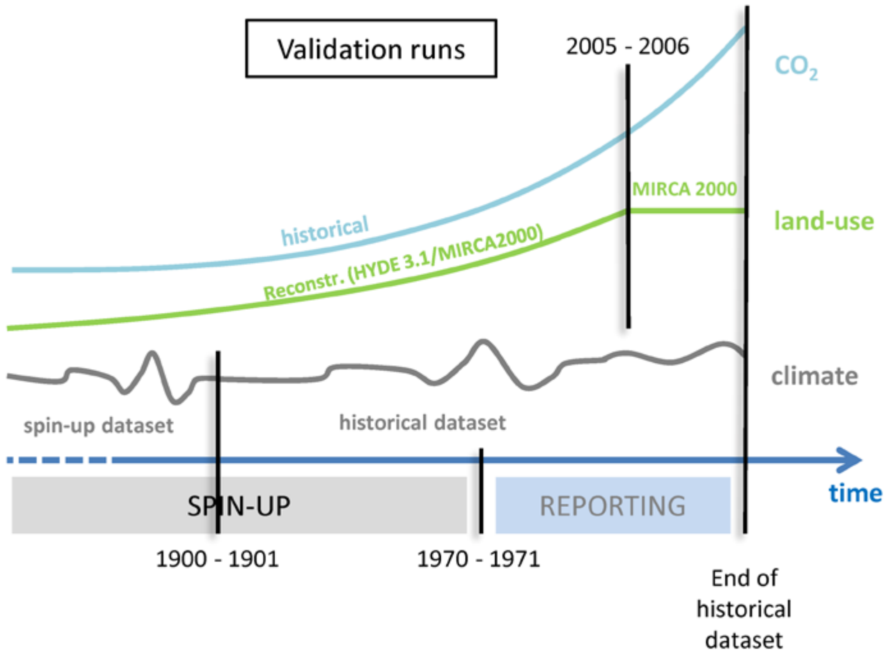

Figure 2: Input data scheme for historical validation runs. Information shown here holds for all sectors, but further details may vary across sectors – see Chapter 7.

5.2 Spin-up procedure – catch-up runs

For the catch-up runs a potentially required spin-up should be identical to the fast track spin-up (see Figure 4). With respect to the atmospheric data please apply the following procedure:

A climate **spin-up data set** has been prepared by de-trending the bias-corrected GCM data between 1951-1980, and is normalized to reflect a climate representative of the 1950 conditions. If your model requires **more than 30 years** of spin-up, the 30-year spin-up data set can be replicated and assembled back-to-back to obtain longer data sets; in this case, **make sure to reverse the order of years in alternate copies** of the 30-year period, in order to minimize potential discontinuities in low-frequency variability. After running as many instances of the 30-year spin-up data set as required, continue using climate input data from the appropriate GCM, from 1951 to 2005 (the RCP projections start in 2006).

For the catch-up runs the **CO_2 concentration** of the spin-up should be fixed at 1950 levels for the (potentially copied) 30 year period and follow the historical time series from 1951 onwards, up until 2005. In 2006, switch to the RCP CO_2 concentration data.

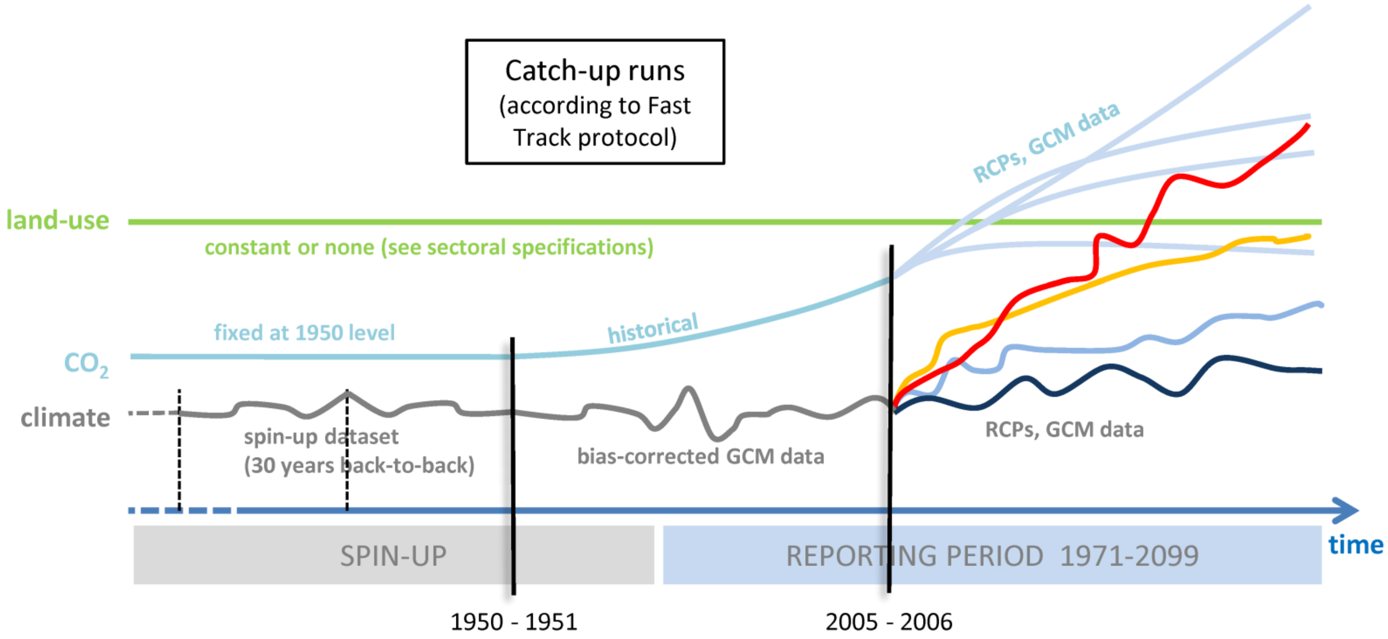

Figure 3: Input data scheme for "catch-up" runs, equivalent to the projections done in the ISIMIP Fast Track.

6 Reporting model results

6.1 Reporting and reference time periods

Table 8 Reporting and reference time periods

Item	Time period	Comments
Reporting time for historical validation runs independent of socioeconomic information about population and GDP	1971-end year of the historical climate input dataset	For transient runs. Please provide output data for the entire period. For Forest models: Please note that the reporting period starts with the first year for which stand data for model initialization is possible. Please see the introduction of the forest protocol (section 7.3.1) for further information.
Reporting time for catch-up runs	1971-2099	For transient runs. Please provide output data for the entire period.
Time slices for catch-up runs	present-day 1980-2010 (middle year 2000) (for 2006-2010 data, please use the RCP 4.5 run of each GCM)	Time slices should be provided if your model is too computationally expensive to do the transient runs, and/or if the application of transient land-use (LU) changes is not feasible. In this case, LU patterns of the corresponding middle year should be applied for the entire time slice.
	near-term 2005-2035 (middle year 2020)	
	mid-century 2035-2065 (middle year 2050)	
	end-of-century 2069-2099 (middle year 2085)	

Present-day population/GDP	2000	
Present-day land-use	2000	
Reference period	1980-2010	The reference period (and reference year) is defined only for post-processing purposes, to describe future projections relative to present-day conditions. Please fill in the years from 2005 to 2010 **by the associated** RCP (depending on the future simulations you consider). When reporting your output data, always provide absolute values.
Reference year	2000	

6.2 Convention for file names and formats

NOTE: For 'catch-up' runs, please use the (slightly different) conventions specified in the Fast Track protocol (see www.ISIMIP.org).

6.2.1 File names

One variable should be reported per file. The file names should follow this convention for the **historical validation runs**:

<modelname>_<obs>_<clim_scenario>_<socio-econ-scenario>_<sens-scenarios>_<variable>_<region>_<timestep>_<start-year>_<end-year>.nc4

where the parts in brackets should be replaced with the appropriate specifier, and where more than one specifier applies, the order in **Table 9** should be respected. Specifiers may be dependent on the sector. The associated sectors are given in brackets in **Table 9**. If there is not specifier for the associated sector it should be omitted from the model name. For example (cf. chapter 7):

lpjml_gswp3_pressoc_co2_qtot_global_annual_1971_2012.nc4 for the water sector and

lpjml_gswp3_firr_co2_default_yield_mai_global_annual_1971_2012.nc4 for a maize crop model run.

If there is more than one indicator specifying the sensitivity experiment (e.g. CO2, full irrigation and default model parameters for crop models simulations, please specify them in the order of the listing in **Table 9**). For example:

lpjml_gswp3_rcp4p5_pop.ssp2_gdp.ssp2_noco2_qtot_global_annual_2005_2099.nc4 for the water sector and

lpjml_gswp3_rcp4p5_noco2_firr_default_yield_mai_global_annual_2005_2099.nc4 for a maize crop model run.

Use **only lowercase** letters in the file names (necessary for some NetCDF viewers). In case of any questions, please contact the coordination team (info@isimip.org) before submitting files.

Table 9: File name specifiers for output data

Item	Possible specifiers (use lowercase letters only!)	Explanation
<modelname>	*(your model name as registered with ISIMIP)*	Name of the impacts model
<GCM/obs>	hadgem2-es, ipsl-cm5a-lr, miroc-esm-chem, gfdl-esm2m, noresm1-m (all sectors)	Name of the General Circulation Model providing the climate forcing data for the catch-up runs
	gswp3, princeton, watch, wfdei (all sectors)	Name of the observations-based dataset providing the climate forcing data
	localclim (Forests)	For locally observed weather data from a weather station or similar which is in direct proximity of the forest stand and has been used for detailed model evaluation runs. Please include in the metadata of the file which local forcing the climate is based on (e.g. German Weather Service) as described in the Forest protocol.
<clim-scenario>	rcp2p6, rcp4p5, rcp6p0, rcp8p5	CO2 concentration scenario (RCP)
	hist	Historical climate information

	presclim	Present-day climate (1980-2010). For agro-economic models it means averaging biophysical information from the present day period of the biophysical model runs (Note: They differ from GCM to GCM). This run is essential to quantify the pure climate induced changes as the difference between the RCP and the presclim run.
	noclim	Demand-side runs; to compute future non-agricultural water use/ withdrawal/ consumption – only for appropriate models (e.g. WaterGAP, H08). Use population and GDP according to SSPs (as provided). For hydrological models only.
<socio-econ-scenario>	For validation experiments	
	nosoc	Naturalized runs (no human impact). No irrigation. No population and GDP data prescribed. For hydrological models only.
	pressoc	Present-day human impact runs: only climate varies; keep all other settings (population, GDP, land-use, technological progress etc.) constant at year 2000 values. This run will be used to quantify adaptation pressure under current socio-economic conditions. For water models that do not run separate irrigation sensitivity scenarios, pressoc includes present-day irrigation.
	varsoc	In addition to climate population, GDP, land-use, technological progress etc. varies over the historical period
	nat	A natural vegetation only run without any land-use pattern (optional for biomes models). This is a reference run to separate fluxes from natural vegetation and agriculture in runs with historic land-use. It is like the nosoc run but without land-use. If your model does not distinguish between natural and managed land, the “nat” run will be identical to the “nosoc” run. For forest models, this means

	man	running the model without any management. For forest models: indicates simulation including forest management
<socio-econ-scenario>	For future runs	
	pop.<x>_gdp.<y> , where x = ssp1, ssp2, ssp3, ssp4, or ssp5 and y = ssp1, ssp2, ssp3, ssp4, or ssp5 (water, biomes)	Shared socio-economic pathways for future projections: population <x> and GDP <y> according to different SSPs
	ssp<x>_pressoc (water, biomes)	population according to SSPx; year 2000 GDP
<sens-scenario>	A combination of the following settings:	
	co2 (only for future runs; water, biomes, crop models)	Transient CO2 concentration (taken from the RCP and historical data) for CO2 fertilization effects. If your model does not implement CO2 fertilization using transient CO2 concentrations, please use your own implementation and include that in the reporting.
	noco2 (only for future runs; water, biomes, crop models)	CO2 concentration fixed at present-day value, i.e. run with transient historical CO2 up to the year 2000 and keep CO2 fixed at 369ppm thereafter. Sensitivity experiment: only applies to models that take CO2 into account.
	co2const	Keep CO2 concentration constant at 1971 level. For spin-up, use time-varying, historical CO2 concentration until 1970.
	firr (for crop models)	Full irrigation, i.e. until the soil is saturated.
	noirr (for crop models)	No irrigation. Both irrigation variations are required for the agro-economic models.

	harmnon (for crop models) fullharm (for crop models) default (for crop models)	full fertilizer run, i.e. ensuring no N constraints, harmonized sowing and harvesting dates full harmonization with regard to fertilizer application rates, sowing, and harvesting dates "best guess" representation of historical conditions regarding fertilizer application rates, sowing and variety settings that best reproduce given harvesting dates.
<variable>	*(variable names listed in the sector specific output tables, see chapter* 7*)*	Output variable of the impact model. The identifier can also be used for information about the plant functional type (pft) in the biomes and permafrost sectors. The pft/species naming is model-specific and hence has to be reported in the impact-model database (see section 6.3 and www.isimip.org/impactmodels). In the forestry sector, the identifier might contain information about the tree species. The species names codes are listed in **Table 29**.
<region>	global short name of focus region as in Table 1 common name of river basin as listed in Table 1 or location forest site name as defined in **Table 24.**	for global simulations simulations covering a focus region for simulations covering one of several basins or a single location within a focus region For simulations of the regional forest models.
<timestep>	monthly, annual, decadal, daily	

6.2.2 Format for gridded data

Gridded data should be returned in NetCDF4 format with a compression level of at least 5. It is important that you comply precisely with the formatting specified below, in order to facilitate the analysis of your simulation results in the ISIMIP framework. Incorrect formatting can seriously delay the analysis. For questions or clarifications, please contact the ISIMIP coordination team. Further information and instructions follow in this section.

Global data are to be submitted for the ranges **-89.75** to **89.75** degrees latitude, and **-179.75** to **179.75** degrees longitude, i.e. 360 rows and 720 columns, or 259200 grid cells total. Please report the output data row-wise starting at 89.75 and -179.75, and ending at -89.75 and 179.75. The standard horizontal resolution is 0.5x0.5 degrees, corresponding to the resolution of the climate input data. Submitting data at lower resolution than 0.5x0.5 degrees is only encouraged in exceptional cases; in those cases the above numbers will change accordingly (e.g., a 1x1 degree grid would have 180 rows, from 89.5 to -89.5 degrees latitude).

Antarctica and Greenland do not have to be simulated. If you are limited by data (e.g. soil data) you can also reduce the latitude range of your simulations, however, the **minimal latitude range** to be simulated is -60 to + 67 degrees. **Important:** When *reporting* results the whole grid as specified above should be reported – pixels you did not simulate should be filled with the missing value marker (1.e+20f).

Regional model teams should interpolate their output data to the same, common 0.5x0.5 degree grid as described above, and submit in the same NetCDF file format. Each file should **cover the entire globe** (even though the filename should contain the name of the region), with any grid cells outside the simulated region to be filled with missing values (1.e+20f). This will not lead to significantly larger files as long as NetCDF compression is used. **Exception:** Single (one-point) timeseries do not have to be embedded into the 0.5x0.5 degree grid, but should be reported as NetCDF 4 files with the coordinates of the point included in the header information.

Note that submitting results in this format is important in order to facilitate comparison among different models and between global and regional scale. The **ISIMIP coordination team will be glad to assist** with the preparation of these files if necessary. **In addition** to the global file, regional model teams may submit a second file containing the output data in their default format. This may be e.g. on a finer resolution than 0.5°, on a non-regular grid, etc.

Please note the corresponding file naming conventions above.

Latitude, longitude and time should be included as individual variables in each file.

6.2.2.1 NetCDF files

Table 10 Naming and format conventions for NetCDF files

Dimension	Name	Unit
X	Lon	degrees east
Y	Lat	degrees north
T	Time	<time steps> since 1901-01-01 00:00:00 (where <time steps> is replaced by days, months, etc., according to the time step the data is reported on) Note: crop models use a different time step; see section 7.4.2.
missing value	1.e+20f	

To facilitate proper formatting of your output files, shell scripts are provided on the ISIMIP website (www.isimip.org > Getting Started > ISIMIP2a Simulation Protocol) that produce “empty” NetCDF files with the correct format and header information. Please use these scripts to write your output data into NetCDF files. A detailed explanation of how to do this is given here and can also be found on the website.

The NetCDF format should adhere to the settings in the shell (bash) script "isimip2_output_<time_step>.sh". Scripts are available for the different time steps: daily, monthly, annual or decadal.

In order to create an empty netcdf file with the correct filename and the required metadata in the header, you must run the script appropriate to the time step of the output data you want to store (e.g. daily data), using the following command:

> output_<time_step>.sh x1 x2 x3 x4 x5 x6 x7 x8

The arguments are given in **Table 11**.

Table 11 Arguments for script to generate netcdf file

Arg	Details	example
x1	The first year of data to be stored in the netcdf file (e.g. '1980'). Each file should contain data for one variable only, and for a time interval as specified in sections 6.1 and 6.2.4 (e.g., monthly data for 1980-1989).	'1980'
x2	Variable name stored in the netcdf file. Please adhere to variable names given in protocol.	'pr'
x3	Long variable name.	'precipitation'
x4	Units of the variable following the CF metadata	'kg m-2 s-1'
x5	transient or time-slice run	'time-slice'
x6	Further room for comments (optional).	'includes rain and snowfall' ' ' if empty
x7	Your institution	
x8	Your email address	

Here is an example how to run the script in a bash shell:

> ./output_daily.sh '1980' 'pr' 'precipitation' 'kg m-2 s-1' '' 'includes rain and snowfall' 'PIK' 'Info@isimip.org' 'im1_hadgem-es_rcp85_ssp2_noco2'

Note: The bash shell is standard on most Linux and Mac systems. For Window systems Cygwin can be used.

Once you have created your NetCDF file, you can check the metadata by running the command "ncdump –h"; an example output is given in the Fast-Track protocol.

6.2.3 Format for non-gridded data

Data that is not defined on a grid, such as point-based data e.g. for particular gauges, or data for world regions, should nonetheless be reported in NetCDF format, e.g. as a separate file for each gauge or region, each file containing a single time series. The ISIMIP coordination team will assist with the preparation of these files where necessary. **It is important that all ISIMIP results exist in NetCDF format**, in order to be compatible with the structure and functionalities of the ESGF repository.

6.2.4 Time intervals

Please submit your output data in chunks according to the **Table 12**, depending on whether you are reporting a transient experiment or a time-slice experiment, and depending on the time step of the output variable you are reporting (the requested time step for each variable is listed in the sector-specific tables in Section 7).

Table 12 Definition of time intervals

Daily time step	Output files should cover **10 years** each (e.g. 1971-1980). Exceptions: The period 2001-2010 should be reported in **two separate files**, broken down in the same way as the respective input data (i.e. in the case of most GCMs, both files will cover 5 years each: 2001-2005 and 2006-2010; in the case of the HadGEM2-ES model, the files will cover 2001-2004 and 2005-2010, respectively). The period 2091-2099 should be reported in a file covering **9 years**
monthly, annual, or decadal time step	Output should be reported in one single file per experiment. In experiments involving future projections (catch-up runs) the historical period should be separated from the RCP period (the separation being between 2005 and 2006 except for

[redacted]	HadGEM2-ES).

6.2.5 Submission

Data should be submitted to a dedicated file system on a central server located at DKRZ Hamburg. Access to this server will be possible via the ISIMIP website, www.ISIMIP.org. Detailed upload instructions will be circulated by email, and will also be available on the website. The ISIMIP coordination team will gladly provide assistance upon request.

6.3 Documentation of models and experiments

In addition to adhering to the common settings described in this protocol, it is essential to keep track of further details regarding the configuration of each individual model. This ensures that the simulation results can appropriately be interpreted by authors of multi-model studies, and can remain transparent and usable for a long time into the future. For this purpose, the ISIMIP coordination team provides a questionnaire that all modelling teams are asked to answer. The questionnaire is accessible online through the ISIMIP website; for assistance please write to Info@isimip.org.

7 Sector-specific sections: input, output, experiments

In this section the specific setup for each sector is specified, including special input needed, output data, and experimental setup. The setup is nevertheless consistent across sectors. Any changes therefore have to be coordinated with the cross-sectoral coordination team.

For ease of reference, at the beginning of each sector, a summary table of simulation experiments is provided.

Please note: these tables do not include all necessary information, and should be used as a reference only once the sector-specific and cross-sectoral protocol has been read in full.

The sectors covered are:

- Water: global and regional
- Biomes: global
- Forests: regional
- Agriculture (crop modelling)
- Agro-economic models
- Infrastructure*
- Fisheries (& Ocean NPP/carbon-cycle)
- Energy supply and demand*
- Permafrost*
- Biodiversity*

*For these sectors, specifications will be added to the protocol at a later stage

IMPORTANT:

1. Please check if your model generates output variables that could be relevant for another sector. If so, please provide them and let us know at Info@isimip.org!
2. Variable names are listed below as they should be used in the output file names (see section 6.2).

8 Water

Table 13 provides an overview of all experiments to be run in the water sector in ISIMIP2a. This table is for your reference only; please read chapters 1-5 and this section carefully before beginning with the experiments.

Table 13 Summary of experiments for water models

	Climate Data	Scenario	Human Impacts	Land use (if applicable)	Other settings (sens-scenario)	# runs
Historical runs	PGMFD v.2 (Princeton)	Hist	nosoc pressoc varsoc	Hyde3 + MIRCA constant (MIRCA2000) Hyde3 + MIRCA	historical CO_2 (co2)	3
	GSWP3	Hist	nosoc pressoc varsoc	Hyde3 + MIRCA constant (MIRCA2000) Hyde3 + MIRCA	historical CO_2 (co2)	3
	WATCH (WFD)	Hist	nosoc pressoc varsoc	Hyde3 + MIRCA constant (MIRCA2000) Hyde3 + MIRCA	historical CO_2 (co2)	3
	WATCH+WFDEI.GPCC	Hist	nosoc pressoc varsoc	Hyde3 + MIRCA Constant (MIRCA2000) Hyde3 + MIRCA	historical CO_2 (co2)	3
	Optional run: Princeton	Hist	varsoc	Hyde3 + MIRCA	constant CO_2 at 1971 levels (co2const)	1

Future runs	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc+ SSP2	Hyde3 + MIRCA Constant from 2000 onwards	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM1 (HadGEM2-ES)	hist+ 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA Constant from 2000 onwards	historical CO2 + fixed CO2 from 2000 onwards (noco2)	1
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA MAgPIE from 2000 onwards	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA Constant from 2000 onwards	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA MAgPIE from 2000 onwards	historical CO2 + RCP2.6 RCP6.0 (co2)	2

8.1 Sector-specific input data

In ISIMIP2a – the historical validation exercise – hydrological modelling teams are asked to take into account the historical evolution of irrigated areas, dams and reservoirs, in order to obtain a more realistic estimate of the historical evolution of runoff and discharge. The data sources to be used are listed in

Table 14, along with a soil and vegetation dataset that may be used optionally.

Table 14: Input data to be used for the historical runs (ISIMIP2a), in addition to the common data listed in chapter 4.

Dataset Mandatory (if feasible)	Description	More info	Scale	Variables included; comments
GranD data base, mapped to DDM30 routing network	Dams/Reservoirs	Documentation: http://www.gwsp.org/products/grand-database.html Note: Simple interpolation can result in inconsistencies between the GranD database and the DDM30 routing network (wrong upstream area due to misaligned dam/reservoir location). We provide a file with locations of all larger dams/reservoirs adapted to DDM30 such as to best match reported upstream areas.	global, 0.5°	location, upstream area, capacity, and construction/commissioning year.
DDM30 routing network, mapped to the CRU land mask	flow directions, slope, and basin numbers	Note: The routing network includes large lakes that are not included in the provided land mask. These cells should not be included when results are submitted and there should be no runoff added to the river network from these cells. I.e. these cells are included only for transportation purposes (streamflow).	global, 0.5°	**for global models only**[6]
Optional (does not have to be harmonized):				
HWSD, or GSWP3 (upscaled version of HWSD)	soil map	see http://hydro.iis.u-tokyo.ac.jp/~sujan/research/gswp3/soil-	global, 30 arc sec (HWSD) or 0.5° (GSWP3), fixed	soil type

[6] To allow a direct intercomparison of river flows between global and regional models on a gridded basis, the runoff produced by the global models could be collected and routed through the HydroSHEDS network as a post-processing step, using a single routing model. Volunteers for this task are welcome.

		texture-map.html, upscaling method A. Each model does have the option to use their own soil datasets if they prefer		
GLIMS (Global Land Ice Measurements from Space)	Glacier distribution	http://www.glims.org/About/		
HydroSHEDS	Topography/routing network	Hydrographically corrected SRTM data. Available in 3 resolutions, includes accumulated upstream area. Also HydroSHEDS is not available north of 60 degrees, due to limitations in the SRTM data at high latitudes		**for regional models only**6
CRU elevation data				

8.2 data

Note that variable names are chosen to comply, where feasible, with the ALMA convention[7] and the names used in WATCH/WaterMIP. Although variable names are mixed-case here, make sure to use **only lower-case** letters in the output filenames (see section 6.2).

All variables are to be reported as time-averages with the indicated resolution; do not report instantaneous values ('snapshots'). An exception is **MaxDis**, which is the maximum daily-average discharge in a given month, to be reported on a monthly basis (see below).

Water balance equation in terms of requested output variables:

rainf + snowf = evap + qtot,

where **Evap** is the sum of interception, transpiration, sublimation, and evaporation from the surface. This equation only holds on timescales long enough for changes in water storage (e.g. in soil and groundwater) to average out.

[7] http://www.lmd.jussieu.fr/~polcher/ALMA/convention_output_3.html

*IMPORTANT Some output variables reported for the water sector are also appropriate for use in the permafrost sector described in Section 7.6; these are marked with an *. Some additional variables are also required for the permafrost sector. The full list can be found in* **Table 37**.

Table 15: Output variables to be reported by water sector models. Highlighted variables are requested from both global and regional models, if computed; others only from global models.

Variable	Variable name	Resolution	Unit (NetCDF format)	Comments
Hydrological Variables				
*Runoff	qtot	daily* (0.5°x0.5°)	kg/m²/s (kg m-2 s-1)	total (surface + subsurface) runoff (Qtot = Qs + Qsb). *if daily resolution not possible, please provide monthly[8]. Please also deliver for the permafrost sector.
Discharge (gridded)	dis	daily* (0.5°x0.5°)	m³/s (m3 s-1)	*if daily resolution not possible, please provide monthly
Discharge (gauge level)	dis	daily* (at gauge locations specified in **Table 17**)	m³/s (m3 s-1)	A file will be provided mapping the gauge coordinates to the 0.5x0.5 degree river network. *if daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	maxdis	monthly (0.5°x0.5°)	m³/s (m3 s-1)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	evap	monthly (0.5°x0.5°)	kg/m²/s (kg m-2 s-1)	sum of transpiration, evaporation, interception and sublimation.

[8] If storage issues keep you from reporting daily data, please contact the ISIMIP team to discuss potential solutions.

Potential Evapotranspiration	potevap	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	as Evap, but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture	soilmoist	monthly (0.5°x0.5°)	kg/m^2 (kg m-2)	please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. Please also deliver for the permafrost sector.
Soil moisture, root zone	rootmoist	monthly (0.5°x0.5°)	kg/m^2 (kg m-2)	Total simulated soil moisture available for evapotranspiration. If simulated by the model. Please indicate the depth of the root zone for each vegetation type in your model
Frozen soil moisture for each layer	soilmoistfroz	monthly (0.5°x0.5°)	kg m-2	Soil_frozen_water_content This variable only for the purposes of the permafrost sector.
*Temperature of Soil	tsl	daily* (0.5°x0.5°)	K	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". THIS IS THE MOST IMPORTANT VARIABLE. Also need depths in meters. Daily would be great, but otherwise monthly would work. This variable only for the purposes of the permafrost sector *if daily resolution not possible, please provide monthly
*Snow depth	snd	monthly (0.5°x0.5°)	m	Grid cell mean depth of snowpack. This variable only for the purposes of the permafrost sector.

*Snow water equivalent	swe	monthly (0.5°x0.5°)	kg/m^2 (kg m-2)	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell. Please also deliver for the permafrost sector.
Annual maximum thaw depth	thawdepth	monthly (0.5°x0.5°)	m	calculated from daily thaw depths
Rainfall	rainf	monthly (0.5°x0.5°)	kg/m^2/s (kg m-2 s-1)	These variables are required for test purposes only. If you need to reduce output data volumes, please provide these variables only once, with the first (test) data set you submit, e.g. for the first decade of each experiment. NOTE: rainf + snowf = total precipitation
Snowfall	snowf	monthly (0.5°x0.5°)	kg/m^2/s (kg m-2 s-1)	
Water management variables (for models that consider water management/human impacts)				
Irrigation water demand (=potential irrigation water Withdrawal)	pirrww	monthly (0.5°x0.5°)	kg/m^2/s (kg m-2 s-1)	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	airrww	monthly (0.5°x0.5°)	kg/m^2/s (kg m-2 s-1)	Irrigation water withdrawal, taking water availability into account; please provide if computed
Potential irrigation water consumption	pirruse	monthly (0.5°x0.5°)	kg/m^2/s (kg m-2 s-1)	portion of withdrawal that is evapo-transpired, assuming unlimited water supply

Actual irrigation water consumption	airruse	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	portion of withdrawal that is evapotranspired, taking water availability into account; if computed
Actual green water consumption on irrigated cropland	airrusegreen	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	actual evapotranspiration from rain water over irrigated cropland; if computed
Potential green water consumption on irrigated cropland	pirrusegreen	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	potential evapotranspiration from rain water over irrigated cropland; if computed and different from AIrrUseGreen
Actual green water consumption on rainfed cropland	arainfusegreen	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	actual evapotranspiration from rain water over rainfed cropland; if computed
Actual domestic water withdrawal	adomww	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed
Actual domestic water consumption	adomuse	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed
Actual manufacturing water withdrawal	amanww	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed
Actual Manufacturing water consumption	amanuse	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed
Actual electricity water withdrawal	aelecww	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed

Actual electricity water consumption	aelecuse	monthly (0.5°x0.5°)	$kg/m^2/s$ (kg m-2 s-1)	if computed
Actual livestock water withdrawal	aliveww	monthly (0.5°x0.5°)	kg/m2/s (kg m-2 s-1)	if computed
Actual livestock water consumption	aliveuse	monthly (0.5°x0.5°)	kg/m2/s (kg m-2 s-1)	if computed
Static output (Note: data that cannot be submitted in NetCDF format may be submitted in another suitable format directly via email to Info@isimip.org)				
Vegetation types	Names to be coordinated with biomes/ecosystem sector	static (0.5°x0.5°)	N/A	Map of vegetation / land surface types as used by the model. Please include a description of the parameters and their values associated with these vegetation types (parameter values could be supplied as spatial fields where appropriate). In your description please also provide details of the evapotranspiration scheme used by your model.
Soil types	soil	static (0.5°x0.5°)		Soil types or texture classes as used by your model. Please include a description of each type or class, especially if these are different from the standard HSWD and GSWP3 soil types. Please also include a description of the parameters and values associated with these soil types (parameter values could be submitted as spatial fields where appropriate).
Leaf Area Index	lai (to be	static (0.5°x0.5°) or monthly		if used by, or computed by the model

	coordinated with other sectors)	(0.5°x0.5°) where appropriate		

8.3 Experiments

8.3.1 ISIMIP2a - Calibration of regional hydrological models

The regional hydrological models should be calibrated and validated as usual[9] for river discharge at the gauge stations indicated in Table 20. The calibration should be done in two steps: firstly using observed climate data (if available), and then re-calibrating to WATCH data. The calibration and validation sub-periods of 8-10 years each should be chosen in the period 1971-2010, depending on availability of data. The re-calibration to WATCH climate data is important as the GCM climate scenario data (to be used for climate impact assessment) are bias-corrected to the WATCH dataset. In case the observational climate data is not available, the calibration should be done using WATCH or WATCH+WFDEI.GPCC data. Although all hydrological models use the daily time step, it is suggested to apply criteria of fit: Nash and Sutcliffe efficiency (NSE) and percent bias (PBIAS) to the monthly time series, and compare the monthly and long-term average monthly dynamics. If possible, some intermediate gauges should also be considered in addition to the gauges indicated in Table 20, and comparison of the simulated and observed time series done for them as well. Human influences (dams/reservoirs, water abstraction for irrigation, etc.) should be considered in catchments where their effects are significant. Otherwise, they can be ignored.

Since the focus topic of ISIMIP2 is “Extreme events and variability”, a special attention should be on the variation characteristics (seasonal, interannual), as well as on simulation of high flows and low flows. The latter could be evaluated using the annual high and low percentiles Q10 and Q90. For that, after the usual calibration and validation are done, and satisfactory results are obtained for both periods, representation of annual Q10 and Q90 in the calibration and validation periods should be checked.

---

[9] I.e. modelling all processes and comparing simulated daily (or monthly) river discharge with the measured one at the predefined gauging station(s). If you have any questions about calibration and validation procedures, please do not hesitate to contact the coordination team.

Following calibration and validation as described above, please run your model for the historical period 1971-2010 for each of the different climate forcing datasets (see Table 5), using the same land use as in the calibration run. No re-calibration is required for the different climate forcing datasets.

8.3.2 ISIMIP2a - Historic runs and validation exercise

Both regional and global hydrological models will be validated for the major river basins in the **ISIMIP2 focus regions** (Figure 1), plus the Blue Nile, Upper Amazon, and Lena basins, for which there are observed discharge and runoff data (see **Table 16** and **Table 17**). The gauging stations for validation (and for calibration of the regional models) are indicated in **Table 17**. In addition, the global models will be validated in additional major river basins, or globally at grid-cell level, where feasible (see below).

If your model accounts for **population and GDP changes** or **technological progress** etc. the available information should be used to prescribe conditions that are as close to the real historical conditions as possible.

Table 16: Observational datasets to be used for validation of the historical runs (ISIMIP2a).

Dataset	Description	More info	Dates	Scale	Variables included	Comment
ISLSCP II UNH-GRDC Composite Monthly Runoff	Observed values of monthly runoff	http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=994	1986-1995	0.5°x0.5° grid	Qtot	for global models
GRDC Global Runoff	Observed values of daily (or monthly, as available) river discharge across the	GRDC (http://www.bafg.de/GRDC/EN/01_GRDC/13_dtbse/database_node.html)	1900-2012 but years vary by	Catchment gauging station	dis (discharge in m3/s)	for global and regional models

Database	globe		catchment.	The gauges to use for the focus regions are listed in **Table 17**.		
FAOSTAT	Historical irrigation water withdrawal (observations/model combination)	http://www.fao.org/nr/water/aquastat/dbase/index.stm	varies by country, mostly 1990-2010	Country	aIrrww (km^3/a); also other sectoral withdrawals	
USGS	US water withdrawal estimates	http://water.usgs.gov/watuse	every 5 years since 1950	US national, county, watershed	aIrrww (Mgal/a); also other sectoral withdrawals	

Table 17: Catchment gauging stations for the hydrological model calibration/validation and intercomparison.

River Basin	GRDC Station for calibration and validation	GRDC Station Code	GRDC availability (monthly discharge)	GRDC availability (daily discharge)	Area upstream of gauge (km2) according to GRDC or DEM

Rhine	Lobith	6435060	1901-1996	1901-2010	160,800
Tagus (Tejo)	Almourol	6113050	1973–1990	1982-1990	67,490
Niger	Lokoja Dire	1834101 1134700	2007-2012 1924-2012	1970-2006 1924-2003	2,074,171 340,000
Blue Nile	Khartoum	1663100	1900-1982	n.a.	325,000
Ganges	Farakka	2846800	1949-1973	n.a.	835,000
Yellow (Huang He)	Tangnaihai Huayuankou***	n.a. 2180800	n.a.** 1946-1988	n.a.** 2004-2004	121,000 730,036
Yangtze	Pingshan Datong***	n.a. 2181900	n.a.** 1922-1988	n.a.** 2004-2004	446,516 1,705,383
Lena	Stolb Krestovski	2903430 2903427	1978-1994 1936-2002	1951-2002 1936-1999	2,460,000 440,000
Mississippi	Alton Vicksburg***	4119800 4127800	1928-1984 1928-1983	1933-1987 1931-2013	444,185 2,964,255
Amazon	Sao Paulo de Olivenca	3623100	1979-1993	1973-2010	990,781
Murray Darling	Louth Wakool Junction***	5204250 5304140	1954-2000 1929-2001	1954-2008 1929-2001	489,300 n.a.

* calculated in GRASS; ** available from China to some groups; *** only for the global-scale modelling

Hydrological modelling groups (both **global and regional**) should conduct, and submit model outputs for the simulations listed in **Table 18**.

Table 18: Simulation settings for hydrological models

Simulation	Comments
Naturalized (nosoc)	*without* human impacts on river flow Models that can include the effects of land use should use time-varying land use from the "Dynamic MIRCA" dataset (see section 4.1.3), in order to be consistent with other sectors (in particular biomes).
Constant human impacts (pressoc)	present-day (year-2000) dams and water use* Models should include present-day human impacts, in the form of dams and reservoirs as well as any forms of human water use that can be represented in the models (e.g. for irrigation, manufacturing, etc.). Models that can include the effects of land use should use constant (year-2000) land use from MIRCA2000 (year 2000 of the "Dynamic MIRCA" dataset, see section 4.1.3).
Time-varying human impacts (varsoc)	time-varying historical dam construction and water use* As pressoc, except that human imacts should now be time-varying according to the historical data provided. Models that can include the effects of land use should use time-varying land use from the "Dynamic MIRCA" dataset (see section 4.1.3).
Natural vegetation reference run (nat)	A natural vegetation only run without any land-use pattern. This is a reference run to separate fluxes from natural vegetation and agriculture in runs with historic land-use. It is like the nosoc run but without land-use. If your model does not distinguish between natural and managed land, the "nat" run will be identical to the "nosoc" run. It is relevant for those models running biome and water simulations in the same simulation.

*Regional models may ignore human impacts in catchments where human impacts are found to be insignificant. For those catchments, all validation exercises should be conducted with the naturalized simulations.

Two main validation exercises will be conducted with the hydrological models, using the results of these simulations.

8.3.3 Validation Task I: "naturalized" (i.e. without human impacts, nosoc) simulated runoff

The naturalized simulations of runoff, Q_{tot} (= Q_s + Q_{sb}), by **global models** will be validated against the ISLSCP II UNH-GRDC Composite Monthly Runoff dataset (Koster, Fekete, Huffman, & Stackhouse, 2006), which is an update of the UNH-GRDC composite runoff fields of Fekete, Vörösmarty, & Grabs (2000), the latter having been used previously to tune and validate global hydrological models (Arnell, 1999; Döll, Kaspar, & Lehner, 2003; Simon N. Gosling & Arnell, 2011). The original UNH-GRDC data set combined observed river discharge from the GRDC with simulated water balance model (WBM) estimates and consisted of monthly climatologies at 0.5°×0.5° spatial resolution. The ISLSCP II UNH-GRDC dataset was generated by revising the raw WBM monthly means through the application of climate forcing (air temperature, precipitation, vapor pressure, solar radiation, wind speed) from the CRU data set. The revised dataset is advantageous because it includes a gridded (0.5°×0.5°) 10-year time series of monthly runoff for 1986–1995 instead of climatologies only. While the runoff fields are influenced by the accuracy of the WBM, the runoff maps are at least calibrated to gauged streamflow. The ISLSCP II UNH-GRDC Composite Monthly Runoff dataset can be downloaded from here: http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=994.

Davie et al. (2013) used the ISLSCP II UNH-GRDC dataset to present a preliminary validation of the ISIMIP hydrological models. This validation exercise will extend that analysis by considering the following observed-simulated comparisons because mean annual runoff is only a first indicator of hydrological behavior (Döll & Schmied, 2012; S. N. Gosling et al., 2011):

1. Catchment-mean monthly and annual runoff climatologies for the ISIMIP2 focus catchments.
2. Catchment-mean timeseries of monthly runoff.
3. Spatial patterns of runoff between simulated and observed.

This validation exercise will be conducted at the global scale by analyzing gridded values and also for the ISIMIP2 focus catchments by analyzing values at gauge locations. Where catchment-mean runoff needs to be computed, this should be calculated by aggregating across all upstream cells (from the gauge) that are included within the catchment boundaries as defined by the DDM30 river network and computing an area-mean (using the DDM30 catchment area). In practice, this means that, similar to the method applied by (Haddeland et al., 2011), an area correction factor is applied to the ISLSCP II UNH-GRDC runoff data to account for the fact that the river network, which is at 0.5°x0.5° spatial resolution, may not perfectly overlap with the river basin boundaries. The gauging stations that should be used for selecting upstream cells are displayed in **Table 17**. These stations have been used to ensure consistency in spatial coverage between the two validation exercise (naturalized and human impacts). Comparison of spatial patterns between observed and simulated data should focus only on the cells included within the catchment boundaries and that are upstream of the gauge in **Table 17**.

An important point is that the GRDC streamflow observations that were used to compute the ISLSCP II UNH-GRDC dataset by correcting the WBM simulations, do not span the entire land area of the globe (Koster et al., 2006). Thus, in non-monitored regions, the runoff estimates are derived from uncorrected WBM estimates alone. This means that for some grid cells, the situation may arise where model results are compared to model results (as opposed to comparing model results with observations). To this end, comparisons will need to be limited to catchments where the WBM simulations were predominantly corrected with GRDC observations. The following text explains how this will be achieved. Gridded datasets (0.5x0.5 degree) of the annual correction coefficient that was applied to WBM for each year (i.e. 1986-1995) can be downloaded from here: http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=994 by using the "Spatial Data Access Tool" (there is one file for each year). These files should be used to create a mask file for each year (e.g. 1=WBM data was corrected and 0=WBM data was not corrected). Then, a final gridded mask file should be created from these 10 annual mask files, which illustrates where at least 5 years of correction coefficients were used (this is similar to the approach adopted by Koster et al., (2006)). This final mask file should then be used to show where the ISLSCP II UNH-GRDC observed runoff data was computed from WBM-corrected data for at least 50% of each respective catchment area displayed in Figure 1. This will minimize the risk of a model-to-model comparison and the validation will only be computed where the above conditions are satisfied. This approach was adopted by Oleson et al. (2008) when validating the land component of the Community Climate System Model (CCSM), Community Land Model version 3 (CLM3).

The naturalized runoff simulated by **regional models** will be validated against the GRDC monthly river discharge data (for gauging stations listed in **Table 17**), see below.

8.3.4 Validation Task II: validation with human impacts (e.g. dams, water-use; pressoc/varsoc).

Simulations of discharge (Dis) with human impacts will be validated against GRDC monthly and daily river discharge time series data.

The catchment gauging stations that should be used for this validation are displayed in **Table 17**; the corresponding data (source: http://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html) will be provided via ISIMIP (subject to agreement of the GRDC). Unlike the naturalized validation exercise discussed previously, the GRDC discharge data is available for differing time periods for the various ISIMIP2 focus catchments (see **Table 17**).

This will facilitate the following analyses, since mean annual runoff is only a first indicator of hydrological behavior (Döll & Schmied, 2012; S. N. Gosling et al., 2011):

1. Comparisons of mean annual discharge.
2. Comparisons of mean monthly discharge climatology and variability.
3. Comparisons of indicators of high and low flow (e.g. Q5 and Q95, and peak over threshold).
4. Comparisons of flood return period levels (only where there is > 30 years of observed and simulated data, based on extreme value distributions fitted to the data).
5. Calculation of Nash Sutcliffe Efficiency (NSE), Percent Bias (PBIAS) and other error statistics on monthly discharge timeseries.
6. Comparison of simulated water withdrawals with FAOSTAT or USGS observed withdrawals (for models that simulate it).

Validation of the runs with constant human impacts (i.e. with present-day (year-2000) dams and water use) will focus primarily on comparing climatologies and flow statistics over multiple decades. For the runs with time-varying human impacts (i.e. with historical dam construction and water use) the focus will be more on validating the historic inter-annual variability (and possibly trends) in annual and monthly river discharge, as well as high and low flow indicators. By comparing the results of runs with constant and with time-varying human impacts an estimate can be made of the effect of changes in human influence in the past few decades on the hydrological behaviour of catchments.

Furthermore, the availability of daily observed and simulated data for some catchments (see Table W1) presents an opportunity to analyse simulated-observed comparisons for specific flood and drought events in each catchment. At least one drought and one flood case study should be identified (e.g. from Q95 and Q5 data) for each ISIMIP2 focus catchment and graphs of observed-simulated daily discharge plotted.

Where catchment-means needs to be computed (or a conversion from m^3/s to mm), this should be calculated by aggregating across all upstream cells (from the gauge) that are included within the catchment boundaries as defined by the DDM30 river network and computing an area-mean (using the DDM30 catchment area). In practice, this means that, similar to the method applied by (Haddeland et al., 2011), an area correction factor is applied to the GRDC discharge data to account for the fact that the river network, which is at 0.5°x0.5° spatial resolution, may not perfectly overlap with the river basin boundaries

8.3.5 ISIMIP2a - Fast track runs for new models

Please consult the fast track protocol Section 7 for those runs and related information. It is available at www.isimip.org/protocol/#isimip-fast-track. In case of any questions please contact info@isimip.org. Please note that aside from harmonized climate and socio-economic input, the default settings of your model should be used. Also note that for output data files the file name (as specified in Section 5.2 of the fast track protocol) is all lower case!

9 Biomes

Table 19 provides an overview of all experiments to be run in the biomes sector in ISIMIP2a. This table is for your reference only; please read chapters 1-5 and this section carefully before beginning with the experiments.

Table 19 Experiment summary for Biomes models

	Climate Data	Scenario	Population/GDP	Land use (LU)	Other settings (sens-scenario)	# runs
Historical runs	PGMFD v.2 (Princeton)	hist	varsoc (see **Table 18**; if varsoc not possible, please submit the presoc run)	Hyde3 + MIRCA (no LU specifier)	historical CO2 (co2)	1
	GSWP3	hist	varsoc	Hyde3 + MIRCA (no LU specifier)	historical CO2 (co2)	1
	WATCH (WFD)	hist	varsoc	Hyde3 + MIRCA (no LU specifier)	historical CO2 (co2)	1
	WATCH+WFDEI.GPCC	hist	varsoc	Hyde3 + MIRCA (no LU specifier)	historical CO2 (co2)	1
	Optional run: PGMFD v.2 (Princeton)	hist	nat	reference run, natural vegetation only, no land-use	historical CO2 (co2)	1
	Optional run: PGMFD v.2 (Princeton)	Hist	varsoc	Hyde3 + MIRCA	fix at pre-industrial levels (pico2) = 280ppm	1

Future runs	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA Constant from 2000 onwards (lufix)	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA Constant from 2000 onwards (lufix)	historical CO2 + fixed CO2 from 2000 onwards (noco2)	2
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA MAgPIE from 2000 onwards (luvar)	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA Constant from 2000 onwards (lufix)	historical CO2 + RCP2.6 RCP6.0 (co2)	2
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6) 6.0 (rcp6p0)	pressoc + SSP2	Hyde3 + MIRCA MAgPIE from 2000 onwards (luvar)	historical CO2 + RCP2.6 RCP6.0 (co2)	2
						13

9.1 Sector-specific input

Table 20 Biomes-specific input data

Dataset	Description	More info	Dates	Scale	Variables included
Optional (does not have to be harmonized):					
GSWP3	soil data	each model does have the option to use their own vegetation and soil datasets if they prefer		global, 30 arc sec (HWSD) or 0.5° (GSWP3), fixed	soil type
CRU elevation data					

9.2 Output data

IMPORTANT: The output variables reported for the biomes sector are also appropriate for use in the permafrost sector described in Section 7.6.

Table 21 Variables to be reported by biomes models

long name	units		output variable name	frequency	comment
Essential outputs					
Pools					
Carbon Mass in Vegetation biomass	kg m-2	per pft and gridcell total	**cveg_<pft>**	year	Gridcell total VegC is essential. Per PFT information is desirable.
Carbon Mass in Litter Pool	kg m-2	per pft and gridcell total	**clitter_<pft>**	year	Info for each individual pool.
Carbon Mass in Soil Pool	kg m-2	per pft and gridcell	**csoil_<pft>**	year	Info for each individual pool.

		total			
Fluxes					
Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	kg m-2 s-1	per pft and gridcell total	**gpp_<pft>**	mon (day)	
Carbon Mass Flux into atmosphere due to Autotrophic (Plant) Respiration on Land	kg m-2 s-1	per pft and gridcell total	**ra_<pft>**	mon (day)	
Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	kg m-2 s-1	per pft and gridcell total	**npp_<pft>**	mon (day)	
Net Primary Production on Land allocated to leaf biomass	kg m-2 s-1	per pft and per gridcell	**npp_landleaf_<pft>**	mon (day)	
Net Primary Production on Land allocated to fine root biomass	kg m-2 s-1	per pft and per gridcell	**npp_landroot_<pft>**	mon (day)	
Net Primary Production on Land allocated to above ground wood biomass	kg m-2 s-1	per pft and per gridcell	**npp_abovegroundwood_<pft>**	mon (day)	
Net Primary Production on Land allocated to below ground wood biomass	kg m-2 s-1	per pft and per gridcell	**npp_belowgroundwood_<pft>**	mon (day)	
Carbon Mass Flux into atmosphere due to Heterotrophic	kg m-2 s-1	per pft and gridcell	**rh_<pft>**	mon (day)	

Respiration on Land		total			
Carbon Mass Flux into atmosphere due to total Carbon emissions from Fire	kg m-2 s-1	per pft and gridcell total	**fireint_<pft>**	mon (day)	
Fraction of cell burnt by fire	Fractional	Per pft and gridcell total	**firefrac_<pft>**		Burnt area fraction: single value for each scenario corresponding to year 2100
Carbon Mass Flux out of Atmosphere due to Net biome Production on Land (NBP) (please specify if NBP≠NPP+HR+Fires in your model)	kg m-2 s-1	per pft and gridcell total	**ecoatmflux_c_<pft>**	mon (day)	This is the net mass flux of carbon between land and atmosphere calculated as photosynthesis MINUS the sum of plant and soil respiration, carbonfluxes from fire, harvest, grazing and land use change. Positive flux is into the land.
Root autotrophic respiration	kg m-2 s-1	per pft and gridcell total	**rr_<pft>**	mon (day)	
Structure					
Fraction of absorbed photosynthetically active radiation	%	per pft and gridcell average	**fapar_<pft>**	mon (day)	
Leaf Area Index	1	per pft and gridcell average	**lai_<pft>**	mon (day)	
Plant Functional Type Grid Fraction	%	per gridcell	**pft_<pft>**	year (or once if static)	The categories may differ from model to model, depending on their PFT definitions. This may include natural PFTs, anthropogenic PFTs, bare soil, lakes, urban areas, etc. Sum of all should equal

					the fraction of the grid-cell that is land.
Hydrological variables					
Total Evapo-Transpiration	kg m-2 s-1	per pft and gridcell	**evap_<pft>**	mon (day)	
Evaporation from Canopy (interception)	kg m-2 s-1	per pft and gridcell	**intercep_<pft>**	mon (day)	the canopy evaporation+sublimation (if present in model).
Water Evaporation from Soil	kg m-2 s-1	per gridcell	**esoil**	mon (day)	includes sublimation.
Transpiration	kg m-2 s-1	per pft and gridcell	**trans_<pft>**	mon (day)	
Total Runoff	kg m-2 s-1	per gridcell	**qtot**	mon (day)	the total runoff (including "drainage" through the base of the soil model) leaving the land portion of the grid cell.
Soil Moisture	kg m-2	per gridcell	**soilmoist**	mon (day)	If possible, please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. Otherwise, provide soil moisture of entire column.
Surface Runoff	kg m-2 s-1	per gridcell	**qs**	mon (day)	the total surface runoff leaving the land portion of the grid cell.

Frozen soil moisture for each layer	kg m-2	per gridcell	**soilmoistfroz**	mon	Please provide soil moisture for all depth levels and indicate depth in m. Please provide for purposes of permafrost sector.
Snow depth	m	per gridcell	**snd**	mon	Grid cell mean depth of snowpack. Please provide for purposes of permafrost sector.
Snow water equivalent	Kg m-2	per gridcell	**swe**	mon	snow depth x snow density
Annual maximum thaw depth	m	per gridcell	**thawdepth**	year	calculated from daily thaw depths
Optional outputs					
Carbon Mass in Leaves	kg m-2	per pft and gridcell	**cleaf_<pft>**	year	
Carbon Mass in Wood	kg m-2	per pft and gridcell	**cwood_<pft>**	year	including sapwood and hardwood
Carbon Mass in Roots	kg m-2	per pft and gridcell	**croot_<pft>**	year	including fine and coarse roots
Others					
Temperature of Soil	K	per gridcell	**tsl**	mon (day)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". **THIS IS THE MOST IMPORTANT VARIABLE FOR THE PERMAFROST SECTOR.** Also need depths in meters. Daily would be great, but otherwise monthly would work.

Burnt Area Fraction	%	per gridcell	**burntarea**	mon (day)	fraction of entire grid cell that is covered by burnt vegetation

Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide it the highest possible resolution of your model. Please contact the coordination team (Info@isimip.org) to for any further clarification, or to discuss the equivalent variable in your model.

9.3 Experiments

9.3.1 Historic runs and validation exercise

Table 22: Validation datasets for biomes models. Please note the data use restrictions indicated below the table.

Dataset	Source and further information	Variables included	Period	Scale	comment
SeaWiFS	Derived from SeaWiFS remotely sensed fAPAR product http://oceancolor.gsfc.nasa.gov/SeaWiFS/ Gobron et al., 2006	fAPAR (fraction of incident Photosynthetically Active Radiation that is absorbed by green vegetation (also called 'green vegetation cover')	1998-2005, monthly resolution	0.5 x 0.5 degrees spatial resolution	Reliable fAPAR values cannot be obtained when solar incidence is > 50°; cells where fAPAR could not be obtained for any month were excluded from the provided data set.
EVI	http://modis.gsfc.nasa.gov/data/dataprod/dataproducts.php?MOD_NUMBER=13	fAPAR	monthly resolution	0.5 x 0.5 degrees spatial resolution	The derivation of the FAPAR data is based on Eq. 11 in Xiao et al., 2005 (Ecological Applications, vol. 15, no. 3, pp. 954--969), which equates MODIS Enhanced Vegetation Index (EVI) to FAPARpav. For upscaling the MODIS monthly EVI data (either MYD13C2 or MOD13C2) from its native 0.05 degree resolution to 0.5 degree, we use a simple averaging method.

GIMMS g3 NDVI	http://www.mdpi.com/2072-4292/5/2/927	fAPAR	from 1981 15-days resolution	0.5 x 0.5 degrees spatial resolution	Zhu et al. *Remote Sens.* **2013**, *5*(2), 927-948; doi:10.3390/rs5020927
NDVI3g		fAPAR	15 days	???	
fapar3g	Upon request to U Boston Contact : Ranga B Myneni <rmyneni@bu.edu>	fAPAR	15 days	Global 0.05°	
Geoland-2 LAI	Fusion of SPOT4-VGT & AVHRR http://www.geoland2.eu/core-mapping-services/biopar.html	LAI	15 days ? TBC ?	Global 0.05° resolution for AVHRR and 1 km resolution for SPOT4-VGT	From 1981 to 1999, LAI, FAPAR and FCover are derived from NOAA/AVHRR Long Term Data Record (LTRD) dataset provided by NASA and the University of Maryland. They cover the globe at 0.05° resolution. From 2000 to the present, LAI, FAPAR and FCover are derived from SPOT/VGT data at 1km resolution.
Processed FLUXNET data [10]		GPP (Gross Primary Production)	monthly values, for the available period at each site	Different sites	Processing means partitioning of net carbon fluxes into GPP and respiration, and screening for outliers. In addition, gap-filling has been applied to shortwave solar radiation, followed by conversion to photosynthetic flux density (PPFD). Monthly GPP has been calculated by applying fitted relationships between GPP and PPFD (based on half-hourly data) throughout each month. Months with inadequate data to fit such relationships have been discarded.

10

					As long as the data are not published they are only available for the sole purpose of model evaluation in the context of ISIMIP. They are provided by Colin Prentice (colin.prentice@mq.edu.au) and Tyler Davis (tyler.davis@imperial.ac.uk) who would welcome any feedback.
Luyssaert forest site productivity dataset and extended version	matteo.campioli@uantwerpen.be Luyssaert et al. forest site data can be found at http://daac.ornl.gov/VEGETATION/guides/forest_carbon_flux.html	GPP (Gross Primary Production) + NPP (Net Primary production) + NEP for various sites where these variables are directly measured	Annual site data. The extended data have not been published yet and will be made available after the first publication		These data concern specific forest ecosystems that are not in equilibrium from previous disturbance. A specific site simulation protocol will be needed for comparison of NEP and carbon stocks. NPP and GPP data can be compared directly with model output, given the ISIMIP simulation protocol
CDIAC atmospheric CO2 concentrations	Carbon Dioxide Information Analysis Center (CDIAC, cdiac.ornl.gov)	Atmospheric CO2 concentration (seasonal phase and concentration)	1998-2005	26 sites	
De-trended CO2 inversion	Keeling, 2008; Bousquet et al., 2000, Rödenbeck et al., 2003; Baker et al., 2006; Chevalier et al., 2010	Atmospheric CO2 concentration (inter-annual comparison)	1980-2006	Different sites	

Data use Restrictions for data sets in Table 26**:**

GPP data derived from FLUXNET data

The data set is provided by Colin Prentice (colin.prentice@mq.edu.au) and Tyler Davis (tyler.davis@imperial.ac.uk) who would welcome any feedback. As long as the data are not published they are only available for the sole purpose of model evaluation in the context of ISIMIP. The underlying FLUXNET measurements and have to be acknowledged in any publication in the following way:

This work used eddy covariance data acquired by the FLUXNET community and in particular - the following networks: AmeriFlux (U.S. Department of Energy, Biological and Environmental Research, Terrestrial Carbon Program (DE-FG02-04ER63917 and DE-FG02-04ER63911)), AfriFlux, AsiaFlux, CarboAfrica, CarboEuropeIP, CarboItaly, CarboMont, ChinaFlux, Fluxnet-Canada (supported - CFCAS, NSERC, BIOCAP, Environment Canada, and NRCan), GreenGrass, KoFlux, LBA, NECC, OzFlux, TCOS-Siberia, USCCC. We acknowledge the financial support to the eddy covariance data harmonization provided - CarboEuropeIP, FAO-GTOS-TCO, iLEAPS, Max Planck Institute for Biogeochemistry, National Science Foundation, University of Tuscia, Université Laval and Environment Canada and US Department of Energy and the database development and technical support from Bekeley Water Center, Lawrence Berkeley National Laboratory, Microsoft Research eScience, Oak Ridge National Laboratory, University of California - Berkeley, University of Virginia.

The processing of the data makes use of the daily shortwave radiation provided by WATCH forcing data. The use of this dataset should also be acknowledged with a citation similar to:

Weedon, G. P., Gomes, S., Balsamo, G., Best, M. J., Bellouin, N. & Viterbo, P. (2012) WATCH forcing databased on ERA-INTERIM. Retrieved 10 September 2013, from ftp://rfdata:forceDATA@ftp.iiasa.ac.at

9.3.2 Basic Metrics to measure the agreement between observations and simulations

1. Spatial agreement (calculated at each point in time)

Step 1

$$NME^{space} = \sum_i \left| x_i^{sim} - x_i^{obs} \right| \, / \, \sum_i \left| x_i^{obs} - \bar{x}^{obs} \right|$$

$$NMSE^{space} = \sum_i (x_i^{sim} - x_i^{obs})^2 \, / \, \sum_i (x_i^{obs} - \bar{x}^{obs})^2$$

Step 2 (removing the influence of the mean)

$$NME^{space} = \sum_i \left| (x_i^{sim} - \bar{x}^{sim}) - (x_i^{obs} - \bar{x}^{obs}) \right| \, / \, \sum_i \left| x_i^{obs} - \bar{x}^{obs} \right|$$

$$NMSE^{space} = \sum_i ((x_i^{sim} - \bar{x}^{sim}) - (x_i^{obs} - \bar{x}^{obs}))^2 \, / \, \sum_i (x_i^{obs} - \bar{x}^{obs})^2$$

Step 3 (removing the influence of the variability)

$$NME^{space} = \sum_i \left| \frac{x_i^{sim} - \bar{x}^{sim}}{\sum_i \left| x_i^{sim} - \bar{x}^{sim} \right| / n} - \frac{x_i^{obs} - \bar{x}^{obs}}{\sum_i \left| x_i^{obs} - \bar{x}^{obs} \right| / n} \right| \, / \, \sum_i \left| x_i^{obs} - \bar{x}^{obs} \right|$$

$$NMSE^{space} = \sum_i \left(\frac{x_i^{sim} - \bar{x}^{sim}}{\sqrt{\sum_i (x_i^{sim} - \bar{x}^{sim})^2 / n}} - \frac{x_i^{obe} - \bar{x}^{obs}}{\sqrt{\sum_i (x_i^{obs} - \bar{x}^{obs})^2 / n}} \right)^2 \, / \, \sum_i (x_i^{obs} - \bar{x}^{obs})^2$$

Where x_i^{obs} and $x_i^{sim}$are the observed and simulated values of variable x in grid cell or at site I, respectively. $\bar{x}^{obs}$ is the mean observed values across all site or grid cells.

2. Temporal agreement (on global or regional level)

$NME^{time}$and $NMSE^{time}$ are calculated analogously to the above specifications where x_i^{obs} and $x_i^{sim}$are the observed and simulated global (or regional) mean values of variable x in year of month i, respectively. $\bar{x}^{obs}$ and $\bar{x}^{sim}$ is the mean observed and simulated values across all years and months, respectively.

3. Agreement with regard to seasonality

To compare the observed and simulated seasonality each simulated or observed month is represented by a vector in the complex plane, where the length of the vector corresponds to the magnitude of the variable for the specific month and the direction of the vector corresponds to the time of the year represented by the angle

$$\theta_t = 2\pi \frac{t-1}{12}$$

with month 1 (January) arbitrarily set to an angle of 0. A mean vector L is calculated by averaging the real and the imaginary parts of the 12 vectors x_t:

$L_x = \sum_t x_t \cos\theta_t$ and $L_y = \sum_t x_t \sin\theta_t$

The length of the mean vector divided by the annual value stands for seasonal concentration, $C = \sqrt{L_x^2 + L_y^2}/\sum_t x_t$ and $P = \arctan(L_x/L_y)$ stands for its phase. Thus if the variable is concentrated all in one month, seasonal concentration is equal to 1 and the phase corresponds to that month. If the variable is evenly spread over all months then the concentration is equal to zero and the phase is undefined. If either modeled or observed values have zero values for all months in a given cell or site then that cell/site is not included in the comparison. Modelled and observed phase are compared using mean phase difference

$$MPD = \frac{1}{\pi}\arccos[\frac{\cos(\omega_i - \vartheta_i)}{n}],$$

where ω_i is the modeled phase and ϑ_i is the observed phase. The measure can be interpreted as the average timing error as a proportion of the maximum error (6 months). For seasonal CO2 concentrations, where the data are monthly deviations from the mean CO2, we compare the seasonal amplitude instead of the seasonal concentration by comparing the simulated and observational sum of the absolute CO2 deviations for each month using the NME or NMSE from step 1 above.

9.3.3 Fast track runs for new models

Please consult the fast track protocol Section 7 for those runs and related information. It is available at www.isimip.org > Getting Started > ISIMIP Fast Track Protocol. In case of any questions please contact info@isimip.org. Please note that aside from harmonized climate and socio-economic input the default settings of your model should be used. Also note that for output data files the file name (as specified in Section 5.2 of the fast track protocol) is all lower case!

10 **Forest Models (Regional, Forest stand-level models)**

PROFOUND Contributors: Christopher Reyer, Susana Barreiro, Harald Bugmann, Alessio Collalti, Klara Dolos, Louis Francois, Venceslas Goudiaby, Carlos Gracia, Thomas Hickler, Mathieu Jonard, Chris Kollas, Koen Kramer, Petra Lasch-Born, Denis Loustau, Annikki Mäkelä, Simon Martel, Daniel Nadal I Sala, Delphine Picart, David Price, Santiago Sabaté, Monia Santini, Rupert Seidl, Felicitas Suckow, Margarida Tomé, Giorgio Vacchiano

10.1 Introduction to multi-model simulations in ISIMIP2a and PROFOUND

This is an overview document to support multi-model simulations of forest stand models for both model evaluation with observed data but also for model projections under climate change. A number of sites has been selected in the COST Action PROFOUND for which a) a wide range of forest models can be rather easily initialized, b) observational data is available for model evaluation and b) additional local driving datasets are available such as N-deposition or locally observed climate (**Table 24**). To get access to this PROFOUND Database, please contact reyer@pik-potsdam.de. A few important particularities for the forest simulations are listed below.

1) **Management:** The modeling experiments mostly encompass managed forests. The standard management ("man") during the historical period is the observed management as defined by the data available for each site (e.g. reduction in stem numbers) and, after the observations end, missing management information is to be substituted with generic future management guidelines from **Table 25** - . This future management corresponds best to "intensive even-aged forestry" as defined by Duncker et al. 2012. After harvesting the stands (c.f. **Table 25** and **Table 26**), please proceed after harvest as your model usually does, e.g. plant the same tree species again or allow for regeneration of the same species according to the regeneration guidelines outlined in Table 27. A "natural reference run (nat)" without any management will help assessing the influence of forest management.

2) **Calibration:** Some of the models may require some kind of calibration or model development before they can contribute to ISIMIP. Such alterations of the model can influence the results of a model comparison and "model calibration" is understood differently by different modelers. All alterations to the model in the framework of this exercise should be reported in the model experiment documentation provided together with the upload of the simulations. Whenever the model calibration or development is driven by an improvement of the model after a comparison to data that were originally made available in ISIMIP for model evaluation, a part of those data should be kept aside for model evaluation and not used for calibration.

a. Model development needed to run a model at specific sites is welcomed and needs to be transparent/ properly documented (e.g. adjustment of phenology model to include chilling effects). This is also applicable for more general calibration (i.e. fixing parameters once but not changing afterwards) for example to include a new tree species in a model.
b. Manual or automatic site-specific “tuning” of species-specific and process-specific parameters should be avoided. The same “model” (i.e. also with the same parameter values) should be used in all simulations. If needed, any tuning needs to be documented in a transparent way and should be backed up by existing data (e.g. from TRY-database). If your model contains genetic processes where the change in parameters is part of the model processes, this is naturally part of “your model approach” and should be clearly spelled out as part of the documentation of your model. In this specific case, please contact the sectoral coordinators to discuss if it makes sense to include a “genetic adaptation” and a “parameter-fixed, control” run.

3) **Reporting Period**: Each phase of ISIMIP has its own reporting period (e.g. 1971-2000 for ISIMIP2A) but since we have sometimes data for model initialization and validation going back even further in time, you should always start your reporting period for the first time step for which stand data is available (e.g. 1948 for the Peitz stand) and run your model until the last point in time where climate data is available. Similarly, if the model runs only start later than, e.g. 1971, the reporting period is shorter. If the data for model initialization is only available very late (e.g. KROOF starts in 1998 only, you do not need to run your model for those climatic datasets which end early (e.g. Watch ending in 2001 already). Likewise, for the future ISIMIPFT runs using GCM data, the sites have to be initialized after 1950 because the GCM historical data is only available from 1950 onwards. This pertains to the sites Peitz and Soro (see **Table 26**).

4) Important amendments to the spin-up as defined in the overall ISIMIP protocol: For those forest models requiring a spin-up, please use the spin-up data as explained in Chapter 5. For the runs using “observations from local meteorological stations or likewise”, Louis Francois will provide time series based on Princeton data but so that it matches the average of the data at the meteorological station during the period where meteorological measurements have been taken.

10.2 Experiments

Table 23 provides an overview of all experiments to be run with regional forest models in ISIMIP. This table is for your reference only; please read chapters 1-6 of the general ISIMIP protocol and this whole section carefully before beginning with the experiments. The future simulations here are meant to be catch-up runs with the ISIMIP Fast track data. In case of any questions please contact info@isimip.org. Please note that aside from harmonized climate, stand, management and soil input, the default settings of your model should be used. Also note that for output data files the **file name is all lower case**! Models should run all four RCPs for each model before moving on to the next GCM.

Table 23 Experiment summary for regional forest models. Each experiment is to be carried out for each site named in **Table 24.** For management scenarios see **Table 25** - .

	Climate Data	Scenario	Management	Other settings (sens-scenario)	# runs
Historical runs without disturbances (Experiment 1a)	Observations from local meteorological station or likewise	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2), EMEP-N-deposition	2
	PGMFD v.2 (Princeton)	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2), EMEP-N-deposition	2
	GSWP3	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2), EMEP-N-deposition	2
	WATCH (WFD)	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2), EMEP-N-deposition	2
	WATCH+WFDEI.GPCC	hist	1. Observed management (man) 2. Natural reference run (nat)	historical CO_2 without disturbances (co2), EMEP-N-deposition	2
Historical & Future runs without disturbances (Experiment 2a – ISIMIP Fast Track catch-up runs)	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat) without management	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2)	8
	GCM1 (HadGEM2-ES)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards (368.87ppm), without disturbances (noco2)	8
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0),	1. Observed management (man) + generic future management after observation stops	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2)	8

		8.5 (rcp8p5)	2. Natural reference run (nat)		
	GCM2 (IPSL-CM5A-LR)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards (368.87ppm), without disturbances (noco2)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2)	8
	GCM3 (MIROC-ESM-CHEM)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards (368.87ppm), without disturbances (noco2)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2)	8
	GCM4 (GFDL-ESM2M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards (368.87ppm), without disturbances (noco2)	8
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + RCP2.6, RCP4.5, RCP6.0, RCP8.5 without disturbances (co2)	8
	GCM5 (NorESM1-M)	hist+ 2.6 (rcp2p6), 4.5 (rcp4p5), 6.0 (rcp6p0), 8.5 (rcp8p5)	1. Observed management (man) + generic future management after observation stops 2. Natural reference run (nat)	historical CO_2 + fixed CO_2 from 2000 onwards (368.87ppm), without disturbances (noco2)	8

10.3 Sector-specific input

The input and evaluation data is provided through the PROFOUND database including a R-package to explore the database. Until the database is officially released, please get in touch with Christopher Reyer (reyer@pik-potsdam.de) to access the database.

Table 24 Overview of the forest stands to be simulated in ISIMIP/PROFOUND.

Site name	Lat	Lon	Country	Forest type	Species	Comments
hyytiala	61.8475	24.295	FI	Even-aged conifer	pisy, piab with some deciduous mix	note that an experimental plot of pine contains a lot of data while footprint of flux tower is larger Please note that the deciduous admixtures only appear in the data at a later stage and hence do not need to be simulated.
peitz	51.9166	14.35	DE	Even-aged conifer	pisy	managed using a weak thinning from below
solling_beech	51.77	9.57	DE	Even-aged deciduous	fasy	
solling_spruce	51.77	9.57	DE	Even-aged conifer	piab	
soro	55.485844	11.644616	DK	Even-aged deciduous	fasy	
kroof	48.25	11.4	DE	Mixed deciduous and conifers	Fasy, piab, acpl, lade, pisy, quro	unmanaged/ thinning from below in past 20 years
le_bray	44.71711	-0.7693	FR	Even-aged conifer	pipi	
collelongo	41.8494	13.5881	IT	Even-aged deciduous	fasy	
bily_kriz	49.3	18.32	CZ	Even-aged conifer	piab	

Table 25 Generic future management for the different tree species. If there is no information about management of the stands available in Table 29, please apply the following generic management guidelines. For past simulations and depending on the model, modellers should use the observed stem numbers from the time series of stand and tree level data to mimick stand management. Future management should then be added according to the generic management guidelines outlined below. E.g., The last management for the Peitz site can be infered from the tree data is taking place in 2011, hence the next management would then happen in 2026 according to **Table 26**.

Species	Thinning regime	Intensity [% of basal area]	Interval [yr]	Stand age for final harvest	Remarks
pisy	below	20	15	140	Pukkala et al. 1998; Fuerstenau et al. 2007; Gonzales et al- 2005; Lasch et al. 2005
piab	below	30	15	120	Pape 2008; Pukkala et al. 1998; Hanewinkel and Pretzsch- 2000; Sterba 1986; Laehde et al. 2010
fasy	above	30	15	140	Schuetz 2006; Mund et al. 2004; Hein and Dhote 2006; Cescatti and Piutti 1998
quro/qupe	above	15	15	200	Hein and Dhote 2006; Fuerstenau et al. 2007; Štefančík 2012; Kerr 1996; Gutsch et al. 2011
pipi	below	20	10	45	Management after Loustau et al. 2005 & Thivolle-Cazat et al. 2013

Table 26 Management schedules for the sites included in the simulation experiments. The first available data point is used for model initialization (Ini). Following data points are used to mimick historic management (HM). When no more observed data is available, the generic management rules from **Table 25** are being used (FM). For a better overview, harvest and planting are marked in bold.

Name	Ini	HM	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FMX	FMX	FMX	FMX	FMX	Remarks
bily_kriz	1997	1998-2015^{T}	2030^{T}	2045^{T}	2060^{T}	2075^{T}	2090^{T}	**2101^{H}**	**2102^{P}**	2117^{T}	…	**2222^{H}**	**2223^{P}**	2238^{T}	…	
collelongo	1992	1997-2012^{T}	2027^{T}	**2032^{H}**	**2033^{P}**	2048^{T}	2063^{T}	2078^{T}	2093^{T}	…	**2173^{H}**	**2174^{P}**	2189^{T}	…	…	
hyytiala*	1995	1996-2011^{T}	2026^{T}	2041^{T}	2056^{T}	2071^{T}	2086^{T}	**2101^{H}**	**2102^{P}**	2117^{T}	…	**2242^{H}**	**2243^{P}**	2258^{T}	…	Only simulate pine and spruce (no hard-woods) **and regenerate as pure pine stand**
kroof*	1997	1999-2010^{T}	2025^{T}	2040^{T}	2055^{T}	2070^{T}	2085^{T}	2100^{T}	**2101^{H}**	**2102^{P}**	2117^{T}	…	**2222^{H}**	**2223^{P}**	…	**Harvest all species at the same time (i.e. 120 years)**
le_bray	1986	1987-2009^{T}	**2015^{H}**	**2016^{P}**	2026^{T}	2036^{T}	2046^{T}	2056^{T}	**2061^{H}**	**2062^{P}**	2072^{T}	…	**2107^{H}**	**2108^{P}**	2026^{T}	
Peitz	1948**	1952-2011^{T}	2026^{T}	**2040^{H}**	**2041^{P}**	2056^{T}	2071^{T}	2086^{T}	2101^{T}	…	**2181^{H}**	**2182^{P}**	2197^{T}	…	…	
solling_beech*	1980	1985-2000^{T}	**2015^{H}**	**2016^{P}**	2031^{T}	2046^{T}	2061^{T}	2076^{T}	2091^{T}	…	**2156^{H}**	**2157^{P}**	2172^{T}	…	**2297^{H}**	
solling_spruce*	1967	1968-2009^{T}	**2024^{H}**	**2025^{P}**	2040^{T}	2055^{T}	2070^{T}	2085^{T}	2100^{T}	…	**2145^{H}**	**2146^{P}**	2161^{T}	…	**2266^{H}**	
Soro	1944**	1945-2005^{T}	2020^{T}	2035^{T}	2050^{T}	**2061^{H}**	**2062^{P}**	2077^{T}	2092^{T}	…	**2202^{H}**	**2203^{P}**	2218^{T}	…	…	

Ini = Initialization data, HM = Historic Management, FM = Future Management, T=Thinning, H= Harvest, P=Planting, *=maximum age extended a bit to match local management during observed period or avoid harvesting just before the end of the simulation, **= the GCM data only starts in 1950, hence for future runs (Experiment 2a), you have to initialize these forests at the first time step after 1949 (i.e. 1952 for Peitz and 1950 for Soro). For the historical validation runs (Experiment 1a) you can start with the first available stand initialization.

Table 27 Planting information for the sites included in the simulation experiments. DBH is defined as diameter at breast height of 1.30m. Thenumbers in brackest indicate plausible ranges.

Name	Density ha^{-1}	Age years	Height m	DBH cm	age when DBH is reached years	Remarks
bily_kriz	4500	4	0.5	na	9	Historical planting density was 5000/ha but current practices are 4500/ha only
collelongo	10000	4	1.3	0.1	**4**	Only a rough approximation, usually natural regeneration is the regeneration method.
hyytala	2250 (2000-2500)	2	0.25 (0.2-0.3)	na	6 (5-7)	
kroof (beech)	6000 (5000-7000)	2	0.6 (0.5-0.7)	0.5	5	The planting density is for single-species stands, hence when regenerating the 2-species-stand KROOF, the planting density of each species should be halved
kroof (spruce)	2250 (2000-2500)	2	0.35 (0.3-0.4)	0.5	7	See above
le_bray	1250 (1000-14000)	1	0.2 (0.1-0.25)	na	3 (2-5)	These are the current practices (*De Lary, 2015*) and should be used for future regeneration. Historically, the site was seeded with 3000-5000 seedlings per ha and then cleared once or twice to reach a density of 1250/ha at 7-year old when seedlings reach the size for DBH recruitment. ➔ modelers could mimic this by "planting" trees with DBH of 7.5cm and 6m height in 1978 with a density of 1250 trees/ha
peitz	9000 (8000-10000)	2	0.175 (0.1-0.25)	**0.1**	**5**	The “age when DBH is reached = 5” is an estimate
solling_beech	6000 (5000-7000)	2	0.6 (0.5-0.7)	0.5	5	
solling_spruce	2250 (2000-2500)	2	0.35 (0.3-0.4)	0.5	7	
soro	6000	4	0.82	na	6	

10.4 Output data

Table 28 Variables to be reported by forest models. Abbreviations are provided in **Table 29**. Variables should be reported as documented in section 6.

Long name	units		output variable name	frequency	comment
Essential (mandatory) outputs					
Mean DBH	cm	per species and stand total	**dbh_<species/total>**	year	
Mean DBH of 100 highest trees	cm	stand total	**Dbh_domhei**	year	100 highest trees per hectare.
Stand Height	m	per species and stand total	**height_<species/total>**	year	For models including natural regeneration this variable may not make sense, please report dom_height
Dominant Height	m	stand total	**dom_height**	year	Mean height of the 100 highest trees
Stand Density	Trees/ha	per species and stand total	**density_<species/total>**	year	
Basal Area	m^2ha^{-1}	per species and stand total	**ba_<species/total>**	year	
Volume of Dead Trees	m^3ha^{-1}	per species and stand total	**mort_<species/total>**	year	
Harvest by dbh-class	m^3ha^{-1}	per species and stand total and dbh-class	**harv_<species/total>_<dbhclass/total>**	year	
Remaining stem number after disturbance and management by dbh class	Trees/ha	per species and stand total	**stemno_<species/total>_<dbhclass/total>**	year	
Stand Volume	m^3 ha^{-1}	per species and stand total	**vol_<species/total>**	year	
Carbon Mass in Vegetation biomass (incl. Soil veg.?)	kg C m^{-2}	per species and stand total	**cveg_<species/total>**	year	
Carbon Mass in Litter Pool	kg C m^{-2}	per species and stand total	**clitter_<species/total>**	year	Info for each individual pool.

Carbon Mass in Soil Pool	kg C m^{-2}	per species and stand total	**csoil_<species/total>**	year	Info for each individual soil layer
Tree age by dbh class	yr	per species and stand total	**age_<species/total>_<dbhclass/total >**	year	
Gross Primary Production	kg m^{-2} s^{-1}	per species and stand total	**gpp_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production	kg m^{-2} s^{-1}	per species and stand total	**npp_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Autotrophic (Plant) Respiration	kg m^{-2} s^{-1}	per species and stand total	**ra_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Heterotrophic Respiration	kg m^{-2} s^{-1}	stand total	**rh_<total>**	day	As kg carbon*m^{-2}*s^{-1}
Net Ecosystem Exchange	kg m^{-2} s^{-1}	per stand	**nee_<total>**	day	As kg carbon*m^{-2}*s^{-1}
Mean Annual Increment	m^3 ha^{-1}	per species and stand total	**mai_<species/total>**	year	
Fraction of absorbed photosynthetically active radiation	%	per species and stand total	**fapar_<species/total>**	day	
Leaf Area Index	m^2 m^{-2}	per species and stand total	**lai_<species/total>**	mon	
Species composition	% of basal area	per ha	**species_<species>**	year (or once if static)	The categories may differ from model to model, depending on their species and stand definitions.
Total Evapotranspiration	kg m-2 s-1	stand total	**evap_<total>**	day	sum of transpiration, evaporation, interception and sublimation. (=intercept+esoil+trans)
Evaporation from Canopy (interception)	kg m-2 s-1	per species and stand total	**intercept_<species/total>**	day	the canopy evaporation+sublimation (if present in model).
Water Evaporation from Soil	kg m-2 s-1	per stand	**esoil**	day	includes sublimation.
Transpiration	kg m-2 s-1	per species and stand total	**trans_<species/total>**	day	
Soil Moisture	kg m-2	per stand	**soilmoist**	day	If possible, please

					provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. Otherwise, provide soil moisture of entire column.
Optional outputs					
Removed stem numbers by size class by natural mortality	Trees ha^{-1}	per species and stand total	**mortstemno_<species/total>_<dbhclass/total>**	year	
Removed stem numbers by size class by management	Trees/ha	per species and stand total	**harvstemno_<species/total>_<dbhclass/total>**	year	
Volume of disturbance damage	m^3ha^{-1}	per species and stand total	**dist_<dist_name>**	year	
Nitrogen of annual Litter	g N $m^{-2}a^{-1}$	per species and stand total	**nlit_<species/total>**	year	
Nitrogen in Soil	g N $m^{-2}a^{-1}$	stand total	**nsoil_<total>**	year	
Net Primary Production allocated to leaf biomass	kg m-2 s-1	per species and stand total	**npp_landleaf__<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to fine root biomass	kg m-2 s-1	per species and stand total	**npp_landroot_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to above ground wood biomass	kg m-2 s-1	per species and stand total	**npp_abovegroundwood_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to below ground wood biomass	kg m-2 s-1	per species and stand total	**npp_belowgroundwood_<species>**	day	As kg carbon*m^{-2}*s^{-1}
Root autotrophic respiration	kg m-2 s-1	per species and stand total	**rr_<species/total>**	day	As kg carbon*m^{-2}*s^{-1}
Carbon Mass in Leaves	kg m-2	per species and stand total	**cleaf_<species>**	year	
Carbon Mass in Wood	kg m-2	per species and stand total	**cwood_<species>**	year	including sapwood and hardwood

Carbon Mass in Roots	kg m-2	per species and stand total	**croot_<species>**	year	including fine and coarse roots
Temperature of Soil	K	per stand	**tsl**	day	Temperature of each soil layer

Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide it the highest possible resolution of your model. Please contact the coordination team (info@isimip.org) to for any further clarification, or to discuss the equivalent variable in your model.

Table 29: Codes for species, disturbance names and dbh classes as used in protocol (species, dist_name, dbhclass).

long name	Short name
Fagus sylvatica	fasy
Quercus robur	quro
Quercus petraea	qupe
Pinus sylvestris	pisy
Picea abies	piab
Pinus pinaster	pipi
Larix decidua	lade
Acer platanoides	acpl
Eucalyptus globulus	eugl
Betula pendula	bepe
Betula pubescens	bepu
Robinia pseudoacacia	rops
Fraxinus excelsior	frex
Populus nigra	poni
Sorbus aucuparia	soau
hard woods	hawo
fire	fi
wind	wi
Insects	ins
Drought	dr
Grazing	graz
Diseases	dis
DBH_class_<X>-<X+5>*	dbh_c<X>
DBH_class_>140*	dbh_c140

*the boundaries of the dbh classes should interpreted as follows: dbh_class_0-5 = 0 to<5 cm; dbh_class_5-10 =5 to<10 cm, etc…. the dbh class dbh_c140 includes all trees of 140cm dbh and larger.

10.5 Experiments and possible analyses

10.5.1 Historic runs and validation exercise – Experiments 1a

These are the core simulations for ISIMIP2a. For the sites mentioned in **Table 24**, a detailed comparison of model-data-(mis)match is envisaged, especially with a focus on past extreme events (e.g. 2003) and variability. These data may also be interesting for some additional validation tasks that can be carried out during postprocessing. The simulations of Experiment 1a listed in **Table 23** are needed for this experiment.

10.5.2 ISIMIP Fast-track catch-up runs – Experiments 2a

These are simulations for the sites mentioned in **Table 24** using ISIMIP Fast track climate scenarios to project forest development under climate change in the future. These are interesting for cross-scale comparisons with DGVMs, cross-sectoral analysis of climate impacts and multi-model climate change impact projections. The simulations of Experiment 2a listed in **Table 23** are needed for this experiment.

10.5.3 Influence of disturbances – (optional, future experiments 1b and 2b)

These are historic and future simulations as described in sections 7.3.5.1 and 7.3.5.2 but with dynamic disturbances switched on for those models that actually simulate such dynamics. These simulations can be used to isolate the effects of disturbances vs. climate or to consider the joint impact of climate change and disturbances on forest products and services. The simulations of Experiment 1b and 2b listed in **Table 23** are needed for this experiment.

10.5.4 Isolation of climate effects (optional, future experiment)

Simulate time slices (i.e. same stand as growing in past simulations is repeatedly simulated for different time slices of maybe 20-30 years) to isolate the effects of climate change from the effects of forest dynamics. Some stands are already very old and would reach 200 years or more of age in 2100.

10.5.5 Climate input uncertainty (optional, future experiments)

What is the influence of the climate data to be used? Currently, we focus on observed time series from stands for model evaluation and GCM-data from the grid-cell in which a forest stand is located for future runs. Further downscaling of GCM data is at the moment not envisaged for consistency with ISIMIP in general. However in the future it could be interesting to design additional runs with downscaled climate data, e.g., using CORDEX runs or data from other sources.

10.5.6 Influence of forest structure (optional, future experiments)

Given the societal and environmental changes affecting forest economics and ecology, forest management systems and practices must be adapted and improved in order to maintain the socio-economic and environmental functions of the European forests. The structurally complex stands such as uneven-aged mixed-species stands are promising to ensure a sustainable wood production while improving forest stand resilience and ecosystem service provision. However, the process-based eco-physiological and biogeochemical models designed to analyze forest ecosystem response to environmental changes generally accounts for the effects of stand structure in very simplified way.

Our objective is to simulate the effects of forest structure in terms of vertical structure and/or species composition and/or cohorts on the main carbon cycle and stand growth variables (e.g. GPP, NPP, Autotrophic Respiration, Mean Annual Volume Increment, Current Annual Volume Increment) and tree attributes (heights, DBHs) .

A first experiment could compare even-aged *vs* uneven-aged stands or pure *vs* mixed stands making sure everything is comparable except stand structure (using eventually virtual stands created based on existing ones but adapted to be more comparable).

A second experiment could be conducted to compare simulations of models with different levels of spatial description (stand, cohort, tree) and identify which approach is most appropriate depending on the stand structure complexity.

A third experiment would consist in simulating the evolution of existing stands with contrasted structure according to different silvicoltural and climate scenarios.

11 **Agriculture (crop modelling)**

This section lays out the global output protocol for the agricultural sector's contribution to ISIMIP. For further details, please contact AgMIP (ag-grid@agmip.org) and ISIMIP (info@isimip.org).

Note that the variable names are chosen to comply with AgMIP conventions, or are harmonized with the conventions used in the ISIMIP water sector (for irrigation water). They are given in lower-case letters only in order to prevent the use of mixed-case names in the file names (see 6.2.1). **Table 30** provides an overview of all experiments to be run in the agriculture (crop modelling) sector in ISIMIP2a. This table is for your reference only; please read chapters 1-5 and this section carefully before beginning with the experiments.

Table 30 Experiment summary for crop models

	Climate Data	Scenario	Management settings	Land use (LU)	Other settings (sens-scenario)	irrigation	# runs
Historical runs	PGMFD v.2 (Princeton)	hist	default (present day) (default)	pure crop run (no LU specifier)	historical CO2 (no co2 specifier)	firr noirr	2
	GSWP3	hist	default (present day) (default)	pure crop run (no LU specifier)	historical CO2 (no co2 specifier)	firr noirr	2
	WATCH (WFD)	hist	default (present day) (default)	pure crop run (no LU specifier)	historical CO2 (no co2 specifier)	firr noirr	2
	WATCH + WFDEI.GPCC	hist	default (present day) (default) fully harmonized (fullharm) harmonized season, no N constraints (harmnon)	pure crop run (no LU specifier)	historical CO2 (no co2 specifier)	firr noirr	6
							12 (per crop)

11.1 Sector-specific input

Some GGCMs require inputs on planting dates, crop variety parameters, fertilizer use and possibly other management specifics. While the agreement for the fast-track was to use each models setting that best represents current management patterns, we'll have specific in puts on planting dates and maturity dates (to allow for spatially-explicit variety parameterization) as well as fertilizer use (N, P, K). Some experiments will be run with harmonized input data (validation and attribution studies), some with default model settings.

Table 31 Crop-model-specific input data

Variable	Source*	Units	Notes
Planting dates	Sacks-2010, Portmann-2010, and environmental-based	Julian days (Jan 1st= 1,…)	Planting dates for primary seasons.
Approximate maturity	Sacks-2010, Portmann-2010, and environmental-based	Days from sowing	Growing season length in days.
Fertilizers and manure	Mueller-2012, Potter-2011, Liu-2010, and Foley-2010	kg ha-1 yr-1	Average nitrogen, phosphorus, and potassium application rates in each grid cell, with organic and inorganic amendments aggregated and converted to an "effective inorganic application rate".
Historical [CO2]	Mauna Loa/RCP historical	ppm	Annual [CO2] values from 1900-2013.

11.2 Output data and definitions

Table 32 Crop-model-specific definitions

Definition of time variable	Protocol choice	"growing seasons since YYYY-01-01"	YYYY is just the first year in the file. For a run 1958-2001, YYYY=1958. Values of time are independent of how to map growing season to calendar.
Season Definition	Protocol choice	Definition	AET and PirrWW defined as accumulated over the growing season, not over the calendar year.
Automatic irrigation	Guidance for parameter choices	Definition	Management depth = 40cm / Efficiency = 100% Upper/Lower event trigger threshold = 90/100% Max single AND annual volume = Unlimited
Automatic planting	Guidance for parameters choices	Definition	Min/max soil water at planting (40 cm) = 40/100% Min/max soil temp at planting (10 cm) = 10/40 C

Crop Priority list:

1. Wheat[11], maize, soy, rice [whe, mai, soy, ric]
2. All others: Sugarcane, sorghum, millet, rapeseed, sugar beet, barley, rye, oat [sug, sor, mil, rap, sgb, bar, rye, and oat] + managed grass [mgr] [12], field peas [pea], cassava [cas], sunflower [sun], groundnuts [nut], bean [ben], potato [pot], …
3. Crop rotation

Note that the key diagnostic variables need only be provided for the minimal setting runs.

[11] There will be no distinction between winter and spring wheat.

[12] We have decided to include only managed grassland productivity in the fast-track comparison.

Table 33 Output variables for crop models

Variable	Variable name	Resolution	Unit	Comments
Key model outputs				
Crop yields	yield_<crop>	annual (0.5°x0.5°)	dry matter t/ha/yr (t ha-1 yr-1)	Crop-specific
Irrigation water withdrawal (assuming unlimited water supply)	pirrww_<crop>	annual (0.5°x0.5°)	mm yr-1	*Irrigation water withdrawn in case of optimal irrigation (in addition to rainfall), assuming no losses in conveyance and application.*
Key diagnostic variables				
Actual evapotranspiration	aet_<crop>	annual (0.5°x0.5°)	mm yr-1	portion of all water (including rain) that is evapo-transpired, the water amount should be accumulated over the entire growing period (**not** the calendar year)
Nitrogen application rate	initr_<crop>	annual (0.5°x0.5°)	kg ha-1 yr-1	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as effective inorganic nitrogen input (ignoring residues).
Actual planting dates	plant-day_<crop>	annual (0.5°x0.5°)	Day of year	
Anthesis dates	anth-day_<crop>	annual (0.5°x0.5°)	Days from planting date	
Maturity dates	maty-day_<crop>	annual (0.5°x0.5°)	Days from planting date	
Additional output variables (optional)				

Biomass yields	biom_<crop>	annual (0.5°x0.5°)	Dry matter t/ha/yr (t ha-1 yr-1)	
Soil carbon emissions	sco2_<crop>	annual (0.5°x0.5°)	kg C ha-1	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	sn2o_<crop>	annual (0.5°x0.5°)	kg N2O-N ha-1	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.

11.3 Experiments

11.3.1Historic runs and validation experiment

Specification of the historical run

Simulations for the historical period should be provided as pure crop runs (i.e. assuming the crop growing all over the world), based on the climate input described in section 4.1. For each crop there should be a full irrigation run (firr) and a no-irrigation run (noirr), as already specified for the Fast Track. In contrast to the Fast Track simulations, however, within ISIMIP2 we ask for historical runs with three different degrees of harmonization as given in **Table 34**.

Table 34: Scenario settings for crop model simulations

Simulation	Comments
Default	Model should use their individual "best representation" of the historical period with regard to sowing dates, harvesting dates, fertilizer application rates and crop varieties.
fully harmonized	Simulations based on prescribed "present day" fertilization rates (available for download) and fixed planting and harvesting dates (also available for download). Modelers should have planting as closely as possible to these dates, but it may be admissible to use these dates as indicators for planting windows (depending on model

	specifics).
Harmonized seasons with no N constraints	For models with an explicit description of the nitrogen cycle: Harmnon simulations should be run with nitrogen stress turned off completely or (if that's not possible) with very high N application rates to make model results comparable between those GGCMs that have explicit N dynamics and those that do not. For models without the nitrogen cycle: harmnon and fullharm simulations are the same and do not need to be duplicated.

Each of these three variants should be combined with a no-irrigation and full irrigation assumption, resulting (for the models with an explicit representation of the nitrogen cycle) in 6 runs for the respective climate input data set (cf. **Table 30**).

Specification of the validation procedure

For the validation task the pure crop simulations should

1) be masked by the following LU patterns: "Dynamic MIRCA" (reconstruction of historical LU based on HYDE and MIRCA2000, see section 4.1.3.

2) averaging and aggregation will be performed in the post-processing and depending on what data we compare to. It could include de-trending (to compare with possibly de-trended observations).

11.3.2 Fast track runs for new models

Please consult the fast track protocol Section 7 for those runs and related information. It is available at www.ISIMIP.org/ under ISIMIP Fast Track -> Simulation Protocol. In case of any questions please contact Info@isimip.org. Please note that aside from harmonized climate and socio-economic input the default settings of your model should be used. Also note that for output data files the file name (as specified in Section 5.2 of the fast track protocol) everything is lower case!

12 Agro-economic Models

This section lays out the global output protocol for the agro-economic sector's contribution to ISIMIP. For further details, please contact Hermann Lotze-Campen (lotze-campen@pik-potsdam.de) and us (Info@isimip.org).

Note that the variable names are chosen to comply with AgMIP conventions, or are harmonized with the conventions used in the water sector (for irrigation water). They are given in lower-case letters only in order to prevent the use of mixed-case names in the file names (see section 0).

Specific settings still have to be discussed with the participating agro-economic modelling groups, also in connection with work in AgMIP GlobEcon and the SSP process. One important issue to be clarified is the timeline of the simulations, i.e. 2050 or 2100.

12.1 Sector-specific input

Most agro-economic models will need three types of inputs. Projections on GDP and Population per country are to be taken from the IIASA database on SSP scenarios. Furthermore, exogenous productivity trends for agriculture can be taken from IFPRI. In AgMIP, the IFPRI-IMPACT team has developed a procedure to adjust baseline productivity shifters to different GDP projections. However, until now this has only be done until 2050. In principle, this procedure could be applied to the ISIMIP scenarios as well.

This has to be further discussed with the participating agro-economic modelling groups.

12.2 Output

This section still has to be discussed with the participating agro-economic modelling groups, also in connection with work in AgMIP GlobEcon and the SSP process. One important issue to be clarified is the timeline of the simulations, i.e. 2050 or 2100.

Output to be reported (list of variables specified in **Table 35**) for:

1) the following crops: wheat, coarse grains (i.e. maize, millet, sorghum, barley, oats, and rye), rice, oilseeds (i.e. soy, groundnut, rapeseed, palm), sugar (cane and beet); aggregate of the five major groups (CR5)

and

2) if possible, the following other quantities: managed grass land, ruminant meat, non-ruminant meat

Table 35: Output variables for agro-economic models.

Variable	Variable name	Resolution (time, spatial)	Unit (NetCDF format)	Comments
Effective crop yields	yield_<crop>[13]	time steps (regional)	dry matter t/ha/yr (t ha-1 yr-1)	Crop-specific, all crops
Total production	prod_<crop>	time steps (regional)	kcal/capita (kcal capita-1)	Crops plus livestock
Applied irrigation water	irrww_<crop>	time steps (regional)	$kg/m^2/s$ (kg m-2 s-1)	Water supplied to the fields
Weighted average producer prices	xprp_<crop>	time steps (regional)	USD2005/t (2005US$)	For outputs listed above
Representative price on int'l markets	xprr_<crop>	time steps (regional)	USD2005/t (2005$)	For outputs listed above
Weighted average export price	xprx_<crop>	time steps (regional)	USD2005/t (2005$)	For outputs listed above
Resource prices for water and land	xprw, xprl	time steps (regional)	$USD2005/m^3$, USD2005/ha (2005$)	Or adequate land/water scarcity index

[13] output codes: whe, mai, ric, soy, mill, sor, sug, rum, nrm, alc, pas, pea, cas, sun, nut, mgr, pst and agt for wheat, maize, rice, soy, sorghum, millet, sugar/sugarcane, ruminant meat, nun-ruminant meat, all crops, pasture, peas, cassava, sunflower, groundnuts, managed grass, pasture and agricultural total , respectively.

Land use patterns, rainfed	lupat_noirr_<crop>	time steps (regional	% (%)	Crop fractions, rainfed For outputs listed above
Land use patterns, irrigated	lupat_firr_<crop>	time steps (regional	% (%)	Crop fractions, irrigated For outputs listed above
Total land use	Area	time steps (regional)	ha (ha)	For outputs listed above, multicropped land should be counted only once
Irrigation pattern	Irrpat	time steps (regional)	% (%)	Fraction of irrigated land
Exogenous rate of crop yield increase	Eryieldincr	time steps (regional)	%/yr (% yr-1)	
Effective Nitrogen application	effnit	annual (regional)	t/ha (t ha-1)	
Total per capita calorie consumption	Totcal	time steps (regional)	kcal/capita /day (kcal cap-1 day-1)	
Animal-based per capita calorie consumption	Anical	time steps (regional)	kcal/capita/day (kcal cap-1 day-1)	To calculate shares
Total domestic consumption	cons_<crop>	time steps (regional)	dry matter t/yr (t yr-1)	Crops plus livestock
Food use	food_<crop>	time steps (regional)	dry matter t/yr (t yr-1)	Crops plus livestock
Feed use (for livestock	feed_<crop>	time steps (regional)	dry matter t/yr	Crops plus livestock

consumption)			(t yr-1)	
Other use	othu_<crop>	time steps (regional)	dry matter t/yr (t yr-1)	Crops plus livestock
Net trade	nett_<crop>	time steps (regional)	dry matter t/yr (t yr-1)	Crop-specific (exports >0, imports <0) Excludes regional intra-trade
Exports	Expo	time steps (regional)	dry matter t/yr (t yr-1)	Excludes regional intra-trade
Imports	Impo	time steps (regional)	dry matter t/yr (t yr-1)	Excludes regional intra-trade

All results should be reported as averages or aggregates over the AgMIP GlobEcon standardized set of geographical regions listed in **Table 36**.

Table 36 Standardized geographical regions

Code	Region	Notes
WLD	World	
CAN	Canada	
USA	United States of America	
BRA	Brazil	
OSA	Other South & Central America	Incl. Caribbean and Mexico
FSU	Former Soviet Union	
EUR	Europe	Excl. Turkey
MEN	Middle-East and North Africa	Incl. Turkey
SSA	Sub-Saharan Africa	
CHN	China	Incl. Hong-Kong, Macao
IND	India	
SEA	South-East Asia	Incl. Japan, Taiwan
OAS	Other Asia	Other South Asia, other Oceania, Mongolia
ANZ	Australia and New Zealand	
NAM	North America	CAN & USA
OAM	South and Central America	BRA & OSA
AME	Africa and Middle East	MEN & SSA
SAS	Southern and Eastern Asia	CHN & IND & SEA & OAS

12.3 Experiments

12.3.1 Historic runs and validation experiment

The participating agro-economic models are currently not prepared to do evaluation runs for e.g. 20-30 years into the past. This is mostly due to data limitations on key parameters and socio-economic model inputs. However, all participating agro-economic models should provide illustrative examples on how they evaluate key model outputs against historic data, at least for some period where observed data and model outputs overlap (e.g. for agricultural prices, cropland and grassland areas).

12.3.2 Fast-Track simulations

10 agro-economic models have participated in the AgMIP GlobEcon Phase 1, in parallel to the ISIMIP fast track. Main results for the timeline until 2050 have been summarized in Nelson et al. (PNAS, 2013). The consolidated output of these model runs still needs to be uploaded to the ISIMIP database.

13 Permafrost

The permafrost sector in ISIMIP2a will not require any additional runs. The runs developed for the biomes sector and the water sector can also be assessed by the permafrost sector (see Section 7.2 for the scenario setup;). Finland (region 12) and the Lena catchment (region 11) are the two regions which are affected by permafrost. Therefore any runs over these regions can be assessed for permafrost. Permafrost will require additional output data. Models which do not include a carbon cycle should still submit the requested hydrological variables as these can be used to assess permafrost extent and thaw.

13.1 Sector-specific input

None

13.2 Output data

Table 37 below is very similar to **Table 21** in the Biomes sector, but with some hydrological variables added. **Soil temperature at each model level is the most important variable – if that is all you can deliver then please do so, it will be useful.**

Table 37 Variables to be reported for the permafrost sector

long name	units		output variable name	frequency	comment
Essential outputs					
Temperature of Soil	K	per gridcell	**tsl**	Day (mon)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". **THIS IS THE MOST IMPORTANT VARIABLE.** Also need depths in meters. Daily would be great, but otherwise monthly would work.

Pools (as Biomes output Table)					
Carbon Mass in Vegetation	kg m-2	per pft and gridcell total	**cveg_<pft>**	year	Gridcell total VegC is essential. Per PFT information is desirable.
Carbon Mass in Litter Pool	kg m-2	per gridcell	**clitter**	year	Total of all pools. Info for each individual pool is desirable.
Carbon Mass in Soil Pool	kg m-2	per gridcell	**csoil**	year	Total of all pools. Info for each individual pool is desirable.
Fluxes (as Biomes output Table)					
Carbon Mass Flux out of Atmosphere due to Gross Primary Production on Land	kg m-2 s-1	per gridcell	**gpp**	mon (day)	
Carbon Mass Flux into Atmosphere due to Autotrophic (Plant) Respiration on Land	kg m-2 s-1	per gridcell	**ra**	mon (day)	
Carbon Mass Flux out of Atmosphere due to Net Primary Production on Land	kg m-2 s-1	per gridcell	**npp**	mon (day)	
Carbon Mass Flux into Atmosphere due to Heterotrophic Respiration on Land	kg m-2 s-1	per gridcell	**rh**	mon (day)	
Carbon Mass Flux into Atmosphere due to CO2	kg m-2 s-	per gridcell	**fireint**	mon (day)	

Emission from Fire	1				
Fraction of cell burnt by fire	Fractional	Per gridcell	**firefrac**		Burnt area fraction: single value for each scenario corresponding to year 2100
Carbon Mass Flux out of Atmosphere due to Net Biospheric Production on Land	kg m-2 s-1	per gridcell	**ecoatmflux_c**	mon (day)	This is the net mass flux of carbon between land and atmosphere calculated as photosynthesis MINUS the sum of plant and soil respiration, carbonfluxes from fire, harvest, grazing and land use change. Positive flux is into the land.
Structure [as Biomes output Table]					
Fraction of absorbed photosynthetically active radiation	%	per pft and gridcell average	**fapar_<pft>**	mon (day)	
Leaf Area Index	1	per pft and gridcell average	**lai_<pft>**	mon (day)	
Plant Functional Type Grid Fraction	%	per gridcell	**pft_<pft>**	year (or once if static)	The categories may differ from model to model, depending on their PFT definitions. This may include natural PFTs, anthropogenic PFTs, bare soil, lakes, urban areas, etc. Sum of all should equal the fraction of the grid-cell that is land.
Soil moisture for each layer	kg m-2	per gridcell	**soilmoist**	mon	Please provide soil moisture for all depth levels and indicate depth in m. (As for Water sector)
Frozen soil moisture for each layer	kg m-2	per gridcell	**soilmoistfroz**	mon	Please provide soil moisture for all depth levels and indicate depth in m. **This is a new variable.**
Snow depth	m	per gridcell	**snd**	mon	Grid cell mean depth of snowpack. **This is a new variable.**

annual maximum thaw depth	m		**thawdepth**	year	calculated from daily thaw depths
Snow water equivalent	kg m-2	per gridcell	**swe**	mon	Total water mass of the snowpack (liquid or frozen) averaged over grid cell (As for Water sector)
Runoff	kg m-2 s-1	Per grid cell	**qtot**	mon (day)	Total runoff leaving the land portion of the grid cell (this is in both Biomes and Water Tables)
Optional outputs					
Carbon Mass in Leaves	kg m-2	per gridcell	**cleaf_<pool>**	year	
Carbon Mass in Wood	kg m-2	per gridcell	**cwood_<pool>**	year	including sapwood and hardwood
Carbon Mass in Roots	kg m-2	per gridcell	**croot_<pool>**	year	including fine and coarse roots
Carbon Mass in Litter Pools	kg m-2	per gridcell	**clitter_<pool>**	year	Non-cmip5, for each litterpool and gridcell
Carbon Mass Soil Pools	kg m-2	per gridcell	**csoil_<pool>**	year	Non-cmip5, for each soil pool and gridcell
Burnt Area Fraction	%	per gridcell	**burntarea**	mon (day)	fraction of entire grid cell that is covered by burnt vegetation

Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide it the highest possible resolution of your model. Please contact the coordination team (Info@isimip.org) to for any further clarification, or to discuss the equivalent variable in your model.

13.3 Experiments

13.3.1ISIMIP2a - Historic runs and validation exercise

Table 38 Potential validation datasets for permafrost sector. These are additional data sets to those already highlighted in the Biomes and Water sectors.

Dataset	Source and further information	Variables included	Period	Scale	comment
Physical state of the permafrost					
Permafrost extent	http://nsidc.org/data/ggd318	What proportion of area is permafrost	Approximately representative of period 1960-1990	12.5km, 25km or 0.5 degree resolution	Gridded data
CALM	http://www.gwu.edu/~calm/	Active layer thickness	1991 – present day	Point sites	
Borehole permafrost temperature data	http://gtnpdatabase.org/	Permafrost temperature		Point sites	These data go fairly deep within the permafrost
Russian historical soil temperature data	http://nsidc.org/data/docs/fgdc/ggd251_soiltemp_fsu/	Soil temperatures and active layer thicknesses	1936-1990	Point sites	These were partly made on cleared sites so temperatures are not necessarily representative of a grid cell.
Land surface temperature	http://doi.pangaea.de/10.1594/PANGAEA.775962	Laud surface temperature	2000-2010	25 km pan arctic, 1km regionally.	Based on satellite data

GlobSnow SWE and SE	http://www.globsnow.info/	Snow water equivalent and snow extent	1979-present	25 km	Based on satellite data
CDR snow and snow cover extent		Snow water equivalent and snow extent			Based on satellite data
Soil moisture and freeze / thaw	http://doi.pangaea.de/10.1594/PANGAEA.775959, http://doi.pangaea.de/10.1594/PANGAEA.779658	Soil moisture of the land surface and freeze thaw	2007	25 km weekly data	Based on satellite data
Freeze thaw	http://doi.pangaea.de/10.1594/PANGAEA.779658	Freeze thaw of the land surface	1979-present	Daily	Based on satellite data
Carbon cycle					
Soil carbon	http://doi.pangaea.de/10.1594/PANGAEA.779658	Soil carbon	Approximately representative of present day	Resolutions from 0.012 degrees to 1 degree	

14 **Marine Fisheries (FISH-MIP)**

14.1 Sector-specific input

14.1.1 Climate-related forcing for historical simulations

Table 39 Historical and future forcing datasets for global and regional models.

Dataset description	Time period	Comments
GFDL reanalysis product CORE-forced MOM-SIS-TOPAZ	1959-2004	observation/re-analysis based time-series as used in Cheung et al. 2013 (1.0° x 1.0° degree) => includes observed climate variability
IPSL-CM5A-LR (ISIMIP GCM2; driven by CMIP5 historical forcing)	1951-2005	GCM data has not been bias-corrected, but a potential drift has been removed using each model's CMIP5 control run, and data has been interpolated to a common grid (1.0° x 1.0°)
GFDL ESM2M (ISIMIP GCM4; driven by CMIP5 historical forcing)		
planned: CESM1-BGC (driven by CMIP5 historical forcing)		
IPSL-CM5A-LR (ISIMIP GCM2; four datasets driven by RCP2.6, RCP4.5, RCP6.0, and RCP8.5 forcing, respectively)	2006-2100	GCM data has not been bias-corrected, and no drift correction was applied (no substantial drift in the future simulations). Data has been interpolated to a common grid (1.0° x 1.0°)
GFDL ESM2M (ISIMIP GCM4; four datasets driven by RCP2.6, RCP4.5, RCP6.0, and RCP8.5 forcing,		

respectively)		
planned: CESM1-BGC (four datasets driven by RCP2.6, RCP4.5, RCP6.0, and RCP8.5 forcing, respectively)		

NOTE: All data will be provided as depth-resolved (3D), depth-integrated, surface and bottom.

Table 40 Forcing variables provided as input for global and regional marine fisheries models.

Variable	Name	Unit	Frequency	Comments
u current	*uo*	m/s	Monthly	
v current	*vo*	m/s	Monthly	
Temperature	*t*	K	Monthly	
Dissolved oxygen concentration	o2	mol / m^3	Monthly	
Primary productivity	*intpp*	mol C / m^3 / s	Monthly	
Phytoplankton carbon concentration	*phyc*	mol / m^3	Monthly	Sum of small and large phytoplankton
Small phytoplankton carbon concentration	*sphyc*	mol / m^3	Monthly	Size range or Min-Max for each GCM, if available
Large phytoplankton carbon concentration	*lphyc*	mol / m^3	Monthly	Size range or Min-Max for each GCM, if available

Zooplankton carbon concentration	*zoo*	mol / m^3	Monthly	Sum of small and large zooplankton
Small (micro)zooplankton carbon concentration	*szoo*	mol / m^3	Monthly	Size range or Min-Max for each GCM, if available
Large (meso)zooplankton carbon concentration	*lzoo*	mol / m^3	Monthly	Size range or Min-Max for each GCM, if available
pH	*Ph*		Monthly	
Salinity	*So*	Psu	Monthly	

14.1.2 Historical fishing effort

For this round, modelers will use their own default fishing effort and catch data. In most cases this will be Sea-Around-Us-Project (SAUP) data obtained through a memorandum of understanding (MOU) or data from Regional Fisheries Management Organizations (RFMOs) or local fisheries agencies.

14.1.3 Spin-up and initialization

Input data is provided from 1951/1959 to 2004/2005. Years until 1970 can be replicated as needed and used for spin-up. Historical reporting is from 1971-2005, but if your model starts later, start when your model normally starts!

14.2 Output data

- ⇨ **Provide temporally (monthly) and spatially (1 x 1 degree grid) explicit column-integrated time series (1971-2005, 2006-2100)** (All files should be saved with .nc4 file extension; a conversion script for .csv files can be found at: http://vre1.dkrz.de).
- ⇨ **Use variable names as specified in Table 41 below, and check the overall ISIMIP simulation protocol for how to name your files.**

⇨ **If there is no data value for outputs, use the value: 1.e+20f**

⇨ **Mandatory output**: this is the priority for first round of model comparisons (provide as many as possible!)

⇨ **Optional output**: if you can, please store or upload all output you receive from your model, we may eventually use it

Table 41 Common output variables to be provided by global and regional marine fisheries models.

Output variable	Variable name	Resolution	Unit (NetCDF format)	Comments
Mandatory output from global and regional models (provide as many as possible)				
TOTAL system biomass density (*tsb*)	*tsb*	monthly	g C / m^2 (g C m-2)	all primary producers and consumers
TOTAL consumer biomass density (t*bc*)	*tcb*	monthly	g C / m^2 (g C m-2)	all consumers (trophic level >1, vertebrates and invertebrates)
Biomass density of consumers >10cm	*b10cm*	monthly	g C / m^2 (g C m-2)	if L infinity is >10 cm, include in >10 cm class
Biomass density of consumers >30cm	*b30cm*	monthly	g C / m^2 (g C m-2)	if L infinity is >30 cm, include in >30 cm class
TOTAL Catch (all commercial functional groups / size classes) (*tc*)	*tc*	monthly	g wet biomass / m^2	catch at sea (commercial landings plus discards, fish and invertebrates)

			(g m-2)	
TOTAL Landings (all commercial functional groups / size classes) (*tla*)	*tla*	monthly	g wet biomass / m^2 (g m-2)	commercial landings (catch without discards, fish and invertebrates)
Optional output from global and regional models				
Biomass density of commercial species (*Bcom*)	*bcom*	monthly	g C / m^2 (g C m-2)	Discarded species not included (Fish and invertebrates)
Biomass density (by functional group / size class) (B_i)	*b-<class>-<group>*	monthly	g C / m^2 (g C m-2)	Provide name of each size class (<class>) and functional group (<group>) used, and provide a definition of each class/group
Catch (by functional group / size class) (C_i)	*c-<class>-<group>*	monthly	g wet biomass / m^2 (g m-2)	Provide name of each size class (<class>) and functional group (<group>) used, and provide a definition of each class/group

14.3 Summary of simulations

Table 42 outlines all experiments (historical and future) for the global and regional fisheries and marine ecosystem models.

- ⇨ Note: the three CMIP5-based runs will continue into the future, reducing the total number of runs to be done!!!
- ⇨ Historical reporting period: 1971-2005 (or when your model starts)

⇨ Future reporting period: 2006-2100

Climate scenarios:

- Historical runs: 1 re-analysis product & IPSL hindcast; Next: GDFL & CESM hindcasts
- Future runs: Priority IPSL 2.6 & 8.5; Next GFDL & CESM 8.5; Next IPSL 4.5 & 6.0

Fishing scenarios:

- Historical runs: Priority (default): use time-varying effort; Next (unfished): zero fishing effort/mortality
- Future runs: Priority (default): keep fishing constant at 2005 levels; Next (unfished): continue historical unfished (zero fishing effort/mortality) run into future

Any other impacts: (default): keep constant at 2005 levels

Table 42 Summary of historical and future runs for global and regional fisheries models

	Climate data GCM	Scenario	Fishing effort	Ocean acidification	# runs
Historical runs	GFDL ESM2 (re-analysis)	hist	default (time-varying effort/mortality) unfished (zero effort/mortality)	default (time-varying pH)	2
	IPSL-CM5A-LR (GCM 2)	hist	default (time-varying effort/mortality) unfished (zero effort/mortality)	default (time-varying pH)	2

Historical runs	GFDL ESM2M (GCM 4)	hist	default (time-varying effort/mortality) unfished (zero effort/mortality)	default (time-varying pH)	2
	CESM BGC	hist	default (time-varying effort/mortality) unfished (zero effort/mortality)	default (time-varying pH)	2
Future runs	IPSL-CM5A-LR (GCM 2)	2.6 (rcp2p6) 8.5 (rcp8p5)	keep constant at 2005 levels unfished (zero effort/mortality)	use time-varying pH with GCM input	4
Future runs	IPSL-CM5A-LR (GCM 2)	4.5 (rcp4p5) 6.0 (rcp6p0)	keep constant at 2005 levels unfished (zero effort/mortality)	use time-varying pH with GCM input	4
	GFDL ESM2M (GCM4)	2.6 (rcp2p6) 8.5 (rcp8p5)	keep constant at 2005 levels unfished (zero effort/mortality)	use time-varying pH with GCM input	2

TBA	CESM BGC	2.6 (rcp2p6) 8.5 (rcp8p5)	keep constant at 2005 levels unfished (zero effort/mortality)	use time-varying pH with GCM input	2

15 References

Arnell, N. . (1999). A simple water balance model for the simulation of streamflow over a large geographic domain. *Journal of Hydrology*, *217*(3–4), 314–335. http://doi.org/10.1016/S0022-1694(99)00023-2

Davie, J. C. S., Falloon, P. D., Kahana, R., Dankers, R., Betts, R., Portmann, F. T., … Arnell, N. (2013). Comparing projections of future changes in runoff and water resources from hydrological and ecosystem models in ISI-MIP. *Earth System Dynamics Discussions*, *4*(1), 279–315. http://doi.org/10.5194/esdd-4-279-2013

Dlugokencky, E., & Tans, P. (2014). Trends in atmospheric carbon dioxide, National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL). Retrieved from www.esrl.noaa.gov/gmd/ccgg/trend

Döll, P., Kaspar, F., & Lehner, B. (2003). A global hydrological model for deriving water availability indicators: Model tuning and validation. *Journal of Hydrology*, *270*(1–2), 105–134. http://doi.org/10.1016/S0022-1694(02)00283-4

Döll, P., & Schmied, H. M. (2012). How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. *Environmental Research Letters*, *7*(1), 14037. http://doi.org/10.1088/1748-9326/7/1/014037

Fekete, B. M., Vörösmarty, C. J., & Grabs, W. (2000). Global Composite Runoff Fields on Observed River Discharge and Simulated Water Balances. *GRDC Reports*, (22), 115. http://doi.org/10.1017/CBO9781107415324.004

Gosling, S. N., & Arnell, N. W. (2011). Simulating current global river runoff with a global hydrological model: Model revisions, validation, and sensitivity analysis. *Hydrological Processes*, *25*(7), 1129–1145. http://doi.org/10.1002/hyp.7727

Gosling, S. N., Warren, R., Arnell, N. W., Good, P., Caesar, J., Bernie, D., … Smith, S. M. (2011). A review of recent developments in climate change science. Part II: The global-scale impacts of climate change. *Progress in Physical Geography*, *35*(4), 443–464. http://doi.org/10.1177/0309133311407650

Haddeland, I., Clark, D. B., Franssen, W., Ludwig, F., Voß, F., Arnell, N. W., … Heinke, J. (2011). Multimodel estimate of the global terrestrial water balance: setup and first results. *Journal of Hydrometeorology*, 110531121709055. Retrieved from http://journals.ametsoc.org/doi/abs/10.1175/2011JHM1324.1

Kim, H. (n.d.). Global Soil Wetness Project Phase 3. Retrieved from http://hydro.iis.u-tokyo.ac.jp/GSWP3/

Koster, R. D., Fekete, B. M., Huffman, G. J., & Stackhouse, P. W. (2006). Revisiting a hydrological analysis framework with International Satellite Land Surface Climatology Project Initiative 2 rainfall, net radiation, and runoff fields. *Journal of Geophysical Research*, *111*(D22), D22S05. http://doi.org/10.1029/2006JD007182

Meinshausen, M., Raper, S. C. B., & Wigley, T. M. L. (2011). Emulating coupled atmosphere-ocean and carbon cycle models with a simpler model, MAGICC6 – Part 1: Model description and calibration. *Atmospheric Chemistry and Physics*, *11*(4), 1417–1456. http://doi.org/10.5194/acp-11-1417-2011

Oleson, K. W., Niu, G.-Y., Yang, Z.-L., Lawrence, D. M., Thornton, P. E., Lawrence, P. J., … Qian, T. (2008). Improvements to the Community Land Model and their impact on the hydrological cycle. *Journal of Geophysical Research*, *113*(G1), G01021. http://doi.org/10.1029/2007JG000563

Sheffield, J., Goteti, G., Wood, E. F., Sheffield, J., Goteti, G., & Wood, E. F. (2006). Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. *Journal of Climate*, *19*(13), 3088–3111. http://doi.org/10.1175/JCLI3790.1

Weedon, G. P., Balsamo, G., Bellouin, N., Gomes, S., Best, M. J., & Viterbo, P. (2014). The WFDEI meteorological forcing data set: WATCH Forcing Data methodology applied to ERA-Interim reanalysis data. *Water Resources Research*, *50*, 7505–7514. http://doi.org/10.1002/2014WR015638

Weedon, G. P., Gomes, S., Viterbo, P., Shuttleworth, W. J., Blyth, E., Österle, H., … Best, M. (2011). Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century. *Journal of Hydrometeorology*, *12*(5), 823–848. http://doi.org/10.1175/2011JHM1369.1

Yoshimura, K., & Kanamitsu, M. (2008). Dynamical Global Downscaling of Global Reanalysis. *Monthly Weather Review*, *136*(8), 2983–2998. http://doi.org/10.1175/2008MWR2281.1

Yoshimura, K., & Kanamitsu, M. (2013). Incremental Correction for the Dynamical Downscaling of Ensemble Mean Atmospheric Fields. *Monthly Weather Review*, *141*(9), 3087–3101. http://doi.org/10.1175/MWR-D-12-00271.1