POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Climate Impacts in the Anthropocene

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Member of Leibniz Association

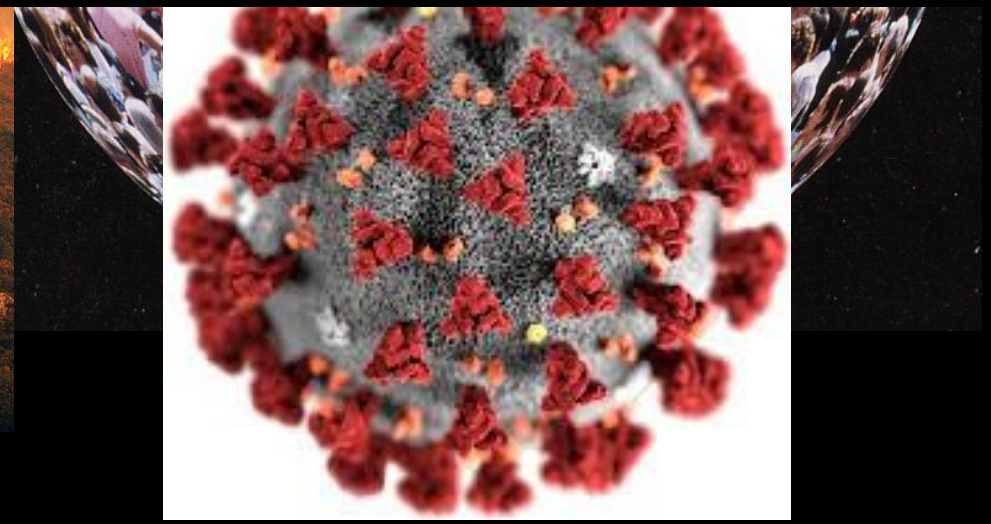
Cross-sectoral ISIMIP and PROCLIAS online workshop 2021,
11 January 2021

Universität Potsdam
Institut für Umweltwissenschaften und Geographie

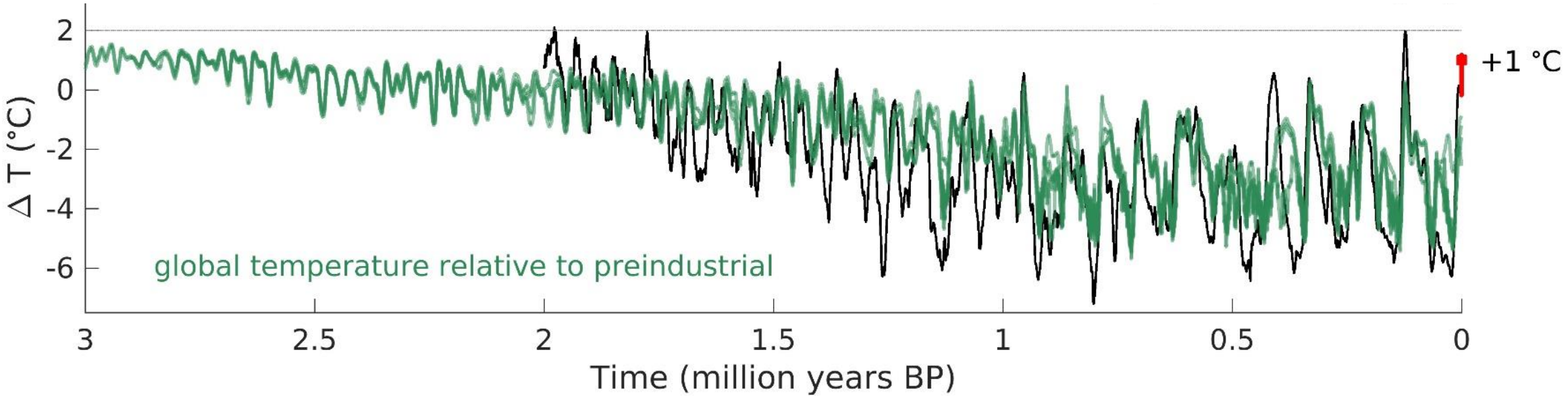
A biosphere shaped by humans

Anthropocene

Scale, Speed, Inter-connections



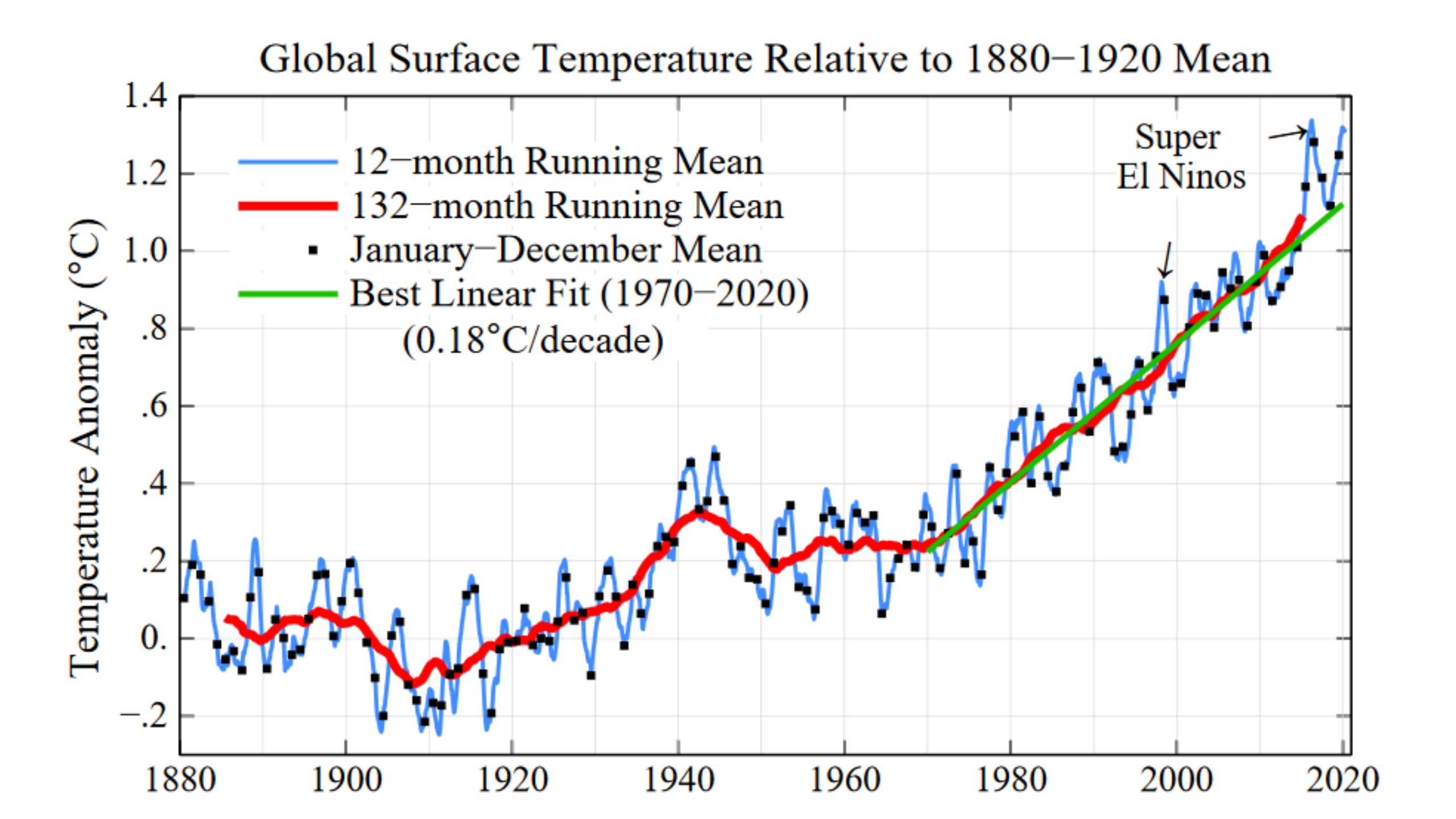
We have never exceeded 2 C in the last Three Million Years



Results of model simulations: Observations shown in black, model results in colour.

PIK

Willeit et al., Science Advances 2019


Global Surface Temperature Relative to 1880–1920 Mean
Temperature Anomaly (°C)
1.4
1.2
1.0
.8
.6
.4
.2
0.
–.2
1880
1900
1920
1940
1960
1980
2000
2020
12–month Running Mean
132–month Running Mean
January–December Mean
Best Linear Fit (1970–2020)
(0.18°C/decade)
Super
El Ninos

Wildfire in California on 27 September 2020. (Josh Edelson/AFP)

ENVIRONMENT

On Top of Everything Else, 2020 Has Tied For The Hottest Year on Record

FIONA MACDONALD 11 JANUARY 2021

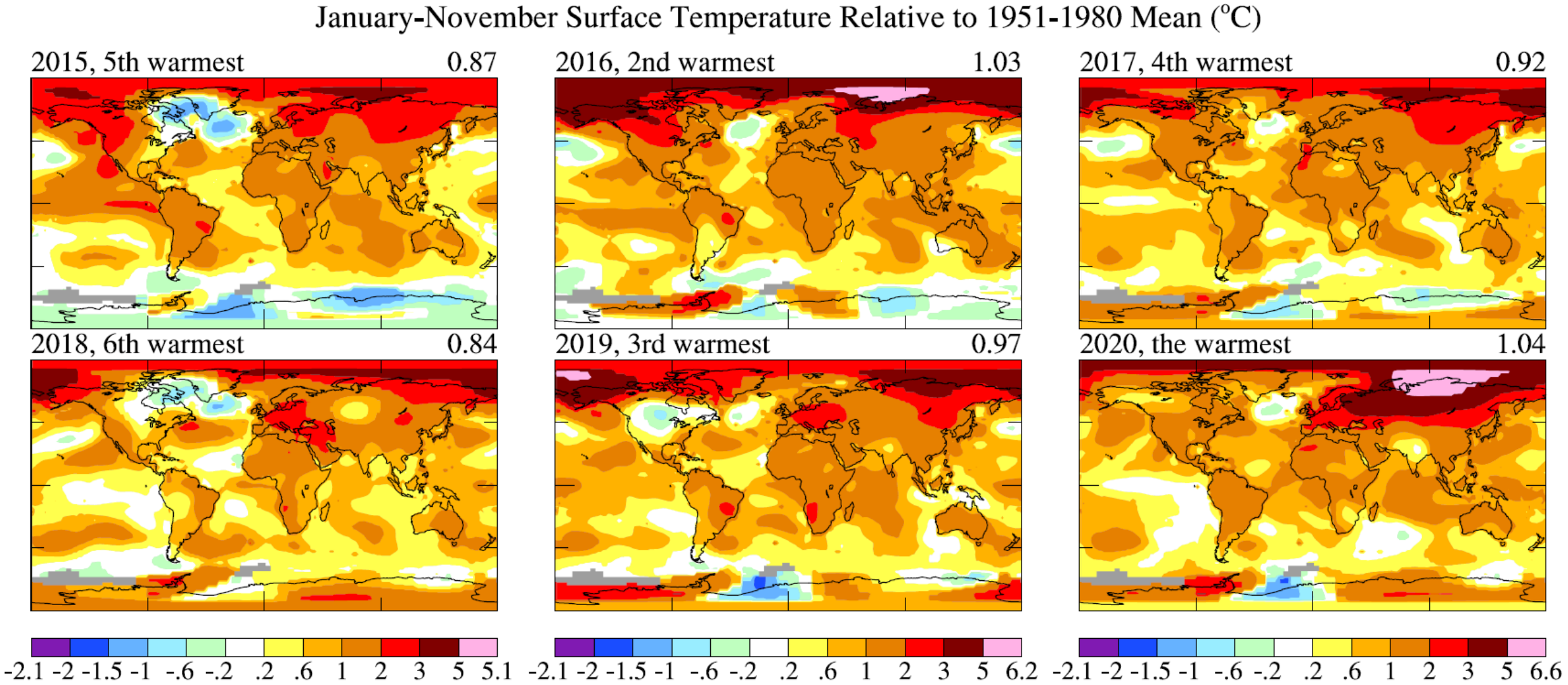
Climate change: 2020 was the joint hottest year on record

ENVIRONMENT 8 January 2021

By Adam Vaughan

Temperatures in Spain peaked above 40°C in August 2020

PIK

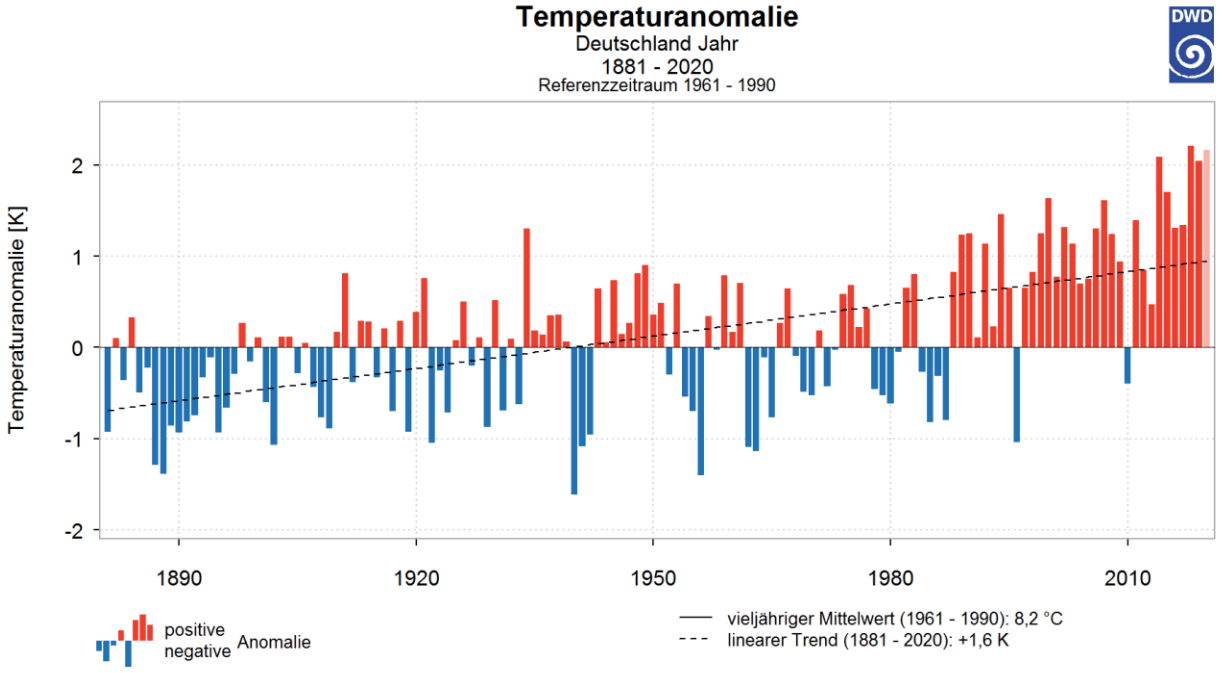


http://www.columbia.edu/

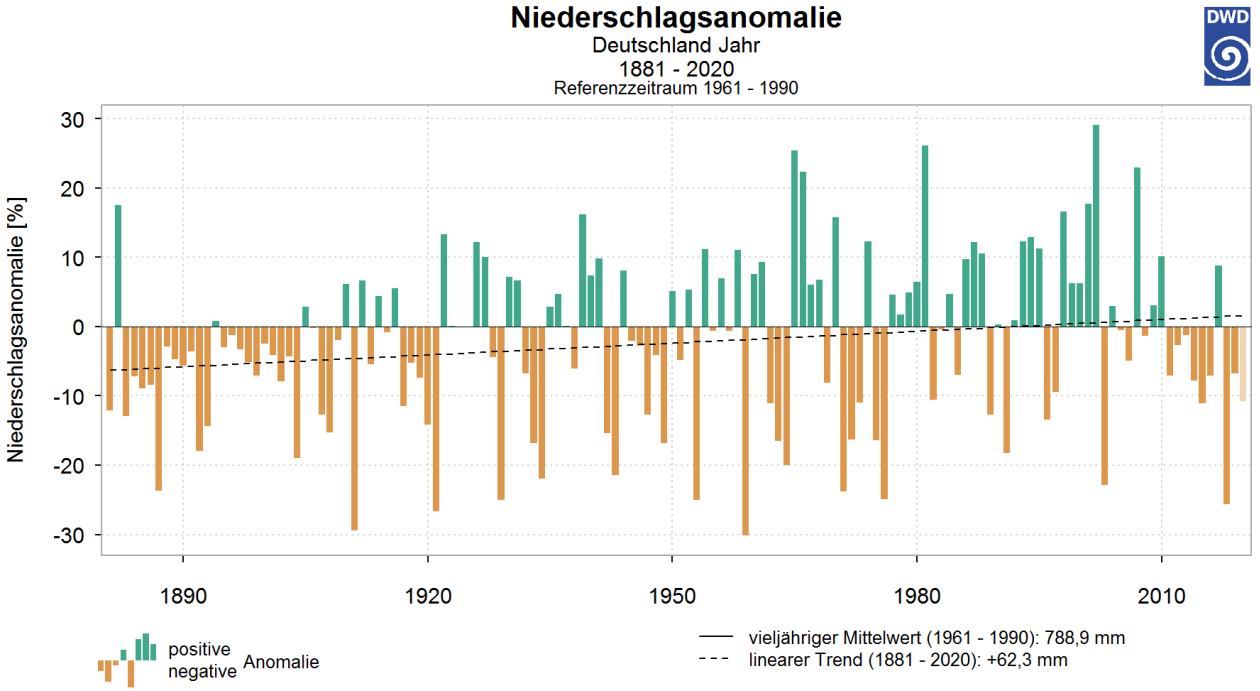
1. Direct Impacts
2. Cascading feedbacks
3. Global systemic risks

1.Direct Impacts

2nd warmest year on record in Germany (DWD)



Temperature Anomaly

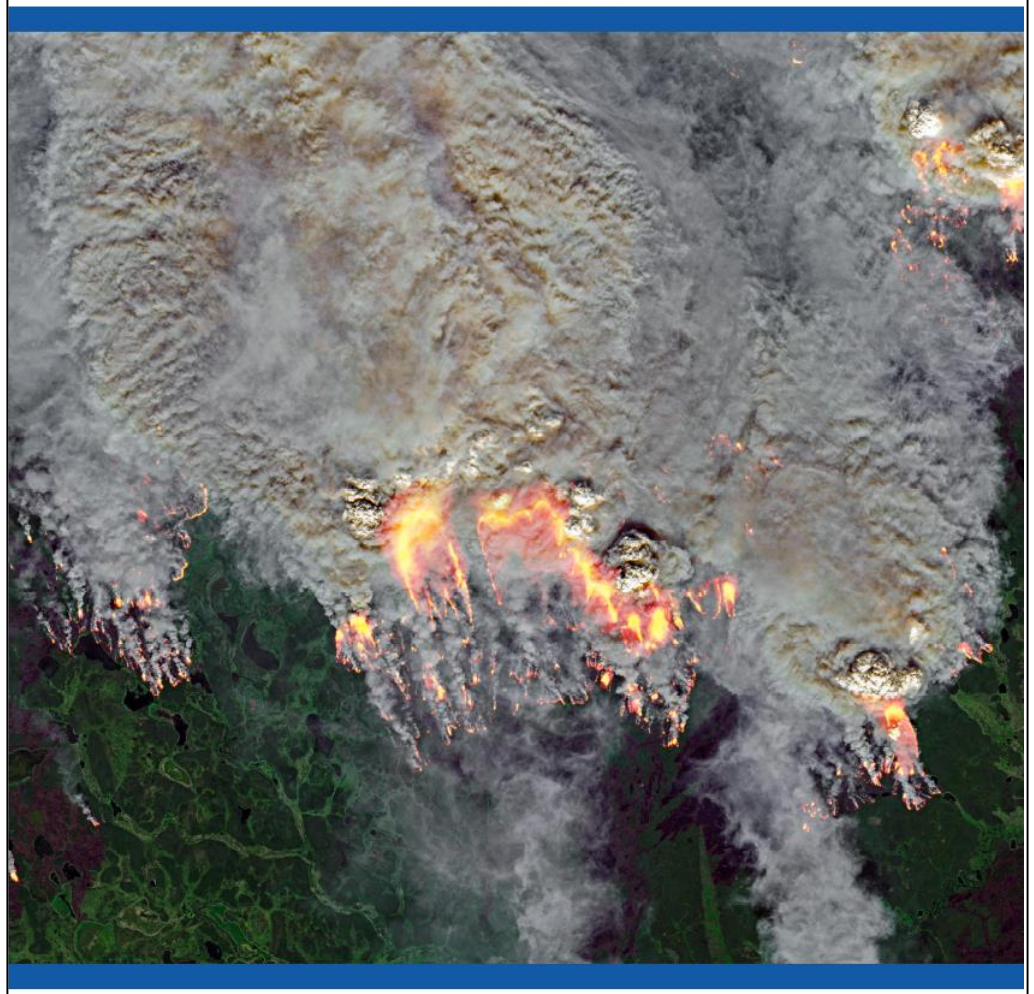


Precepitation Anomaly

Average temperature in 2020 about 2,2 °C above international reference period 1961 - 1990.

United in Science 2020

A multi-organization high-level compilation of the latest climate science information



WORLD METEOROLOGICAL ORGANIZATION · UN environment programme · GLOBAL CARBON project · ipcc · Met Office

2020 – A record setting year

- 2020 (a La Niña year) Hottest year on record together with 2016 (an El Niño year)
- The wild 2020 Atlantic hurricane season
- Record-high atmospheric carbon dioxide levels despite record emissions drop
- An apocalyptic wildfire season
- Super Typhoon Goni: Strongest landfalling tropical cyclone on record
- Hottest reliably measured temperature: 130°F in Death Valley
- Most expensive 2020 disaster: Flooding in China causes $32 billion in damage
- Near-record low Arctic sea ice
- U.S. withdrawal from Paris Climate Accord and election of Joe Biden
- A near-record number of global billion-dollar weather disasters

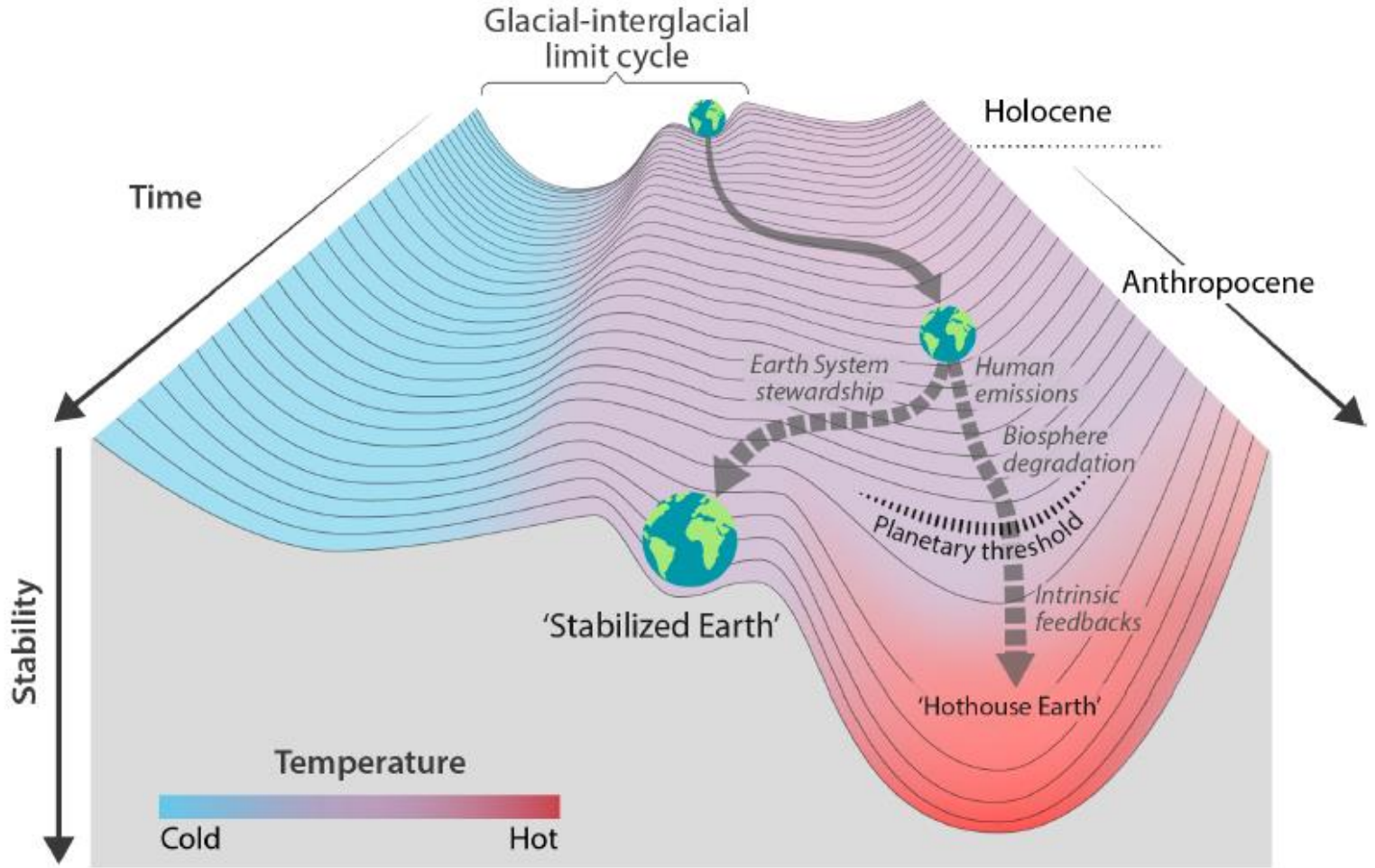
Source: yaleclimateconnections.org

2. Cascading feedbacks

Trajectories of the Earth System in the Anthropocene

Will Steffen[a,b]*, Johan Rockström[a], Katherine Richardson[c], Timothy M. Lenton[d], Carl Folke[a,e], Diana Liverman[f], Colin P. Summerhayes[g], Anthony D. Barnosky[h], Sarah E. Cornell[a], Michel Crucifix[i,j], Jonathan F. Donges[a,k], Ingo Fetzer[a], Steven J. Lade[a,b], Marten Scheffer[l], Ricarda Winkelmann[k,m], Hans Joachim Schellnhuber[a,k,m]*

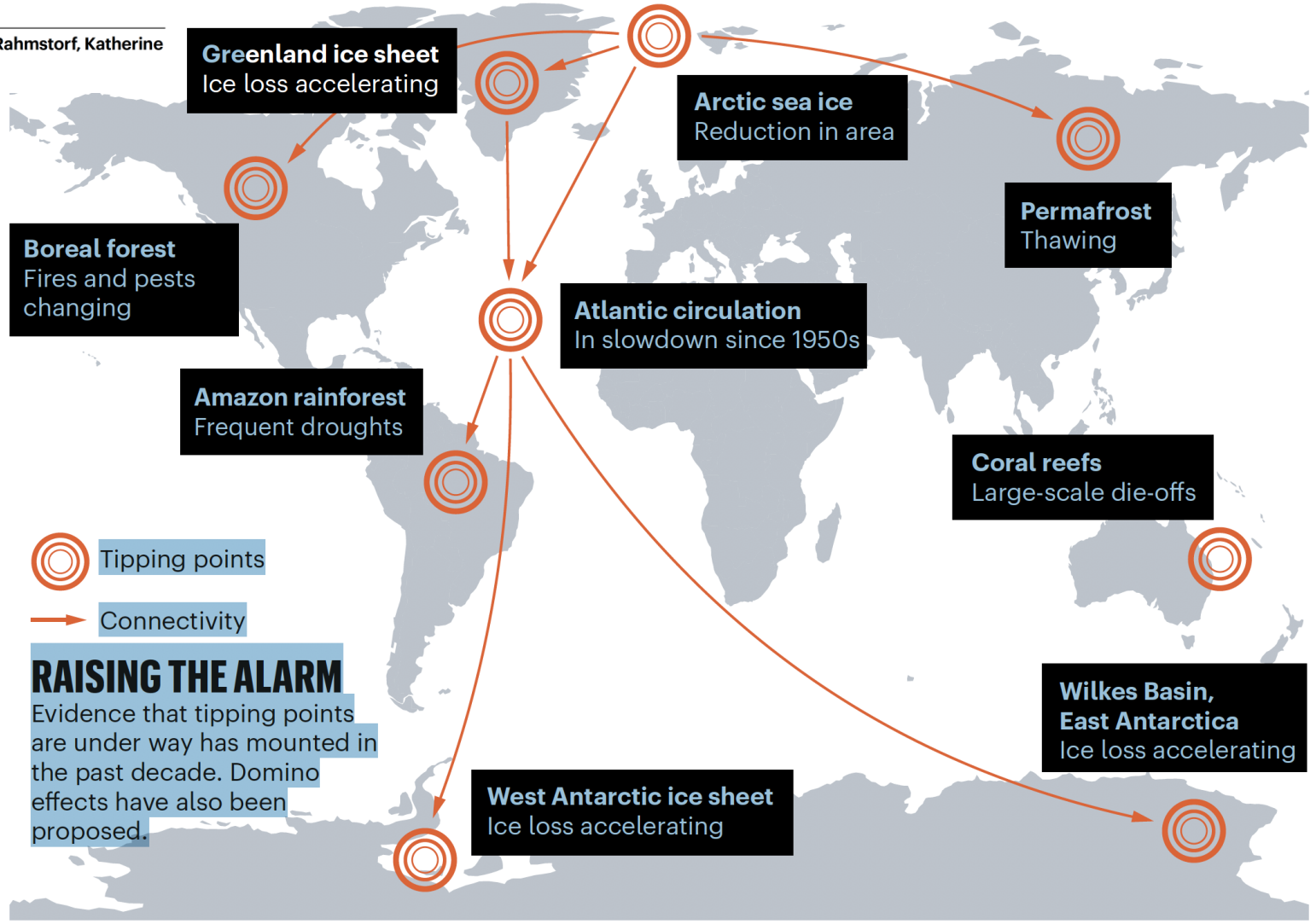
Proceedings of the National Academy of Sciences of the United States of America, accepted



Stability landscape showing the pathway of the Earth System out of the Holocene

Climate tipping points – too risky to bet against

Timothy M. Lenton, Johan Rockström, Owen Gaffney, Stefan Rahmstorf, Katherine Richardson, Will Steffen & Hans Joachim Schellnhuber



Ice loss due to warming leads to warming due to ice loss: a vicious circle

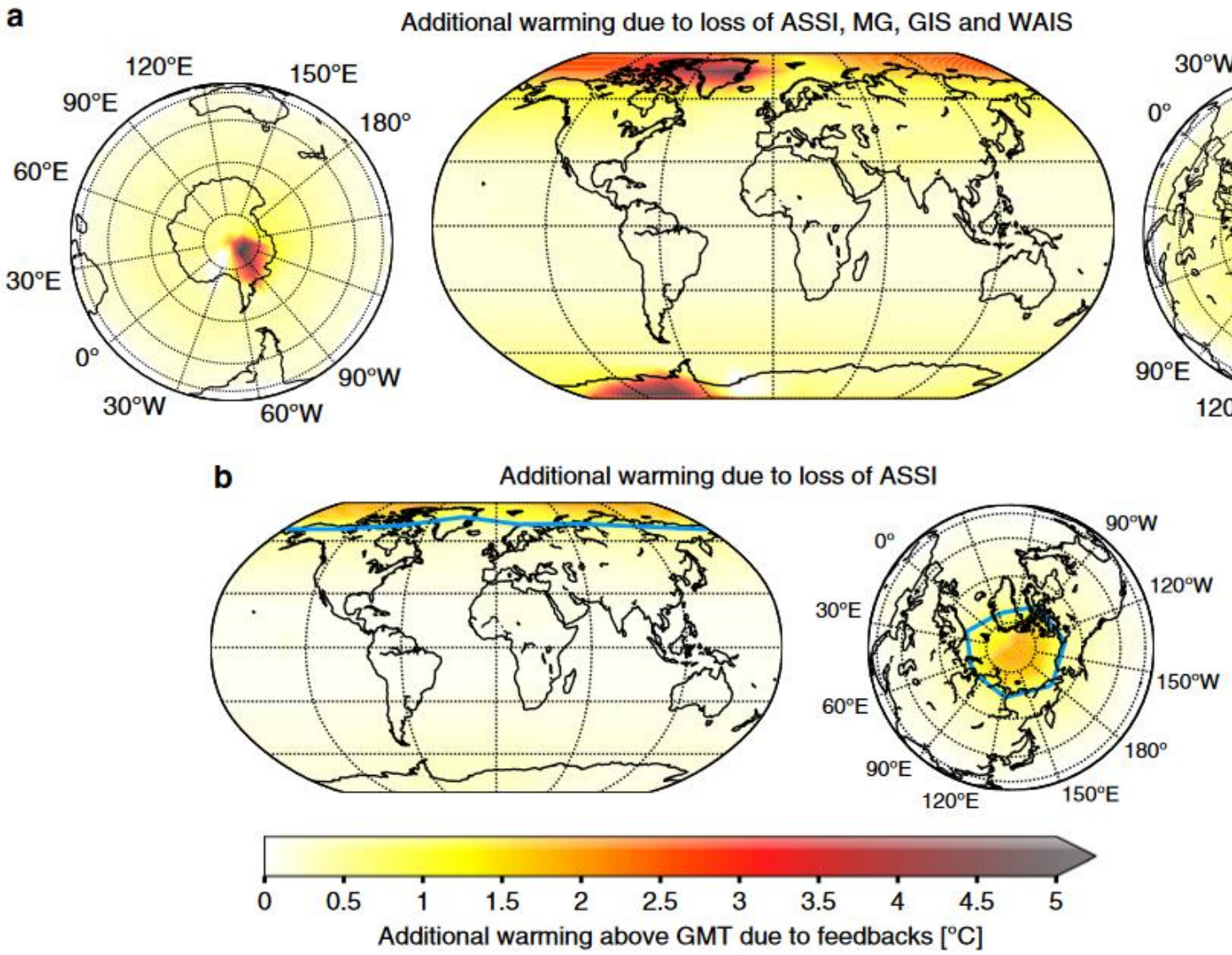


Fig. 1 Regional warming due to feedbacks

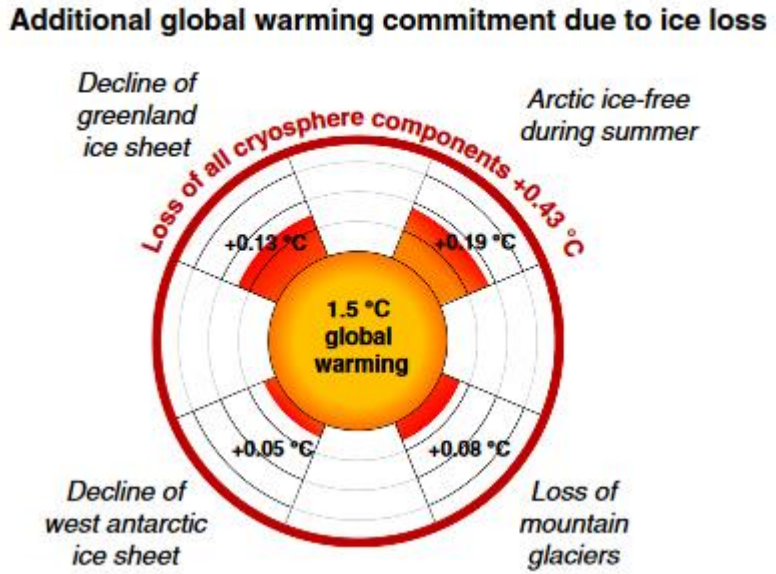


Fig. 2 GMT increase through disappearance of cryosphere elements

Wunderling et al. 2020, Nature Communications

@2°C global warming, West Antarctica committed to long-term partial collapse owing to marine ice-sheet instability

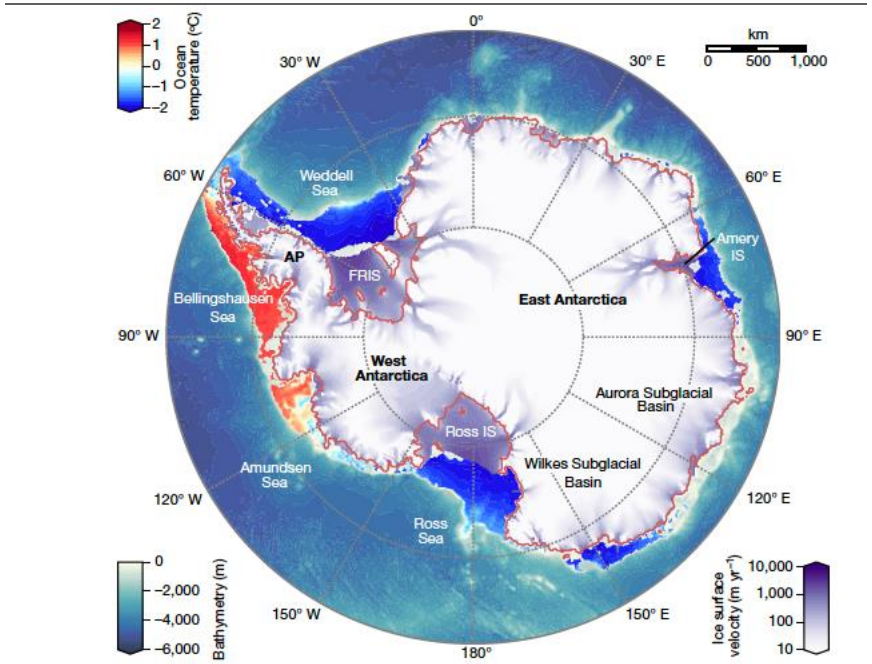
Article

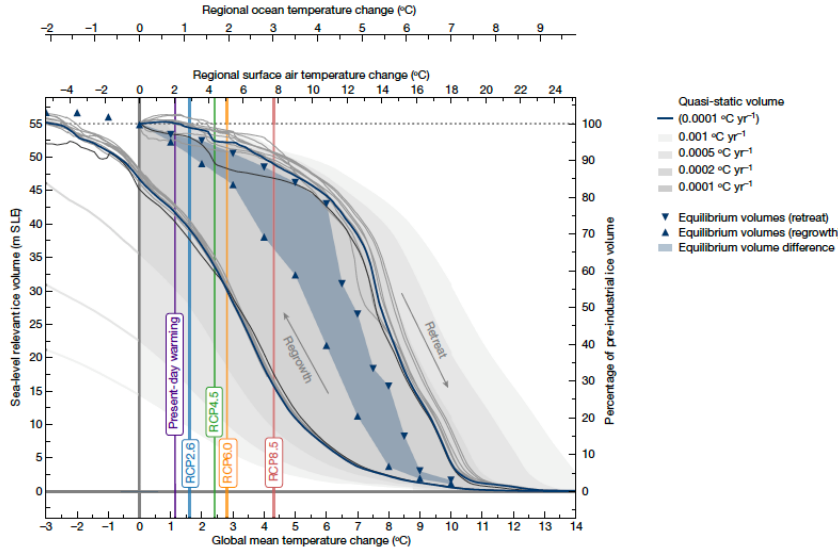
The hysteresis of the Antarctic Ice Sheet

https://doi.org/10.1038/s41586-020-2727-5
Received: 5 April 2019

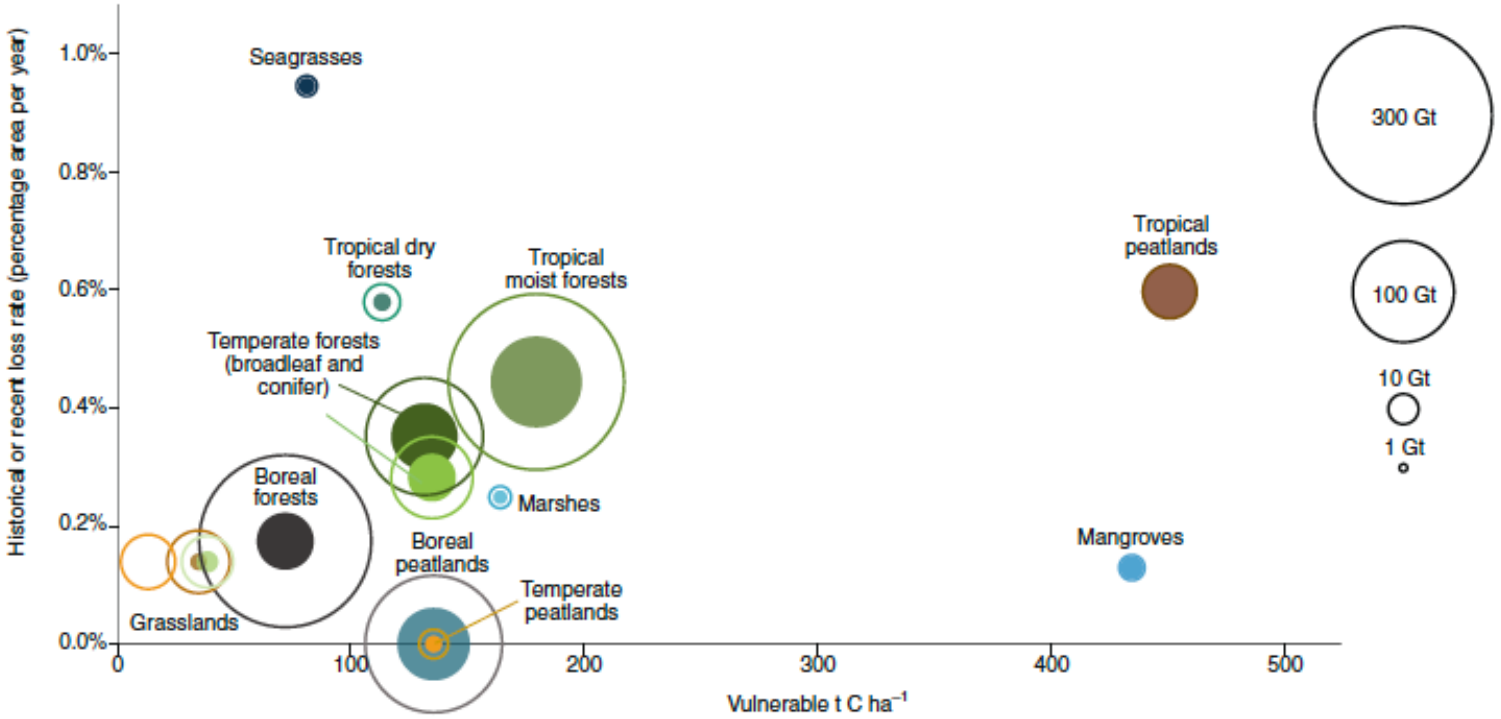
Julius Garbe[1,2], Torsten Albrecht[1], Anders Levermann[1,2,3], Jonathan F. Donges[1,4] & Ricarda Winkelmann[1,2]✉

The ice sheet's temperature sensitivity is 1.3 metres of sea-level equivalent per degree of warming up to 2 degrees above pre-industrial levels, almost doubling to 2.4 metres per degree of warming between 2 and 6 degrees and increasing to about 10 metres per degree of warming between 6 and 9 degrees





Safeguarding Irrecoverable Carbon in Earth‘s Ecosystems



nature climate change

PERSPECTIVE

https://doi.org/10.1038/s41558-020-0738-8

Check for updates

Protecting irrecoverable carbon in Earth's ecosystems

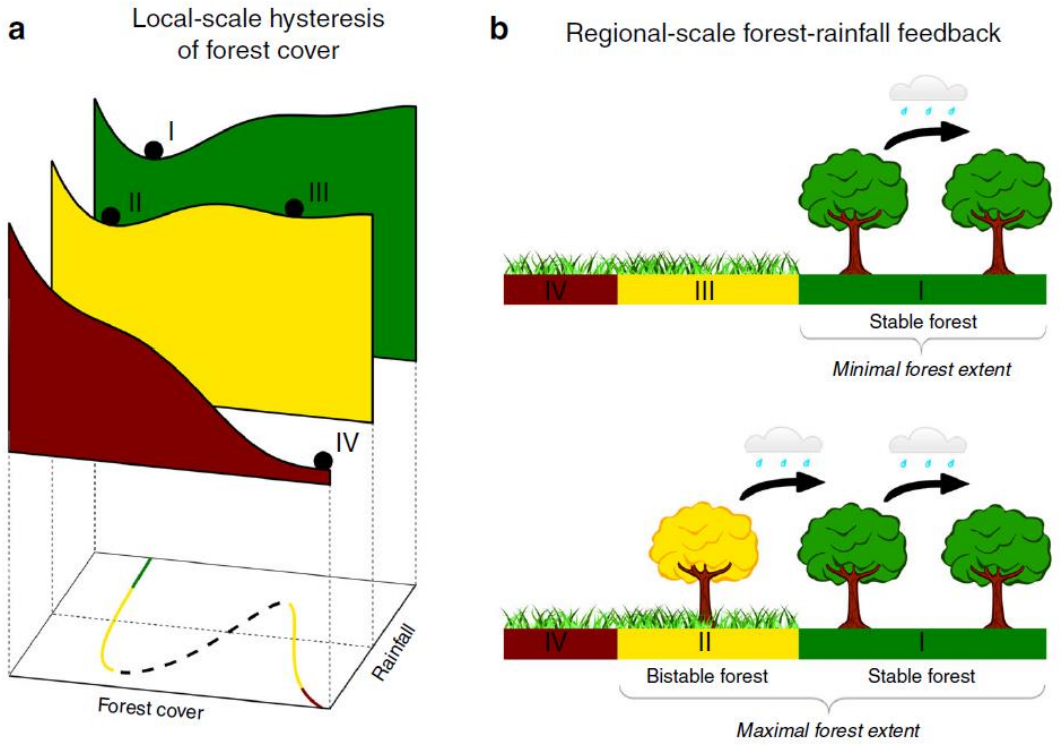
Allie Goldstein[1✉], Will R. Turner[1], Seth A. Spawn[2,3], Kristina J. Anderson-Teixeira[4], Susan Cook-Patton[5], Joseph Fargione[5], Holly K. Gibbs[2,3], Bronson Griscom[1], Jennifer H. Hewson[1], Jennifer F. Howard[1], Juan Carlos Ledezma[6], Susan Page[7], Lian Pin Koh[8], Johan Rockström[9], Jonathan Sanderman[10] and David G. Hole[1]

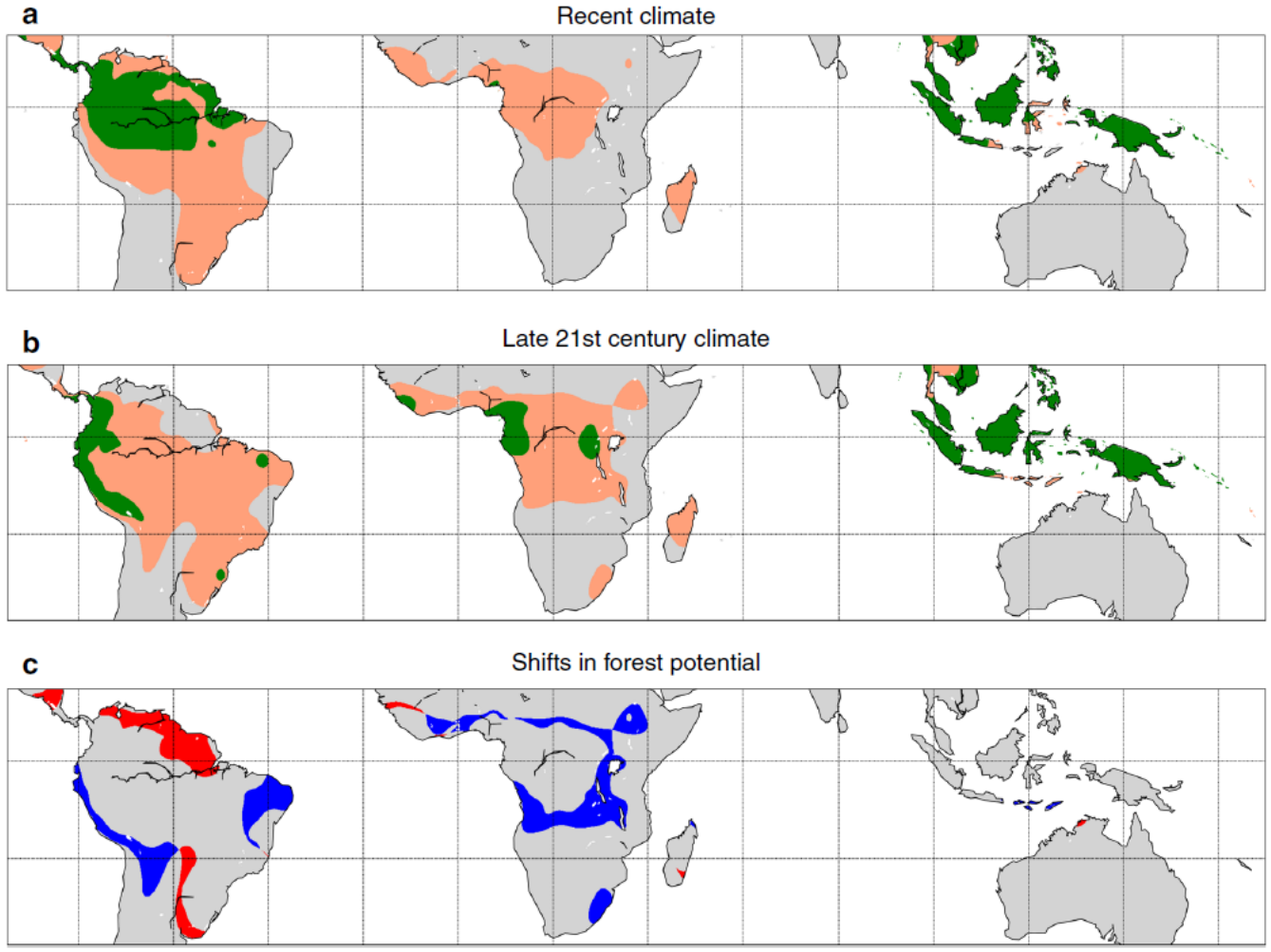
Larger part of Amazon rainforest at risk of tipping

nature COMMUNICATIONS

Hysteresis of tropical forests in the 21st century

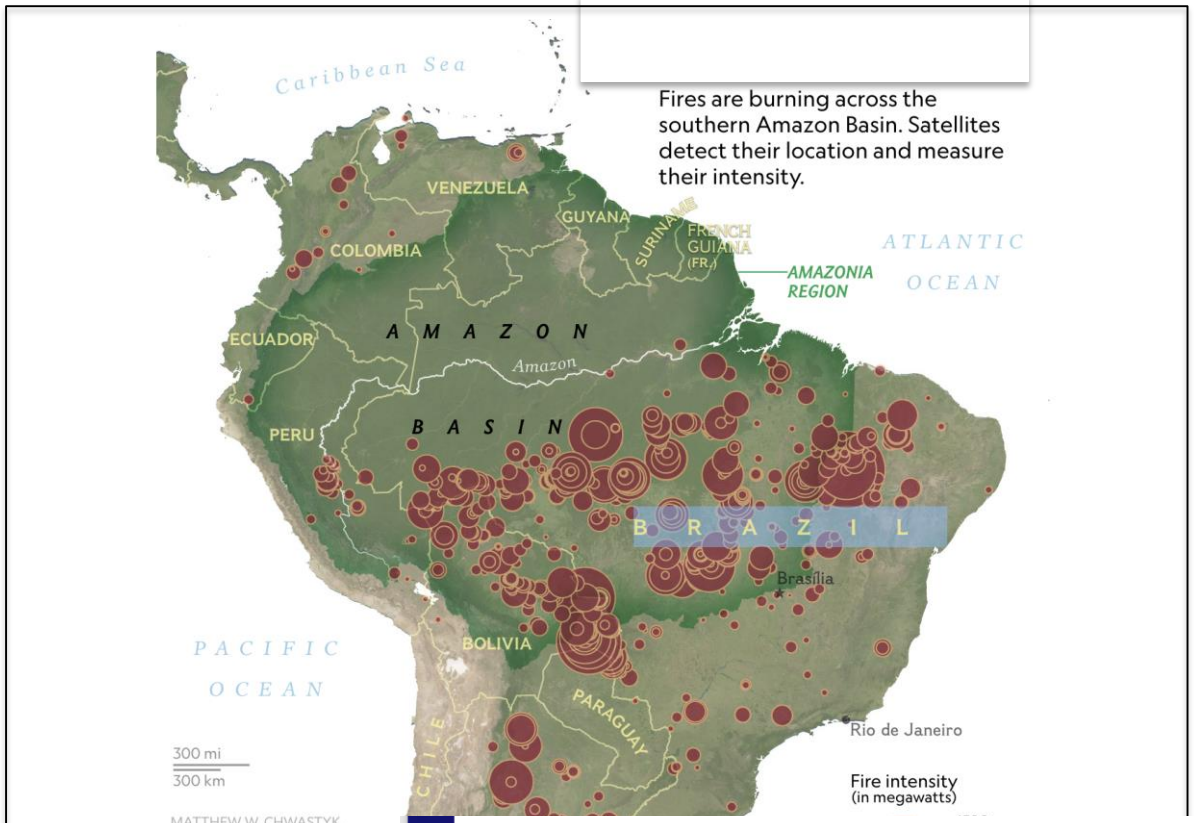
Arie Staal[1,2✉], Ingo Fetzer[1], Lan Wang-Erlandsson[1], Joyce H. C. Bosmans[3], Stefan C. Dekker[2], Egbert H. van Nes[4], Johan Rockström[1,5] & Obbe A. Tuinenburg[2]





Amazon rainforest thresholds

Deforestation threshold ≈40%



Temperature threshold ΔT≈4°C

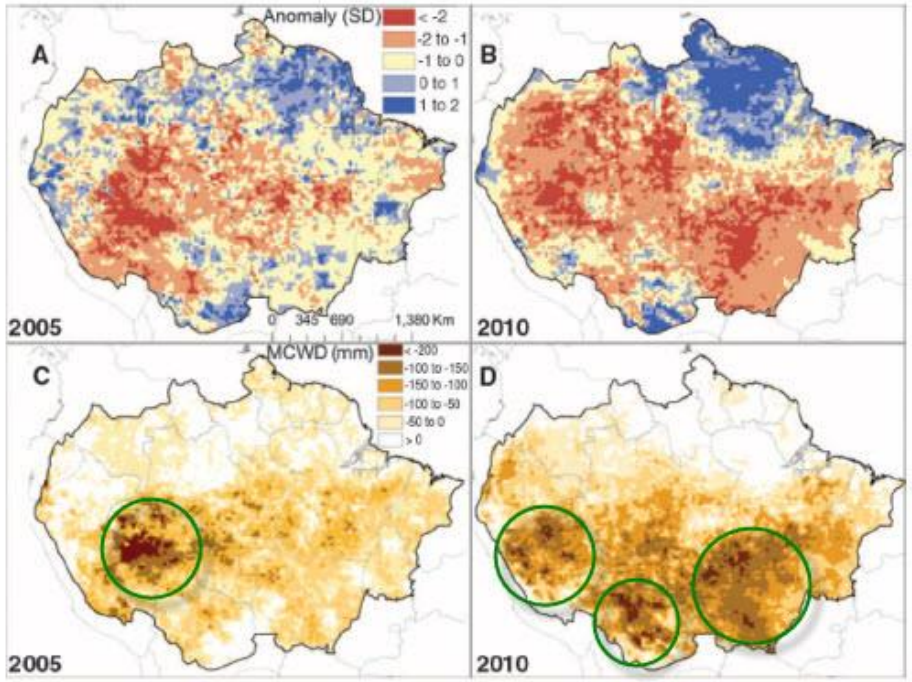


Fig. 1. (**A** and **B**) Satellite-derived standardized anomalies for dry-season rainfall for the two most extensive droughts of the 21st century in Amazonia. (**C** and **D**) The difference in the 12-month (October to September) ng 2005 and 2010), a measure of drought intensity that correlates e 2005 drought; (B) and (D) show the 2010 drought.

Lewis et al 2010, Nature

Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm

Carlos A. Nobre[a,1], Gilvan Sampaio[b], Laura S. Borma[c], Juan Carlos Castilla-Rubio[d], José S. Silva[e], and Manoel Cardoso[c]

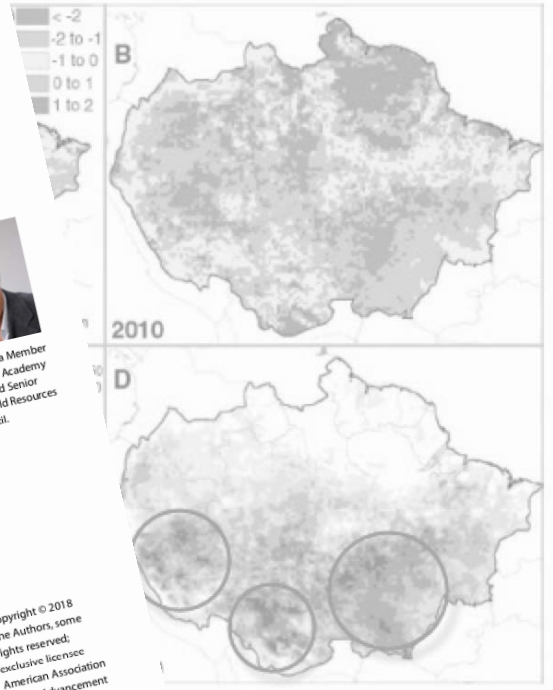
[a]National Center for Monitoring and Early Warning of Natural Disasters, São José dos Campos 12247-016, Brazil; [b]Center for Weather Forecasting and Climate Studies, National Institute for Space Research, Cachoeira Paulista 12630-000, Brazil; [c]Center for Earth System Science, National Institute for Space Research, São José dos Campos 12227-010, Brazil; [d]Planetary Skin Institute, São Paulo 05462-010, Brazil; and [e]Department of Ecology, University of Brasília, Brasilia DF CEP 70910900, Brazil

This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected in 2015.

Amazon rainforest thresholds

Deforestation 20-25%?

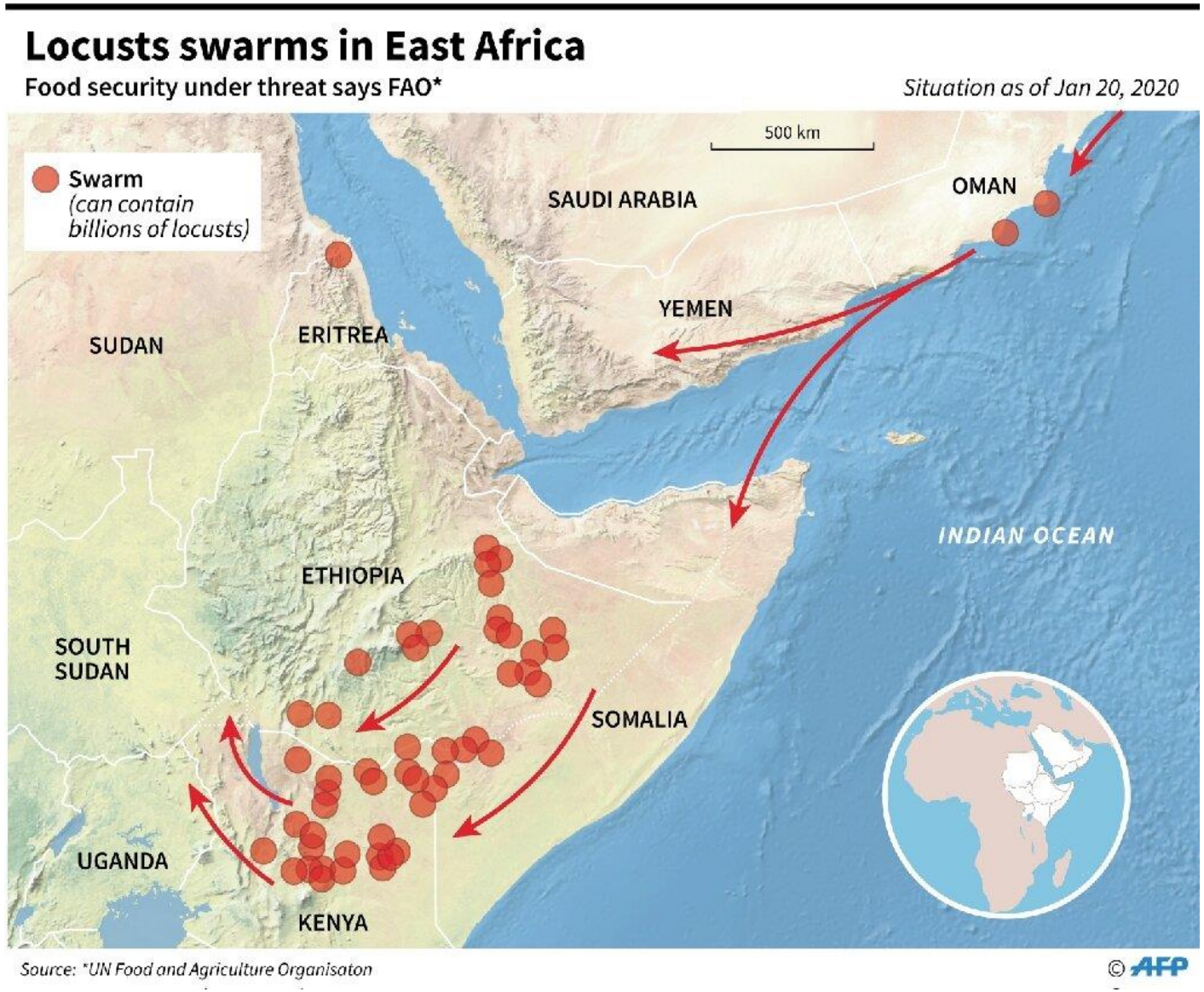
ΔT=?



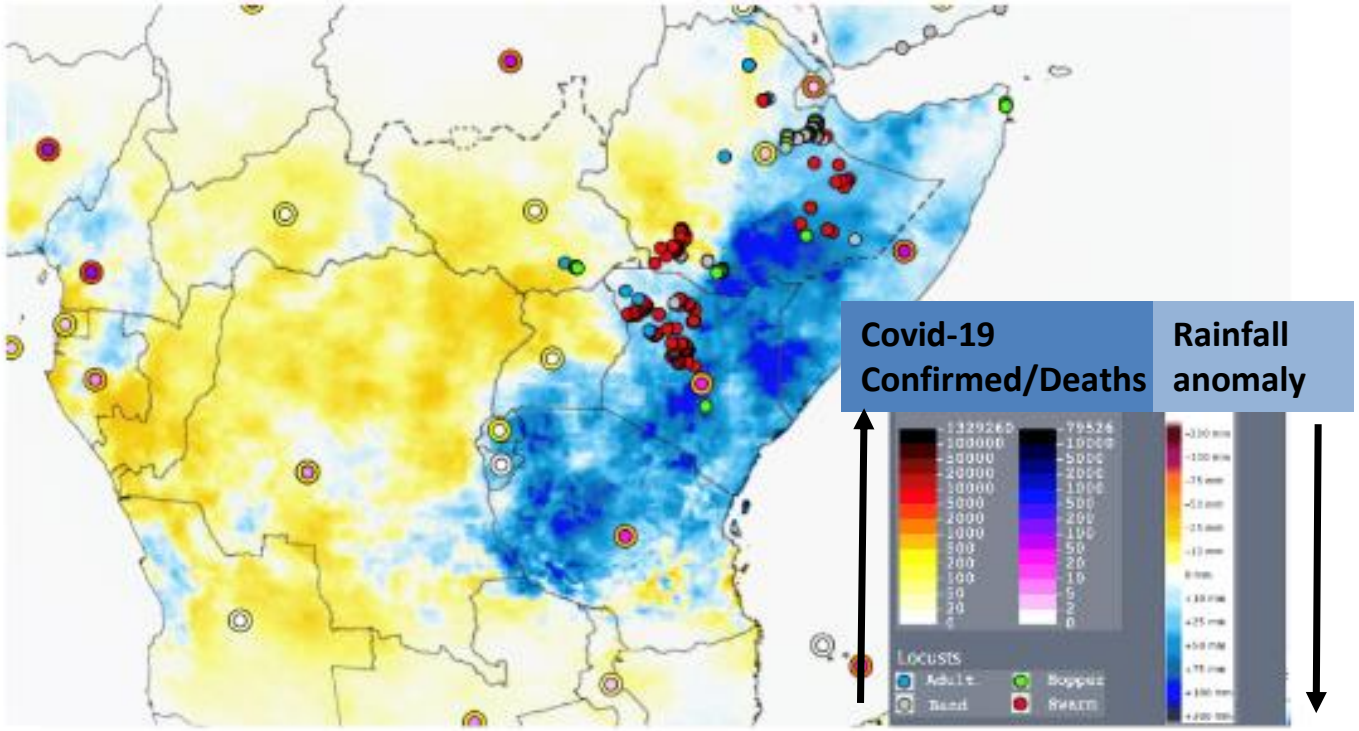
dry-season rainfall for the two most extensive
nce in the 12-month (October to September)
easure of drought intensity that correlates
(D) show the 2010 drought.

3. Global Systemic Risks

Locust outbreak in East Africa, 2020



A Perfect Storm in East Africa?

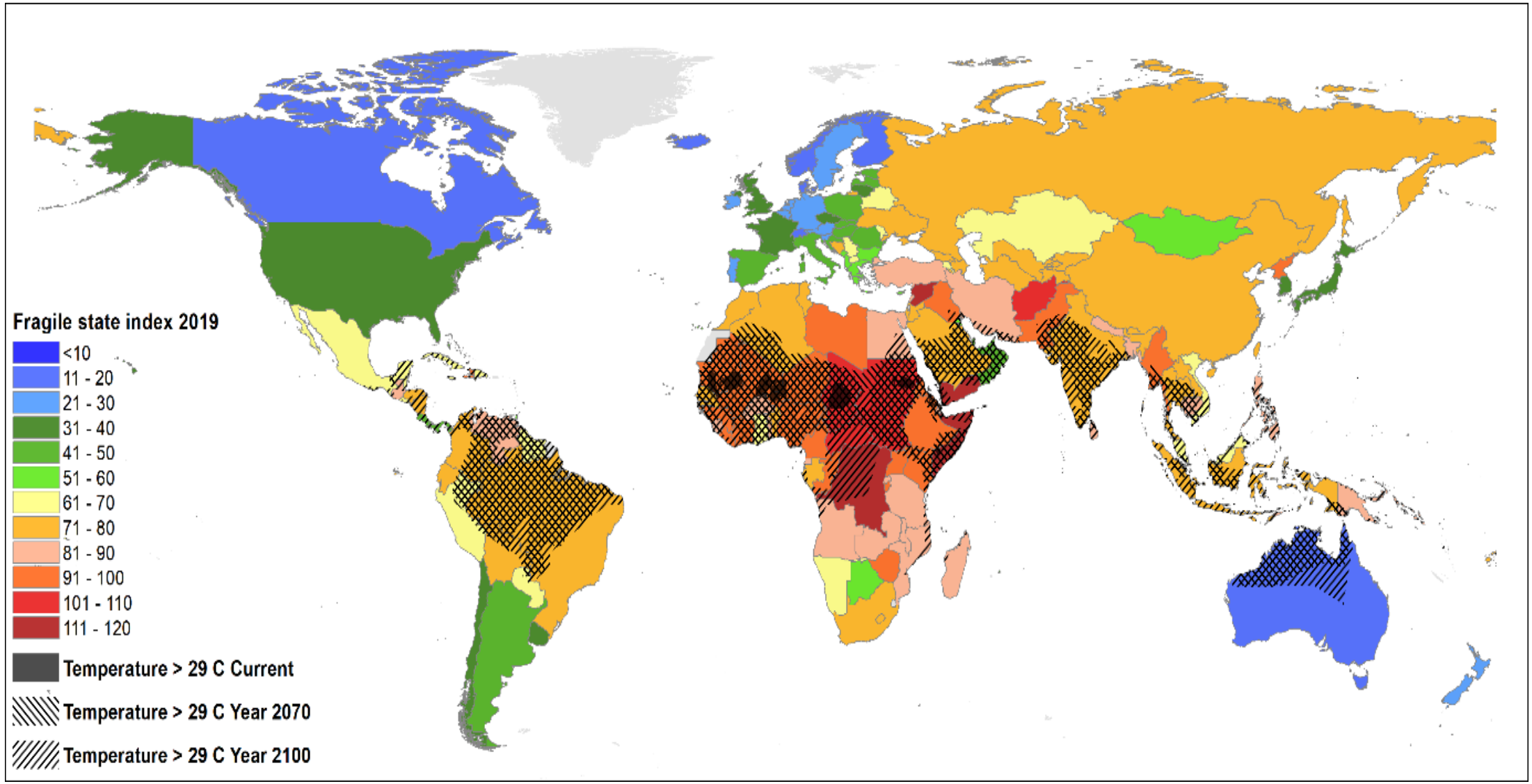


Source: FAO/Desert Locust Watch, Johns Hopkins CSSE /COVID-19 Data Repository, CHRIPS (Climate Hazards Group InfraRed Precipitation with Station data)

https://www.theguardian.com/world/gallery/2020/jan/24/billions-of-locusts-swarm-through-kenya-in-pictures

- A “Triple Menace”: Covid-19, Locusts And Heavy Rains

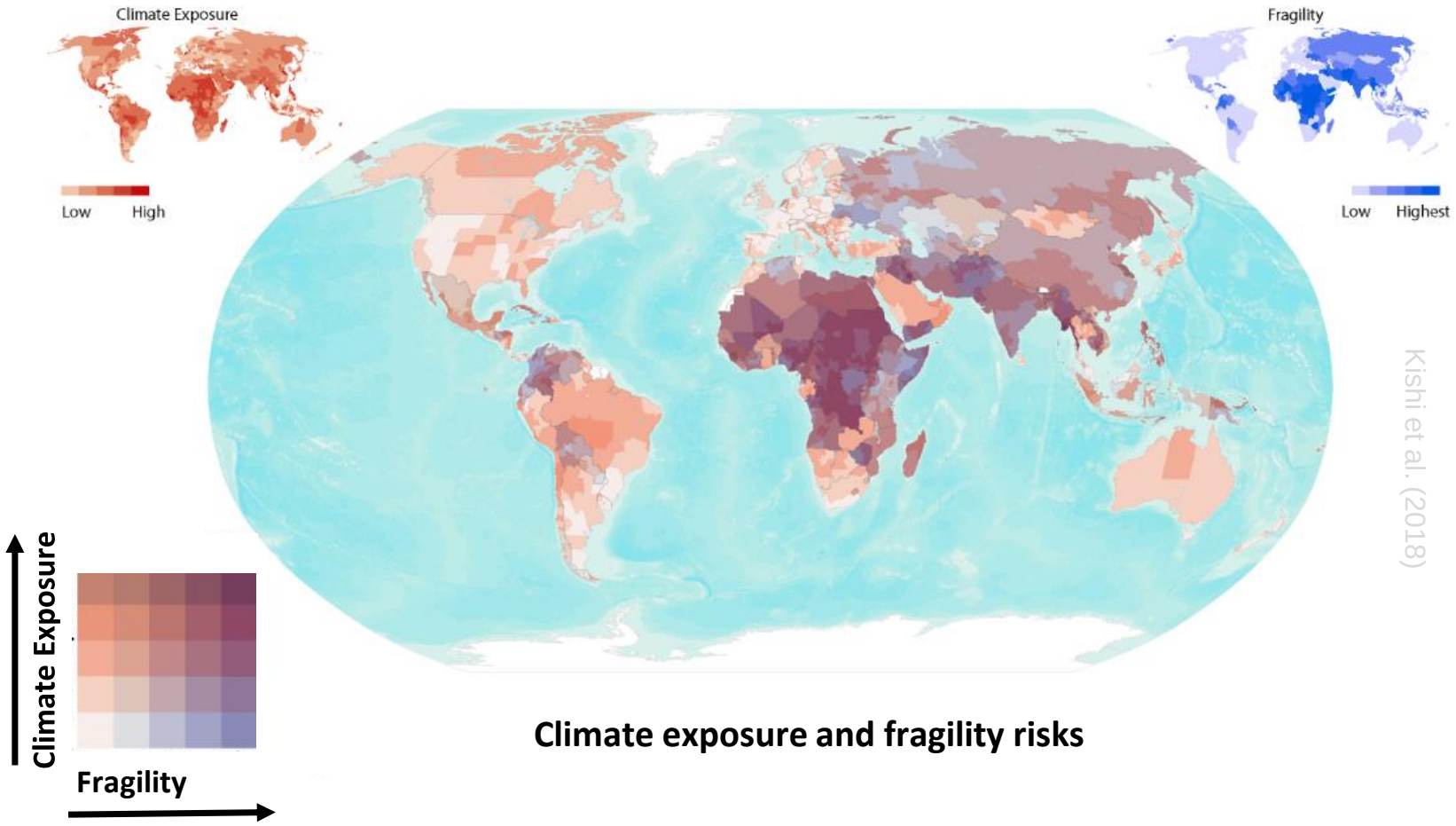
UN (2020):The Impact of COVID-19 on Food Security and Nutrition



Future of the human climate niche

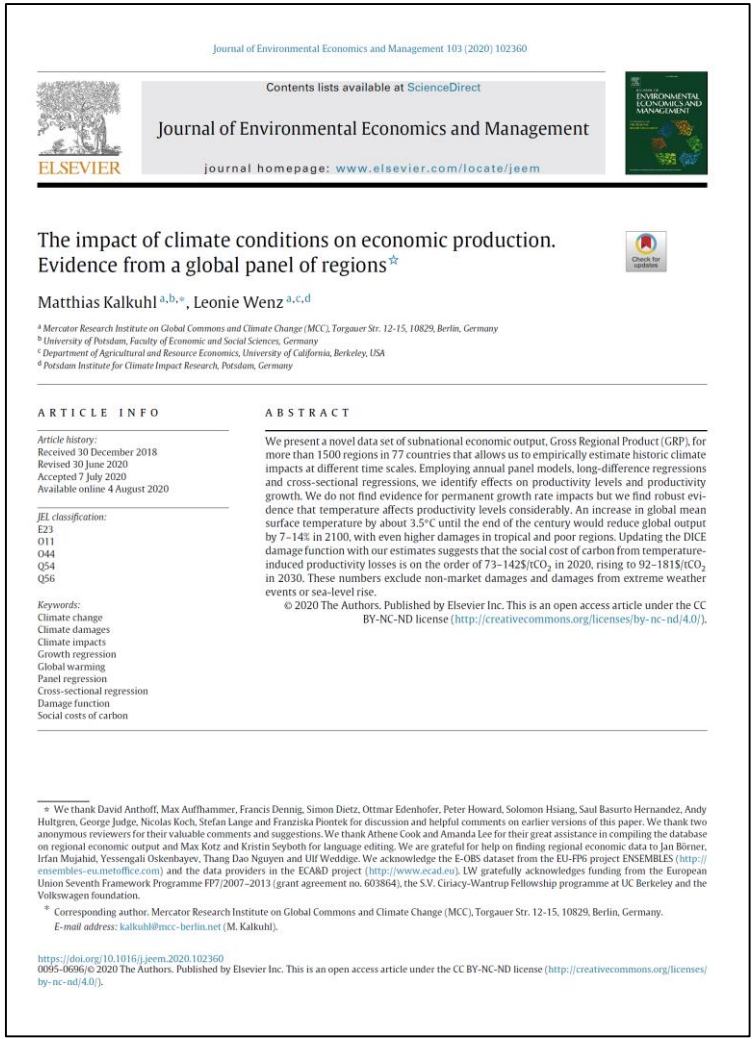
Chi Xu (徐驰)[a,1], Timothy A. Kohler[b,c,d,e], Timothy M. Lenton[f], Jens-Christian Svenning[g], and Marten Scheffer[c,h,i,1]

Climate Change Impacts Already Pose Risks to Peace and Security



Climate exposure and fragility risks

Heating our climate damages our economies – study reveals greater costs than expected



Journal of Environmental Economics and Management 103 (2020) 102360

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

The impact of climate conditions on economic production. Evidence from a global panel of regions☆

Matthias Kalkuhl [a,b,*], Leonie Wenz [a,c,d]

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[b] University of Potsdam, Faculty of Economic and Social Sciences, Germany
[c] Department of Agricultural and Resource Economics, University of California, Berkeley, USA
[d] Potsdam Institute for Climate Impact Research, Potsdam, Germany

ARTICLE INFO

Article history:
Received 30 December 2018
Revised 30 June 2020
Accepted 7 July 2020
Available online 4 August 2020

JEL classification:
E23
O11
O44
Q54
Q56

Keywords:
Climate change
Climate damages
Climate impacts
Growth regression
Global warming
Panel regression
Cross-sectional regression
Damage function
Social costs of carbon

ABSTRACT

We present a novel data set of subnational economic output, Gross Regional Product (GRP), for more than 1500 regions in 77 countries that allows us to empirically estimate historic climate impacts at different time scales. Employing annual panel models, long-difference regressions and cross-sectional regressions, we identify effects on productivity levels and productivity growth. We do not find evidence for permanent growth rate impacts but we find robust evidence that temperature affects productivity levels considerably. An increase in global mean surface temperature by about 3.5°C until the end of the century would reduce global output by 7–14% in 2100, with even higher damages in tropical and poor regions. Updating the DICE damage function with our estimates suggests that the social cost of carbon from temperature-induced productivity losses is on the order of 73–142$/tCO$_2$ in 2020, rising to 92–181$/tCO$_2$ in 2030. These numbers exclude non-market damages and damages from extreme weather events or sea-level rise.

☆ We thank David Anthoff, Max Auffhammer, Francis Dennig, Simon Dietz, Ottmar Edenhofer, Peter Howard, Solomon Hsiang, Saul Basurto Hernandez, Andy Hultgren, George Judge, Nicolas Koch, Stefan Lange and Franziska Piontek for discussion and helpful comments on earlier versions of this paper. We thank two anonymous reviewers for their valuable comments and suggestions. We thank Athene Cook and Amanda Lee for their great assistance in compiling the database on regional economic output and Max Kotz and Kristin Seyboth for language editing. We are grateful for help on finding regional economic data to Jan Börner, Irfan Mujahid, Yessengali Oskenbayev, Thang Dao Nguyen and Ulf Weddige. We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu). LW gratefully acknowledges funding from the European Union Seventh Framework Programme FP7/2007–2013 (grant agreement no. 603864), the S.V. Ciriacy-Wantrup Fellowship programme at UC Berkeley and the Volkswagen foundation.

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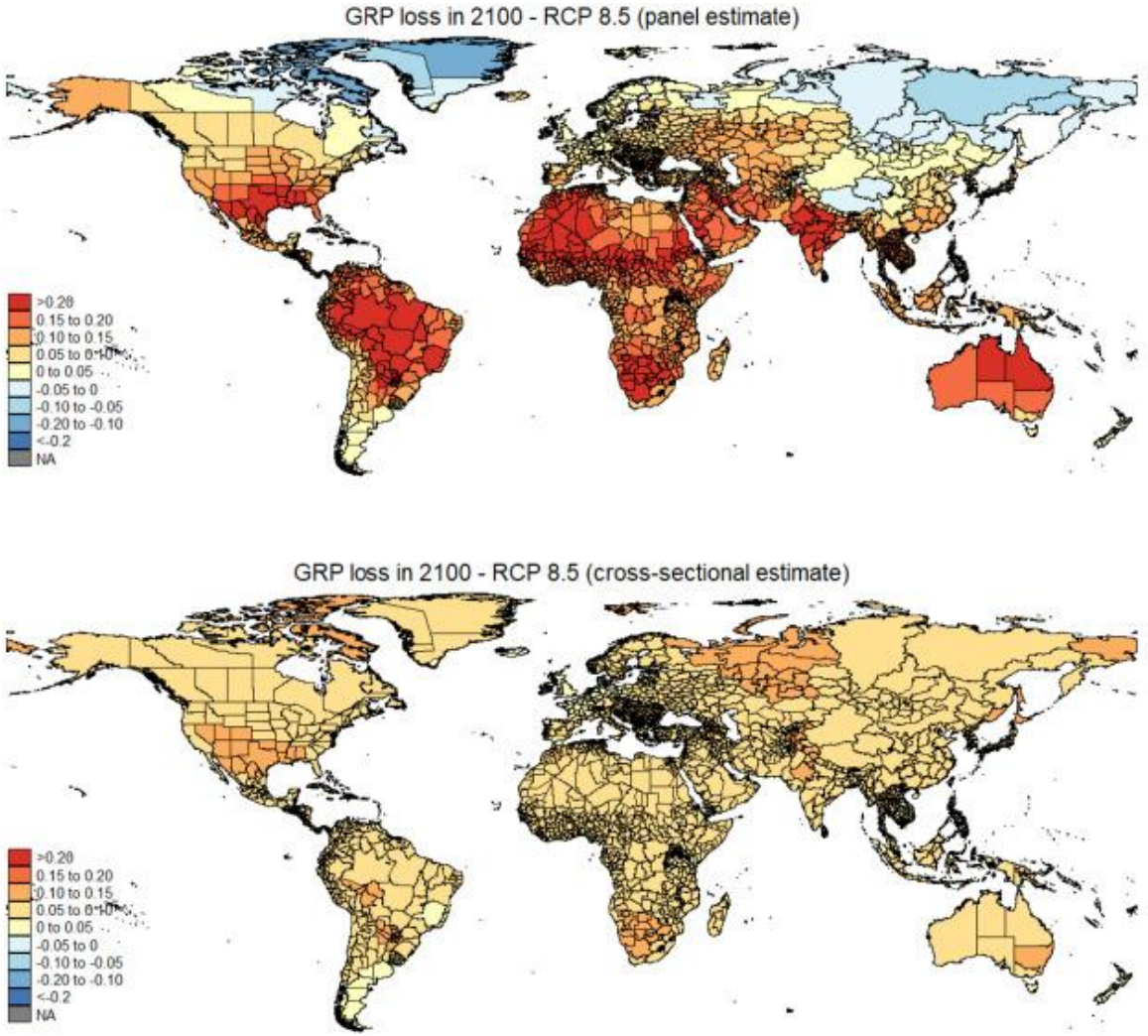
E-mail address: kalkuhl@mcc-berlin.net (M. Kalkuhl).

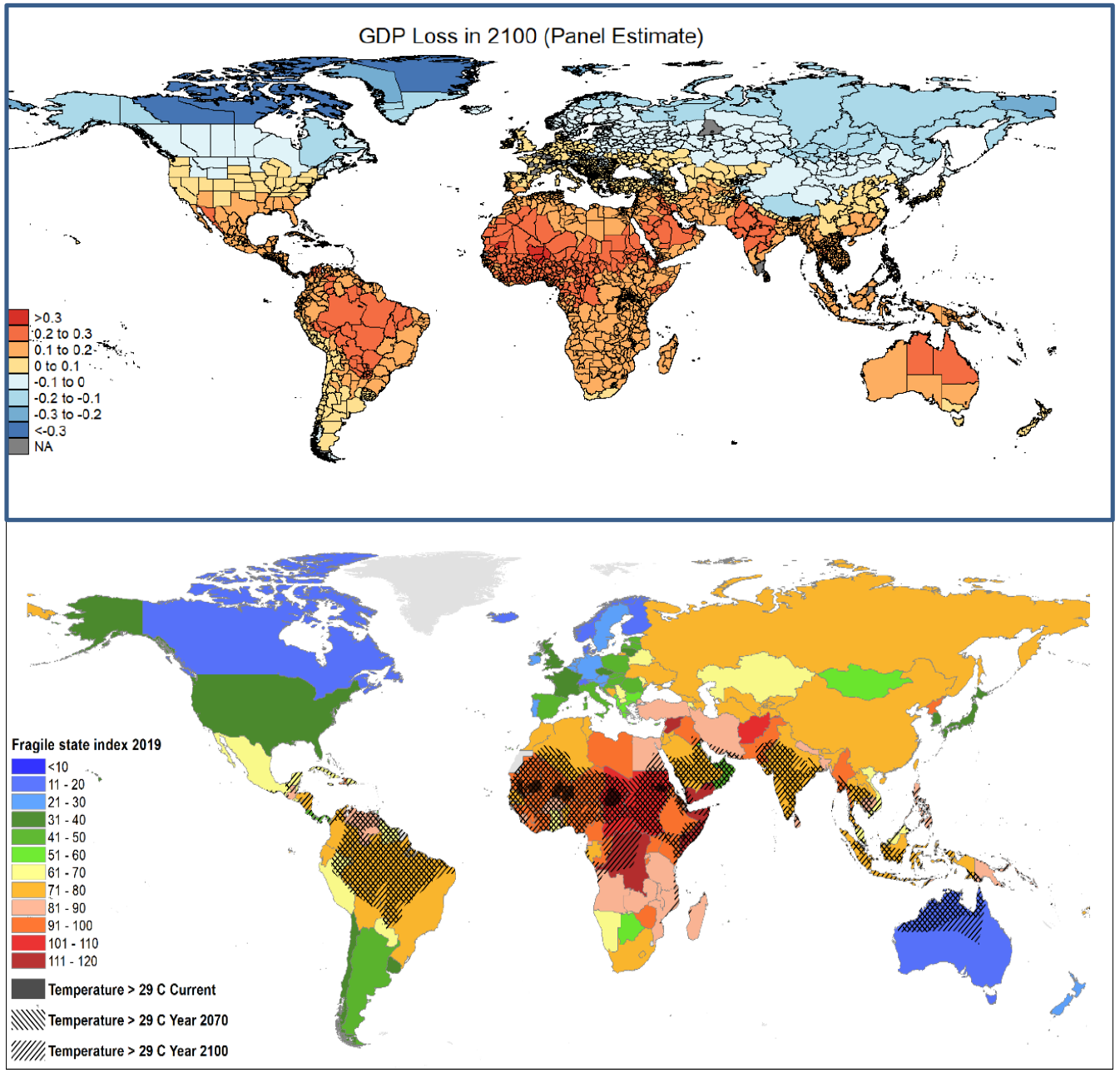
https://doi.org/10.1016/j.jeem.2020.102360

Kalkuhl & Wenz 2020,
Journal of Environ. Economics and Management



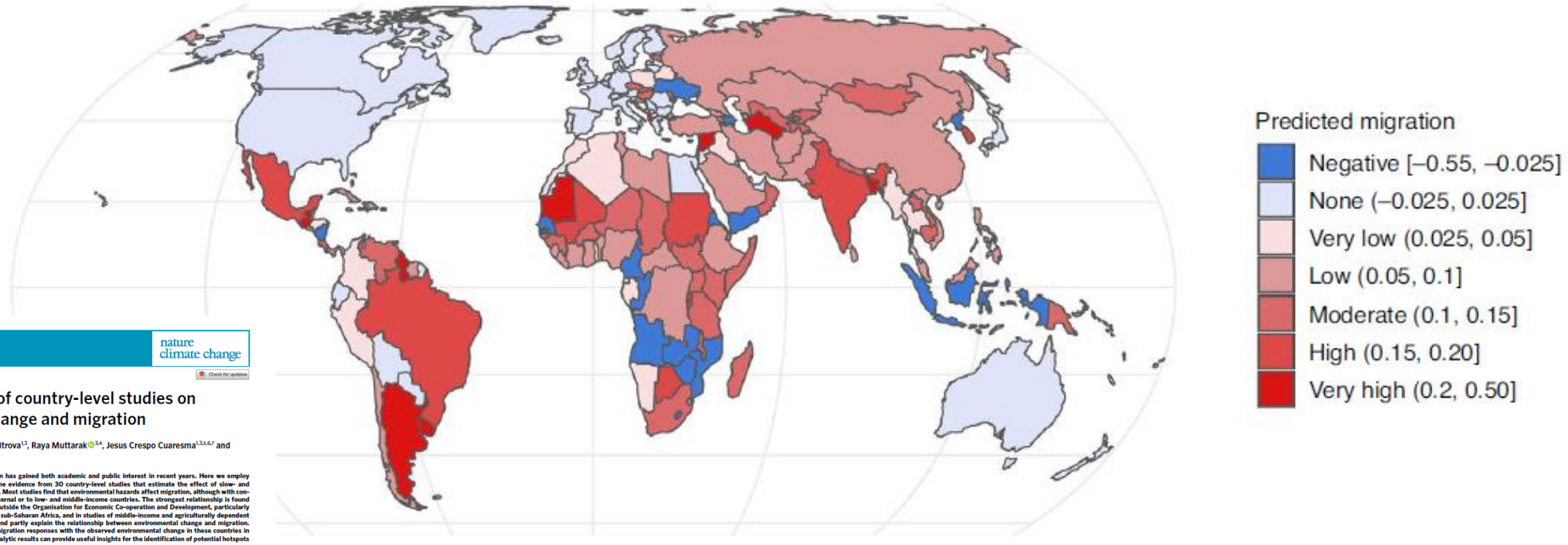
Losses in Gross Regional Product (GRP) in 2099 under a business-as-usual warming scenario (RCP-8.5).

Increasing North-South Divide



Kalkuhl & Wenz, 2020

Climate Change triggers migration – particularly in middle-income and agricultural countries



ARTICLES
https://doi.org/10.1038/s41558-020-0898-6
nature climate change

A meta-analysis of country-level studies on environmental change and migration

Roman Hoffmann[1,2], Anna Dimitrova[1,3], Raya Muttarak[3,4], Jesus Crespo Cuaresma[1,3,5,6,7] and Jonas Peisker[3]

The impact of climate change on migration has gained both academic and public interest in recent years. Here we employ a meta-analysis approach to synthesize the evidence from 30 country-level studies that estimate the effect of slow- and rapid-onset events on migration worldwide. Most studies find that environmental hazards affect migration, although with contextual variation. Migration is primarily internal or to low- and middle-income countries. The strongest relationship is found in studies with a large share of countries outside the Organisation for Economic Co-operation and Development, particularly from Latin America and the Caribbean and sub-Saharan Africa, and in studies of middle-income and agriculturally dependent countries. Income and conflict moderate and partly explain the relationship between environmental change and migration. Combining our estimates for differential migration responses with the observed environmental change in these countries in recent decades illustrates how the meta-analytic results can provide useful insights for the identification of potential hotspots of environmental migration.

The potential effect of climate change on worldwide migration is highly present in the public debate. Recent mass migration episodes such as the Syrian refugee crisis in 2015 and the 'migrant caravan' from Central America to the United States in 2018 have been partly attributed to severe droughts experienced in these countries[1–3]. Possible relationships between changing environmental conditions and subsequent migration have also been observed in other parts of the world (Extended Data Fig. 1). The extent to which environmental factors fuel economic and sociopolitical crises and influence migration has led to controversial discussions in the literature[4]. If the claim that adverse climatic conditions drive migration is true, it can be expected that an increase in average global temperature of 2 °C or more above pre-industrial levels would result in substantially higher migration flows in the future[5–8].

In the past decade, the number of empirical studies focusing on climate and other environmental drivers of migration has increased notably. Yet, there is little consensus concerning the direction and the extent to which these factors influence migration. Environmental change has been found to contribute to increased human migration in some studies, whereas no effect or a decline in migration has been reported in others[9–14]. The empirical results differ depending on the environmental factors considered, the data and scale of the analysis, the methodology employed and the geographical contexts covered. Even within the same studies, estimates of the size and direction of environmental migration flows vary considerably. The heterogeneity of the existing evidence hampers policy efforts to address the challenges related to potential increases in global migration flows due to future environmental change.

Here we use a meta-analysis approach to synthesize the results of 30 scientific papers published between 2006 and 2019, which quantitatively analyse the influence of different environmental factors on migration (Fig. 1)[15–44]. We focus on macro studies that estimate the effects on migration using longitudinal country-level data and exploiting variations both across countries and over time. The considered studies focus on a broad range of environmental drivers, such as changing temperatures, rainfall anomalies and heavy storms. Typically, they estimate separate regression models considering the impacts of different environmental factors and other migration drivers, using different modelling techniques, country samples and specifications.

From the 30 selected studies (n) and their models, we extracted a total of 1,803 effect estimates (k) of the relationship between individual environmental factors and migration (Supplementary Fig. 1). Each model estimate represents a separate observation in our analysis. To achieve comparability, we standardize the estimates using distributional information for each of the environmental and migration variables considered. The standardized effects show the estimated change in migration in standard deviations corresponding to a one standard deviation change in the respective environmental factor. In our meta-analysis, we take an exploratory approach aiming at unveiling patterns in the environment–migration relationships estimated by the pool of existing studies and analysing drivers of heterogeneity in the empirical findings.

The focus on country-level studies allows us to retrieve and recalculate the distributional information required for standardization, a process that is not feasible for idiosyncratic micro-level studies. The standardization enables us to effectively compare the size of different effects across models despite differences in measurement and scaling of the key variables. The estimation methodology used in the country-level studies is broadly similar, allowing for a direct comparison of the results. By extracting further information on study characteristics, modelling techniques, the

[1]Vienna Institute of Demography/Austrian Academy of Sciences, Wittgenstein Centre for Demography and Global Human Capital (IIASA, OeAW, University of Vienna), Vienna, Austria. [2]Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany. [3]International Institute for Applied Systems Analysis (IIASA), Wittgenstein Centre for Demography and Global Human Capital (IIASA, OeAW, University of Vienna), Laxenburg, Austria. [4]School of International Development, University of East Anglia, Norwich, UK. [5]Department of Economics, Vienna University of Economics and Business, Vienna, Austria. [6]Austrian Institute of Economic Research (WIFO), Vienna, Austria. [7]Center for Economic Studies (CESifo), Munich, Germany. ✉e-mail: roman.hoffmann@pik-potsdam.de

Predicted environmental migration worldwide measured in standard deviation changes in migration.

Environmental hazards affect populations worldwide and can drive migration under specific conditions. Changes in temperature levels, increased rainfall variability, and rapid-onset disasters, such as tropical storms, are important - environmental migration is most pronounced in middle-income and agricultural countries but weaker in low-income countries, where populations often lack resources needed for migration.

These Risks Emerge in Interaction with Other Pressures and Contextual Factors

- Local resource competition (e.g. land and water)
- Livelihood insecurity, human mobility, and engagement in illegal coping mechanisms
- Extreme food price spikes and food insecurity
- Extreme weather events
- Poorly designed (climate and security) policies
- Weak or failing governance

Climate Crisis

Health Crisis

Ecosystem Crisis

Rainforest is cleared for cattle farming along the Trans-Amazonian Highway. Clearing like this is

NATIONAL GEOGRAPHIC

SCIENCE

Deforestation is leading to more infectious diseases in humans

As more and more forest is cleared around the world, scientists fear that the next deadly pandemic could emerge from what lives within them.

6 MINUTE READ

BY KATARINA ZIMMER

PUBLISHED NOVEMBER 22, 2019

In 1997, clouds of smoke hung over the rainforests of Indonesia as an area roughly the size of Pennsylvania was burned to make way for agriculture, the fires exacerbated by drought. Smothered in haze, the trees couldn't produce fruit, leaving resident fruit bats with no other option than to fly elsewhere in search of food, carrying with them a deadly disease.

ELSEVIER

Travel Medicine and Infectious Disease

Volume 31, September–October 2019, 101474

Brazil burning! What is the potential impact of the Amazon wildfires on vector-borne and zoon... an in...

D.Katterin... Gómez-M... Juan Javier...

Show mo...

https://doi...

PNAS

Check for updates

Amazon deforestation drives malaria transmission, and malaria burden reduces forest clearing

Andrew J. MacDonald[a,b,1] and Erin A. Mordecai[a]

[a]Department ...

Edited by Burt...

Deforestatio... anthropoger... malaria in re... ment in the ... increase in m... cause of this... each other i... creases malar... deforestation... strength of t... transformatic... dataset enco... and show de... cidence. Our ... a 3.3% increa... ated with 1...

VECTOR-BORNE AND ZOONOTIC DISEASES
Volume 15, Number 7, 2015
© Mary Ann Liebert, Inc.
DOI: 10.1089/vbz.2013.1563

Targeting Transmission Pathways for Emerging Zoonotic Disease Surveillance and Control

Abstract

We used litera... most importan... Our results su... approximately... specific under... be used to dev... regions under...

Key Words: Su...

Journal of Applied Ecology

BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

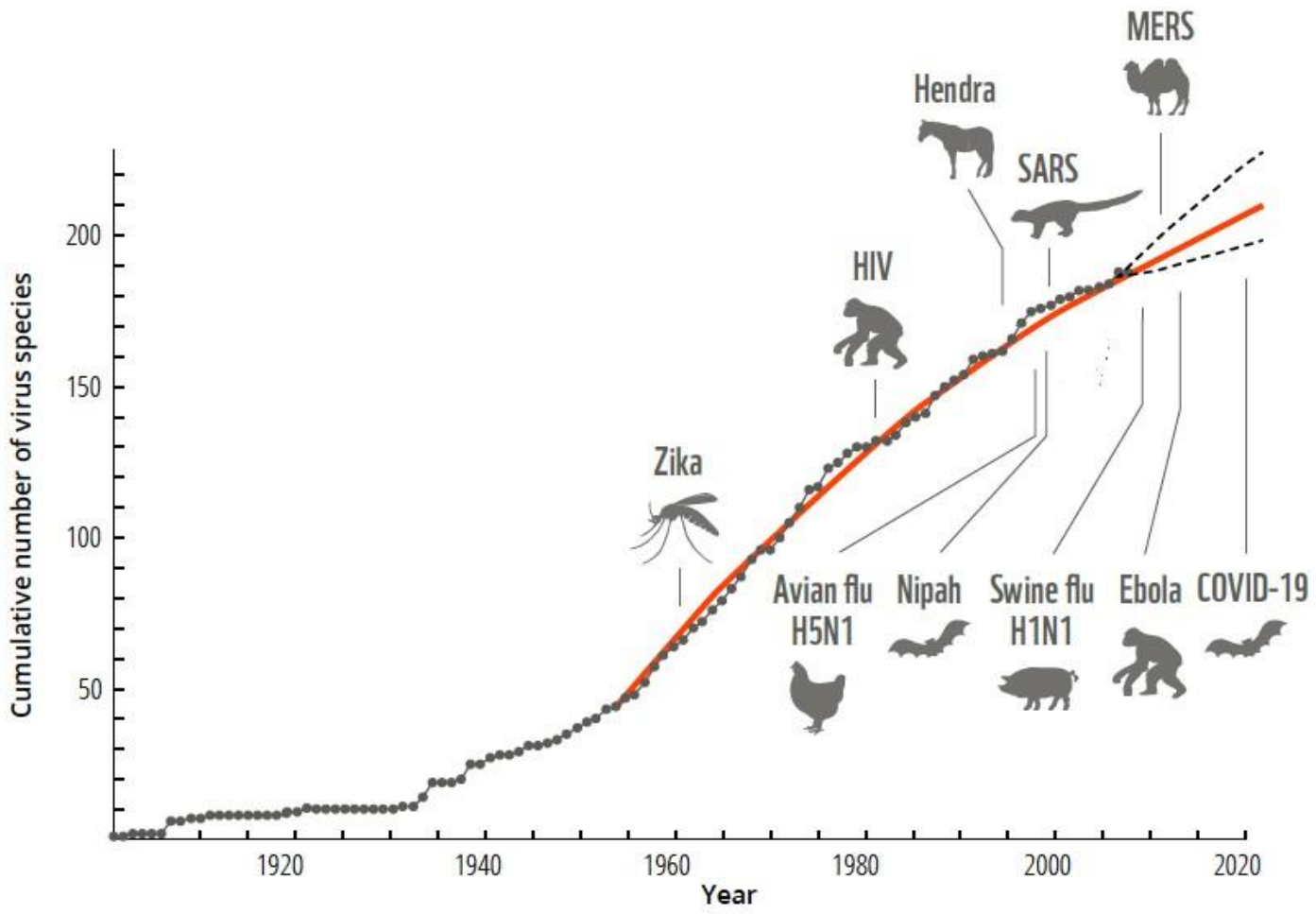
Missing the people for the trees: Identifying coupled natural–human system feedbacks driving the ecology of Lyme disease

Andrew J. MacDonald, Ashley E. Larsen, Andrew J. Plantinga

First published:20 October 2018 | https://doi.org/10.1111/1365-2664.13289 | Citations: 3

PDF TOOLS SHARE

Zoonotic Virus diseases on the rise

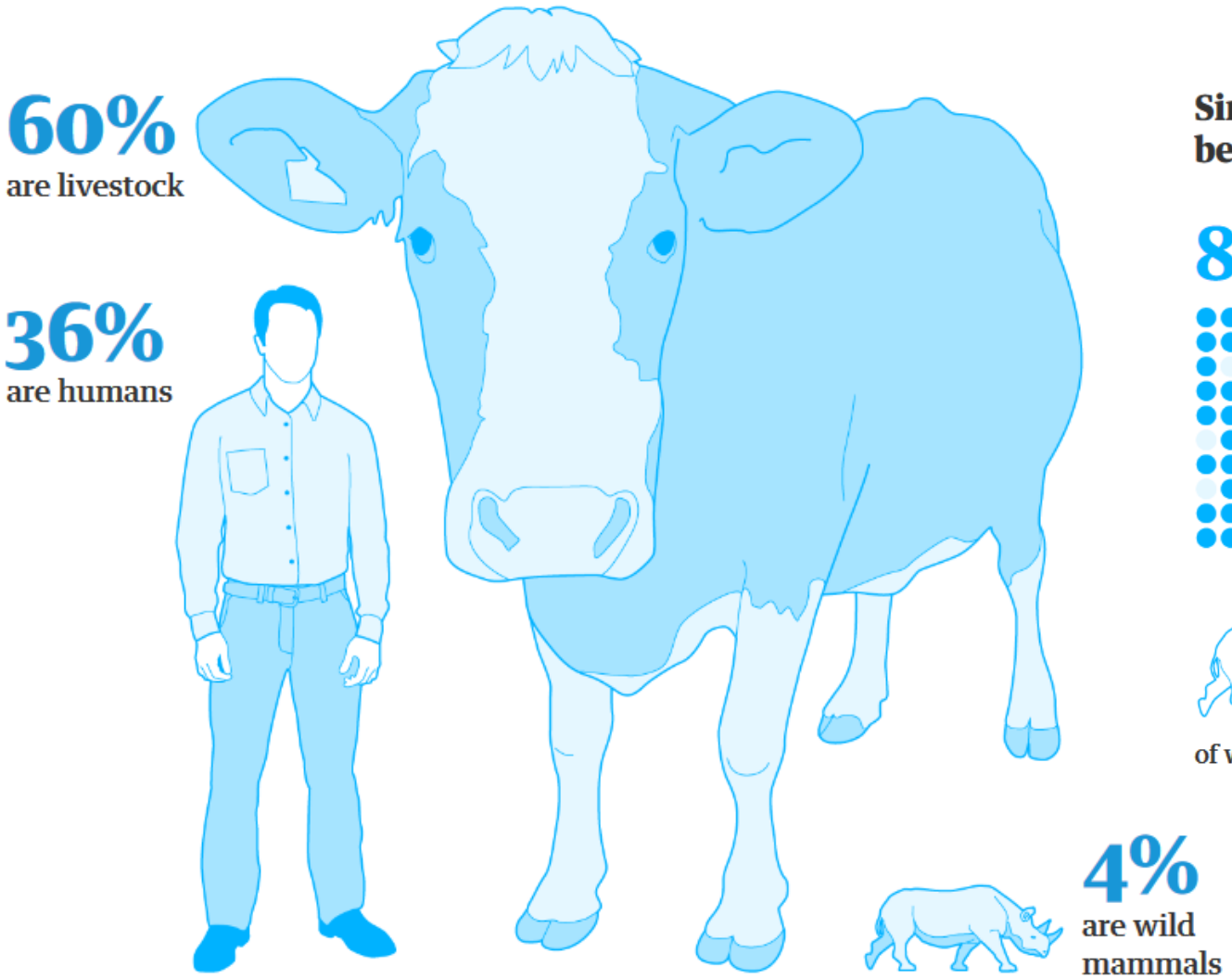


Majority (70%) of emerging infectuous diseases are zoonoses, and essentially all Pandemics

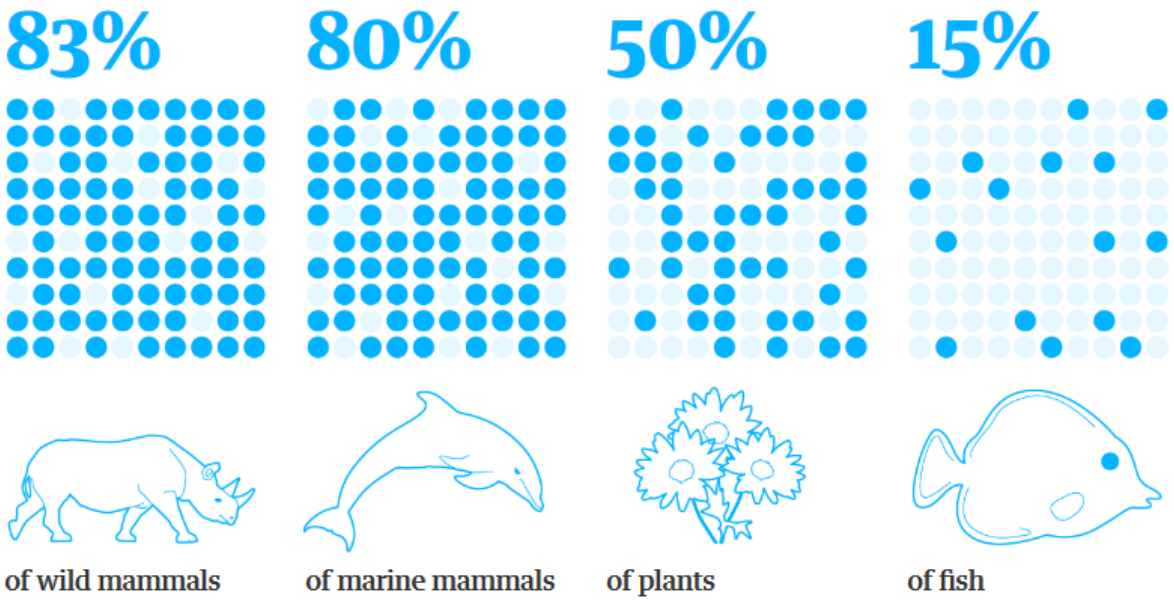
WWF Global Science. *Beyond Boundaries: Insights into emerging zoonotic diseases, nature, and human well-being.* (2020)

Of all the mammals on Earth, 96% are livestock and humans, only 4% are wild mammals

The Guardian



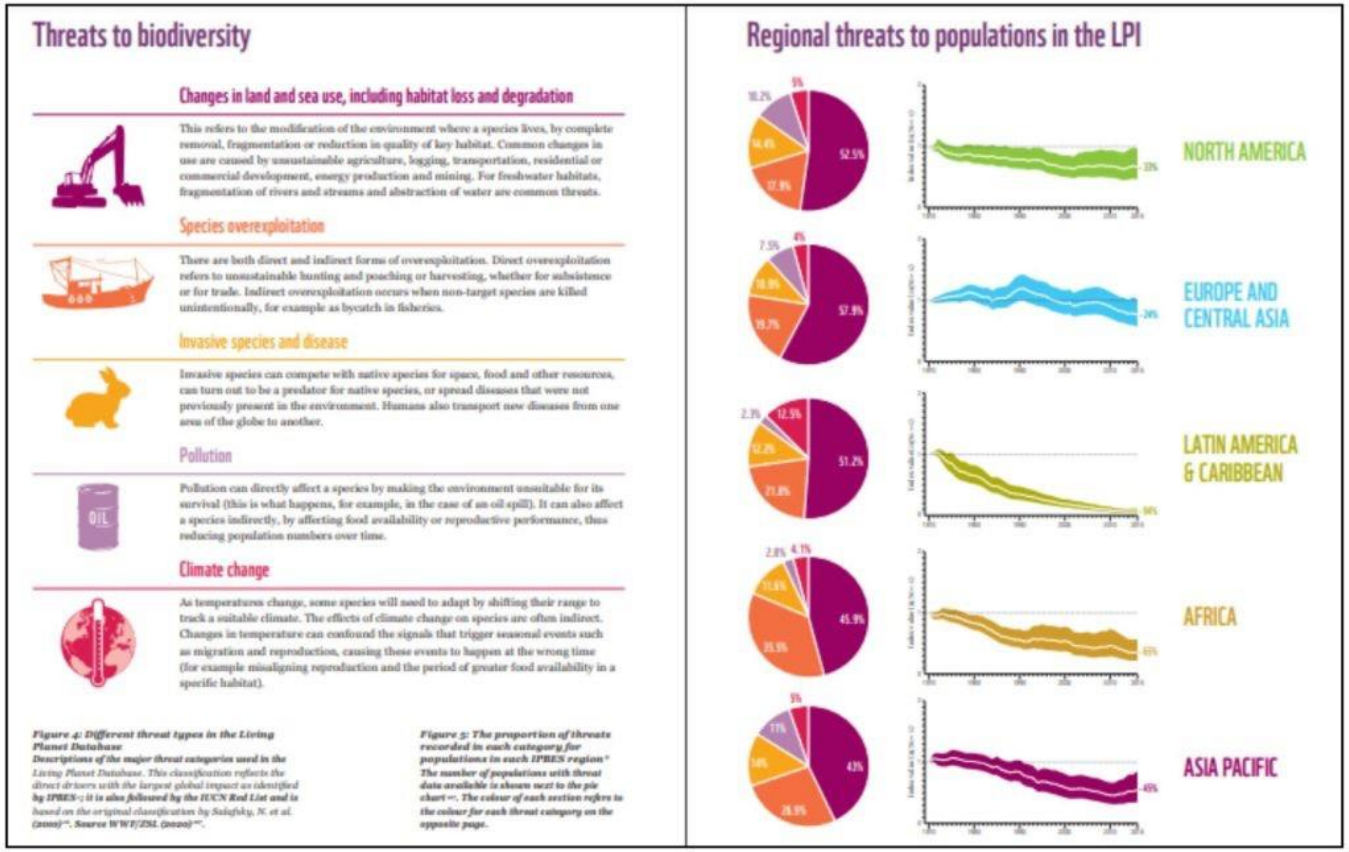
Since the rise of human civilisation 83% of wild mammals have been lost

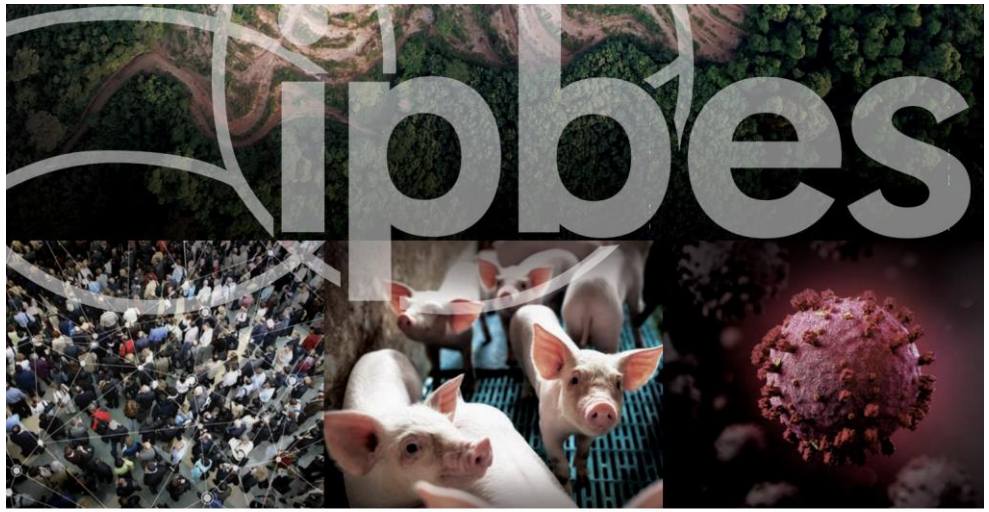


Bar-On et al., PNAS, 2018; Guardian graphic, 21 May 2018

Trend of Mass extinction continues

The population sizes of mammals, birds, fish, amphibians and reptiles have seen an alarming average drop of **68**% since 1970





IPBES WORKSHOP ON BIODIVERSITY AND PANDEMICS

WORKSHOP REPORT

Intergovernmental Science-Policy Platform
on Biodiversity and Ecosystem Services

ipbes

Pandemics emerge from the microbial diversity found in nature

- The majority (70%) of emerging diseases (e.g. Ebola, Zika, Nipah encephalitis), and almost all known pandemics (e.g. influenza, HIV/AIDS, COVID-19), are zoonoses – i.e. are caused by microbes of animal origin. These microbes 'spill over' due to contact among wildlife, livestock, and people.
- An estimated 1.7 million currently undiscovered viruses are thought to exist in mammal and avian hosts. Of these, 631,000–827,000 could have the ability to infect humans.
- The most important reservoirs of pathogens with pandemic potential are mammals (in particular bats, rodents, primates) and some birds (in particular water birds), as well as livestock (e.g. pigs, camels, poultry).

Human ecological disruption and unsustainable consumption drive pandemic risk

- The risk of pandemics is increasing rapidly, with more than five new diseases emerging in people every year, any one of which has the potential to spread and become pandemic. The risk of a pandemic is driven by exponentially increasing anthropogenic changes. Blaming wildlife for the emergence of diseases is thus erroneous, because emergence is caused by human activities and the impacts of these activities on the environment.
- Unsustainable exploitation of the environment due to land-use change, agricultural expansion and intensification, wildlife trade and consumption, and other drivers, disrupts natural interactions among wildlife and their microbes, increases contact among wildlife, livestock, people, and their pathogens and has led to almost all pandemics.

LETTER

https://doi.org/10.1038/s41586-018-0071-9

Large potential reduction in economic damages under UN mitigation targets

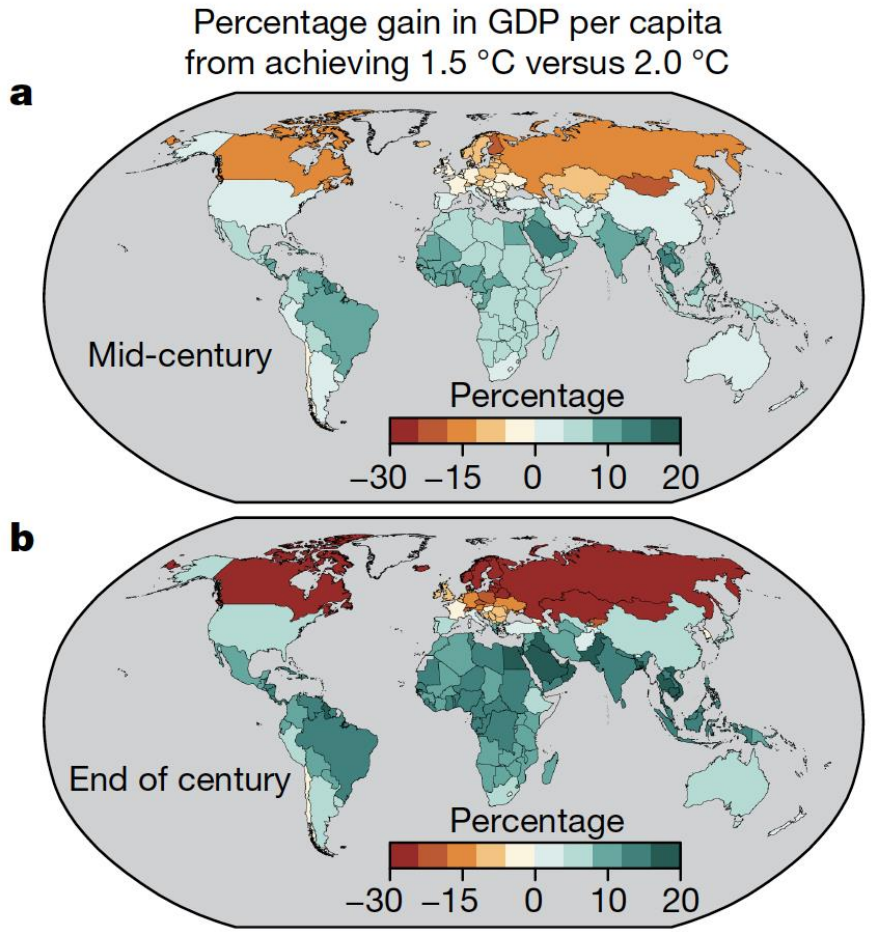
Marshall Burke[1,2,3]*, W. Matthew Davis[2] & Noah S. Diffenbaugh[1,4]

The Nobel Prize for Climate Catastrophe

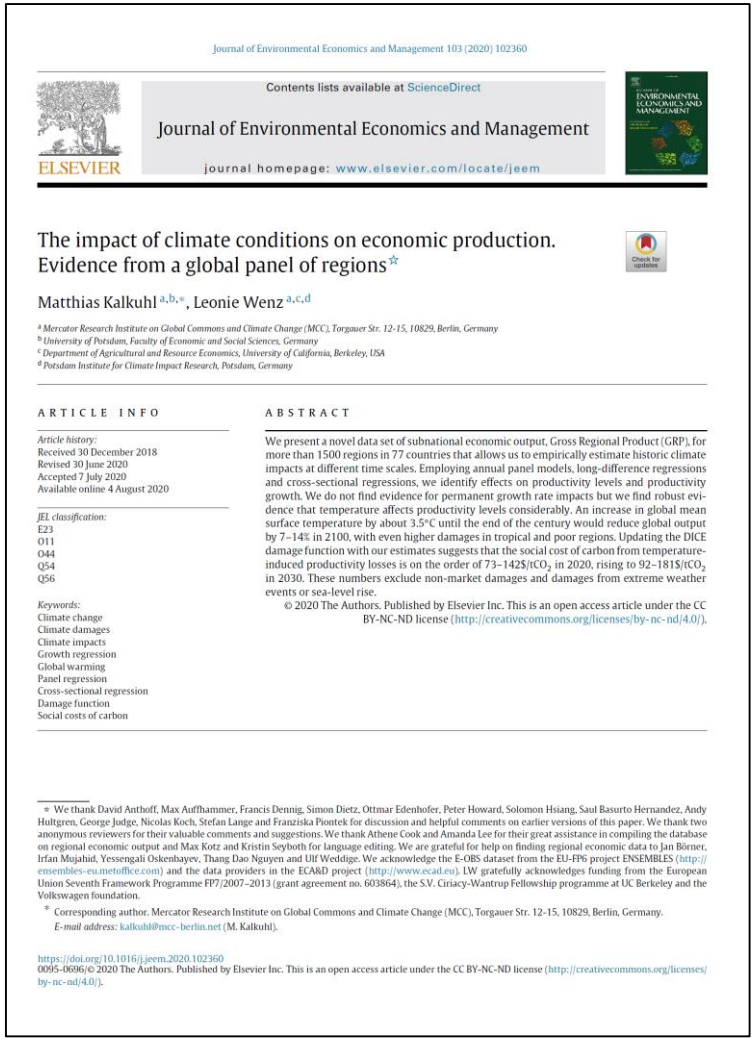
The economist William Nordhaus will receive his profession's highest honor for research on global warming that's been hugely influential—and entirely misguided.

BY JASON HICKEL

DECEMBER 6, 2018, 1:42 PM



Heating our climate damages our economies – study reveals greater costs than expected



Journal of Environmental Economics and Management 103 (2020) 102360

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

journal homepage: www.elsevier.com/locate/jeem

The impact of climate conditions on economic production. Evidence from a global panel of regions☆

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ARTICLE INFO

Article history:
Received 30 December 2018
Revised 30 June 2020
Accepted 7 July 2020
Available online 4 August 2020

JEL classification:
E23
O11
O44
Q54
Q56

Keywords:
Climate change
Climate damages
Climate impacts
Growth regression
Global warming
Panel regression
Cross-sectional regression
Damage function
Social costs of carbon

ABSTRACT

We present a novel data set of subnational economic output, Gross Regional Product (GRP), for more than 1500 regions in 77 countries that allows us to empirically estimate historic climate impacts at different time scales. Employing annual panel models, long-difference regressions and cross-sectional regressions, we identify effects on productivity levels and productivity growth. We do not find evidence for permanent growth rate impacts but we find robust evidence that temperature affects productivity levels considerably. An increase in global mean surface temperature by about 3.5°C until the end of the century would reduce global output by 7–14% in 2100, with even higher damages in tropical and poor regions. Updating the DICE damage function with our estimates suggests that the social cost of carbon from temperature-induced productivity losses is on the order of 73–142$/tCO$_2$ in 2020, rising to 92–181$/tCO$_2$ in 2030. These numbers exclude non-market damages and damages from extreme weather events or sea-level rise.

☆ We thank David Anthoff, Max Auffhammer, Francis Dennig, Simon Dietz, Ottmar Edenhofer, Peter Howard, Solomon Hsiang, Saul Basurto Hernandez, Andy Hultgren, George Judge, Nicolas Koch, Stefan Lange and Franziska Piontek for discussion and helpful comments on earlier versions of this paper. We thank two anonymous reviewers for their valuable comments and suggestions. We thank Athene Cook and Amanda Lee for their great assistance in compiling the database on regional economic output and Max Kotz and Kristin Seyboth for language editing. We are grateful for help on finding regional economic data to Jan Börner, Irfan Mujahid, Yessengali Oskenbayev, Thang Dao Nguyen and Ulf Weddige. We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu). LW gratefully acknowledges funding from the European Union Seventh Framework Programme FP7/2007–2013 (grant agreement no. 603864), the S.V. Ciriacy-Wantrup Fellowship programme at UC Berkeley and the Volkswagen foundation.

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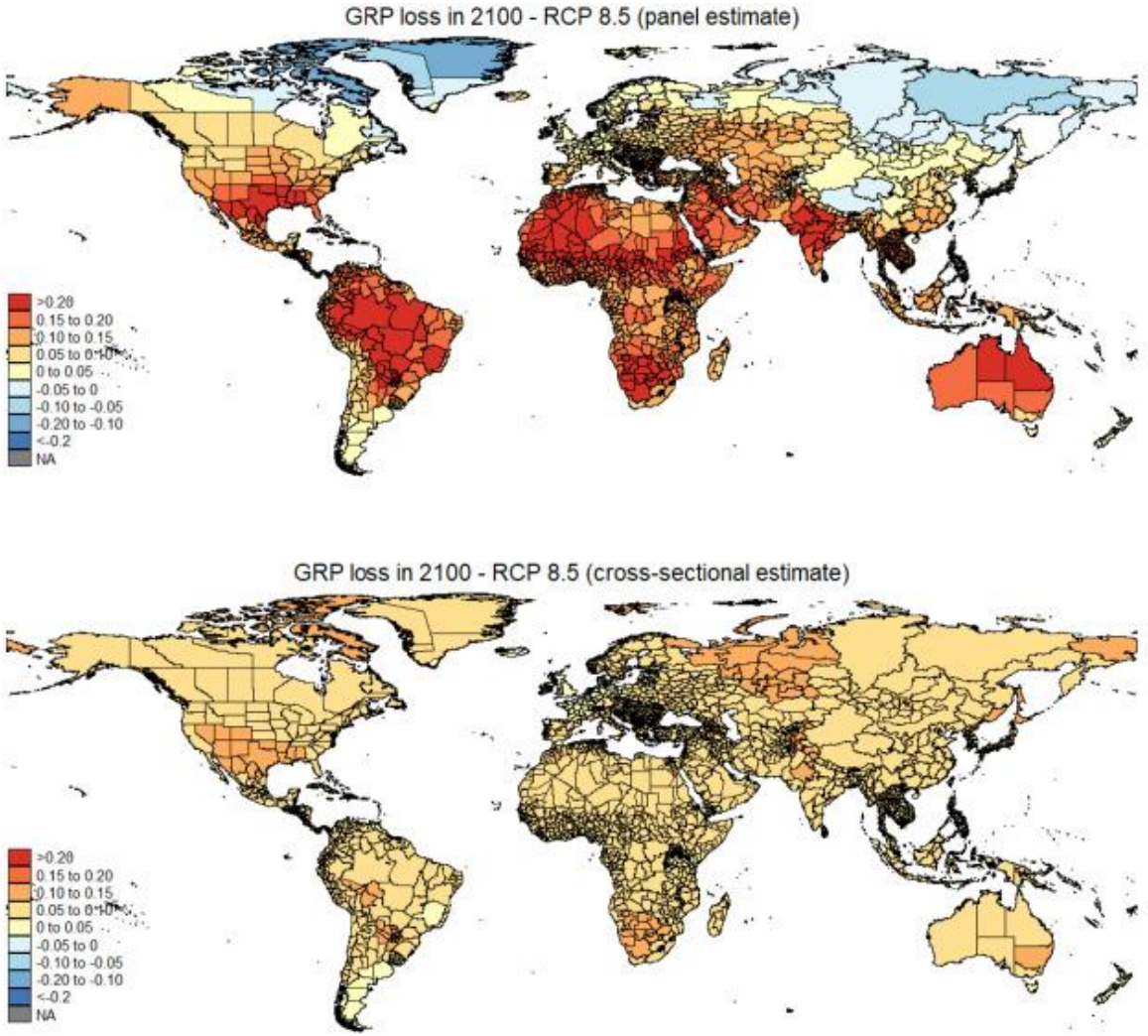
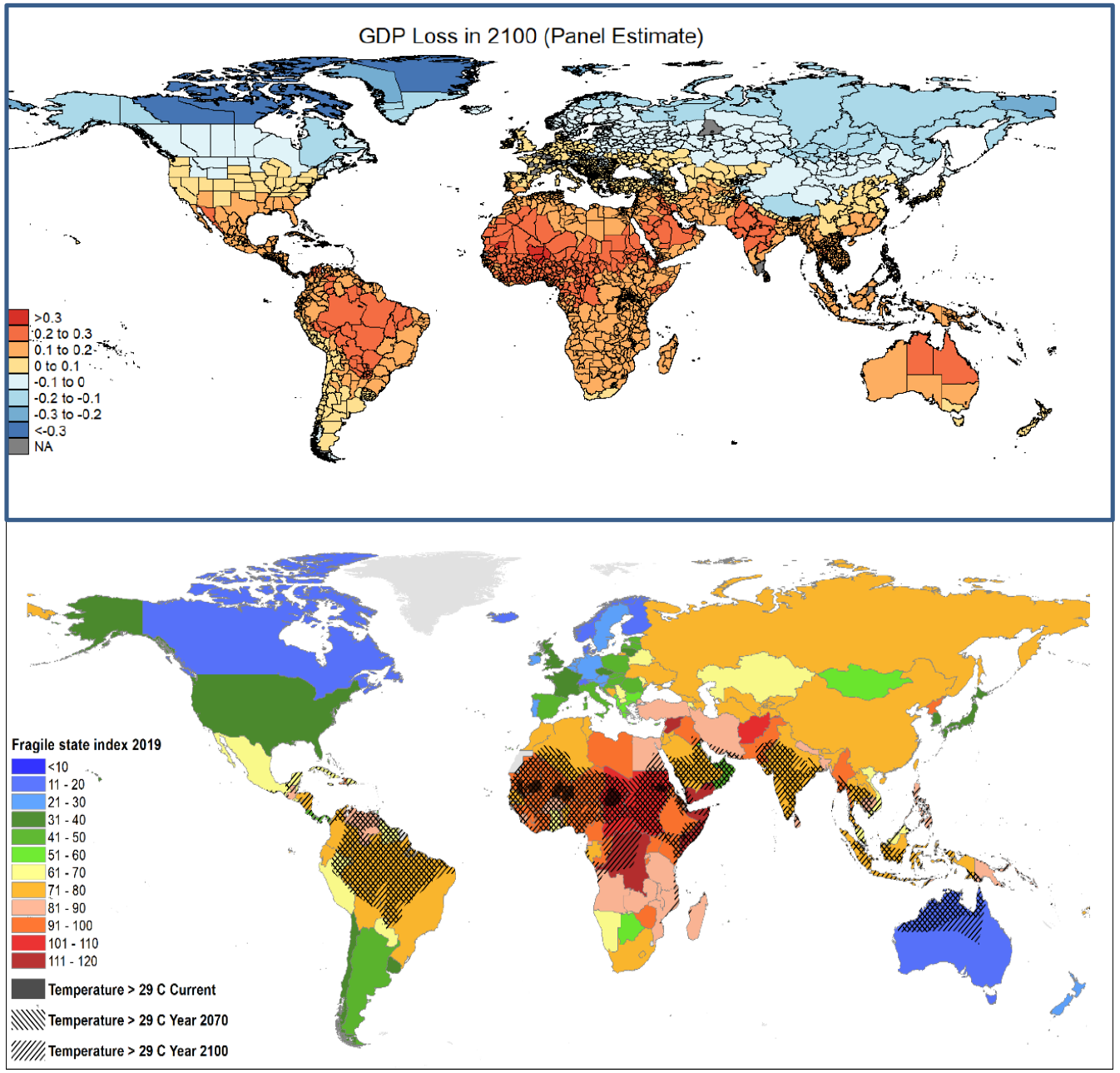
https://doi.org/10.1016/j.jeem.2020.102360

Kalkuhl & Wenz 2020,
Journal of Environ. Economics and Management



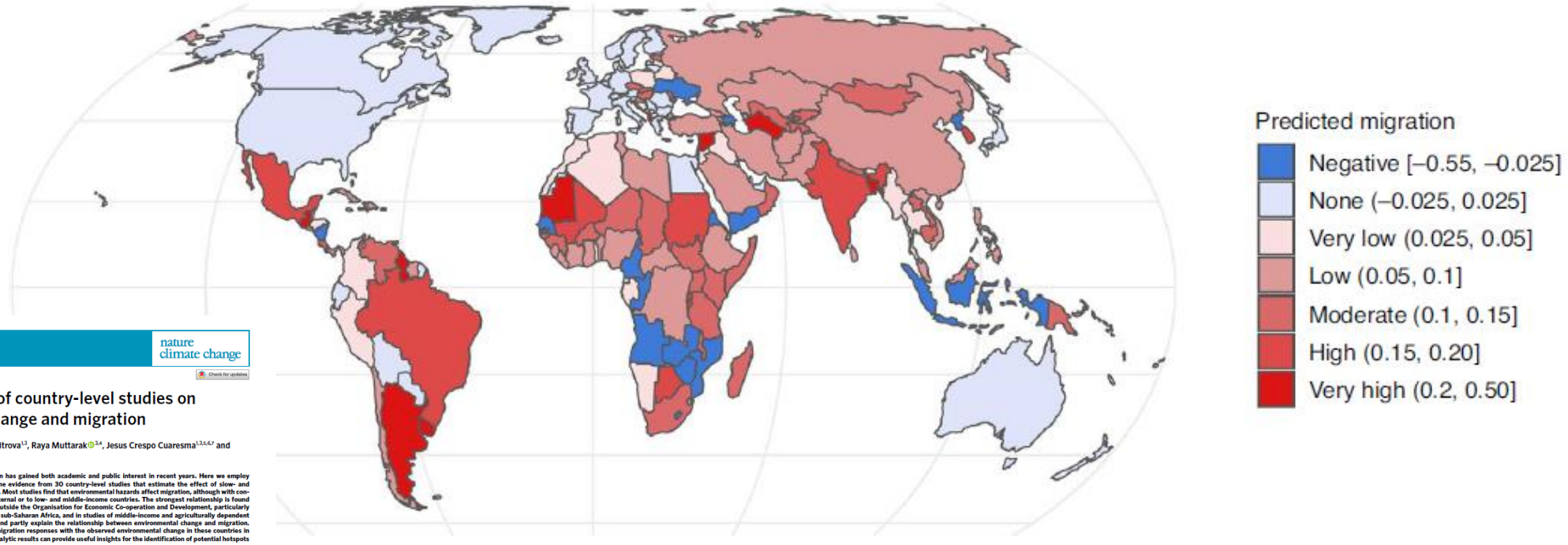
Losses in Gross Regional Product (GRP) in 2099 under a business-as-usual warming scenario (RCP-8.5).

Increasing North-South Divide



Kalkuhl & Wenz, 2020

Climate Change triggers migration – particularly in middle-income and agricultural countries



ARTICLES
https://doi.org/10.1038/s41558-020-0898-6
nature climate change

A meta-analysis of country-level studies on environmental change and migration

Roman Hoffmann[1,2], Anna Dimitrova[1,3], Raya Muttarak[3,4], Jesus Crespo Cuaresma[1,3,5,6,7] and Jonas Peisker[3]

The impact of climate change on migration has gained both academic and public interest in recent years. Here we employ a meta-analysis approach to synthesize the evidence from 30 country-level studies that estimate the effect of slow- and rapid-onset events on migration worldwide. Most studies find that environmental hazards affect migration, although with contextual variation. Migration is primarily internal or to low- and middle-income countries. The strongest relationship is found in studies with a large share of countries outside the Organisation for Economic Co-operation and Development, particularly from Latin America and the Caribbean and sub-Saharan Africa, and in studies of middle-income and agriculturally dependent countries. Income and conflict moderate and partly explain the relationship between environmental change and migration. Combining our estimates for differential migration responses with the observed environmental change in these countries in recent decades illustrates how the meta-analytic results can provide useful insights for the identification of potential hotspots of environmental migration.

The potential effect of climate change on worldwide migration is highly present in the public debate. Recent mass migration episodes such as the Syrian refugee crisis in 2015 and the 'migrant caravan' from Central America to the United States in 2018 have been partly attributed to severe droughts experienced in these countries[1–3]. Possible relationships between changing environmental conditions and subsequent migration have also been observed in other parts of the world (Extended Data Fig. 1). The extent to which environmental factors fuel economic and sociopolitical crises and influence migration has led to controversial discussions in the literature[4]. If the claim that adverse climatic conditions drive migration is true, it can be expected that an increase in average global temperature of 2 °C or more above pre-industrial levels would result in substantially higher migration flows in the future[5–8].

In the past decade, the number of empirical studies focusing on climate and other environmental drivers of migration has increased notably. Yet, there is little consensus concerning the direction and the extent to which these factors influence migration. Environmental change has been found to contribute to increased human migration in some studies, whereas no effect or a decline in migration has been reported in others[9–14]. The empirical results differ depending on the environmental factors considered, the data and scale of the analysis, the methodology employed and the geographical contexts covered. Even within the same studies, estimates of the size and direction of environmental migration flows vary considerably. The heterogeneity of the existing evidence hampers policy efforts to address the challenges related to potential increases in global migration flows due to future environmental change.

Here we use a meta-analysis approach to synthesize the results of 30 scientific papers published between 2006 and 2019, which quantitatively analyse the influence of different environmental factors on migration (Fig. 1)[15–44]. We focus on macro studies that estimate the effects on migration using longitudinal country-level data and exploiting variations both across countries and over time. The considered studies focus on a broad range of environmental drivers, such as changing temperatures, rainfall anomalies and heavy storms. Typically, they estimate separate regression models considering the impacts of different environmental factors and other migration drivers, using different modelling techniques, country samples and specifications.

From the 30 selected studies (n) and their models, we extracted a total of 1,803 effect estimates (k) of the relationship between individual environmental factors and migration (Supplementary Fig. 1). Each model estimate represents a separate observation in our analysis. To achieve comparability, we standardize the estimates using distributional information for each of the environmental and migration variables considered. The standardized effects show the estimated change in migration in standard deviations corresponding to a one standard deviation change in the respective environmental factor. In our meta-analysis, we take an exploratory approach aiming at unveiling patterns in the environment–migration relationships estimated by the pool of existing studies and analysing drivers of heterogeneity in the empirical findings.

The focus on country-level studies allows us to retrieve and recalculate the distributional information required for standardization, a process that is not feasible for idiosyncratic micro-level studies. The standardization enables us to effectively compare the size of different effects across models despite differences in measurement and scaling of the key variables. The estimation methodology used in the country-level studies is broadly similar, allowing for a direct comparison of the results. By extracting further information on study characteristics, modelling techniques, the

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Predicted environmental migration worldwide measured in standard deviation changes in migration.

Environmental hazards affect populations worldwide and can drive migration under specific conditions. Changes in temperature levels, increased rainfall variability, and rapid-onset disasters, such as tropical storms, are important - environmental migration is most pronounced in middle-income and agricultural countries but weaker in low-income countries, where populations often lack resources needed for migration.

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