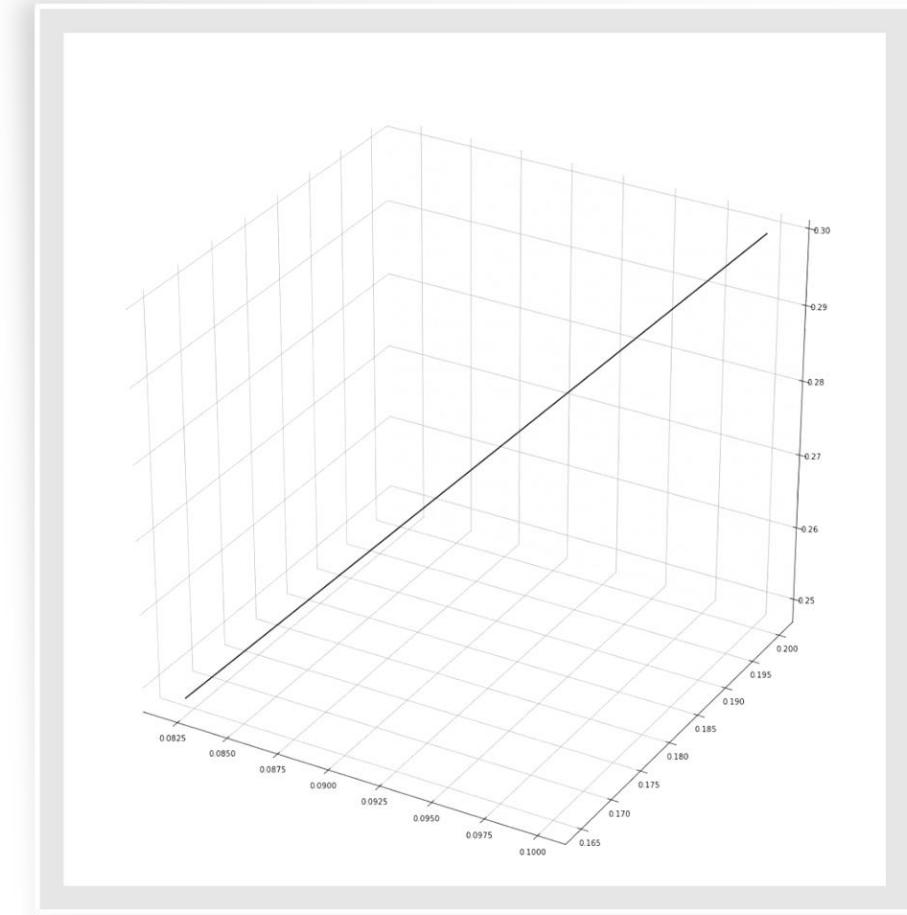




POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH

Die Faltung der Welt

Grenzen als Innovationstreiber und gesellschaftlichen
Zusammenhalt im Angesichts des Klimawandels

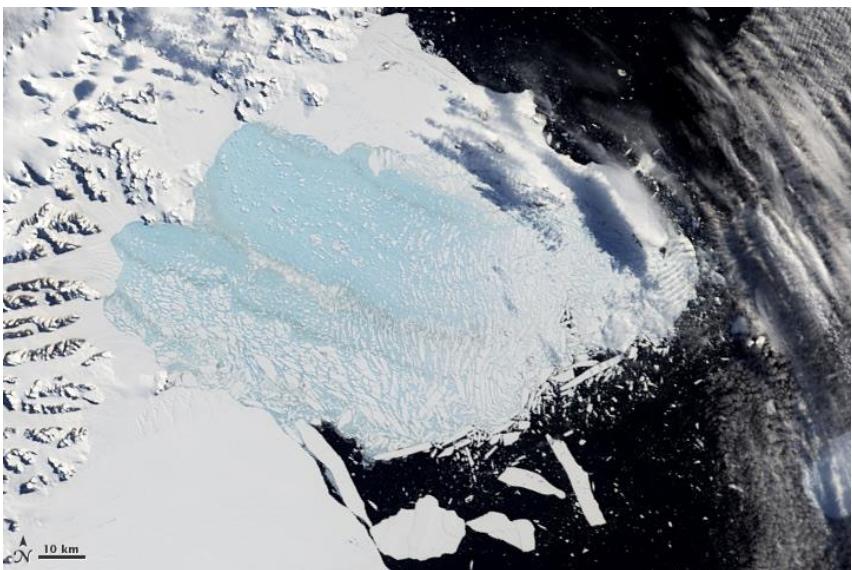
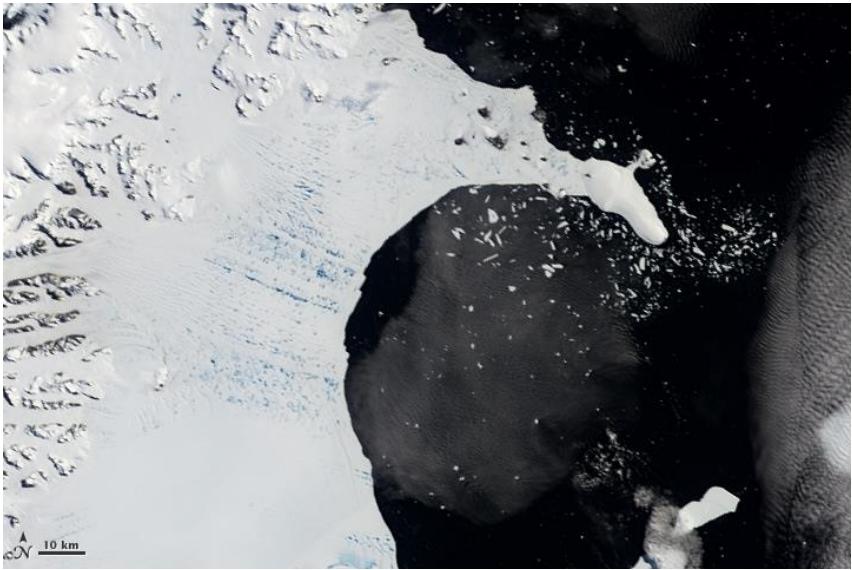


Prof. Anders Levermann, PhD



Potsdam-Institut für Klimafolgenforschung

www.pik-potsdam.de/~anders
@ALevermann@bsky.social



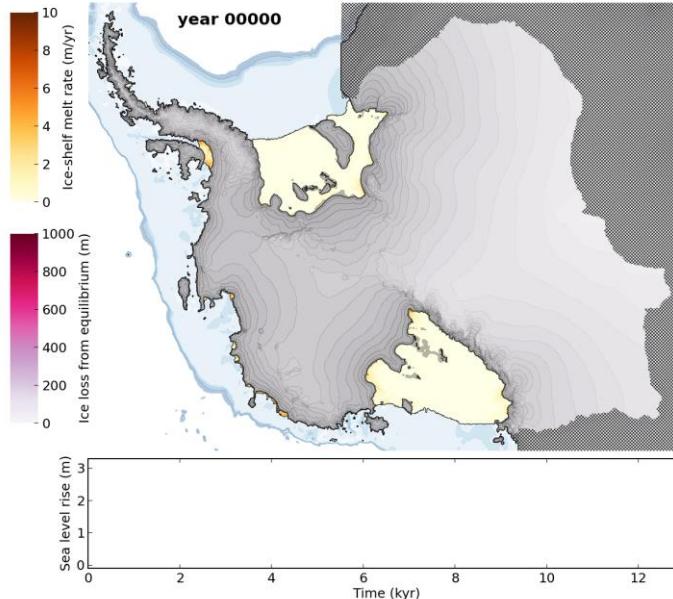
„In Physics We Trust“

John Mercer (Nature, 1978):

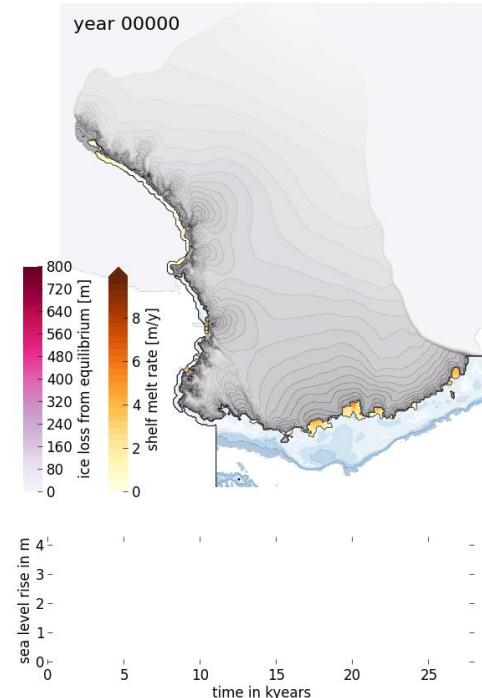
- Kohlendioxid wird sich innerhalb von 50 Jahren verdoppeln.
- Eisschelfe der Antarktis werden kollabieren.
- Die Westantarktis wird instabil werden.

Die Westantarktis ist destabilisiert.

.. die Ostantarktis noch nicht.

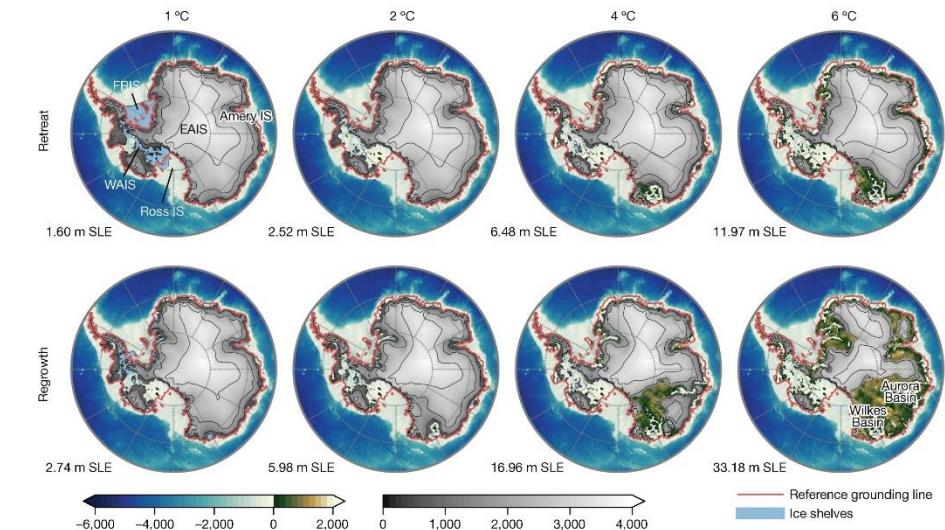


Feldmann & Levermann, PNAS, 2015.



Mengel & Levermann
Nature Climate Change, 2014.

Garbe, Albrecht, Levermann,
Donges, Winkelmann,
Nature, 2020.

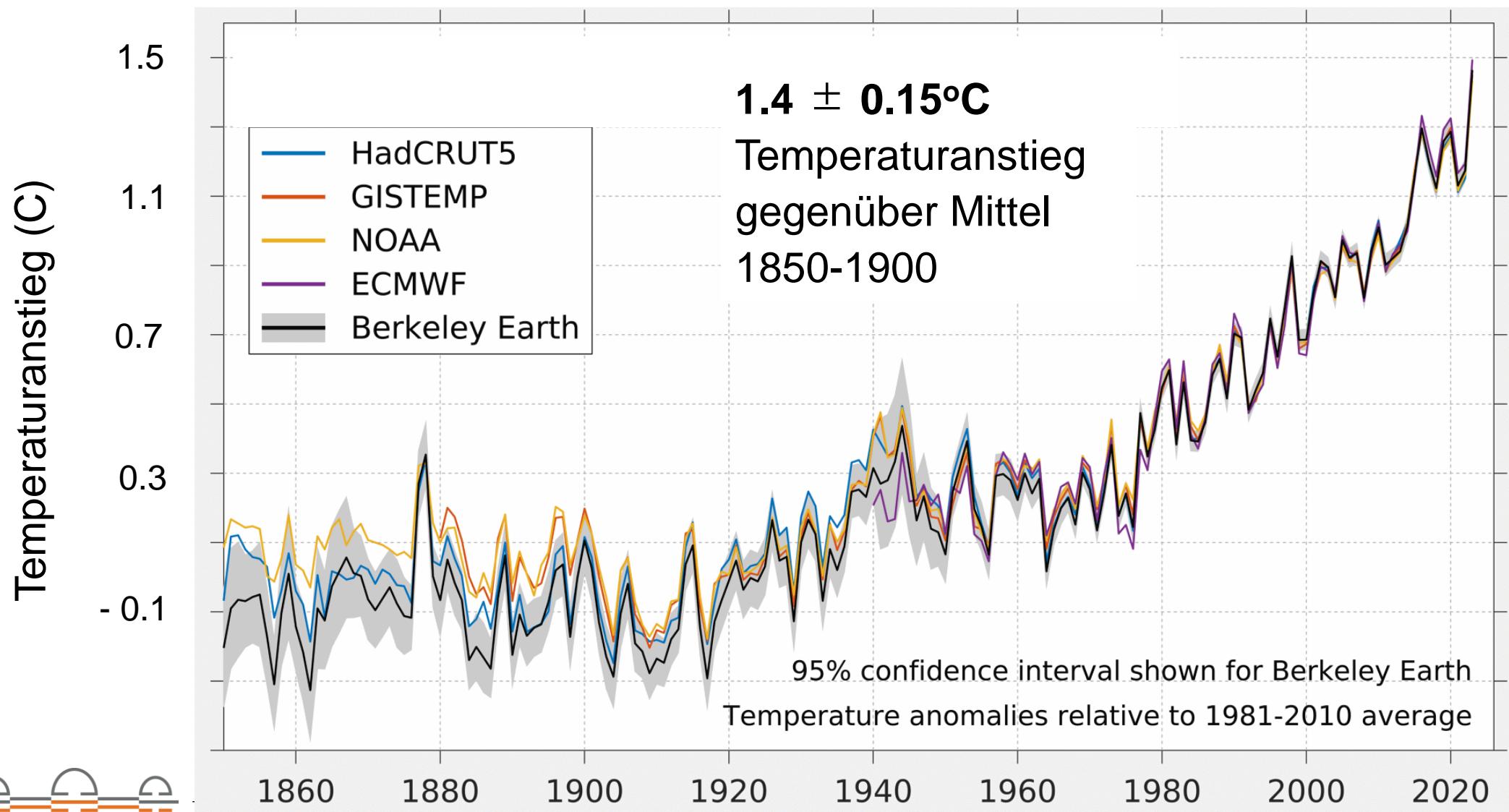


1. Persönlicher Grund für Stabilisierung des Klimas

Verlust von Kulturerbe



Die Erde erwärmt sich.

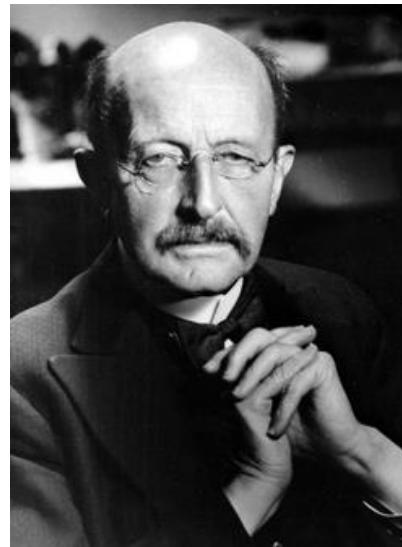


2023
2016
2020
2019
2017
2015
2022
2021
2018
2014
2010
2013
2005
2009
1998
2003
2002
2006
2007
2012
2004
2001

Grundgesetze der Physik



Albert
Einstein

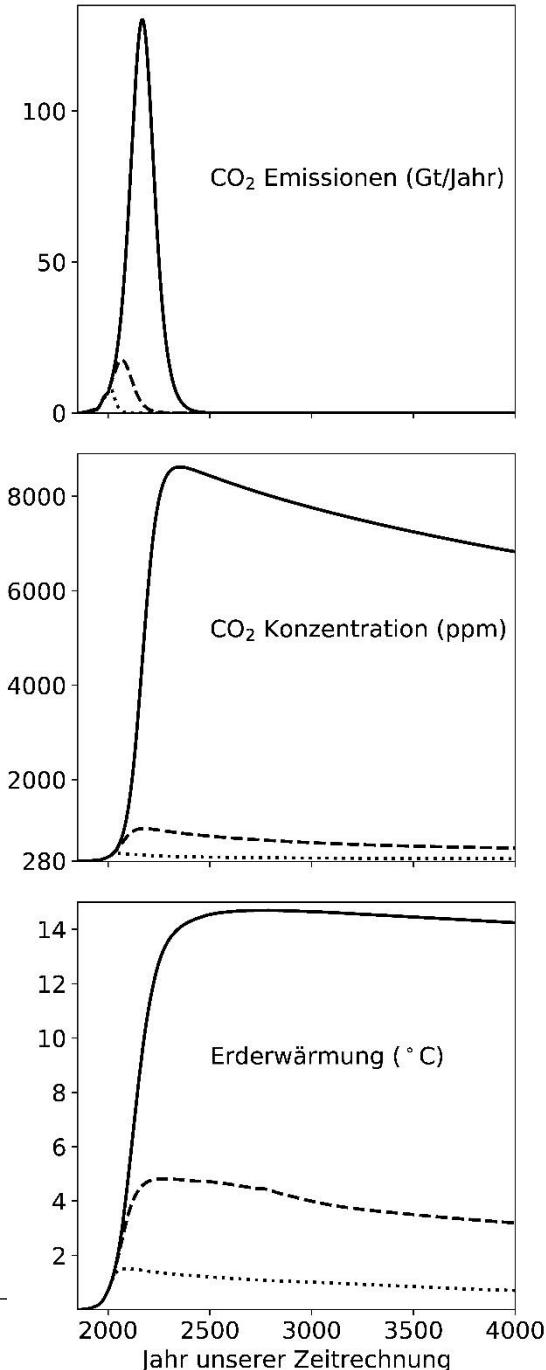


Max
Planck



Ludwig
Boltzmann

Fossiler Kohlenstoff bleibt für praktisch immer in der Atmosphäre



*Winkelmann,
Levermann,
Ridgwell,
Caldeira,
2015,
Sciences Advances.*

Die Temperatur der Erde steigt an
solange wir Gas, Öl oder Kohle verbrennen.



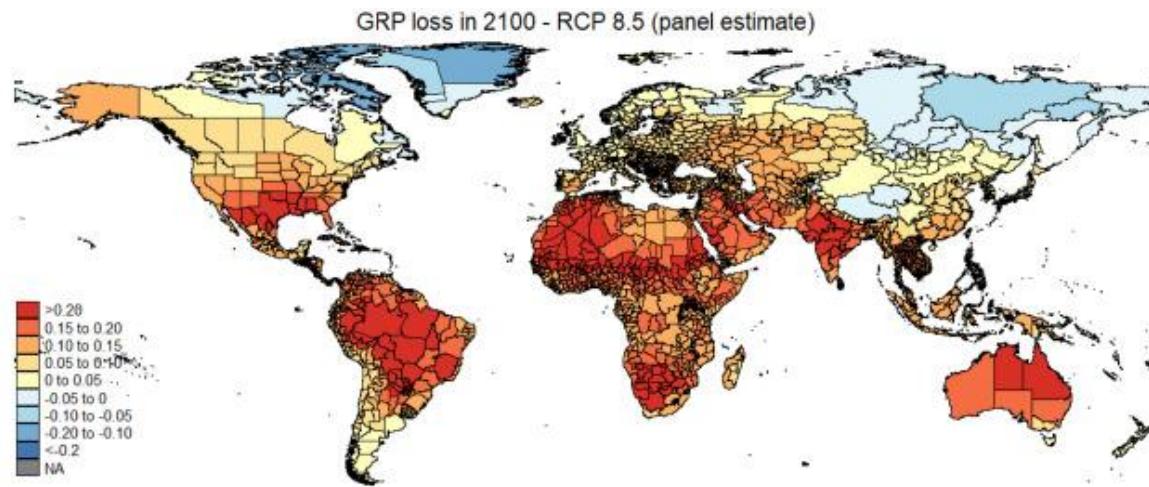
2. Persönlicher Grund für Stabilisierung des Klimas

Wirtschaftliche Schäden

Hurricane Sandy impacted New York City in 2012.



Die wirtschaftlichen Kosten des Klimawandels entstehen durch **Störung** nicht durch **Zerstörung**.



Kalkuhl & Wenz

Journal of Environmental Economics and Management. (2020).

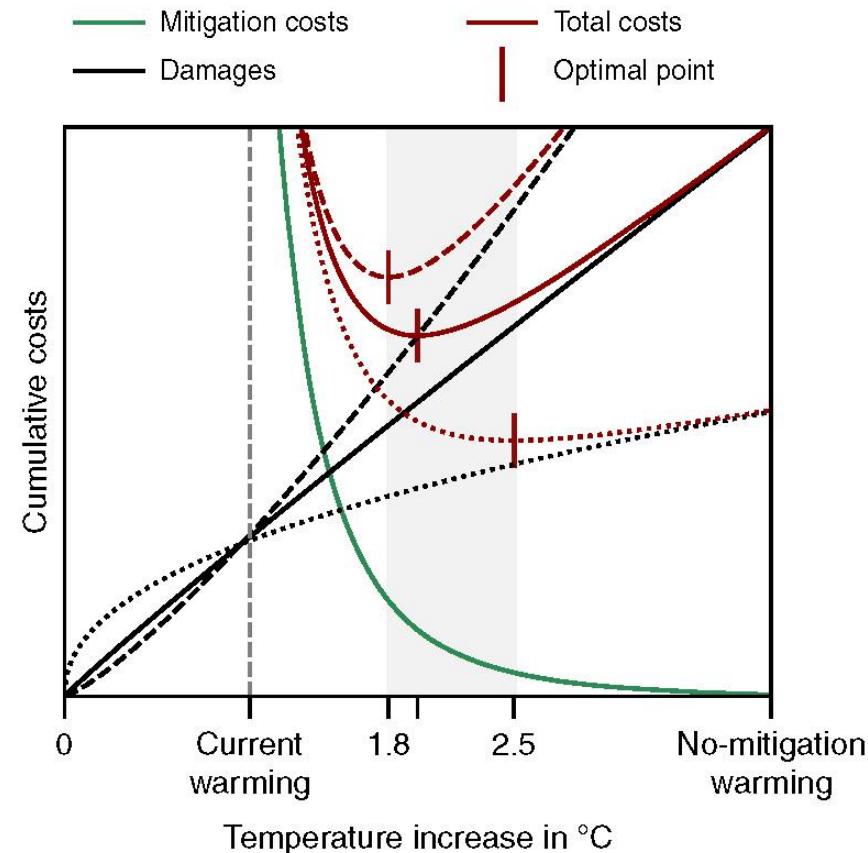


*Kotz, Wenz, Levermann,
Nature, 2022.*



Das politische Ziel des
ist auch das

Pariser Klimaabkommens wirtschaftlich optimale.



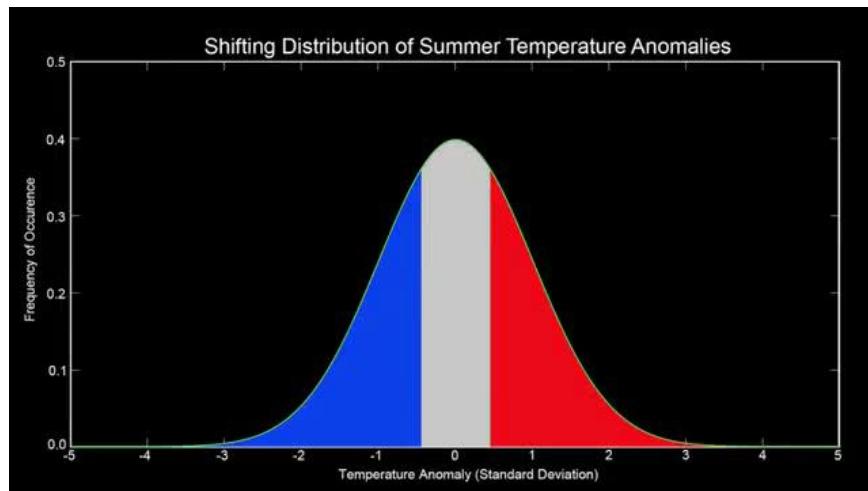
Glanemann, Willner, Levermann,
Nature Comm. (2020).



Wir wissen, dass

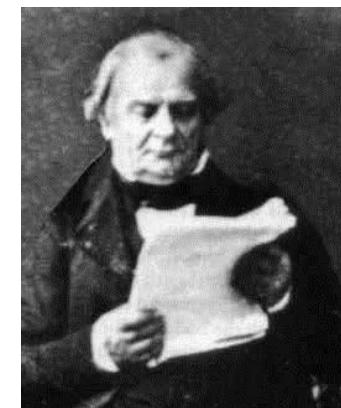
Wetterextreme heftiger und häufiger werden

Aus Statistik



Europäische Sommertemperaturen

Aus Physik



$$k = \left(1 - \frac{\delta}{\varrho}\right) \frac{dp}{dt} C.$$

E. Clapeyron (1834)

$$\tau = C \cdot (s - \sigma) \frac{dp}{dt}$$

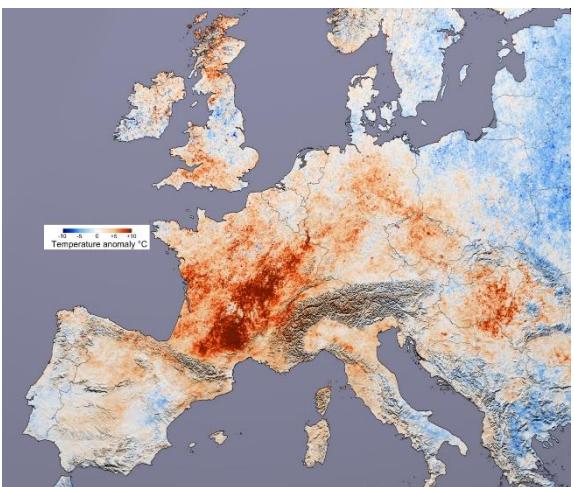
R. Clausius (1850)



Clausius-Clapeyron equation

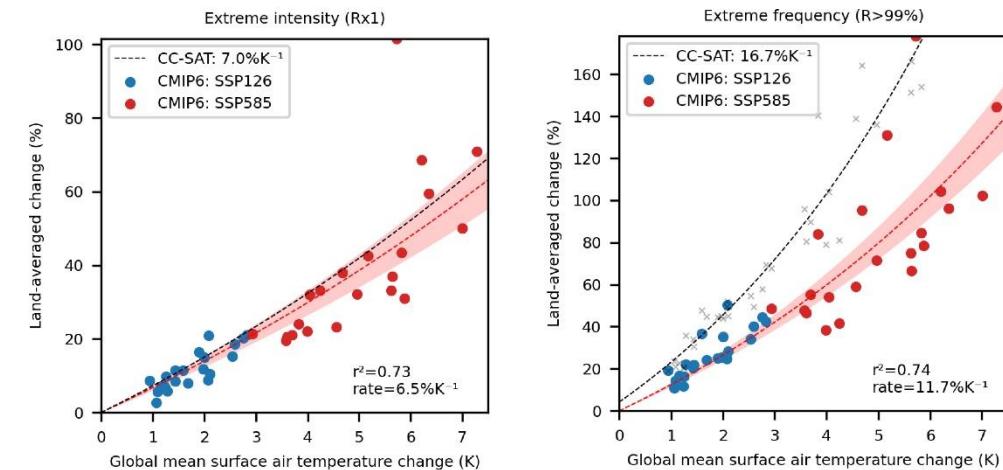
Zwei Beispiele

Statistik: Hitze



Europa 2003

Physik: Überschwemmungen



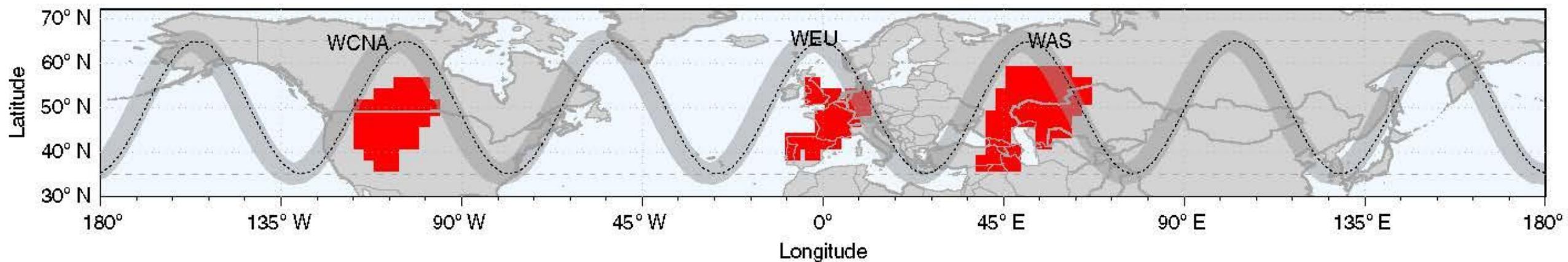
Starkniederschlag unterschätzt von Modellen

Kotz, Lange, Wenz, Levermann, J Clim, 2023.



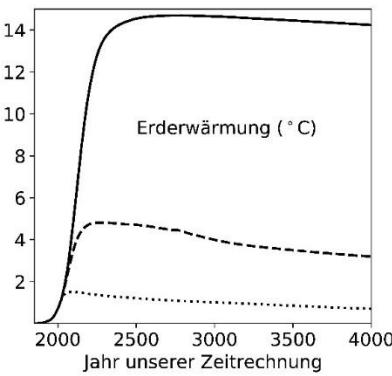
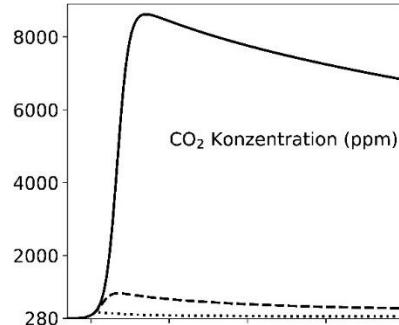
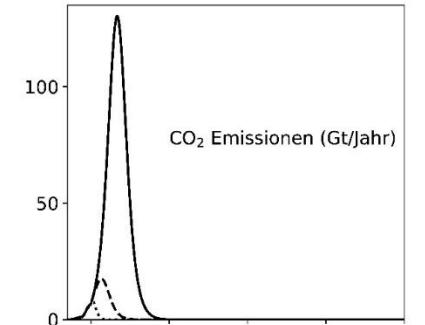
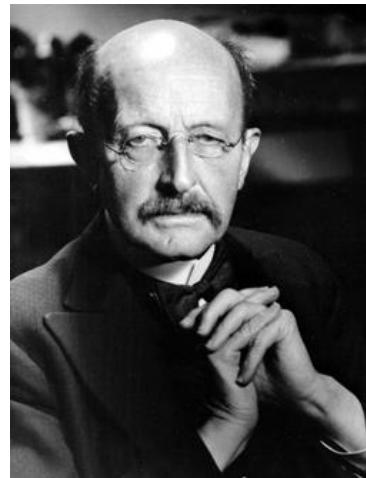
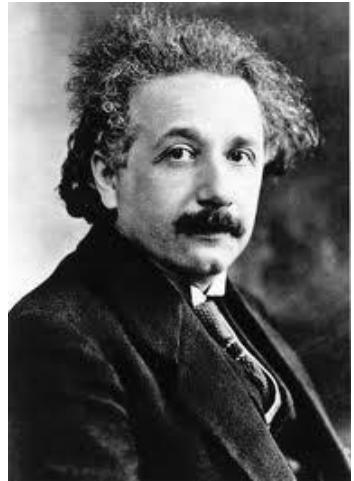
Jet Stream Resonanz 2019

Dürre in allen drei Brotkörbe der Erde gleichzeitig.



Kornhuber et al. ERL (2019).
Kornhuber et al. Nature CC (2020).

Wir müssen auf Null Emissionen.



Das Dilemma der zwei Notwendigkeiten

Endlicher Planet



Unaufhörliche Entwicklung



Die Faltung in einem Satz:

“I could be bounded in a nutshell
and count myself a king of infinite space.,,

“Ich könnte in einer Nußschale gefangen sein
und mich doch als König unendlicher Weiten fühlen.”

Shakespeare in Hamlet



Frankfurter Allgemeine
ZEITUNG FÜR DEUTSCHLAND



Prof. Anders Levermann, PhD, Potsdam-Institut für Klimafolgenforschung



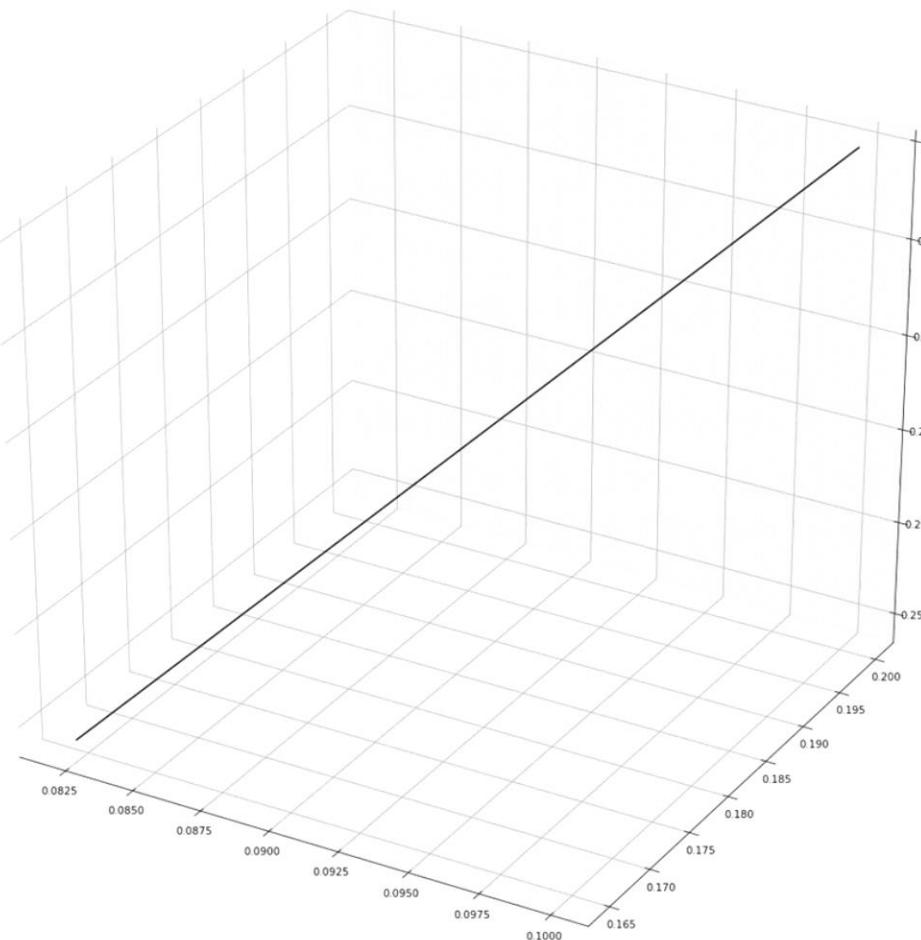
Die Faltung der Welt

DIE ZEIT



Leipzig, April 2024

Eine Illustration der Faltung



$$\frac{d\mathbf{r}}{dt} = -\nabla L(\mathbf{r})$$
$$L(\mathbf{x}, t) = L_b(\mathbf{x}) + \lambda \cdot L_h(\mathbf{x}, t)$$
$$L_b(\mathbf{x}) = (1 - |\mathbf{x}|)^{-1}$$
$$\frac{dL_h}{dt}(\mathbf{x}) = \left(1 + \frac{|\mathbf{r}(t) - \mathbf{x}|}{\rho}\right)^{-1} - \frac{L_h}{\tau}$$



Sieben Beispiele für Faltungsgrenzen



1. Beispiel für Faltungsgrenze

Die Einführung von Privateigentum



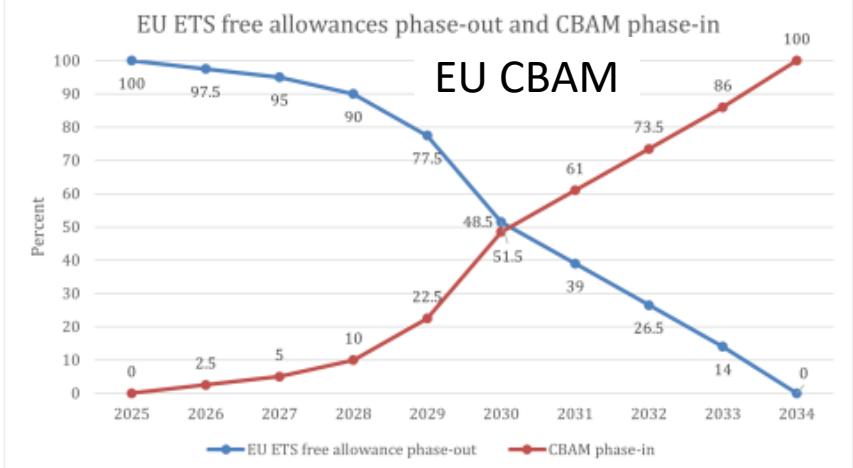
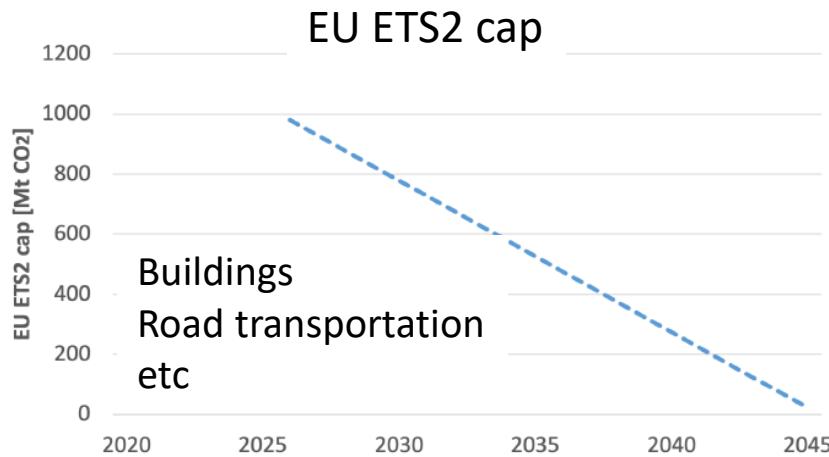
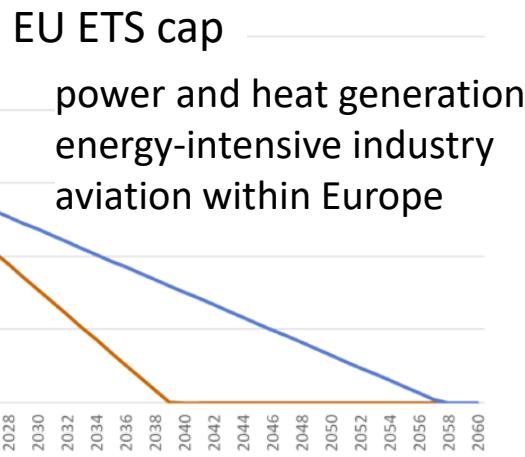
2. Beispiel für Faltungsgrenze

Die Erklärung der Menschenrechte



3. Beispiel für Faltungsgrenze

Der Europäische Emissionshandel



4. Beispiel für Faltungsgrenze

Globales Plastikverbot



5. Beispiel für Faltungsgrenze

Ein globales Abbauverbot für Rohstoffe



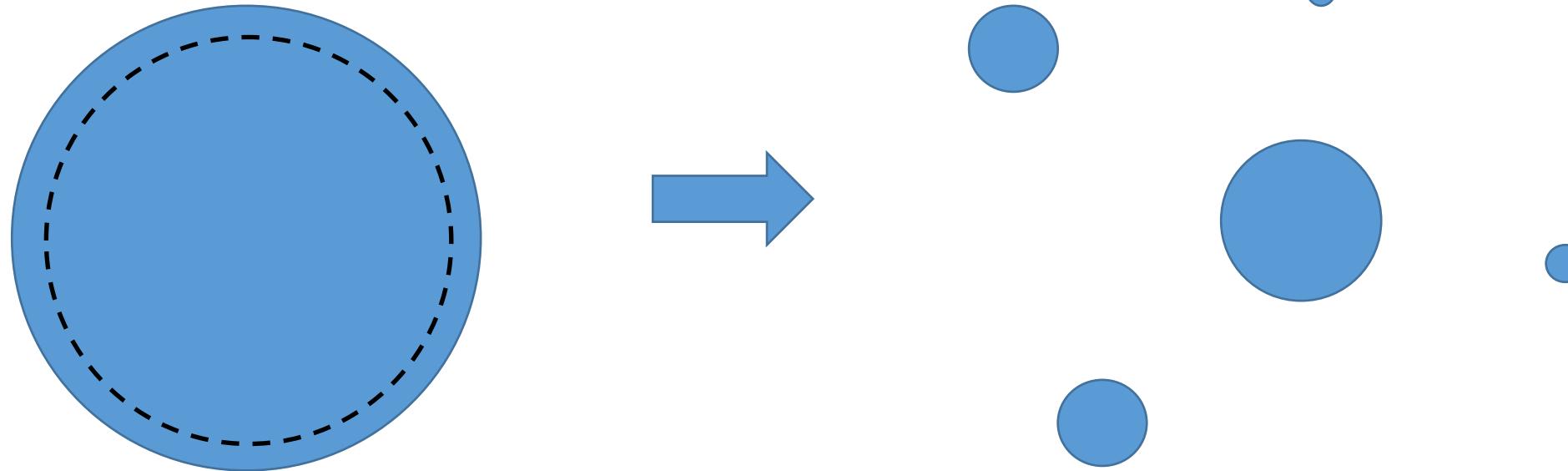
6. Beispiel für Faltungsgrenze

Die Souveränität der Bevölkerung



Was wäre, wenn sich die Gesellschaft entscheiden würde, ...

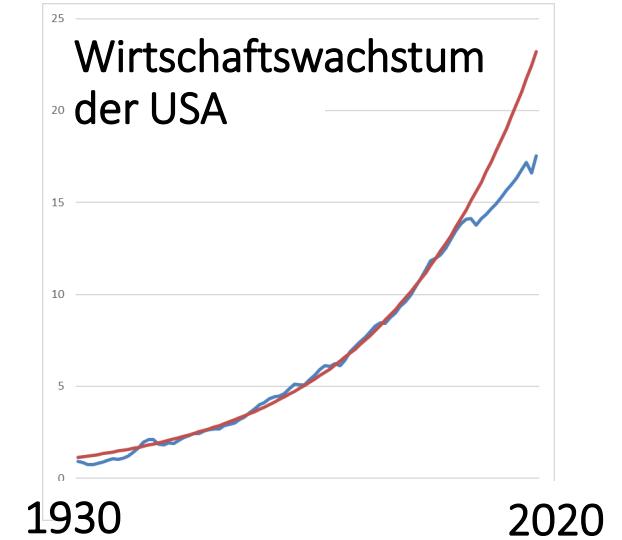
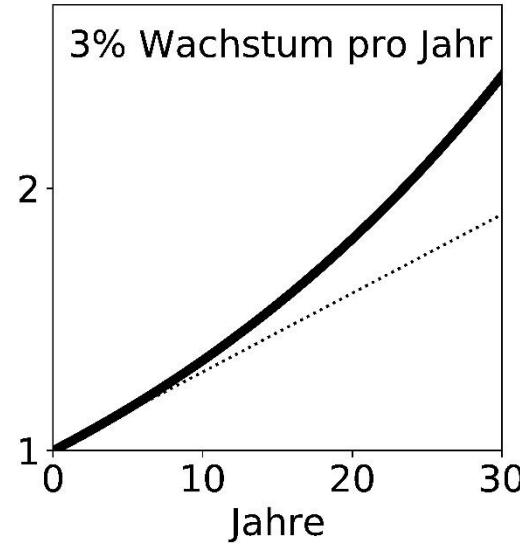
...dass kein Unternehmen mächtiger werden darf als der Staat, in dem es verkauft?



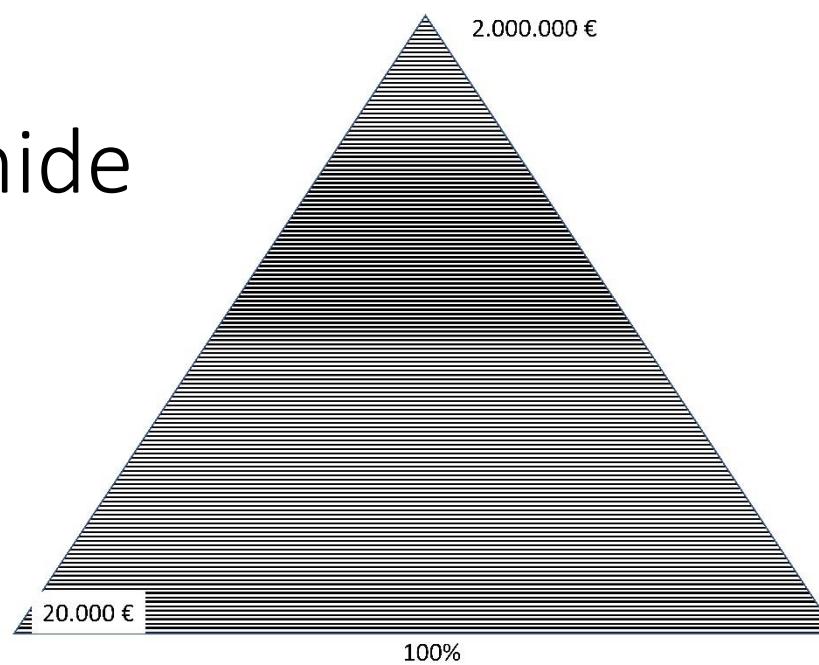
Gleiche Möglichkeiten bei der Geburt



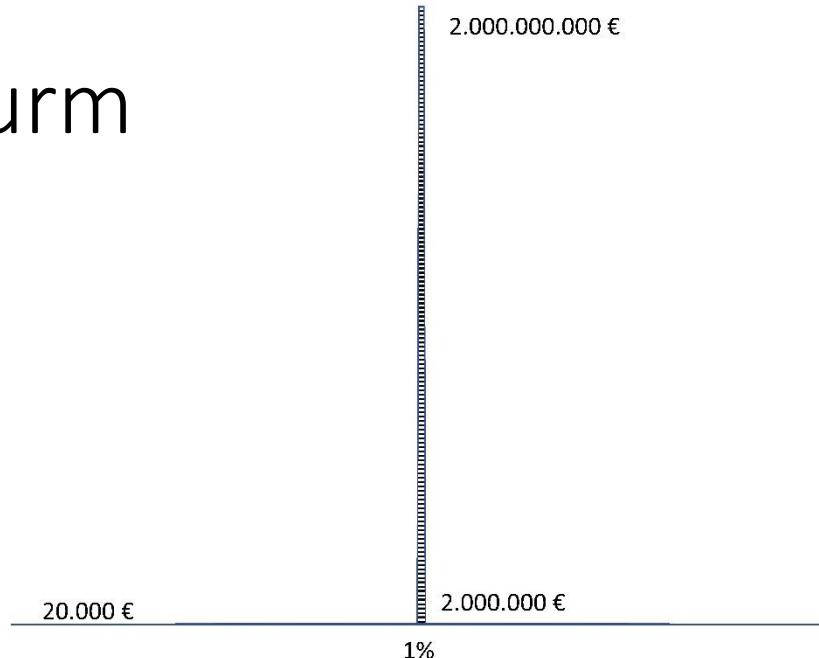
Selbstverstärkungen sind Explosionen



Einkommenspyramide



Herrschaftsturm



Was wäre, wenn sich die Gesellschaft entscheiden würde,...

1

...dass niemand in einem Jahr mehr verdienen sollte als ein anderer im ganzen Leben:

Jährliches Mindesteinkommen 20 000 €

Jährliches Höchsteinkommen 100 mal so viel also 2 000 000 €

2

...dass niemand mit übermäßigem Reichtum starten:

Höchstes Erbe an eine Person 2 000 000 €





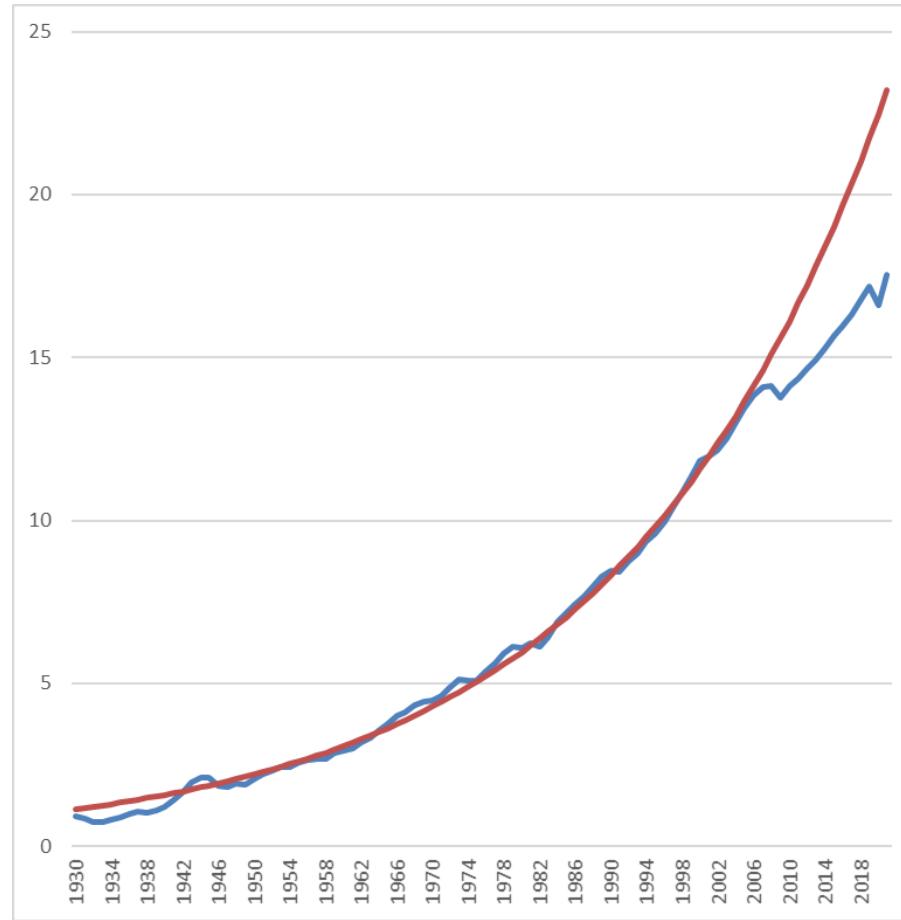
Prof. Anders Levermann, PhD



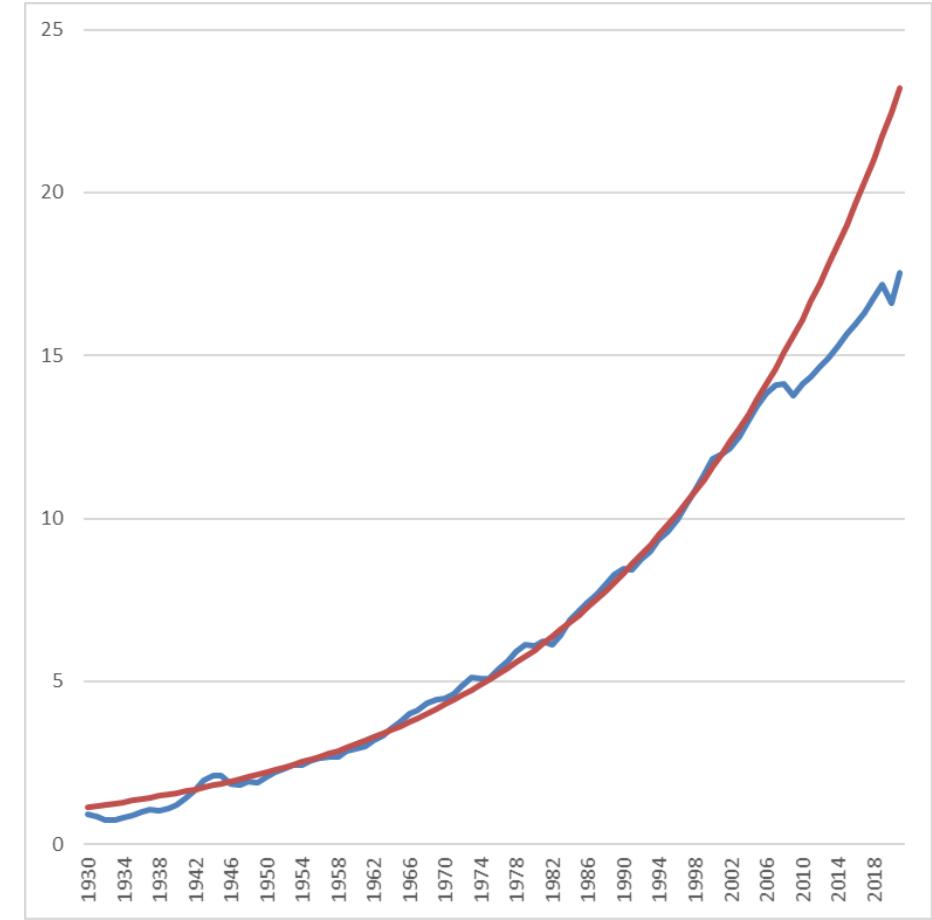
Potsdam-Institut für Klimafolgenforschung

www.pik-potsdam.de/~anders
[@ALEvermann.bsky.social](https://ALEvermann.bsky.social)

Was wächst da?



Brauchen wir Wirtschaftswachstum?



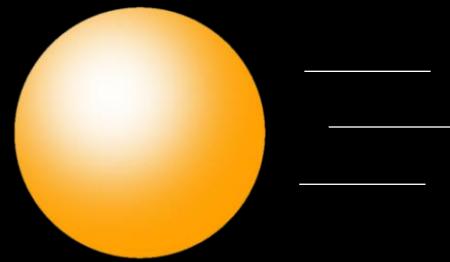
Können wir auf Wirtschaftswachstum verzichten ?



Wie viele Zahlen liegen zwischen 0 und 1?



Die Faltung



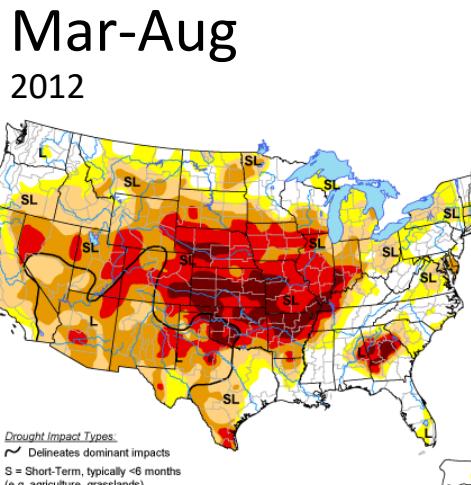
des Tischtennisballs

3. Persönlicher Grund für Stabilisierung des Klimas

Zunahme von Wetterextremen



Schneechaos
NY-Chicago



Dürre im mittleren
Westen der USA

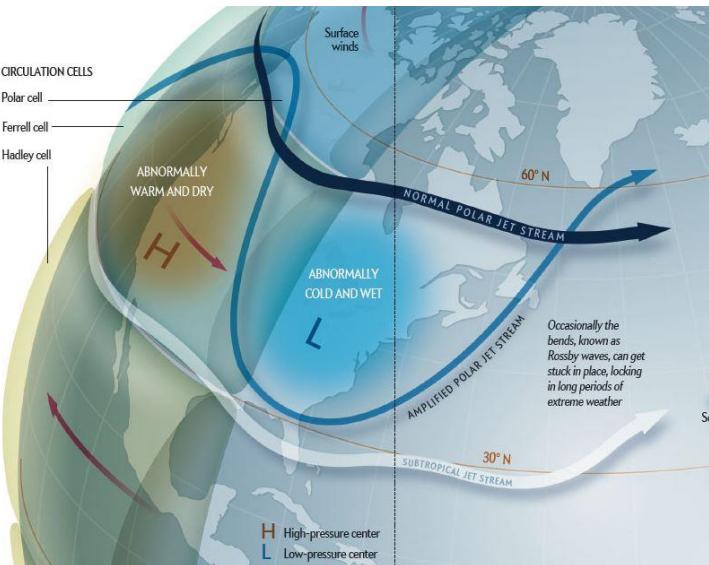


Schneechaos
NY-Chicago

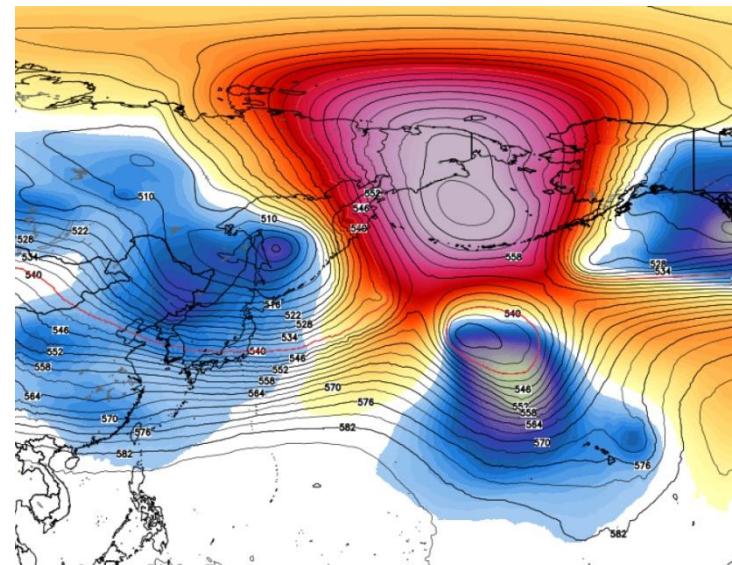


Der Winter 2017-2018

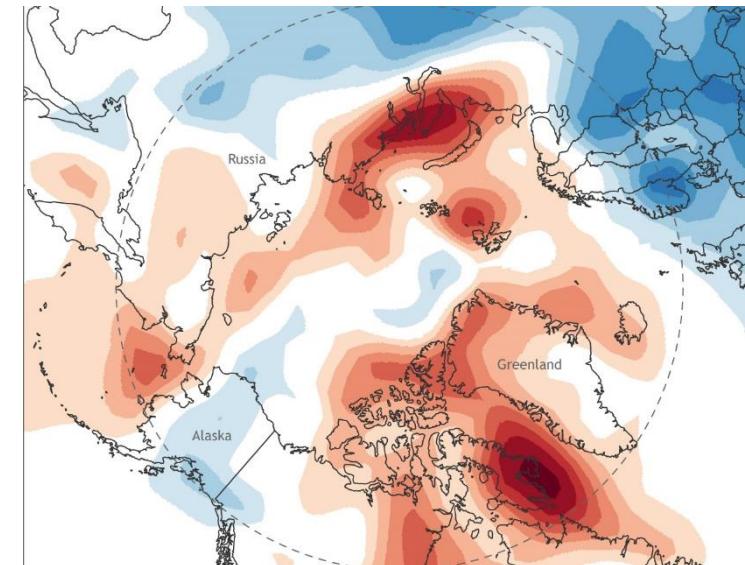
Dezember
Schneekatastrophe
USA



Januar
Temperatursprung
Sibirien



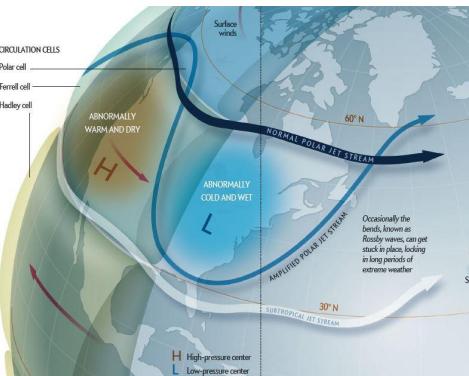
Februar
Schmelzender
Nordpol



Wetterextreme: immer mehr immer heftiger

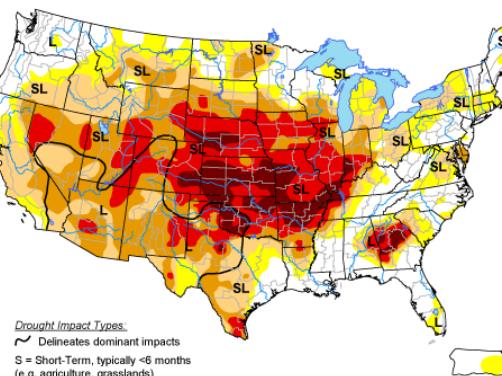
Was wenn wir keine Zeit mehr haben aufzuräumen?

Dec
2018



Schneechaos
NY-Chicago

Mar-Aug
2012



Dürre im mittleren
Westen der USA

Aug
2005



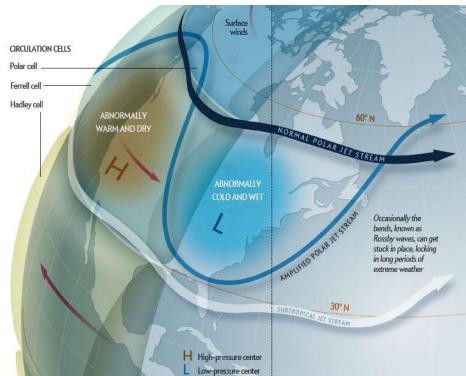
Hurricane
Katrina

Oct-Nov
2012



Hurricane
Sandy

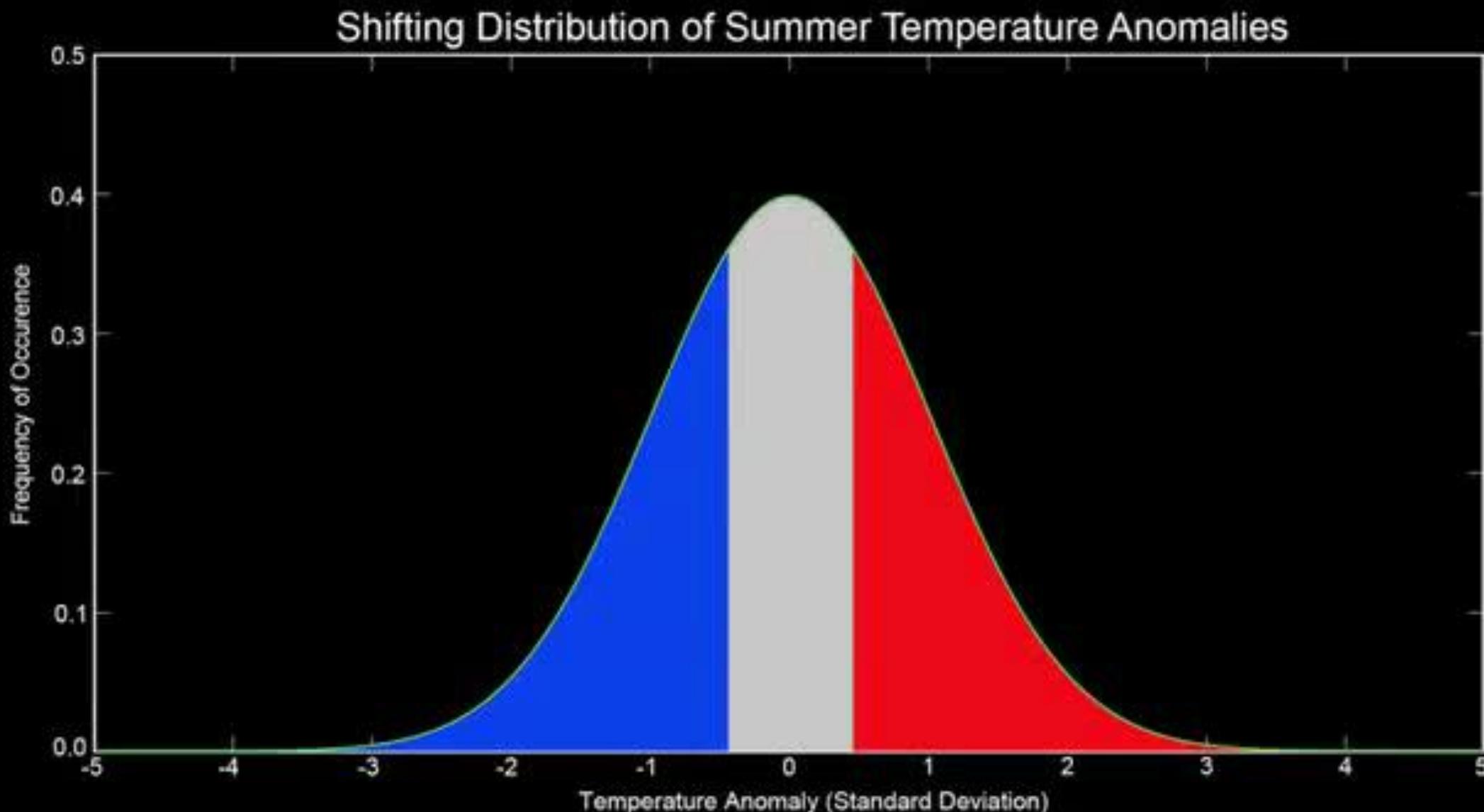
Dec
2019



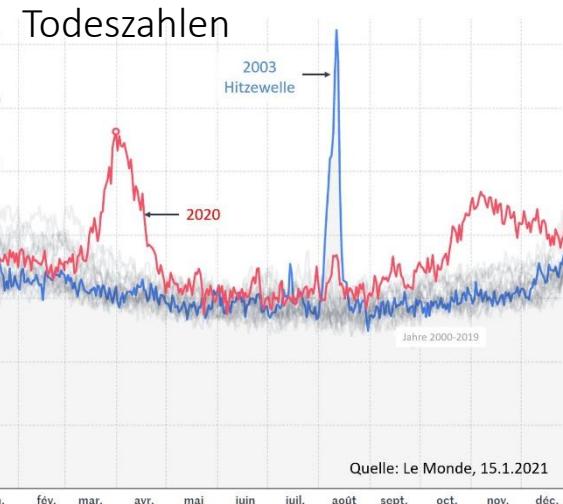
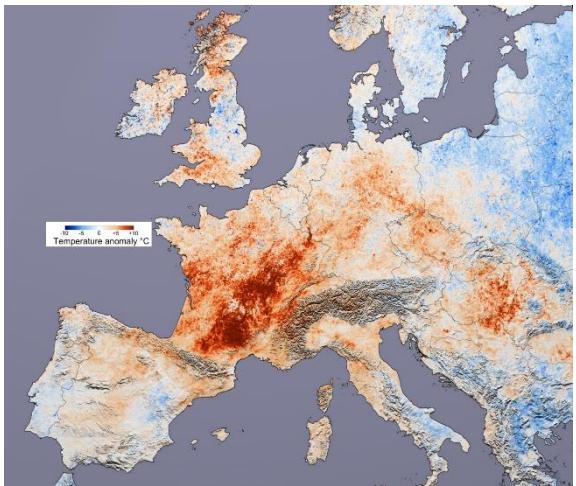
Schneechaos
NY-Chicago



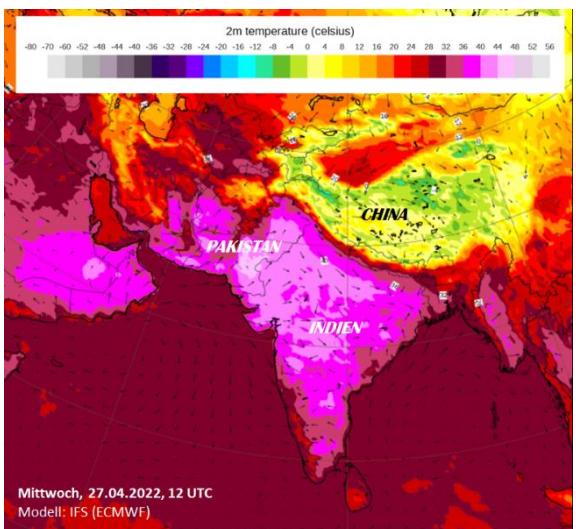
Wetterextreme werden häufiger.



Europa 2003

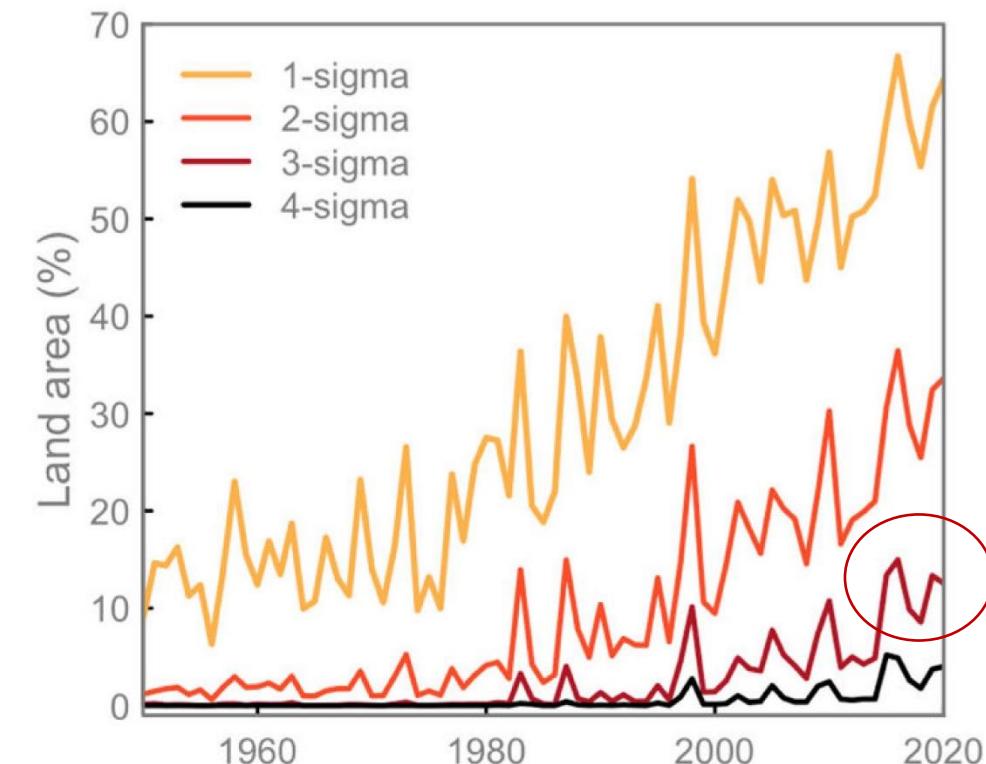


Indien 2022



Hitzewellen

Jahrhundert - Hitzemonate haben um den Faktor 90 zugenommen

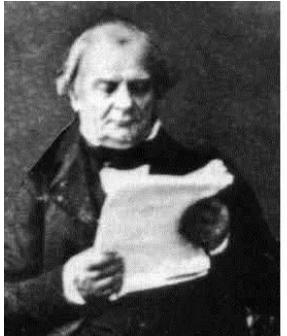


Robinson, Lehmann, Barriopedro, Rahmstorf, Coumou,
Nature's Climate and Atmospheric Science. (2021).



Wetterextreme werden heftiger.

Clausius-Clapeyron equation



$$k = \left(1 - \frac{\delta}{\rho}\right) \frac{dp}{dt} C.$$

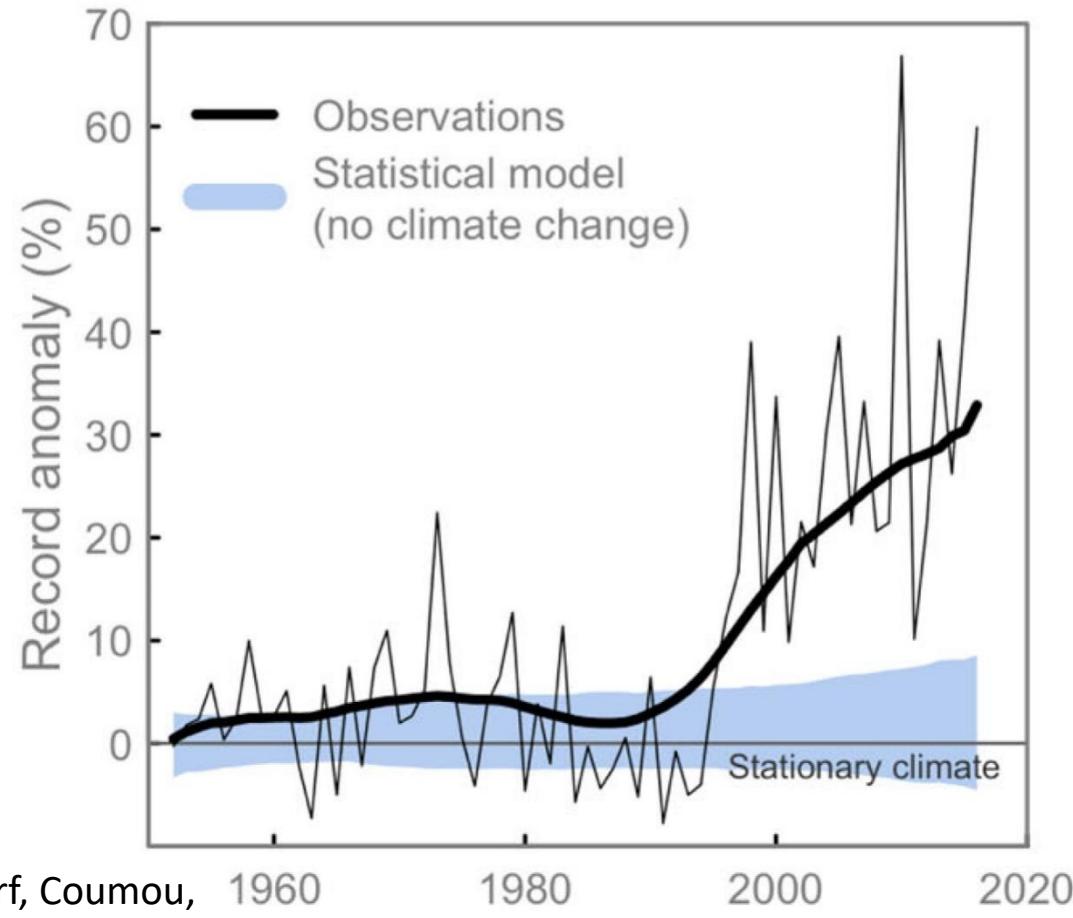
E. Clapeyron (1834)



$$r = C \cdot (s - \sigma) \frac{dp}{dt}$$

R. Clausius (1850)

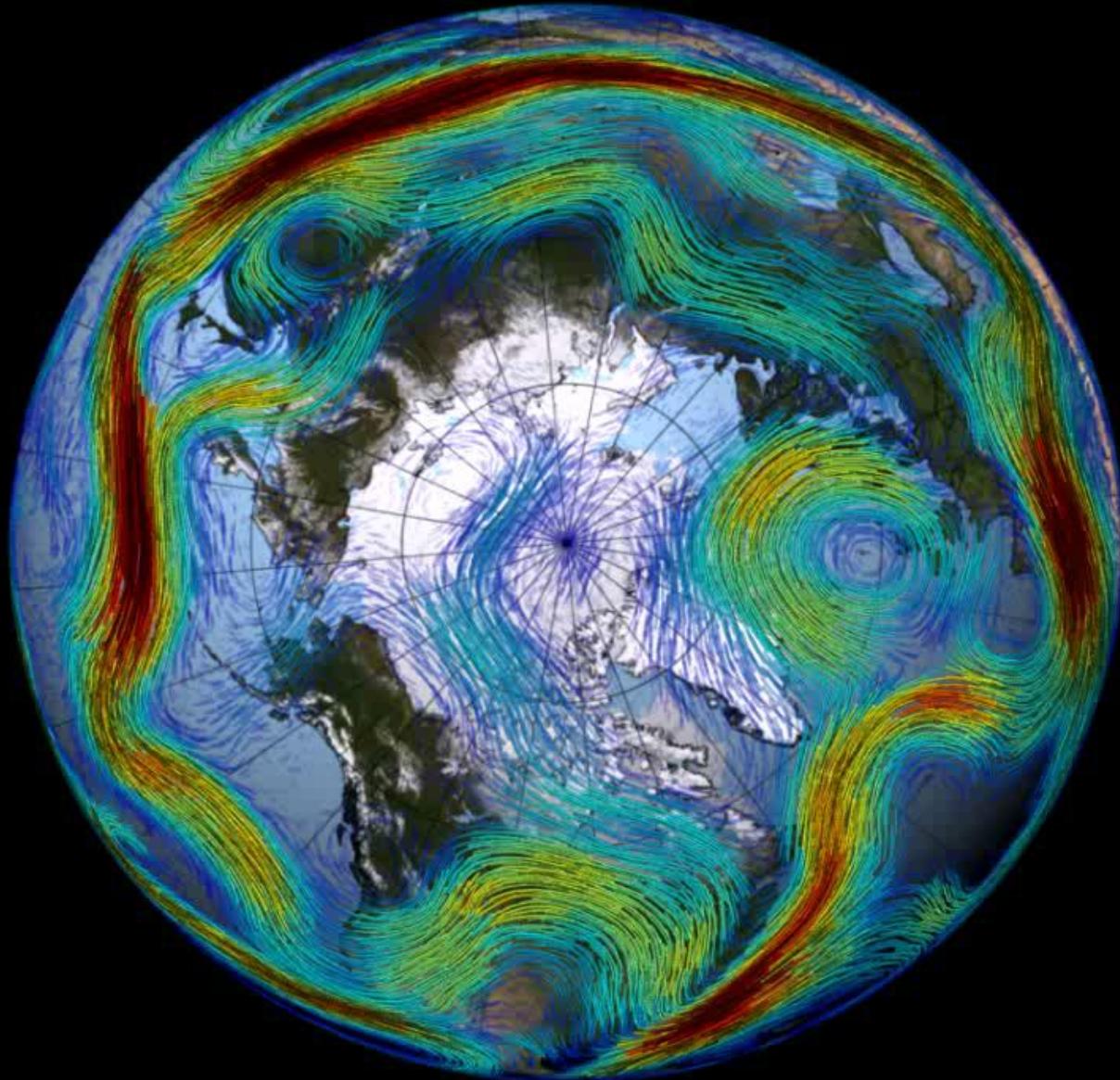
Niederschlagsrekorde nehmen zu.



Robinson, Lehmann, Barriopedro, Rahmstorf, Coumou,
Nature's Climate and Atmospheric Science. (2021).



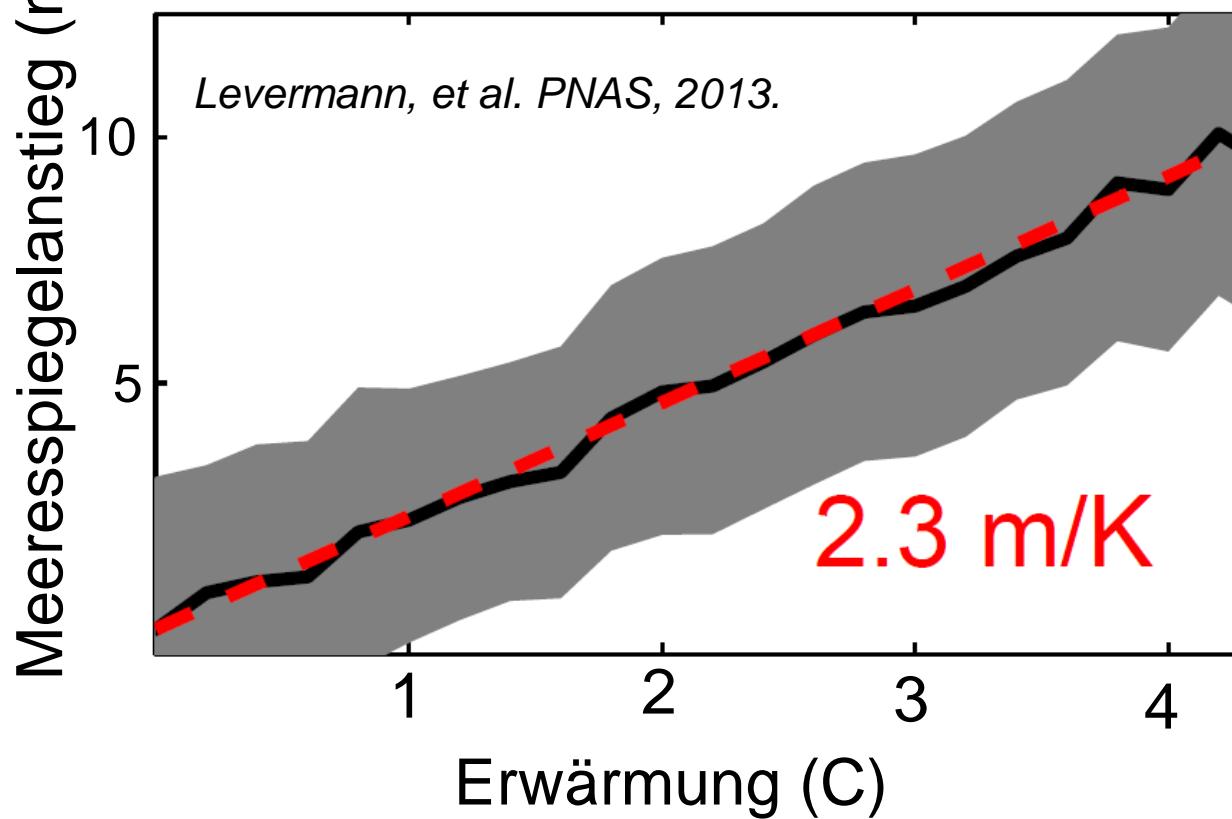
Der Jetstream



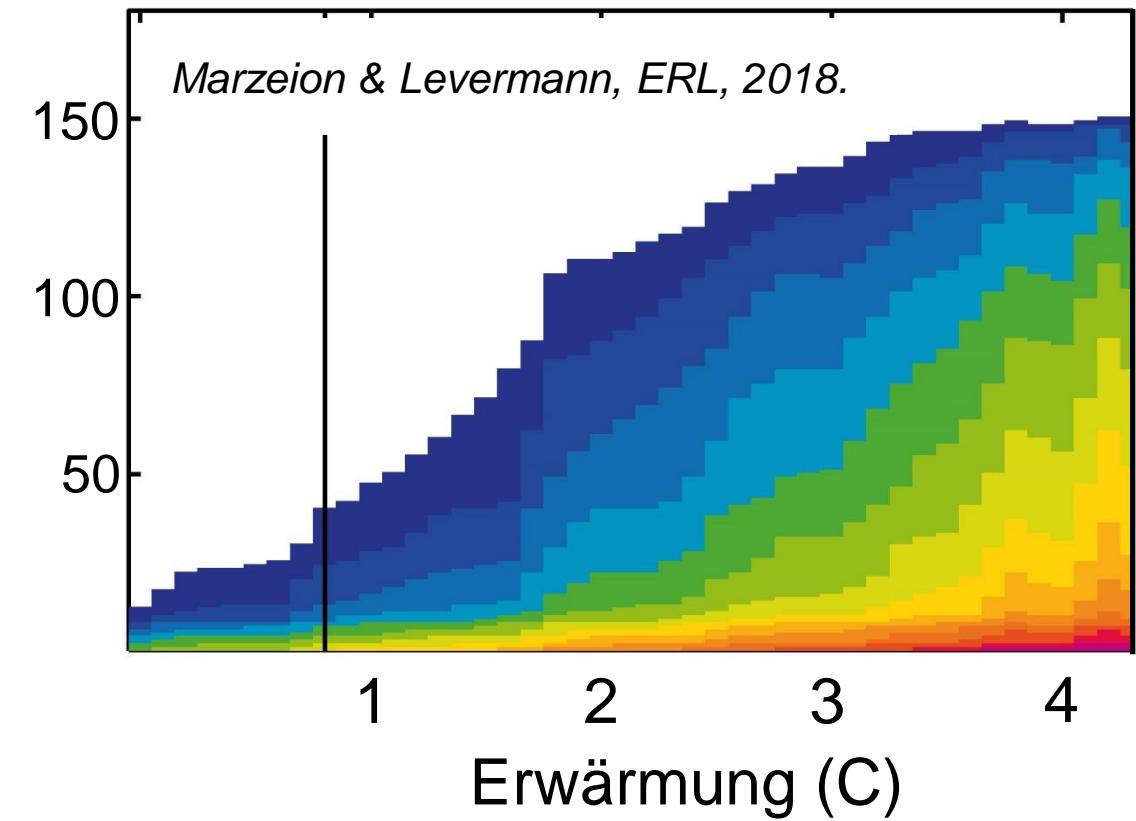
Quelle: NASA

Langfristiger Meeresspiegelanstieg

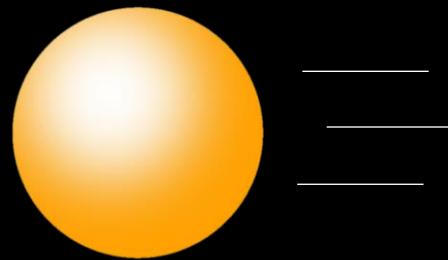
2.3 m pro Grad Erwärmung



UNESCO Weltkulturerbe unter Wasser



Die Faltung des Tischtennisballs



Kinematik

Festes Wertesystem

Zusammenstöße

Wertesystem anpassen

Auf der Erde

Eigene Bewegung

Festes Wertesystem

Wertesystem und Flugrichtung anpassen

Sommer 2010

COLD AIR breaks
European warm spell

JET STREAM

Russische Hitzewelle



Pakistanische
Überschwemmung







COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Die Faltung der Welt

Prof. Anders Levermann, PhD



Potsdam Institute for Climate Impact Research, Germany
Columbia University, New York, USA

www.pik-potsdam.de/~anders
[@ALEvermann](https://twitter.com/ALEvermann)

1. Beispiel

Plastik



1. Beispiel

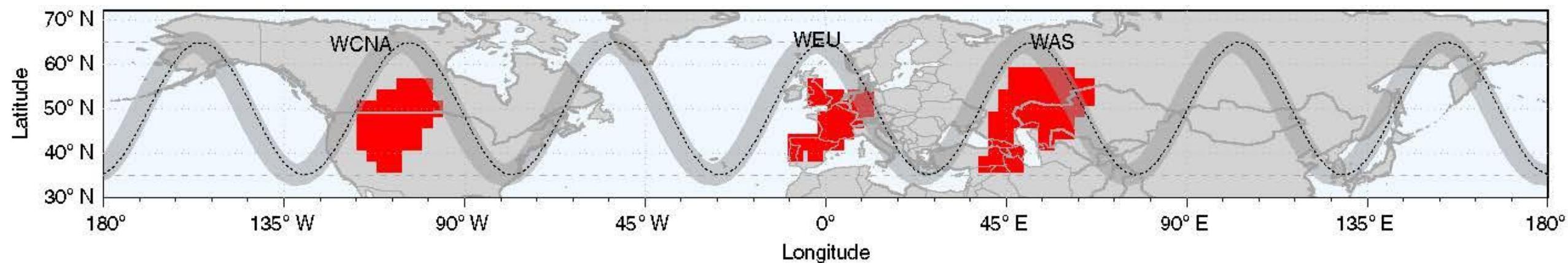
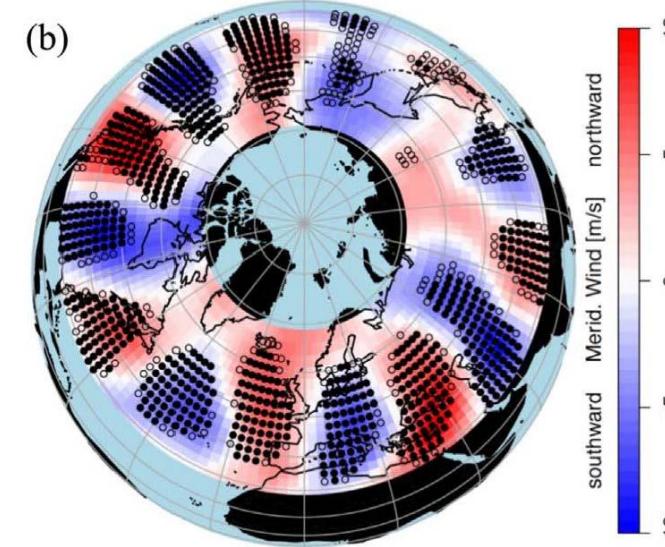
Plastik



Consecutive impacts

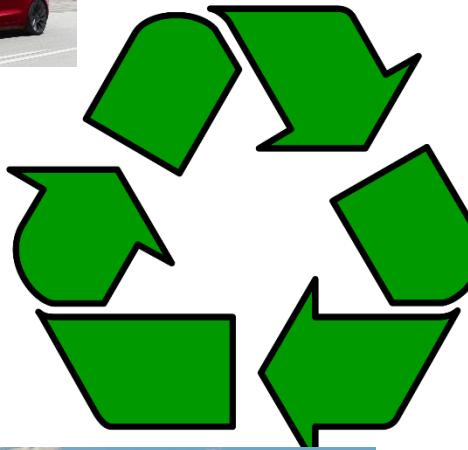
What if we are impacted simultaneously?

What if the jet stream experiences a wave number 7 event synchronized by the Rocky Mountains to create a drought over all three bread baskets of the planet?



...and that is just global warming

We have a large number of other sustainability problems



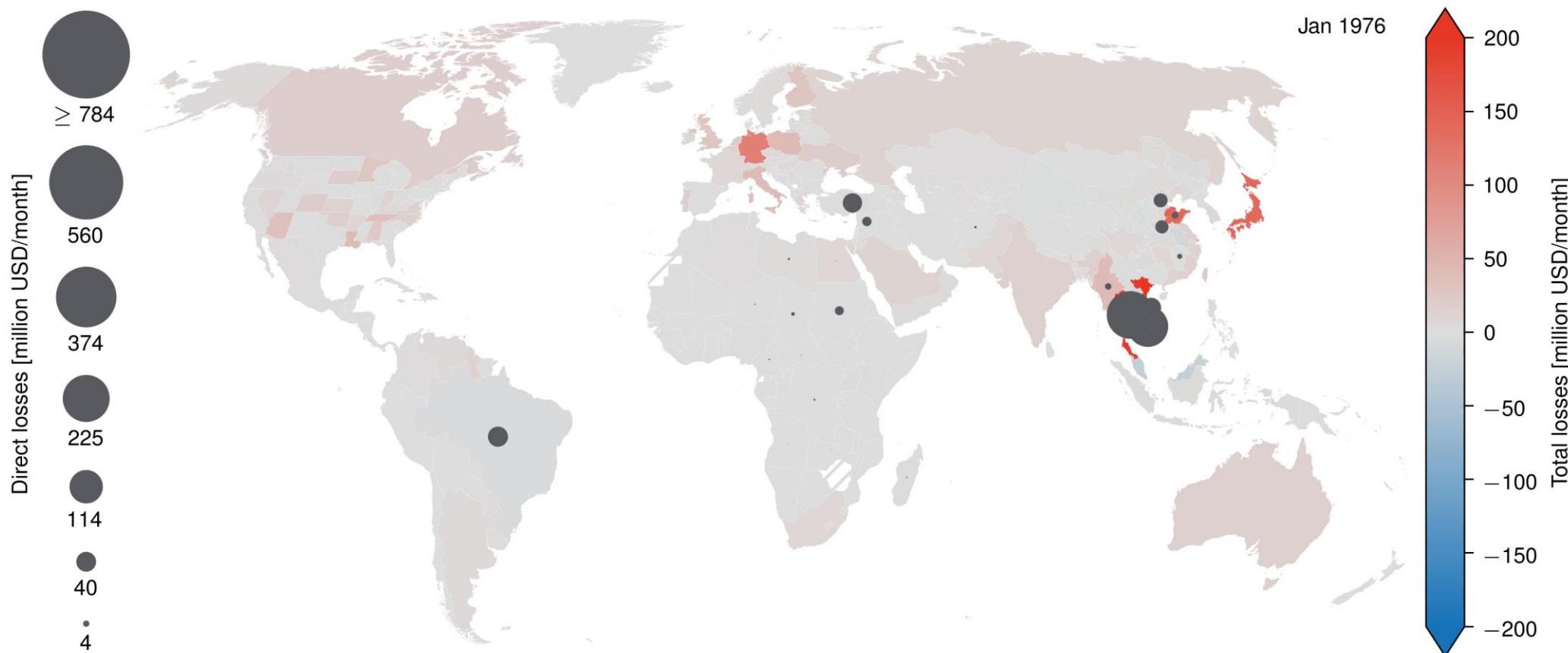
Any questions ?



© Jesko Denzel

Weather extremes impact a globalized society

Global economic response to river floods



Willner, Levermann, Zhao, Frieler
Science Advances (2018).

Otto, Willner, Wenz, Frieler, Levermann
J Econ Dyn Control (2017).

Willner, Otto, Levermann
Nature Climate Change (2018).



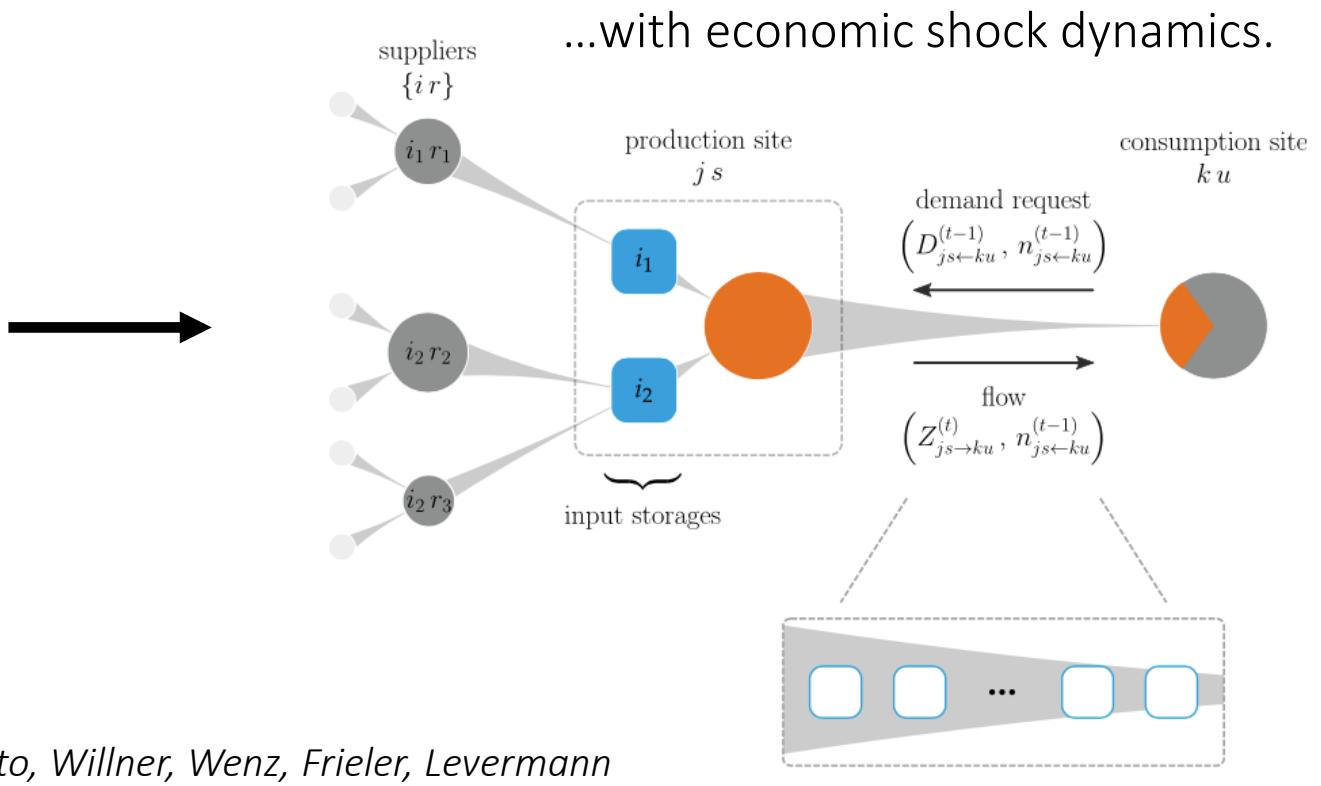
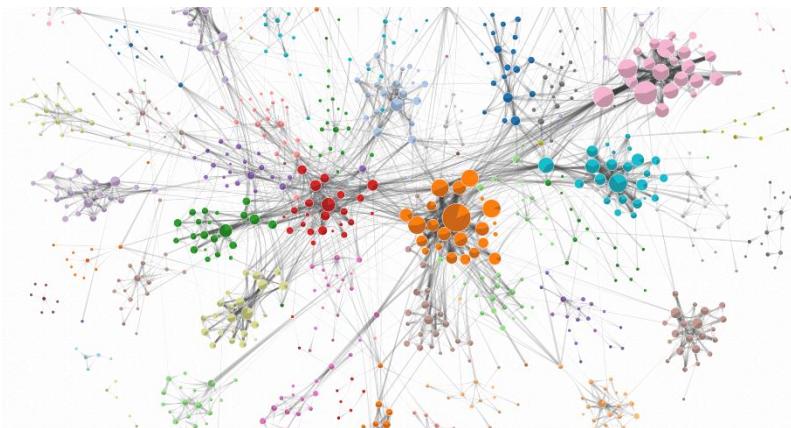
Weather extremes impact a globalized society

Track weather shocks along economic network with locally optimizing shock dynamics

Global economic supply network...



...becomes complex network..



Otto, Willner, Wenz, Frieler, Levermann
J Econ Dyn Control (2017).

Introduce Ergodic Search as technology

in standard macro-economic growth model

$$Y = T \cdot L^{1-\alpha} \cdot K^\alpha$$

$$I = Y - C = (1 - s) \cdot Y$$

$$\frac{dK}{dt} = I - \delta \cdot K$$

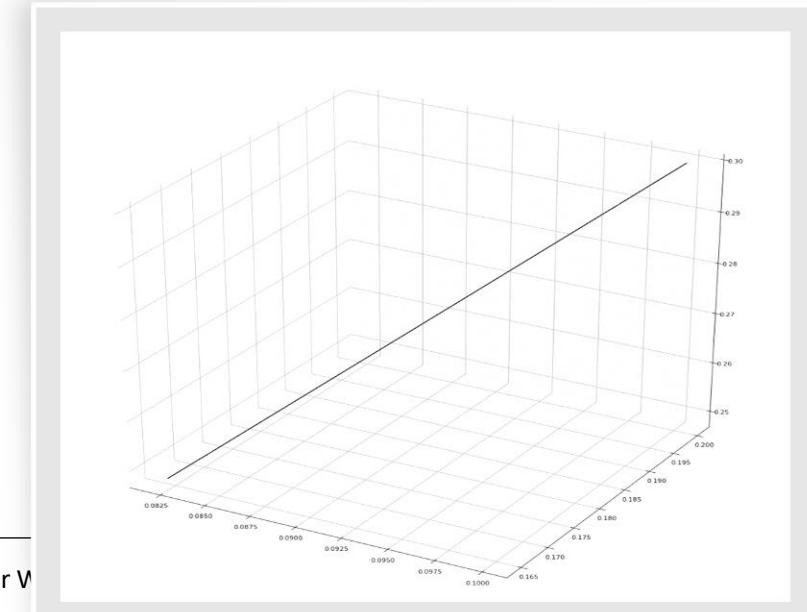
includes capital growth, BUT saturates to steady state unless

1. Labor growth or
2. Technology growth

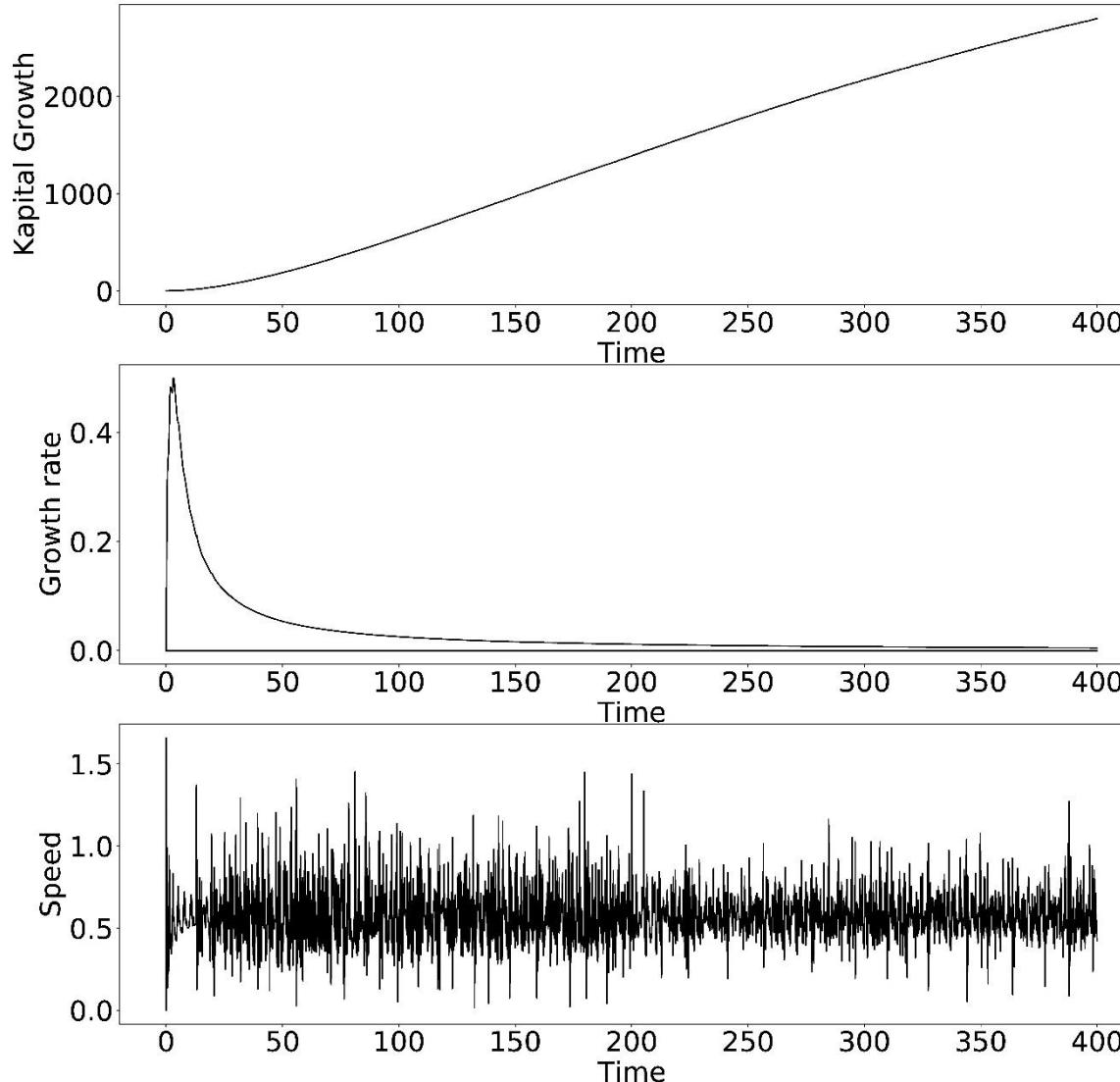
$$T = \beta \cdot \int_{t_0}^t dt' \left| \frac{d\mathbf{r}(t')}{dt} \right|$$



$$\begin{aligned}\frac{d\mathbf{r}}{dt} &= -\nabla L(\mathbf{r}) \\ L(\mathbf{x}, t) &= L_b(\mathbf{x}) + \lambda \cdot L_h(\mathbf{x}, t) \\ L_b(\mathbf{x}) &= (1 - |\mathbf{x}|)^{-1} \\ \frac{dL_h}{dt}(\mathbf{x}) &= \left(1 + \frac{|\mathbf{r}(t) - \mathbf{x}|}{\rho}\right)^{-1} - \frac{L_h}{\tau}\end{aligned}$$



Infinite capital growth within planetary boundaries



$$\frac{d\mathbf{r}}{dt} = -\nabla L(\mathbf{r})$$
$$L(\mathbf{x}, t) = L_b(\mathbf{x}) + \lambda \cdot L_h(\mathbf{x}, t)$$
$$L_b(\mathbf{x}) = (1 - |\mathbf{x}|)^{-1}$$
$$\frac{dL_h}{dt}(\mathbf{x}) = \left(1 + \frac{|\mathbf{r}(t) - \mathbf{x}|}{\rho}\right)^{-1} - \frac{L_h}{\tau}$$

$$Y = T \cdot L^{1-\alpha} \cdot K^\alpha$$

$$I = Y - C = (1 - s) \cdot Y$$

$$T = \beta \cdot \int_{t_0}^t dt' \left| \frac{d\mathbf{r}(t')}{dt} \right|$$

$$\frac{dK}{dt} = I - \delta \cdot K$$

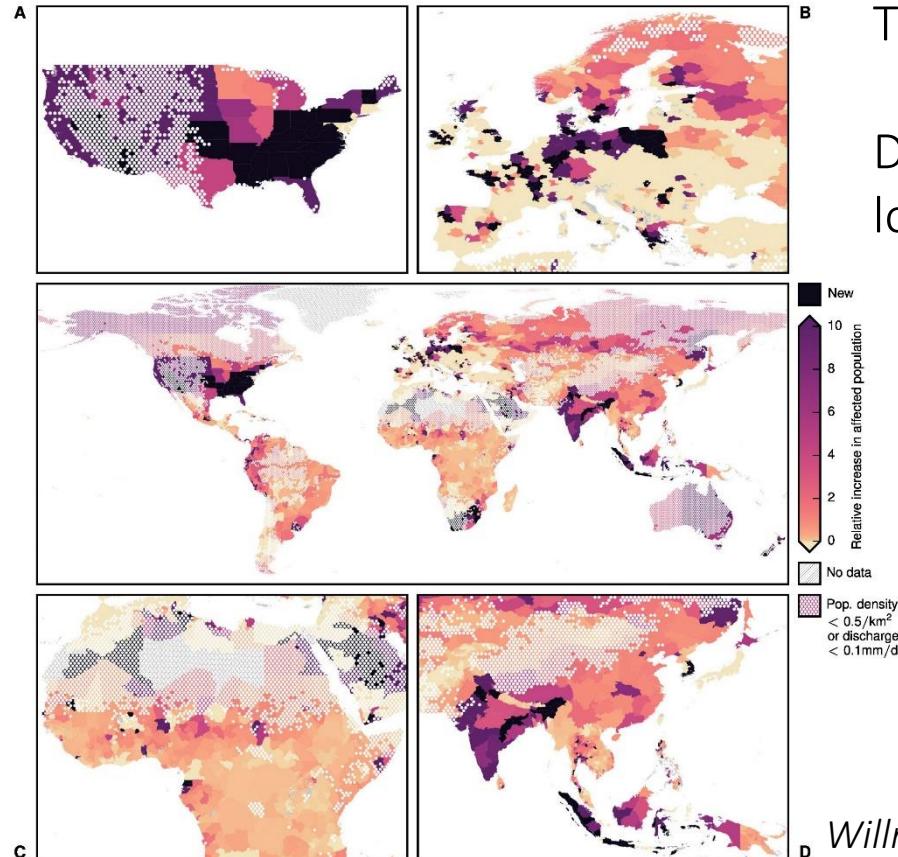
Conclusions

1. In order to stabilize the temperature of the planet we need to get to basically zero carbon emissions
2. For any temperature target beyond 2C, climate change is more expensive than climate mitigation
3. Accounting for variability generally increases the cost estimates
4. It is not just the extremes in temperature and precipitation, but the general hindering of economic flow and prosperity.
5. The global economic commitment of the next 20 years is much larger than the mitigation costs to keep the Paris Climate Agreement.



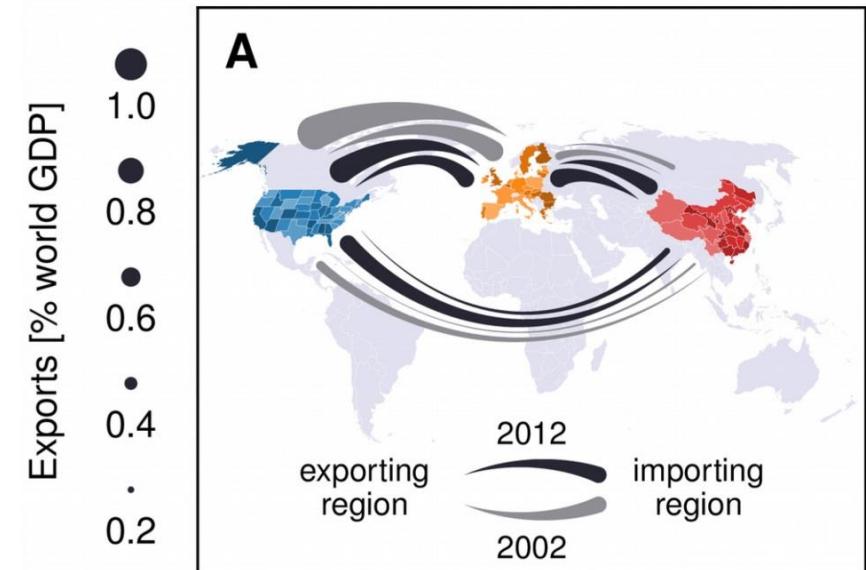
Cost of emitting carbon

One way to estimate the social costs of carbon: process-based



B The economic risk of weather extremes is imported, e.g., from China.

Due to its equilibrated trade balance, the EU can compensate for these losses while the US can not.



Willner, Otto, Levermann
Nature Climate Change (2018).

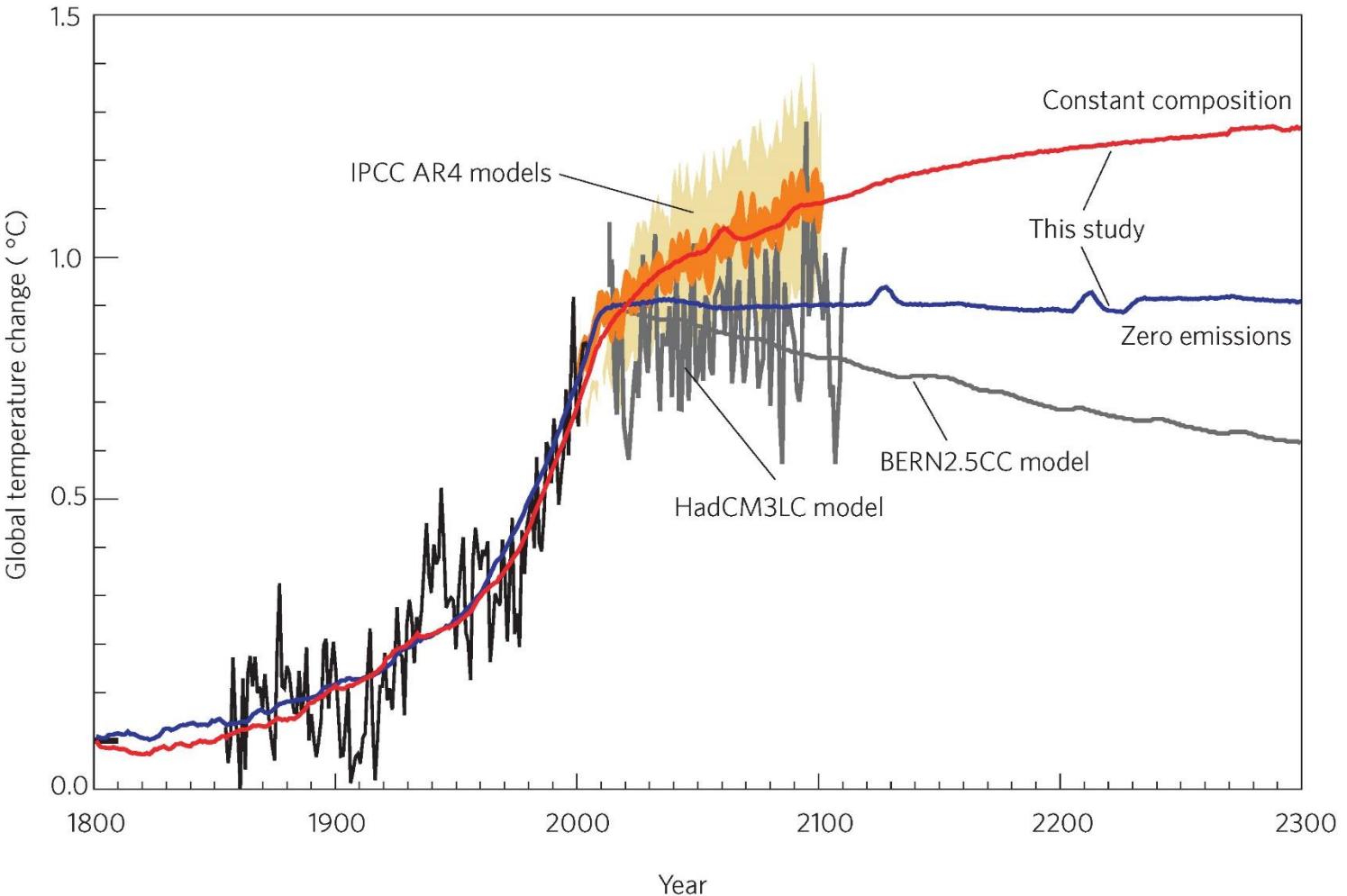
Willner, Levermann, Zhao, Frieler
Science Advances (2018).



The concept of commitment

The warming commitment of carbon dioxide

Matthews & Weaver
Nature, 2010.



Cost of emitting carbon - empirical estimates

Another way to estimate the social costs of carbon: empirical

American Economic Journal: Macroeconomics 2012, 4(3): 66–95
<http://dx.doi.org/10.1257/mac.4.3.66>

Temperature Shocks and Economic Growth: Evidence from the Last Half Century[†]

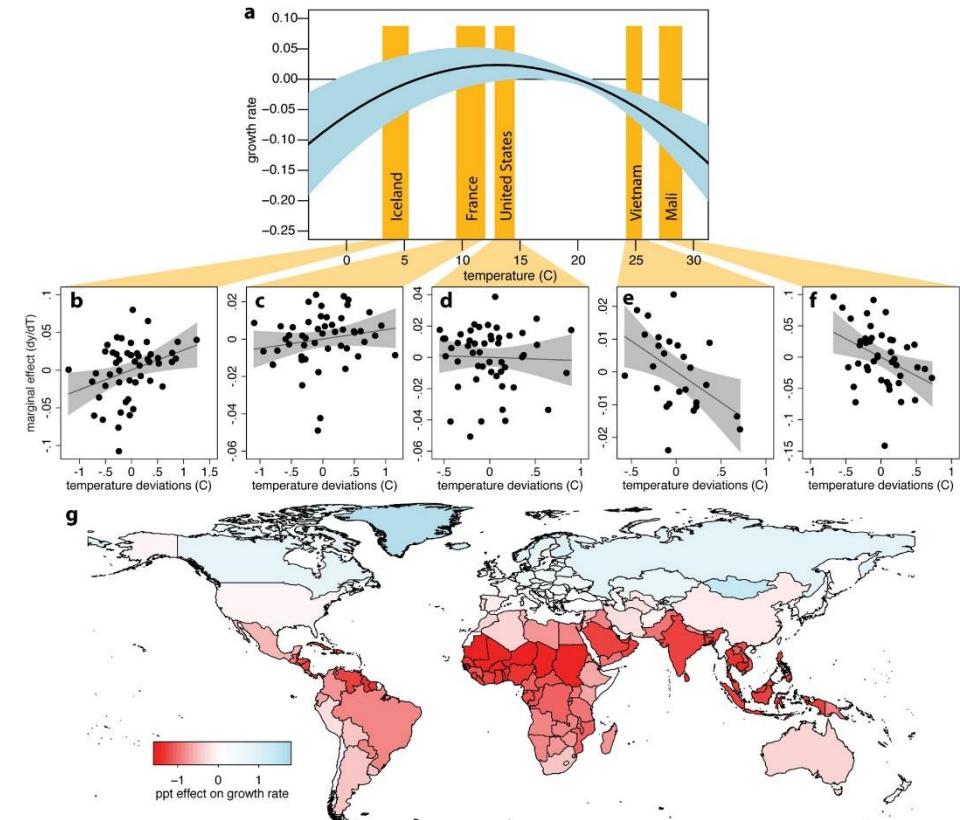
By MELISSA DELL, BENJAMIN F. JONES, AND BENJAMIN A. OLKEN*

This paper uses historical fluctuations in temperature within countries to identify its effects on aggregate economic outcomes. We find three primary results. First, higher temperatures substantially reduce economic growth in poor countries. Second, higher temperatures may reduce growth rates, not just the level of output. Third, higher temperatures have wide-ranging effects, reducing agricultural output, industrial output, and political stability. These findings inform debates over climate's role in economic development and suggest the possibility of substantial negative impacts of poor countries. (JEL E23, O13, Q54, Q56)

LETTER

Global non-linear effect of temperature on economic production

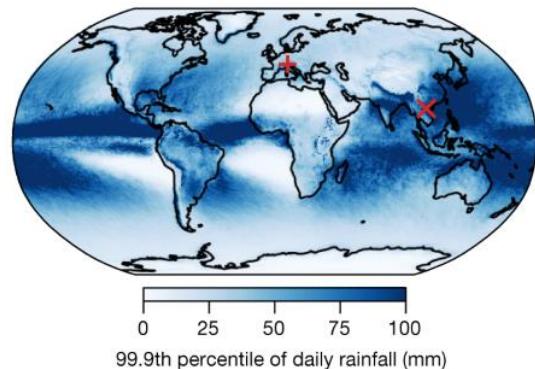
Marshall Burke^{1,2*}, Solomon M. Hsiang^{3,4*} & Edward Miguel^{4,5}



Cost of emitting carbon - empirical estimates

Method

Historical climate data (ERA5,
MSWEP, PGF)



Fixed-effects panel regression models
to assess effects on economic growth

$$\Delta \log(GRP_pc)_{r,y} \sim \alpha RD_{r,y} + \mu_r + \eta_y + \varepsilon_{r,y}$$

Design climate measures

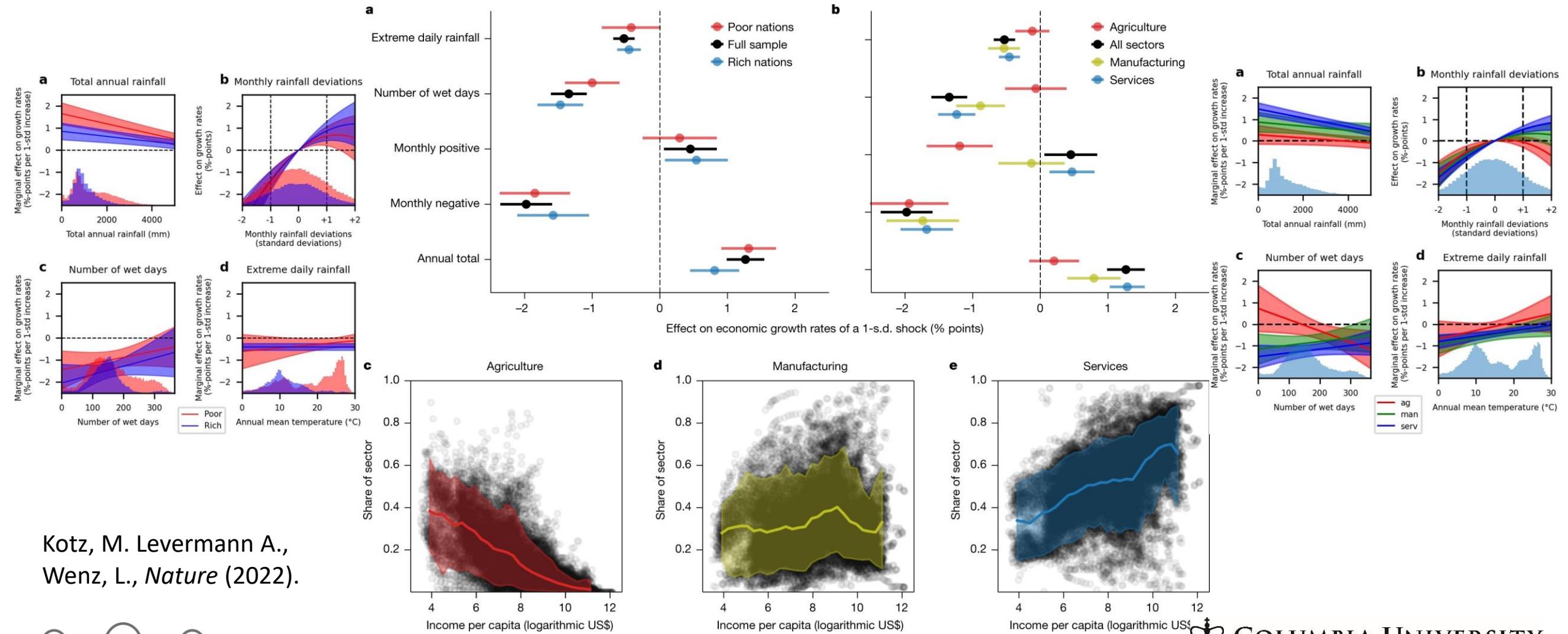
$$\text{e.g. } RD_{x,y} = \sum_{d=1}^{D_y} R_{x,d} H(R_{x,d} - R_C)$$

Spatially aggregate to sub-national
regions to match economic data



Cost of emitting carbon - empirical estimates

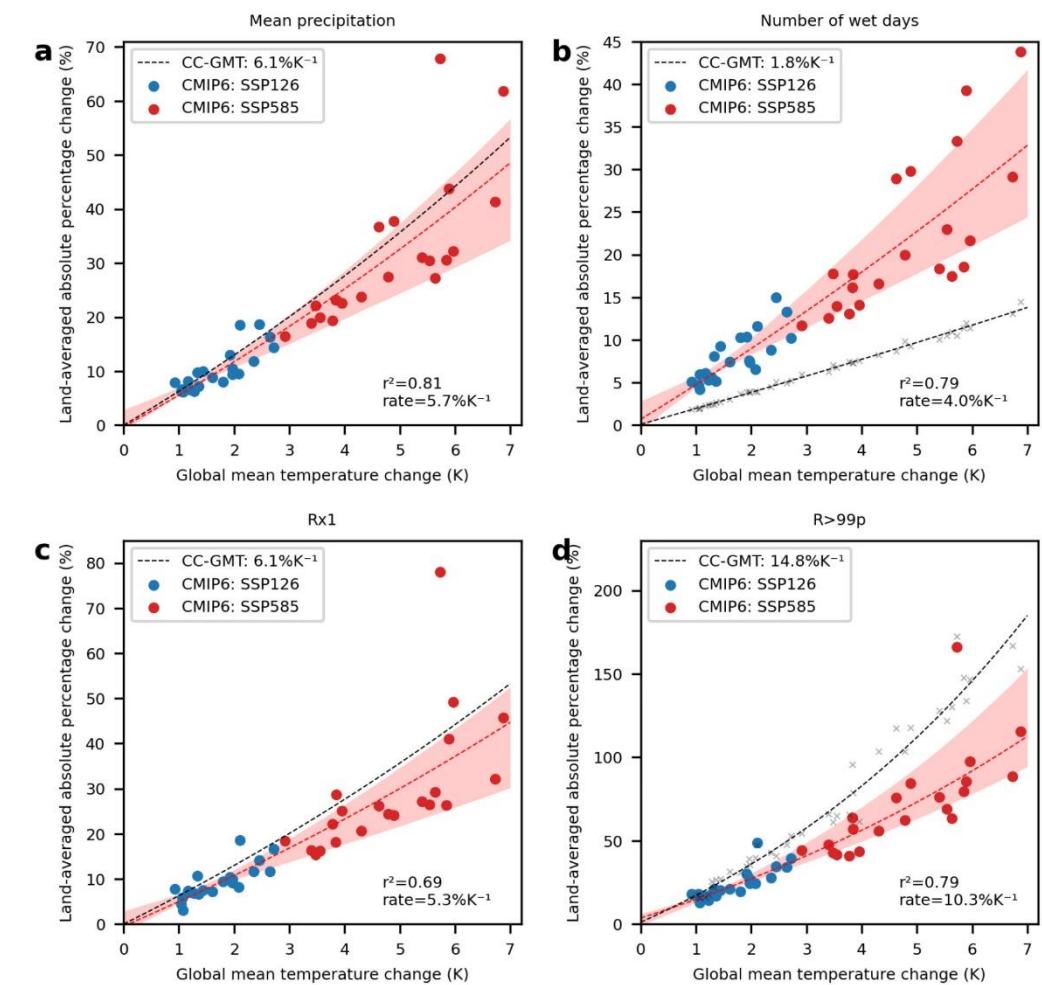
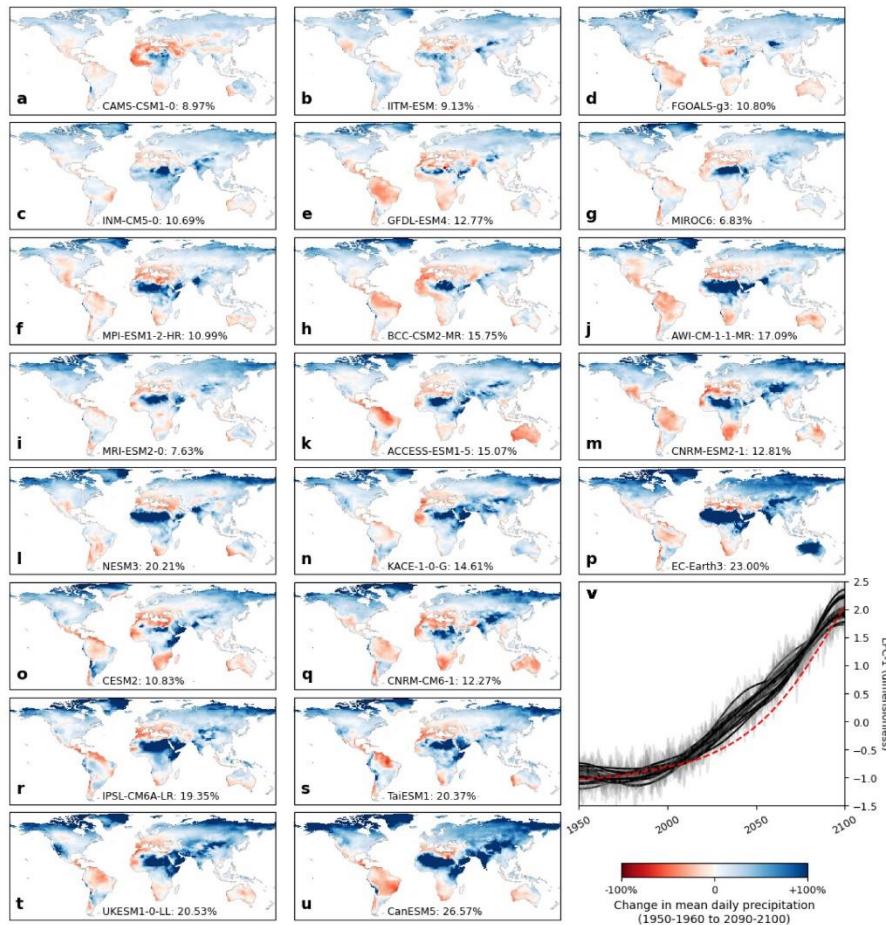
Differences in wealth and economic sector



Kotz, M., Levermann A.,
Wenz, L., *Nature* (2022).



Pattern of changes in Precipitation measures



M. Kotz, S. Lange, L. Wenz, A. Levermann A. *Journal of Climate* (2022), submitted

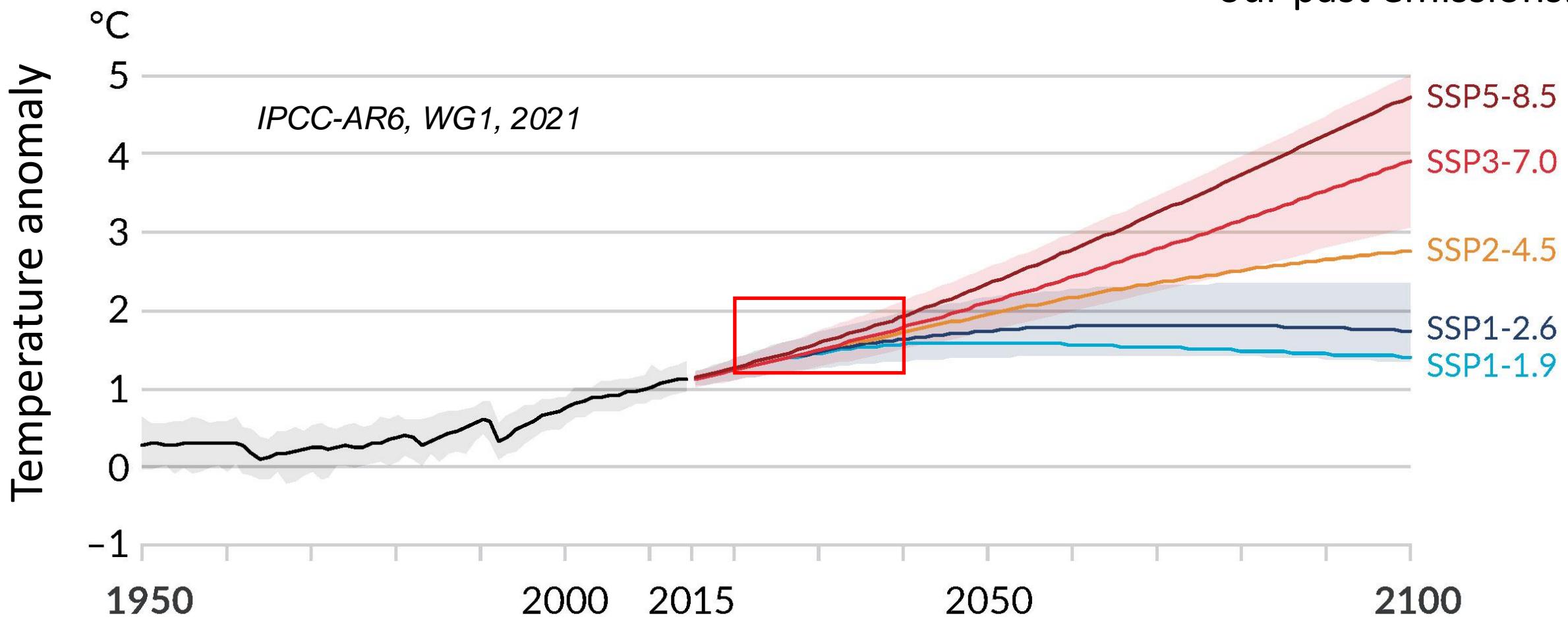


Prof. Anders Levermann, PIK, Potsdam Institute for Climate Impact Research, Germany. Die Erde November, 2022.

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK
Leipzig, April 2024

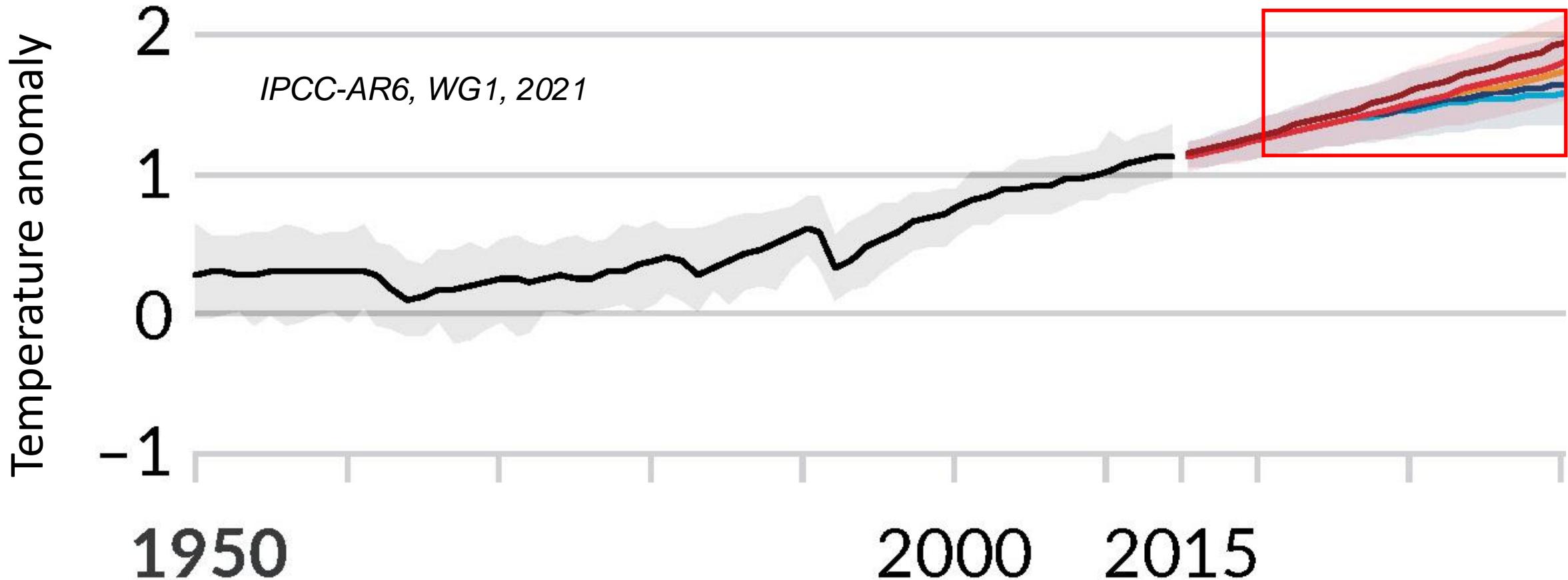
The economic commitment of carbon dioxide

The next 20 years of temperature change are already locked in by our past emissions.

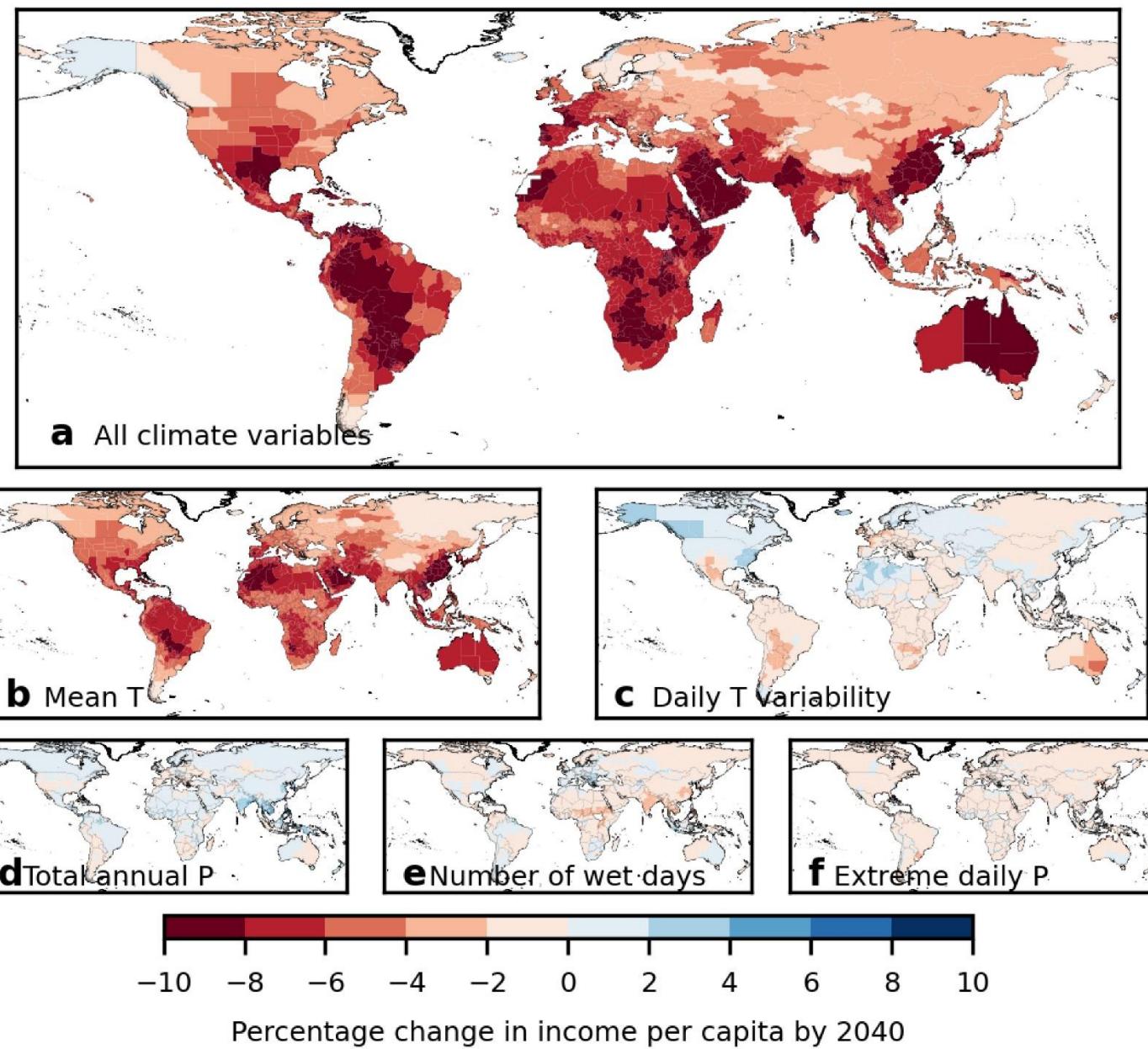


The economic commitment of carbon dioxide

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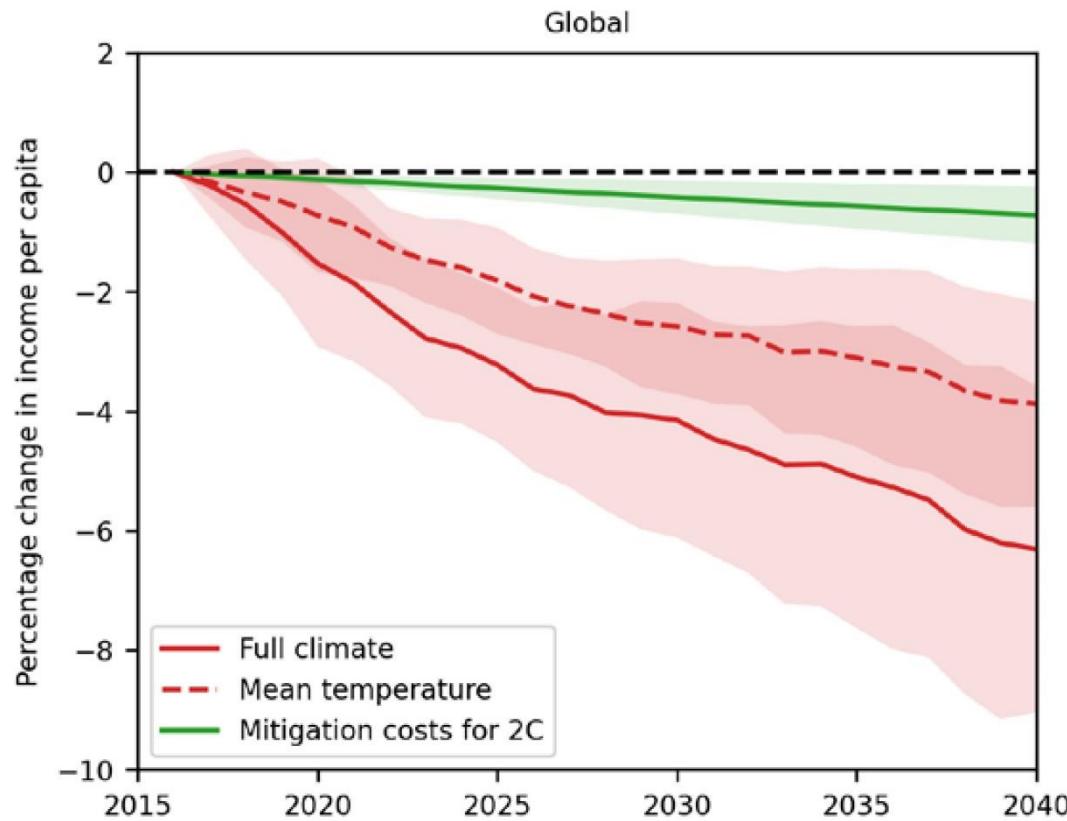
The economic commitment of carbon dioxide



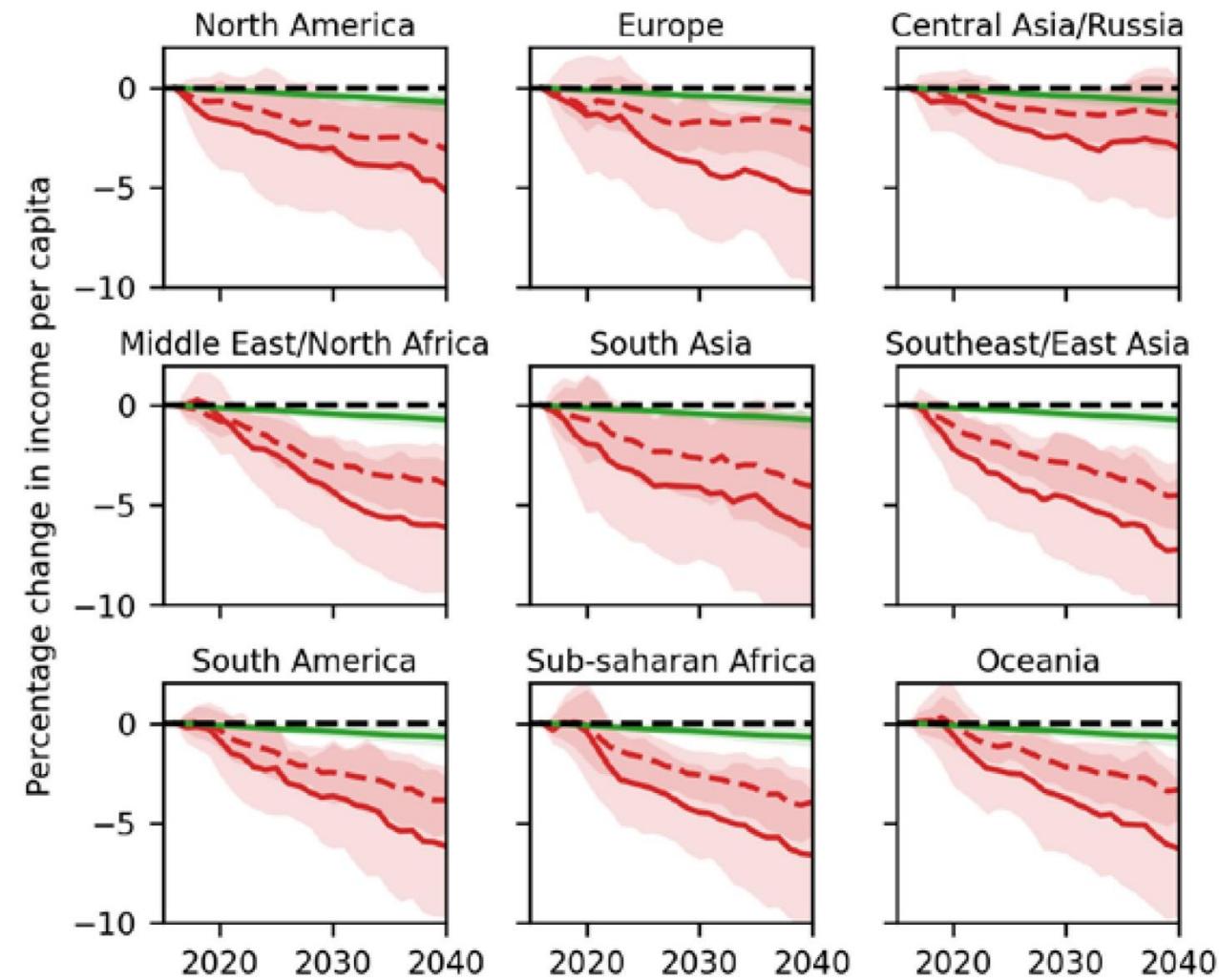
Kotz, Levermann, Wenz
Science, under review.



The economic commitment of carbon dioxide



Kotz, Levermann, Wenz
Science, under review.



Cost of emitting carbon

One way to motivate a price for carbon emissions

$$\text{Social cost of carbon} = \sum_{t=0}^{\infty} \delta t \frac{\delta \text{Damage}_t}{\delta \text{Temp}_t} \frac{\delta \text{Temp}_t}{\delta \text{CO2}_{t=0}} e^{-dt}$$


Damage Function



What if society decides that...

...no company should be more powerful than a democratic state?

