

Die Faltung des Wassers

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www.pik-potsdam.de/~anders



Die Faltung

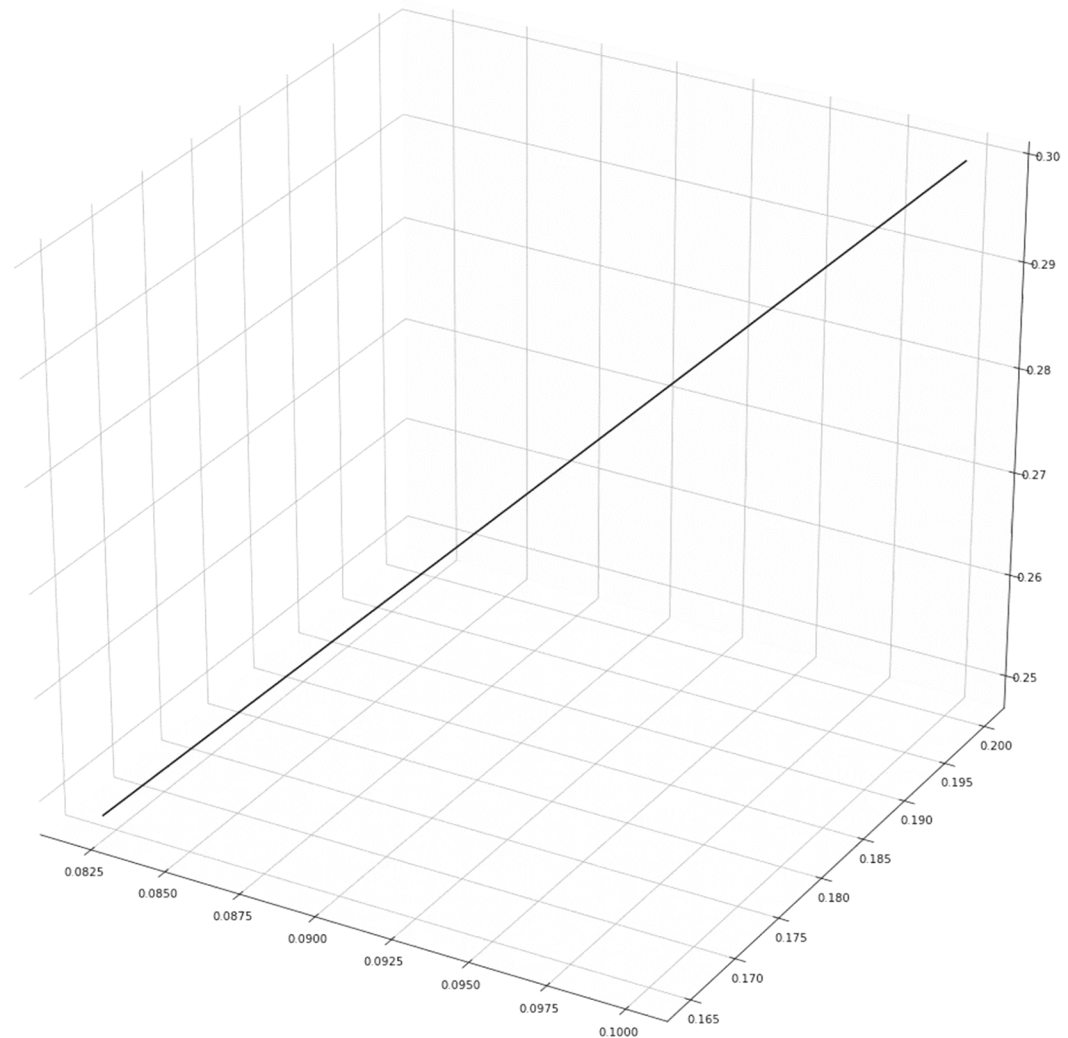
Ein Konzept aus der
theoretischen Physik

$$\frac{d\mathbf{r}}{dt} = -\nabla L(\mathbf{r})$$

$$L(\mathbf{x}, t) = L_b(\mathbf{x}) + \lambda \cdot L_h(\mathbf{x}, t)$$

$$L_b(\mathbf{x}) = (1 - |\mathbf{x}|)^{-1}$$

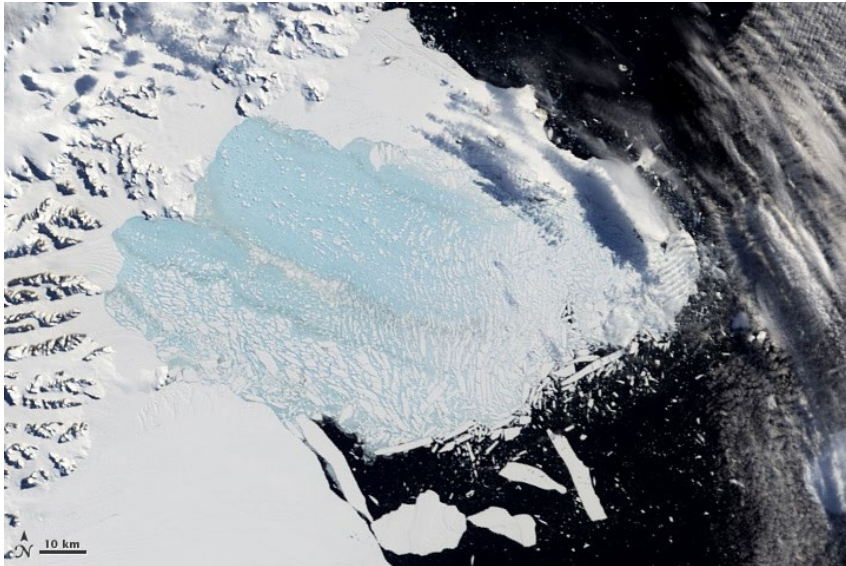
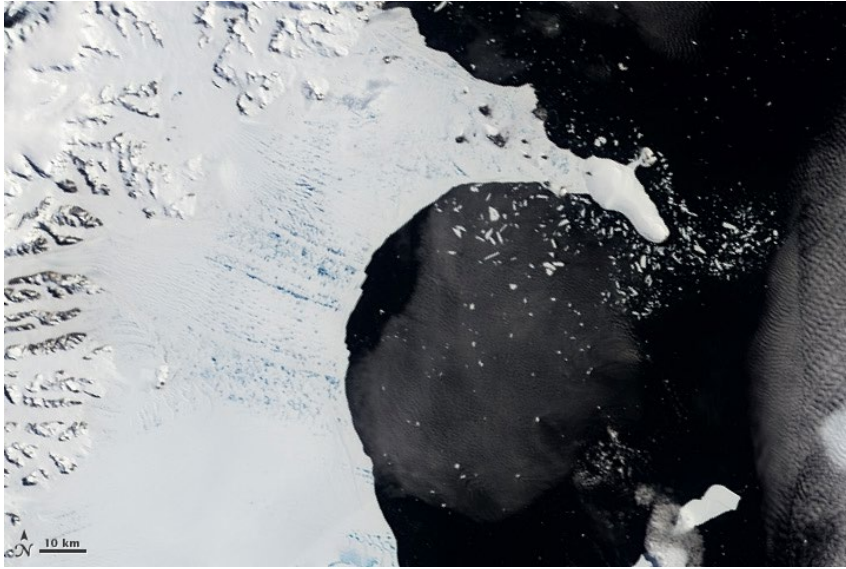
$$\frac{dL_h}{dt}(\mathbf{x}) = \left(1 + \frac{|\mathbf{r}(t) - \mathbf{x}|}{\rho}\right)^{-1} - \frac{L_h}{\tau}$$



„In Physics We Trust“

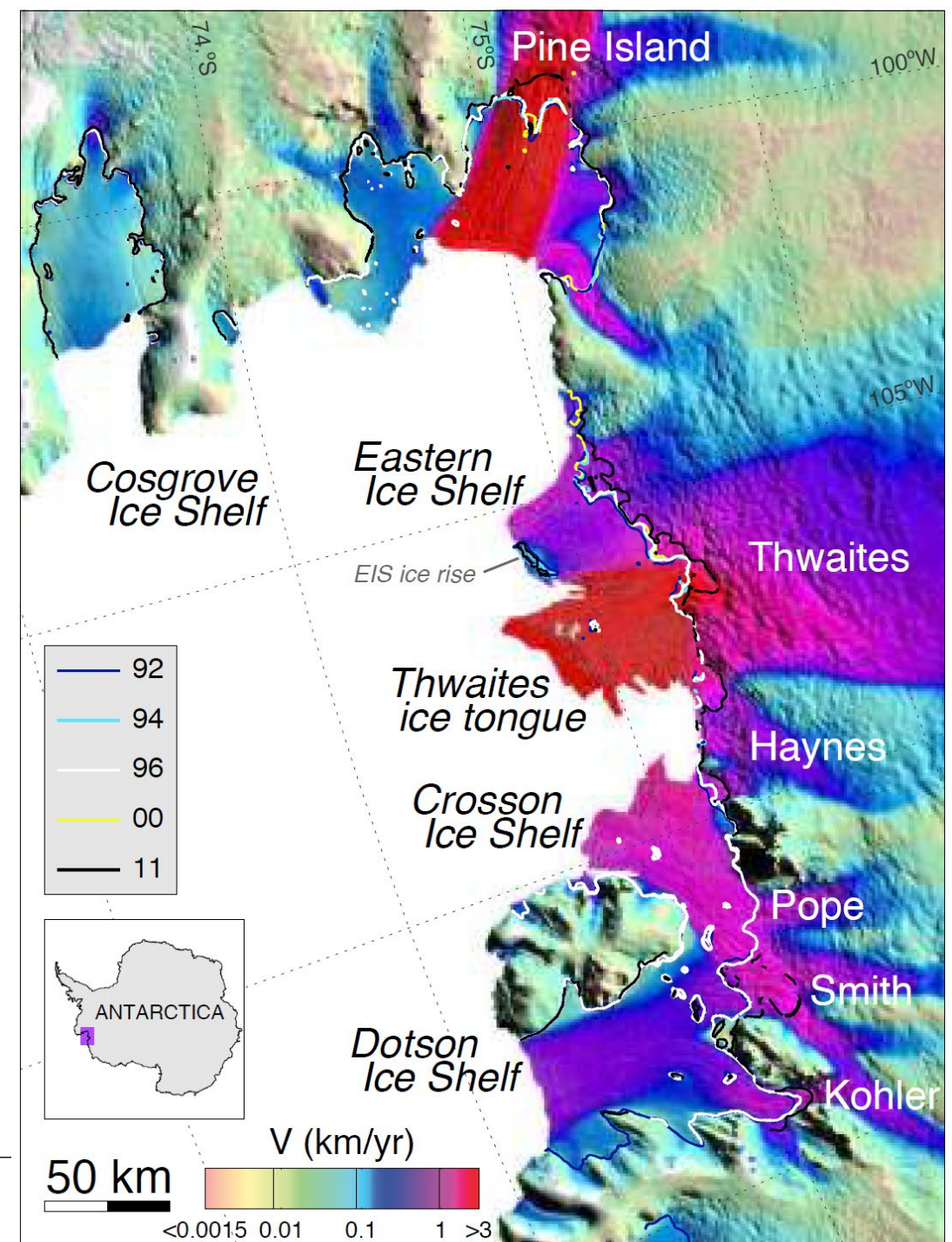
John Mercer (Nature, 1978):

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

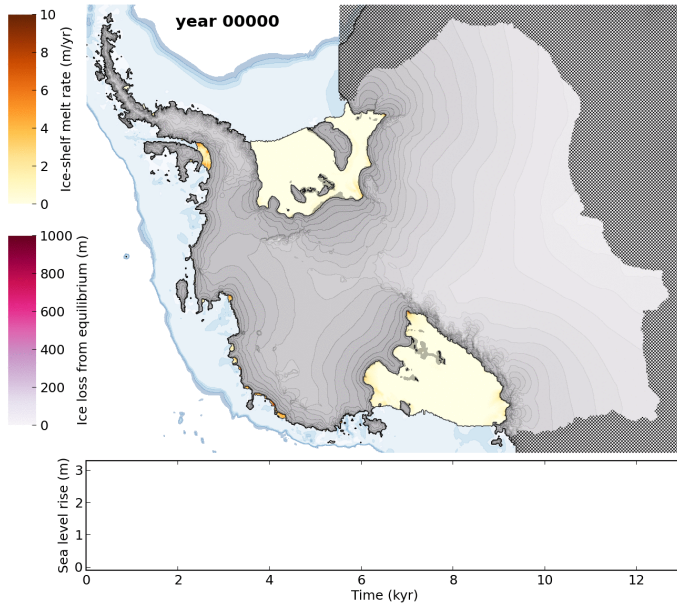


Die Westantarktis ist destabilisiert.

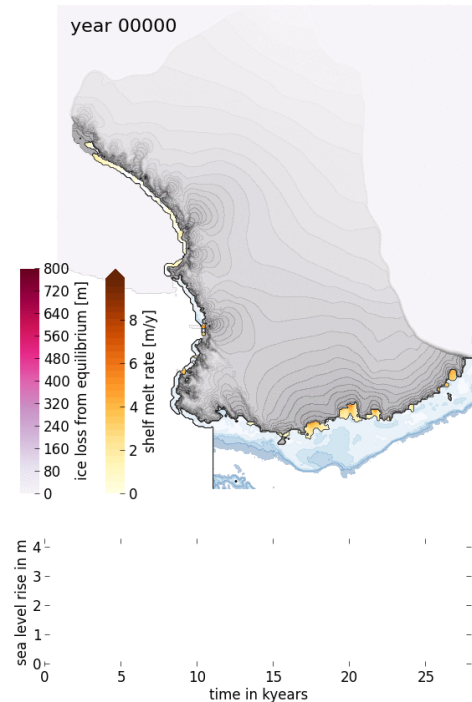
Rignot et al., GRL, 2014.
Joughin et al., Science, 2014.
Favier et al. Nature CC, 2014.



Die Westantarktis ist destabilisiert. .. die Ostantarktis noch nicht.



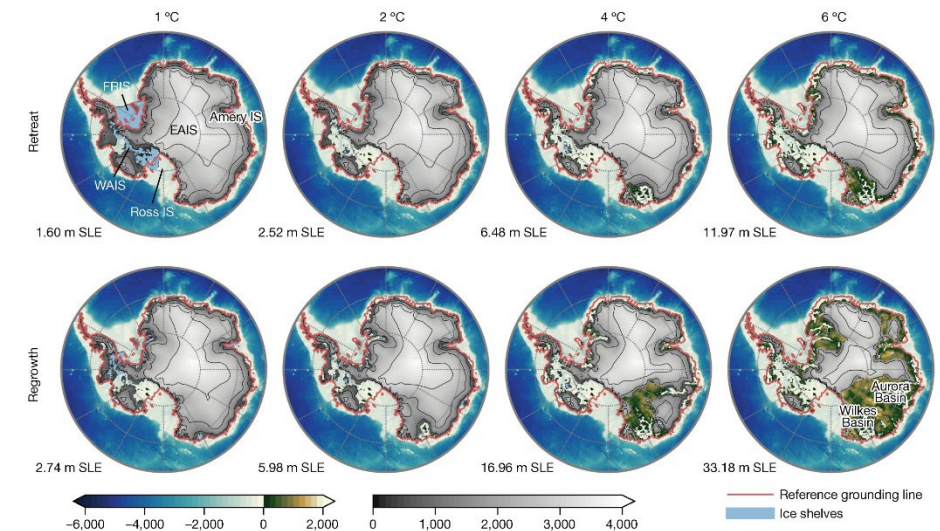
Feldmann & Levermann, PNAS, 2015.



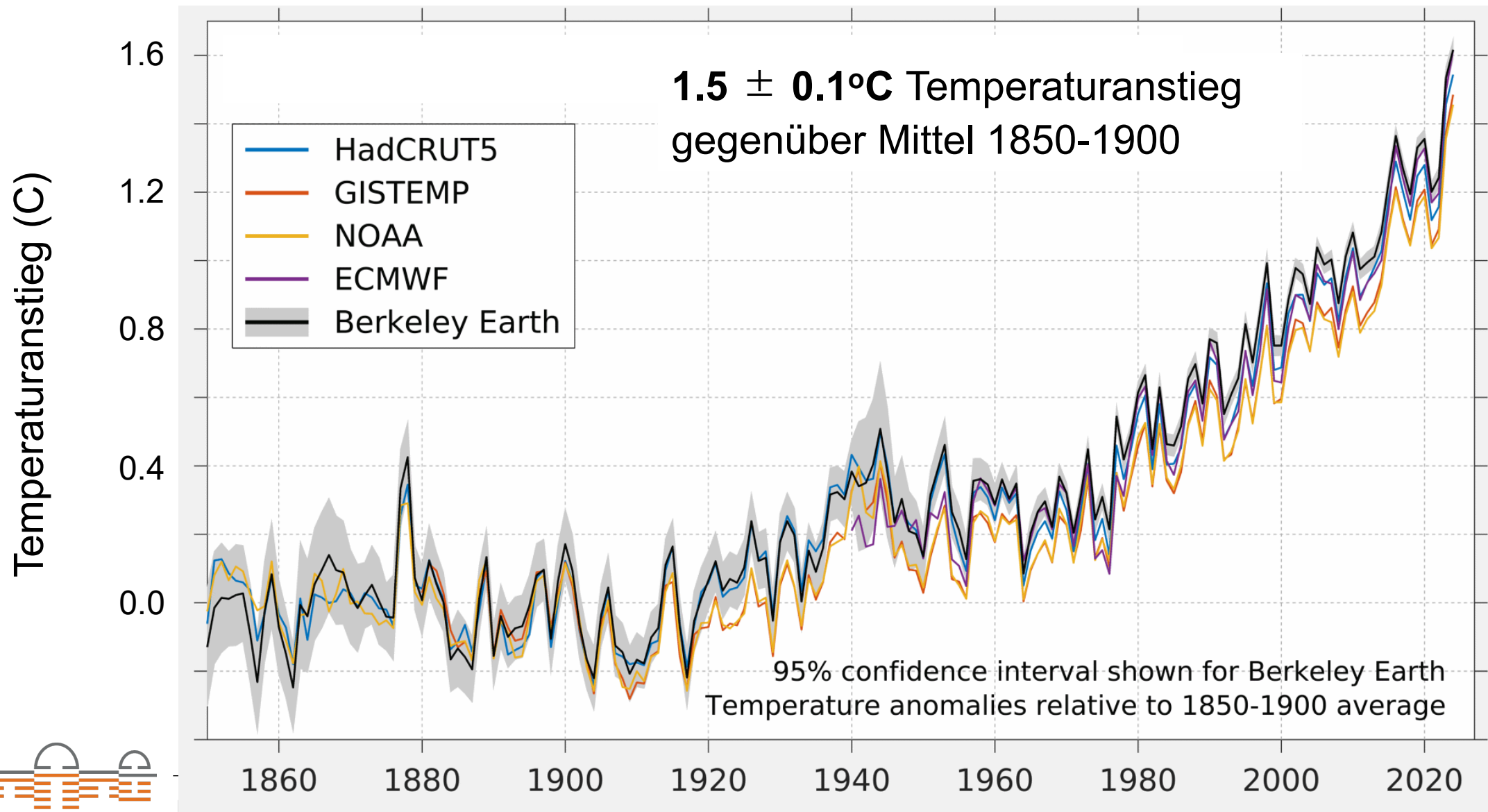
Mengel & Levermann
Nature Climate Change, 2014.



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



Die Erde erwärmt sich.

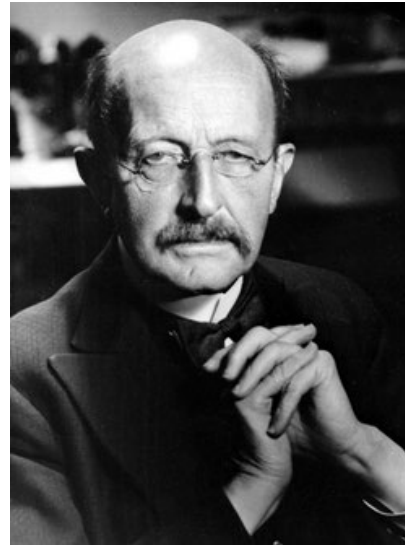


2024
2023
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2004

Grundgesetze der Physik



Albert
Einstein

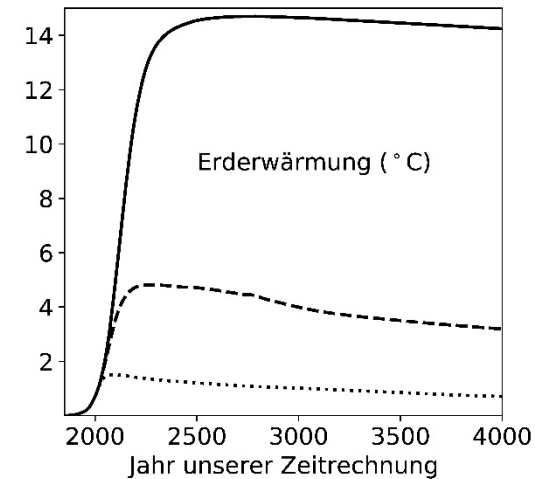
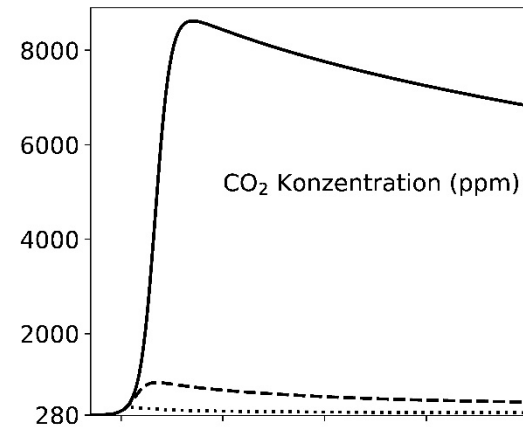
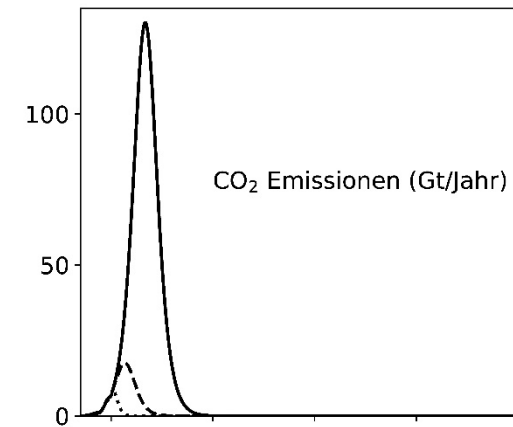


Max
Planck



Ludwig
Boltzmann

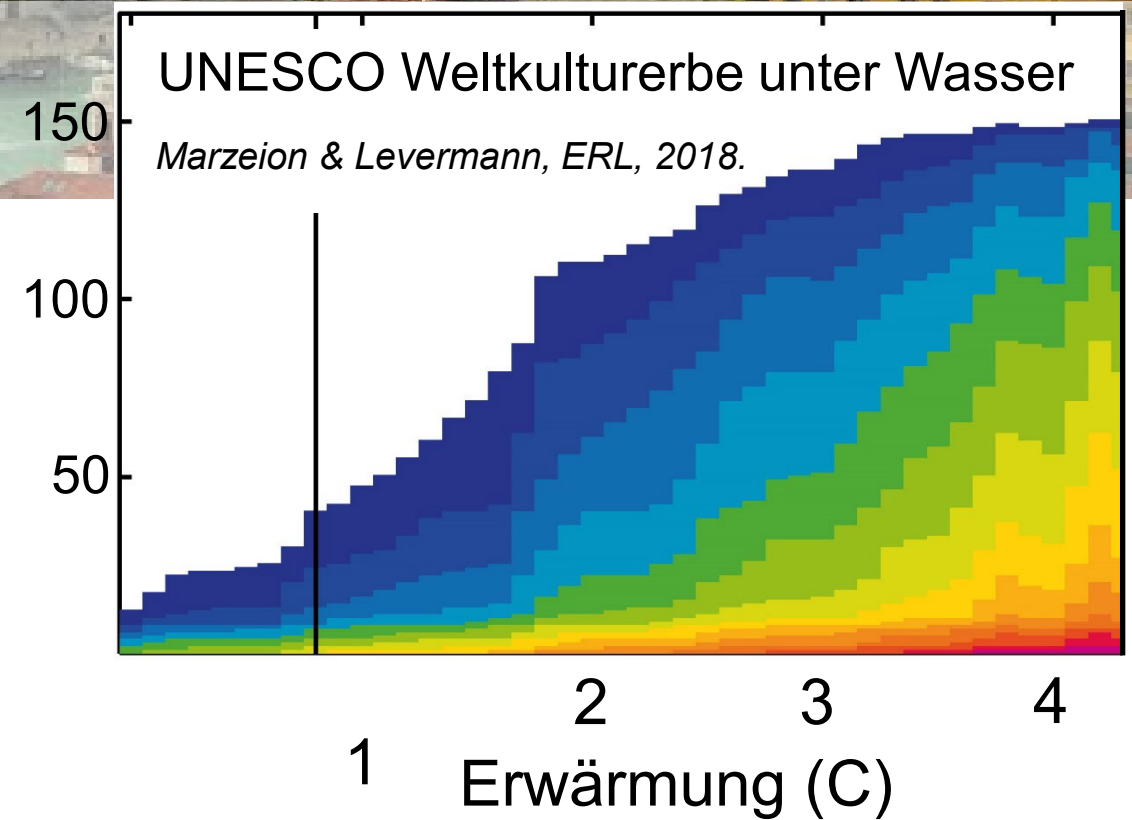
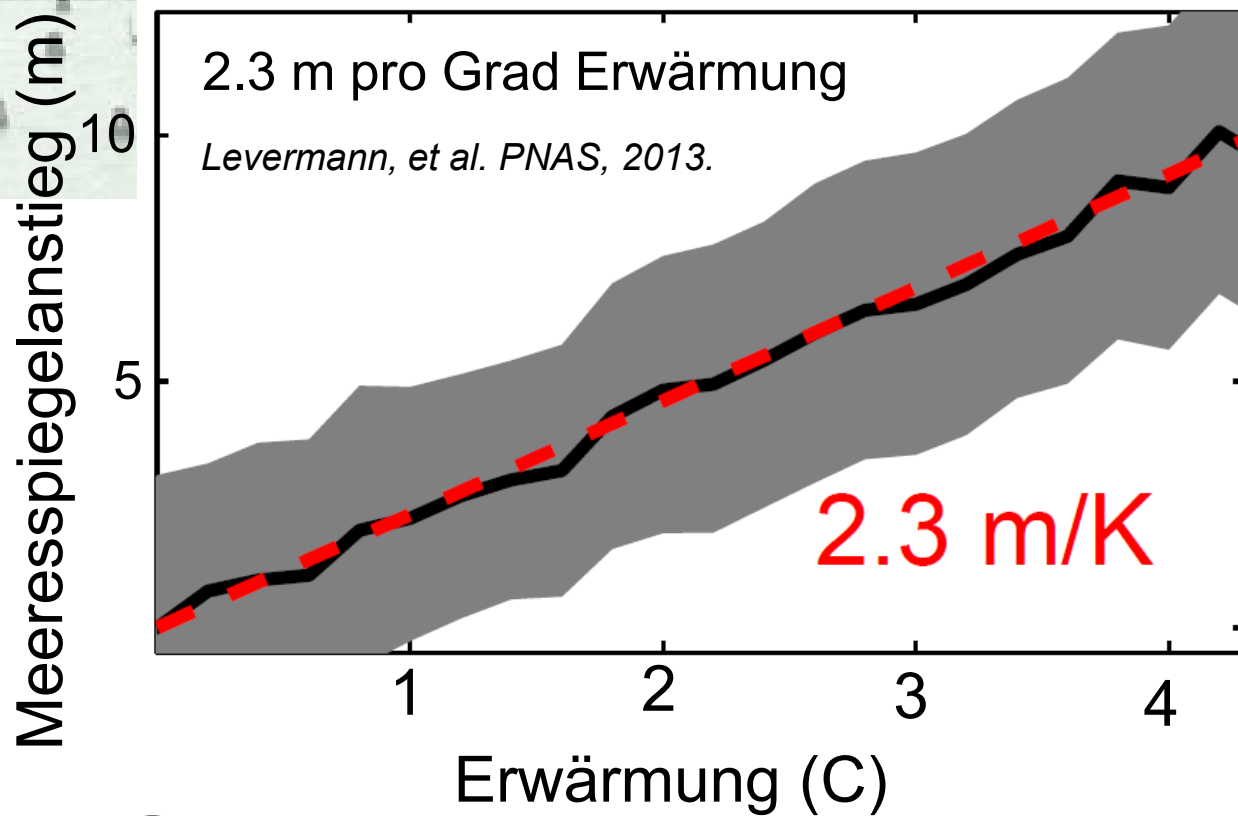
Fossiler Kohlenstoff bleibt für praktisch immer in der Atmosphäre



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

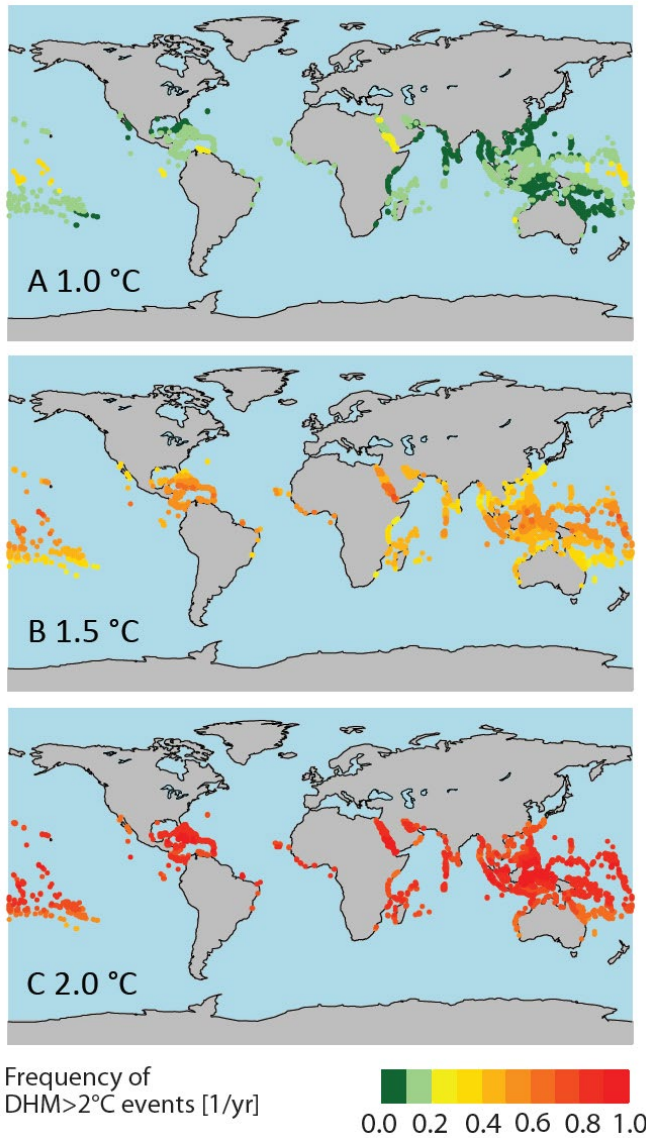
Die Temperatur der Erde steigt an
solange wir Gas, Öl oder Kohle verbrennen.

Verlust von Kulturerbe durch Meeresspiegelanstieg

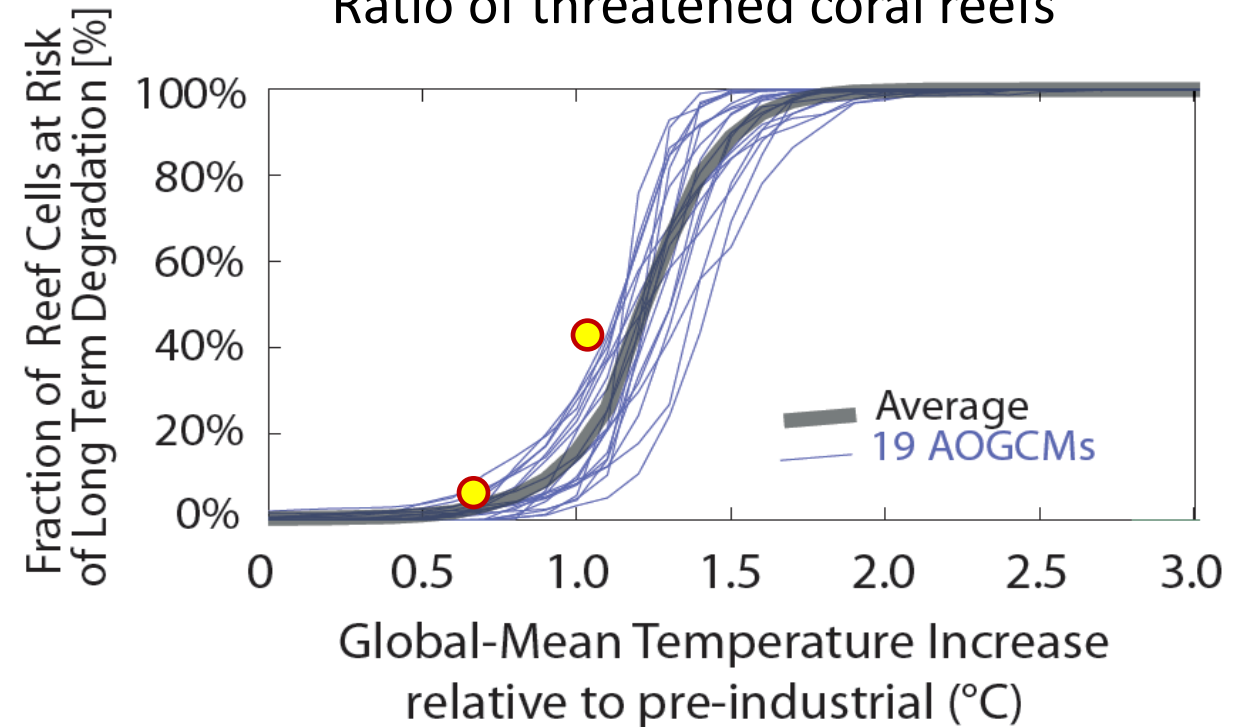


Korallenriffe sterben

Frequency of bleaching events



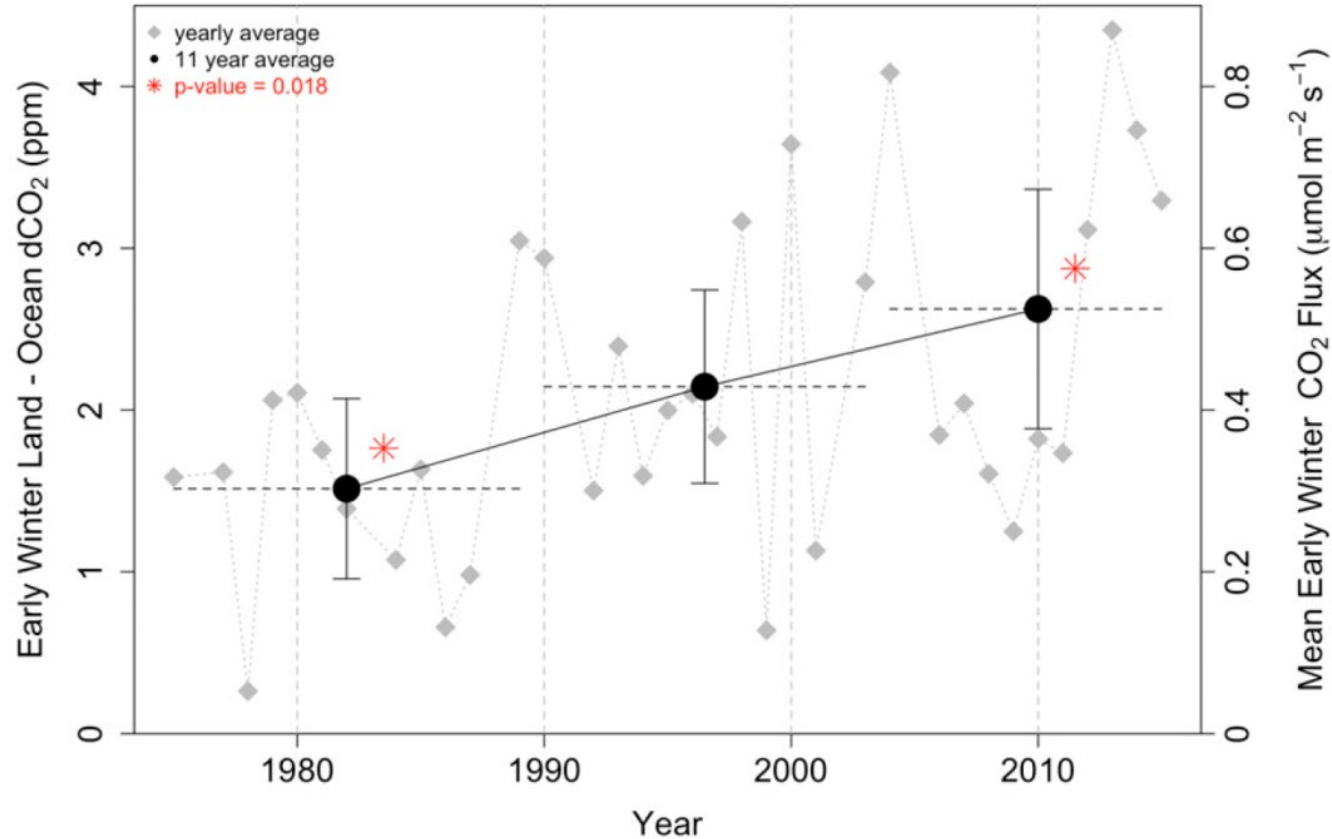
Ratio of threatened coral reefs



Frieler et al. Nature Clim. Ch. (2012).

Permafrost taut auf

Nord-Amerika

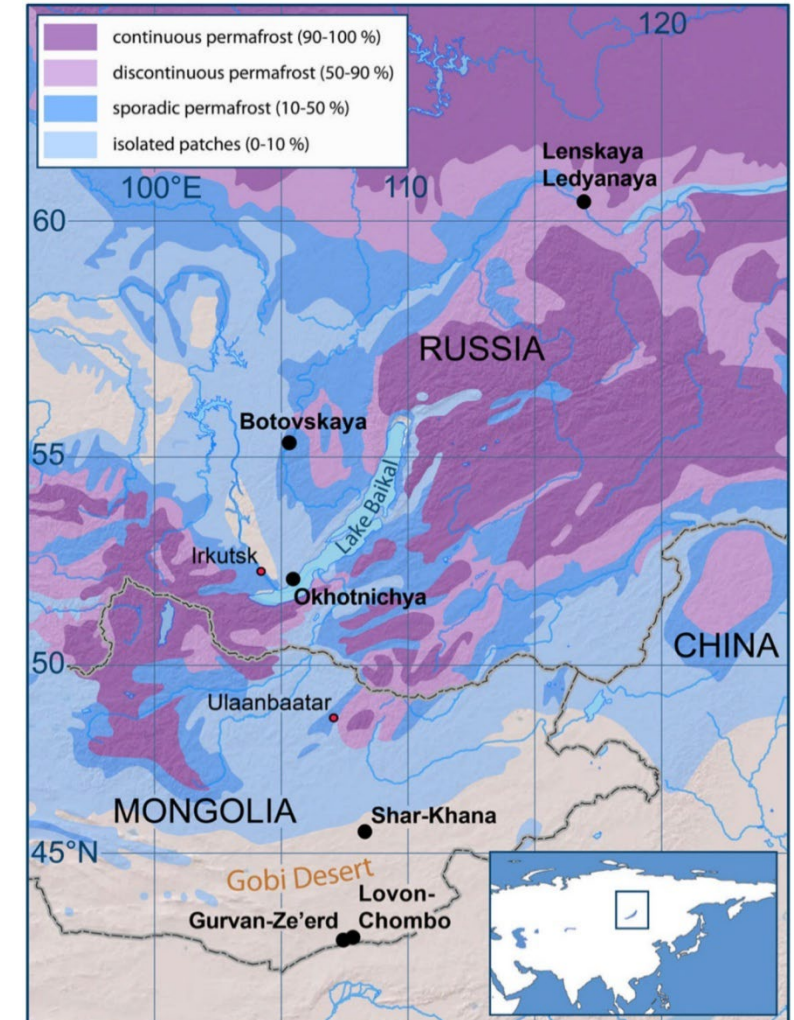


Commane et al. 2017, PNAS.



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

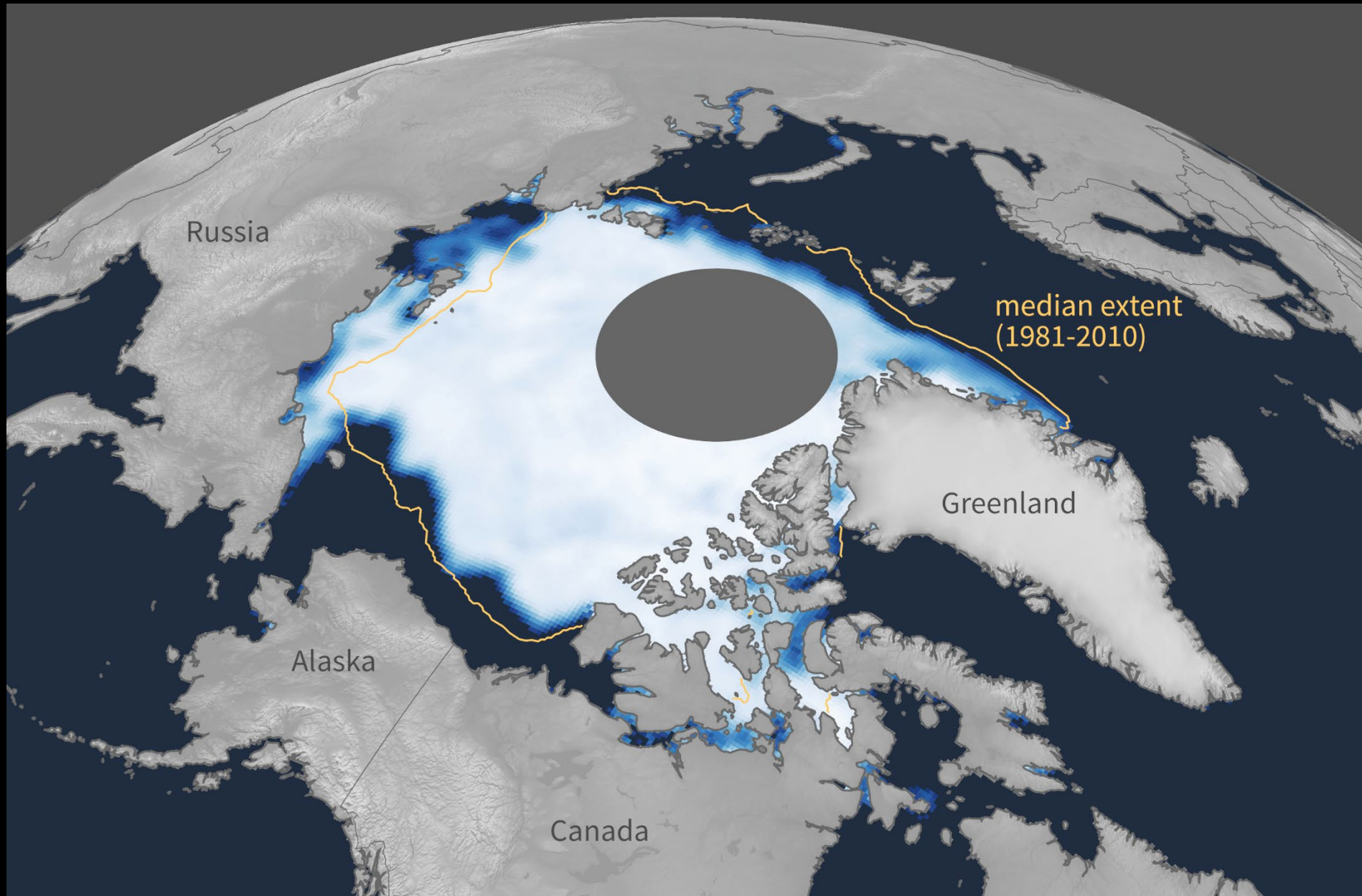
Sibirien

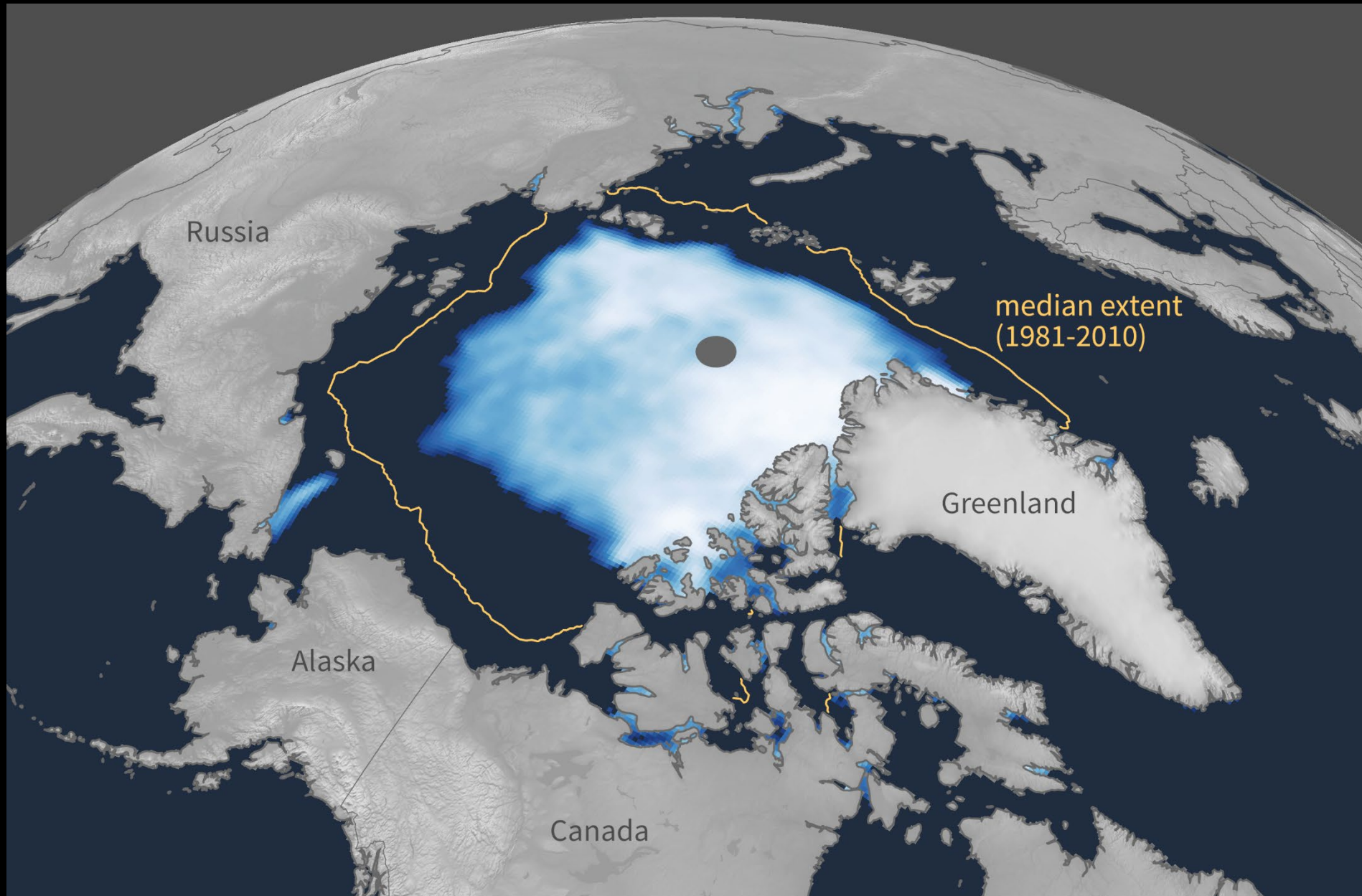


Vaks et al. 2013, Science.

Die Faltung des Wassers

Dresden, Juli 2026





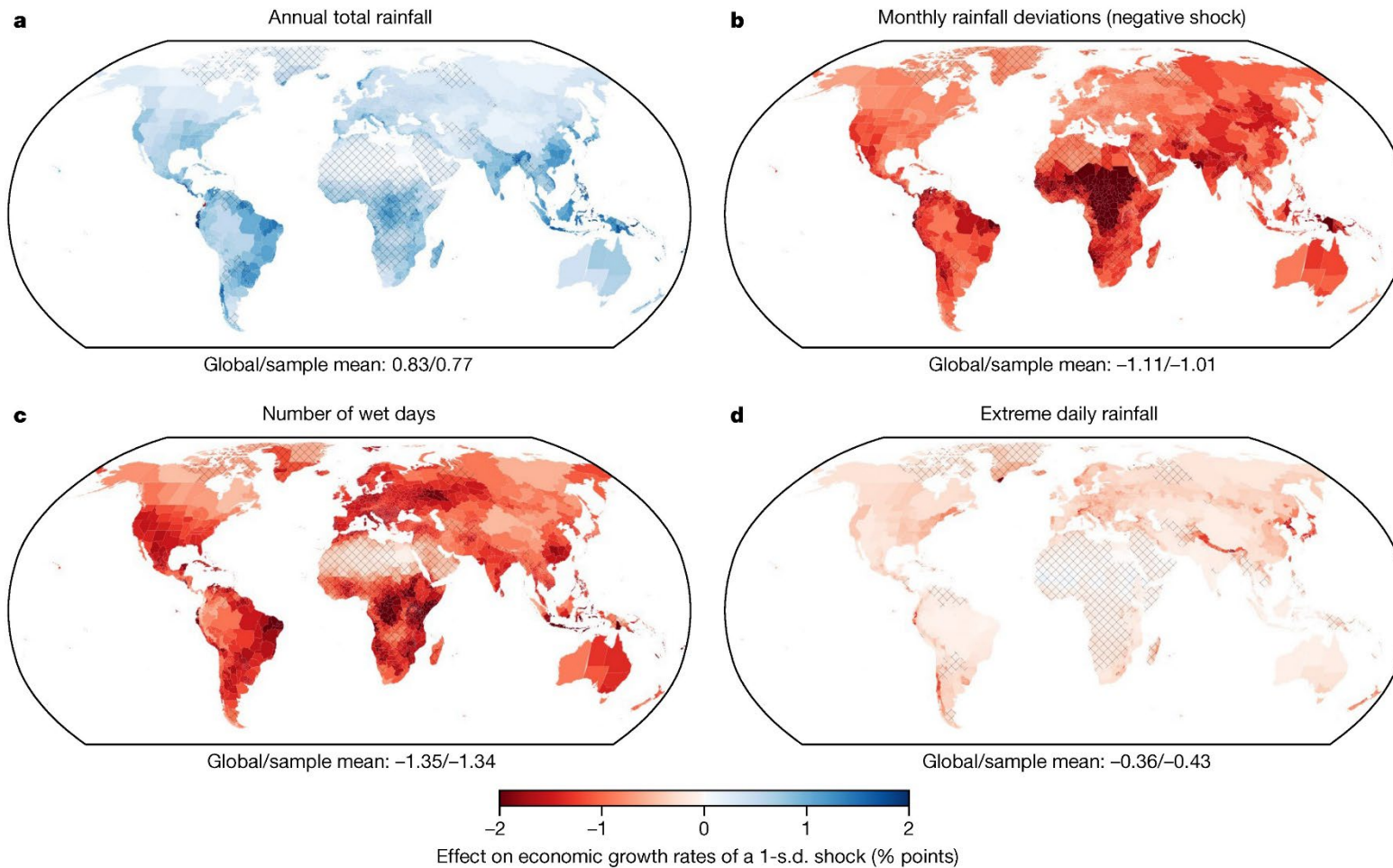
Wirtschaftliche Schäden

Hurricane Sandy impacted New York City in 2012.



Sand im Wirtschaftsgetriebe

Wetterschwankungen schlecht für Wirtschaftswachstum

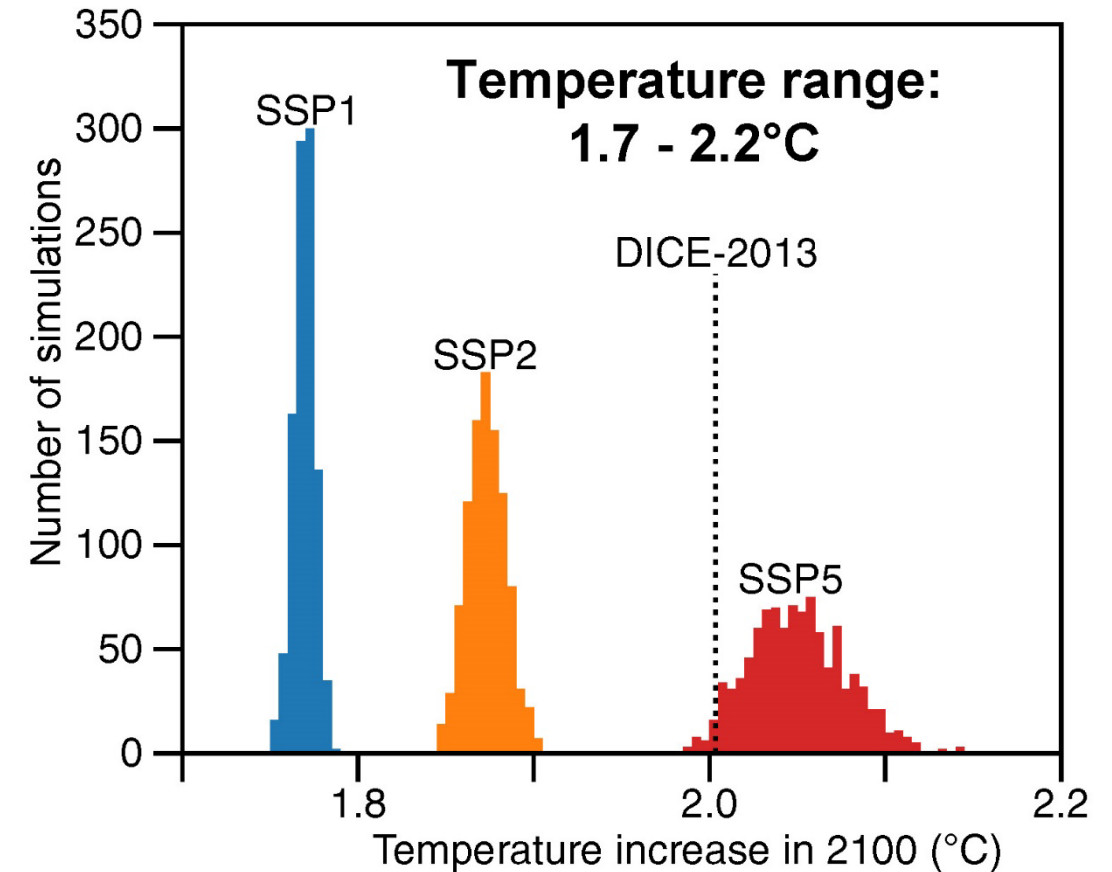
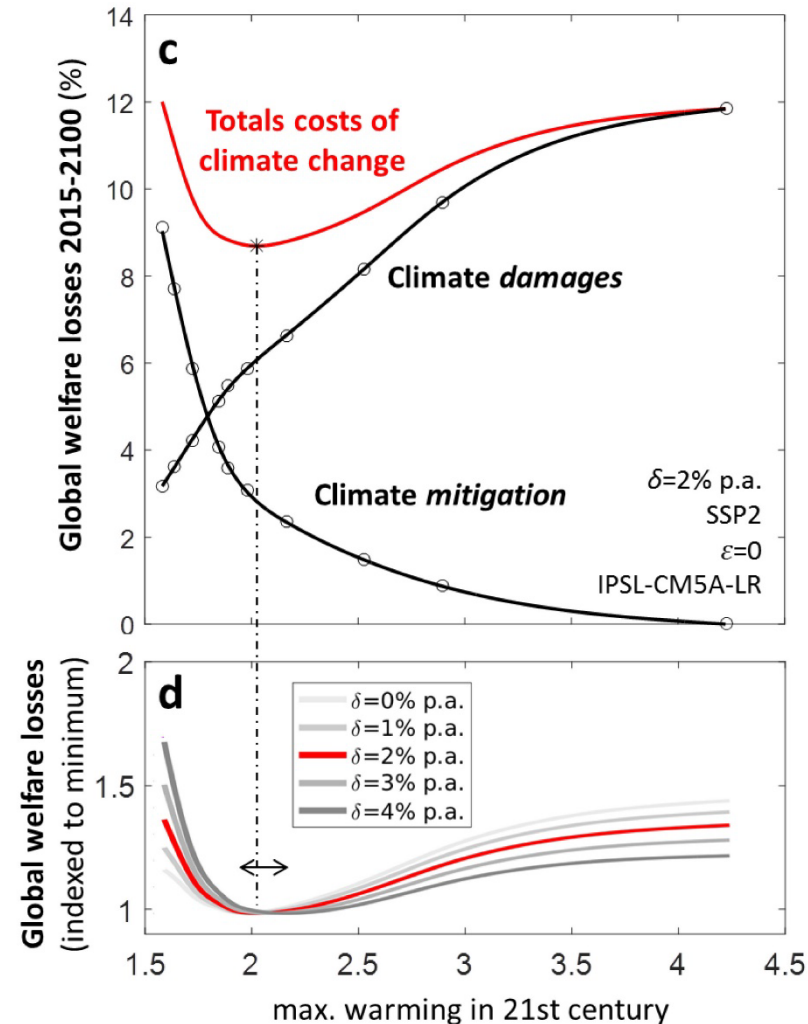


Kotz, Levermann, Wenz, 2022, Nature.

Kotz, Wenz, Stechemesser, Kalkuhl, Levermann, 2021, Nature Climate Change.

Ökonomisch optimale Strategie

ist das Pariser Klimaabkommen mit 2 Grad Grenze



Glanemann, Willner, Levermann, *Nature Comm.*, 2020.

Ueckerdt, Frieler, Lange, Wenz, Luderer, Levermann, *Earth Sys. Dyn.*, 2019.

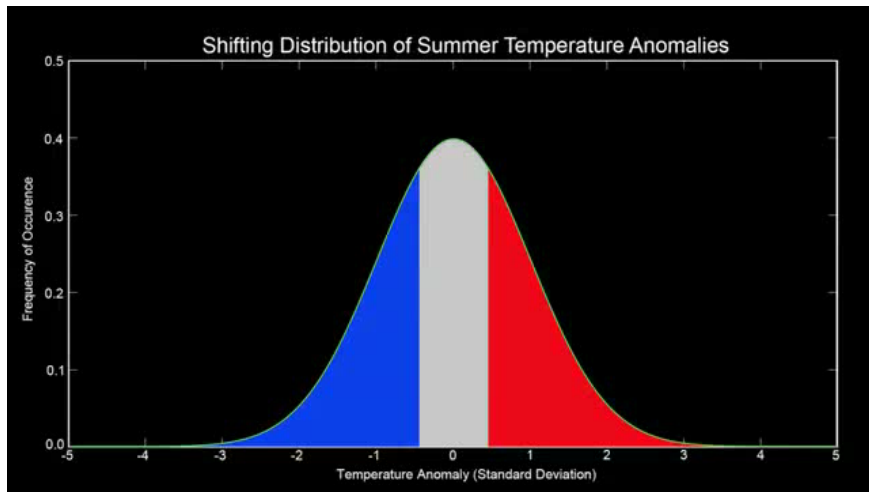
Wetterextreme



Wir wissen:

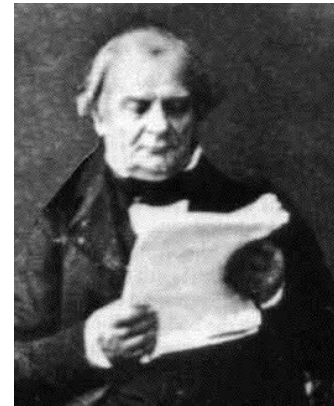
Wetterextreme werden heftiger und häufiger

Statistik



Europäische Sommertemperaturen

Physik

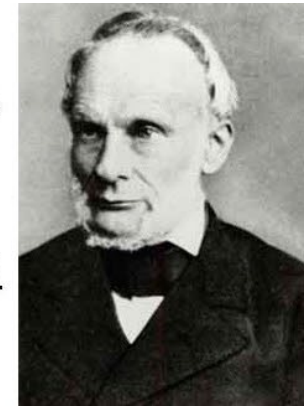


$$k = \left(1 - \frac{\delta}{\rho}\right) \frac{dp}{dt} C.$$

E. Clapeyron (1834)

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

R. Clausius (1850)

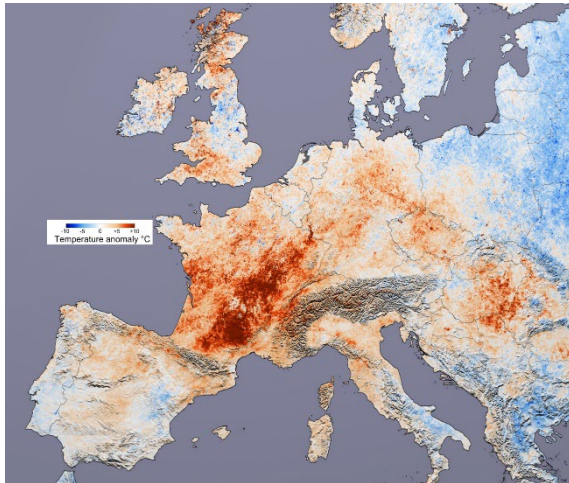


Clausius-Clapeyron equation

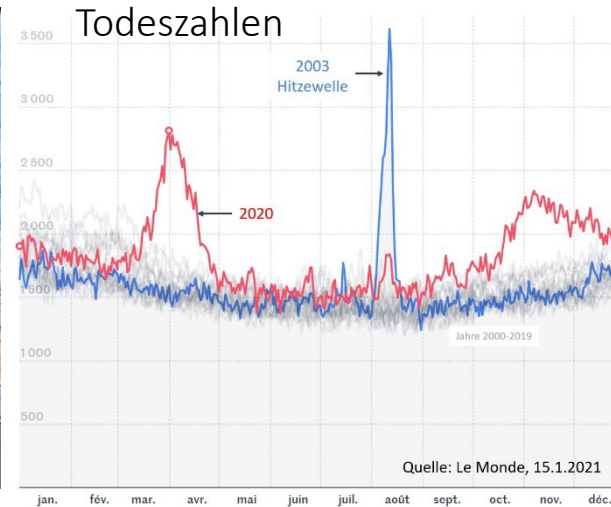
Zwei Beispiele

Wetterextreme werden heftiger und häufiger

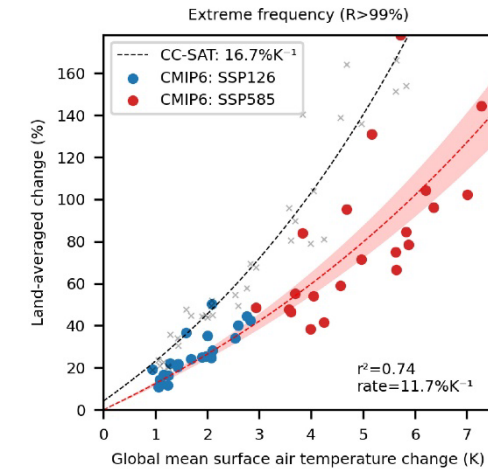
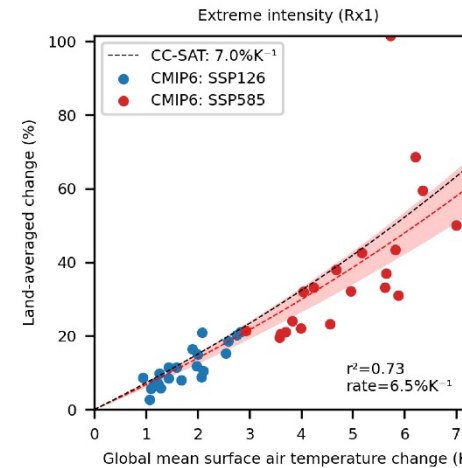
Statistik: Hitze



Europa 2003



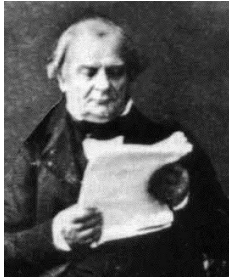
Physik: Überschwemmungen



Starkniederschlag unterschätzt von Modellen

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

Globales Überschwemmungsrisiko steigt



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

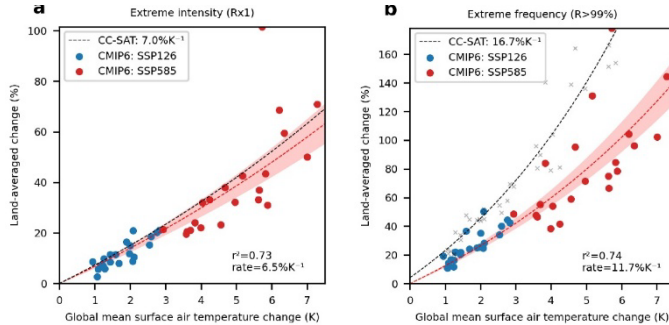
E. Clapeyron (1834)

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

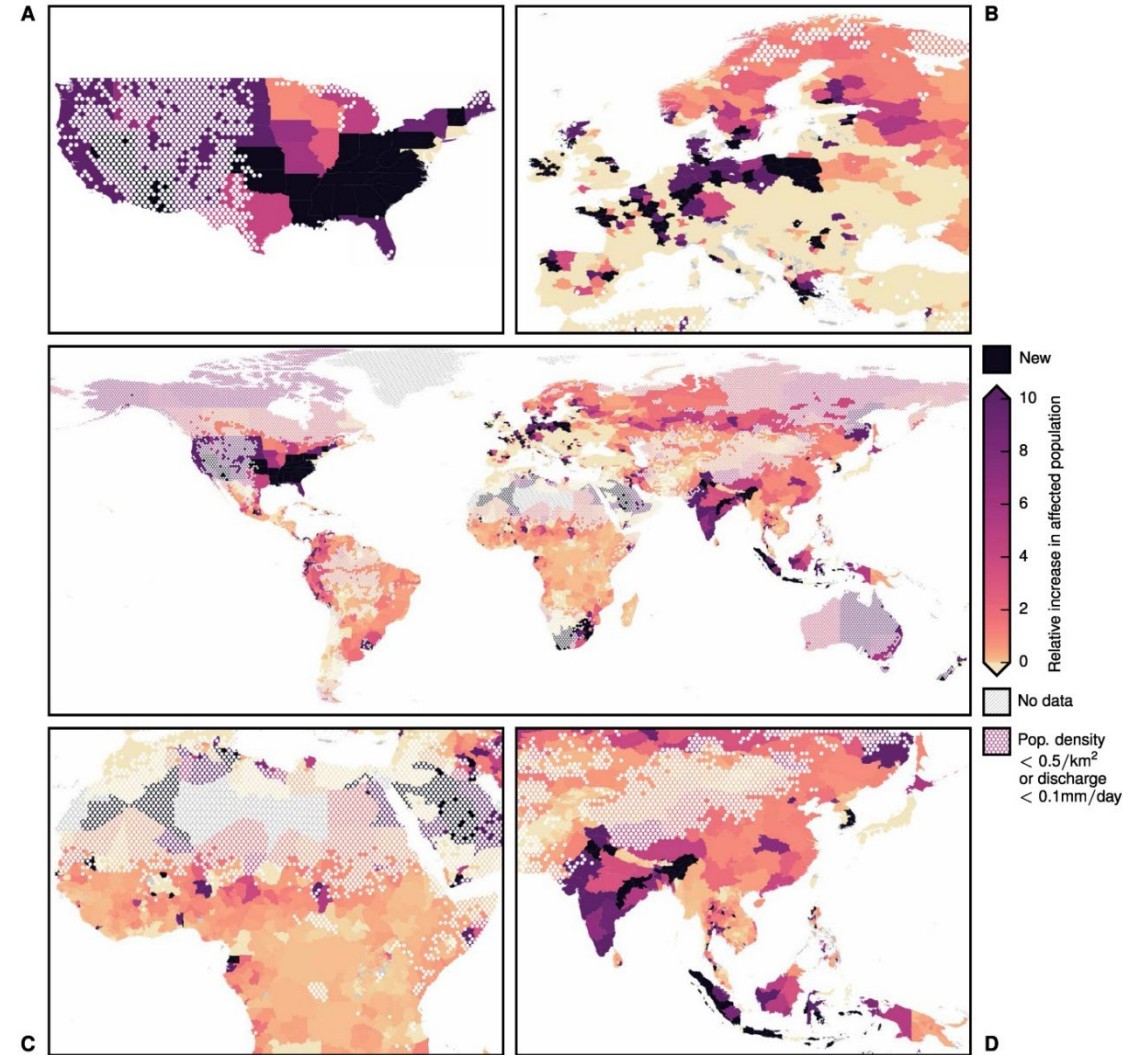
R. Clausius (1850)



Clausius-Clapeyron equation



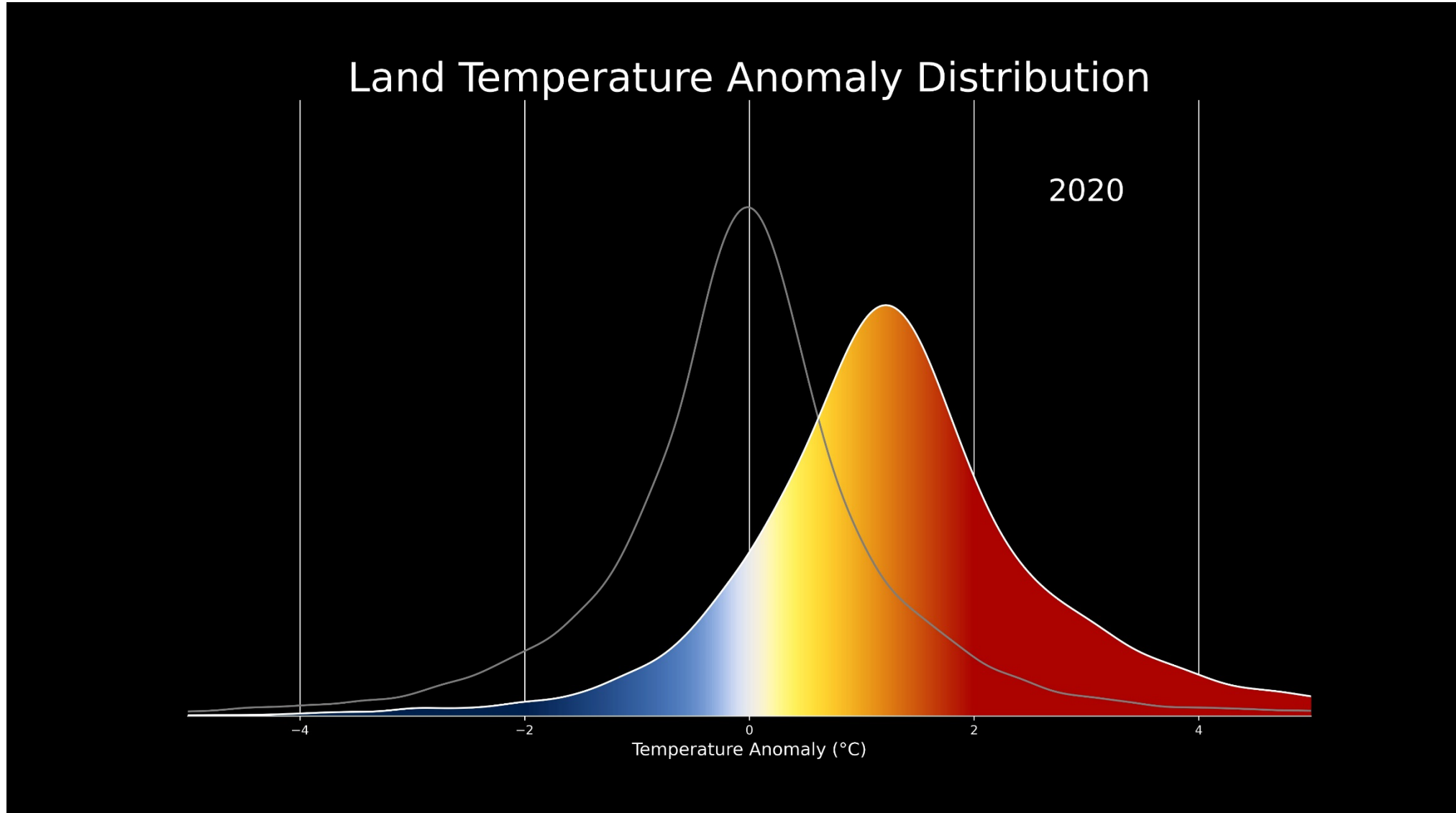
Computersimulationen



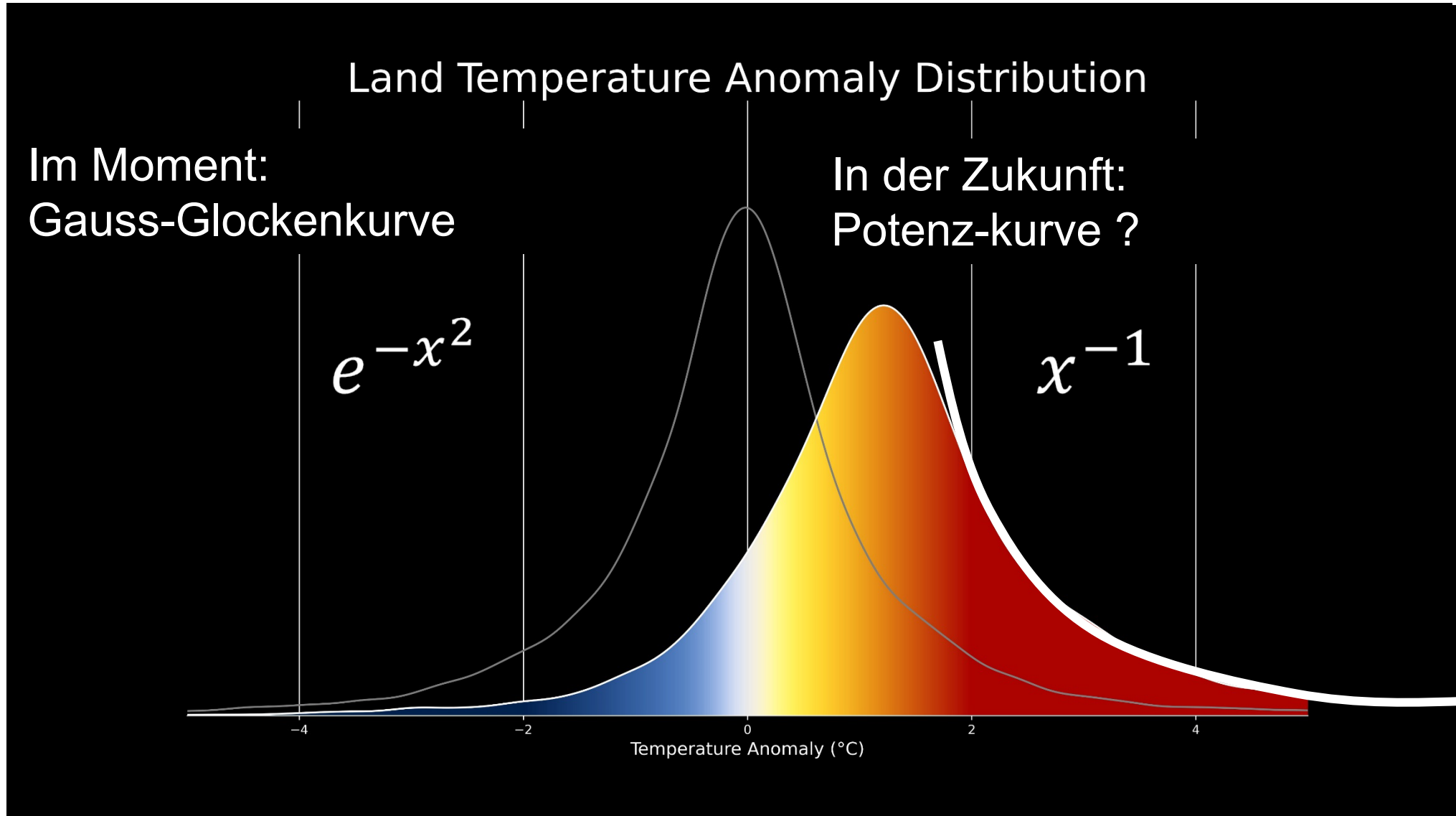
Betroffene Bevölkerung in 2045.

*Willner, Levermann et al.,
Science Adv, 2018.*

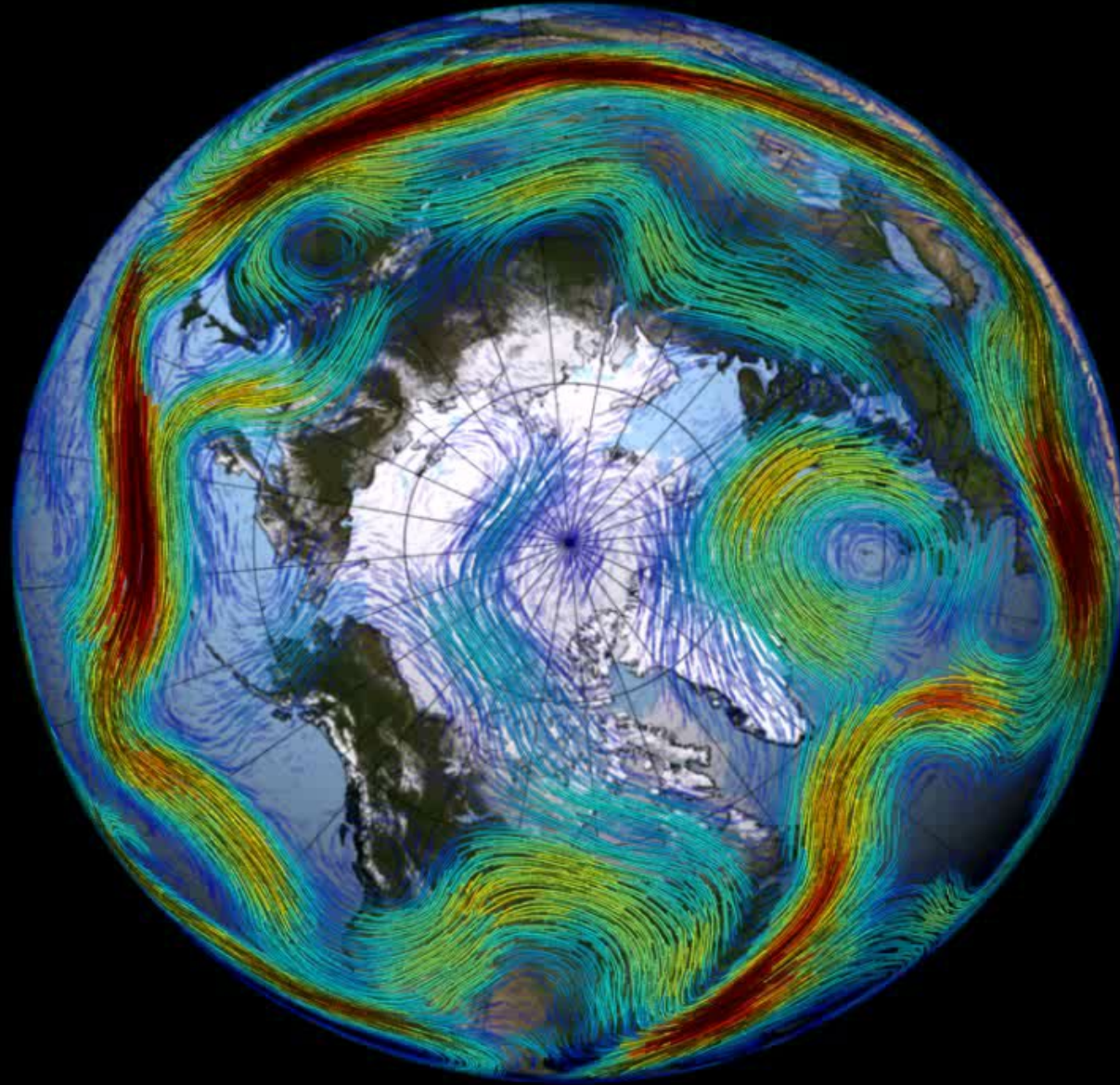
Versicherungsrisiko



Die Versicherungskatastrophe

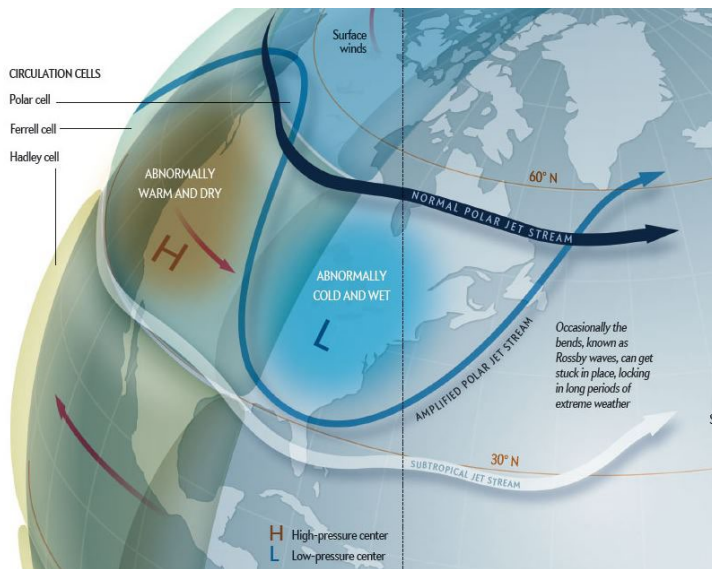


Der Jetstream

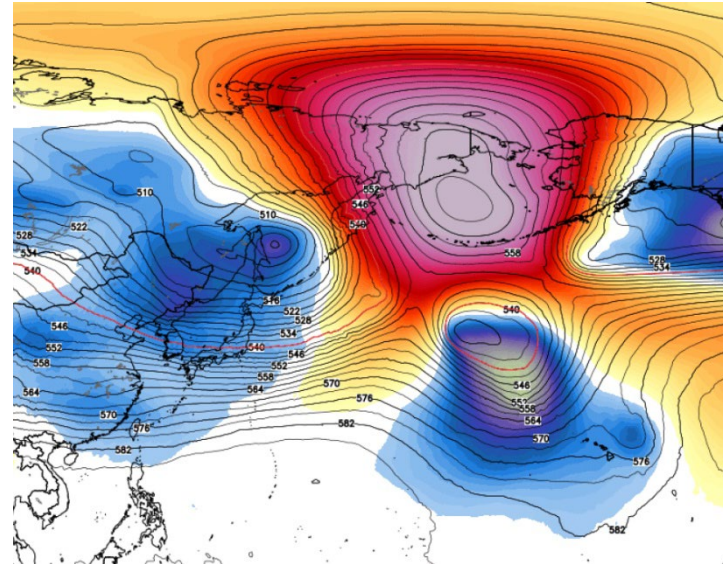


Der Winter 2017-2018

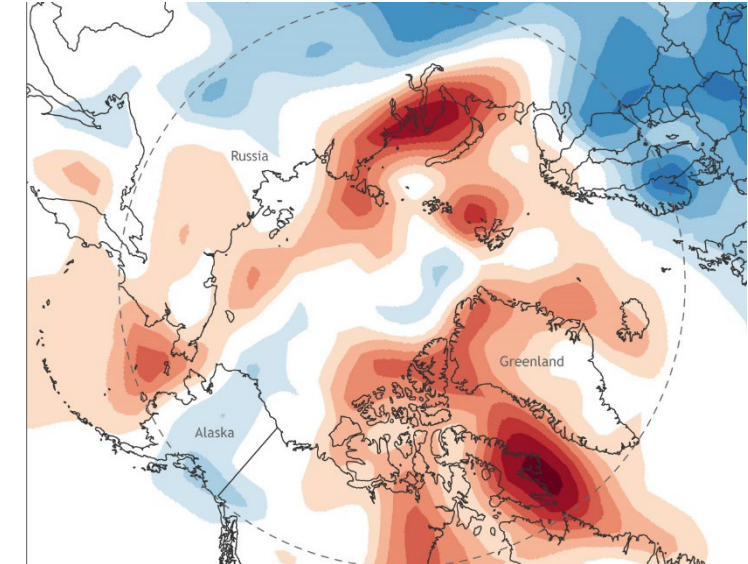
Dezember
Schneekatastrophe
USA



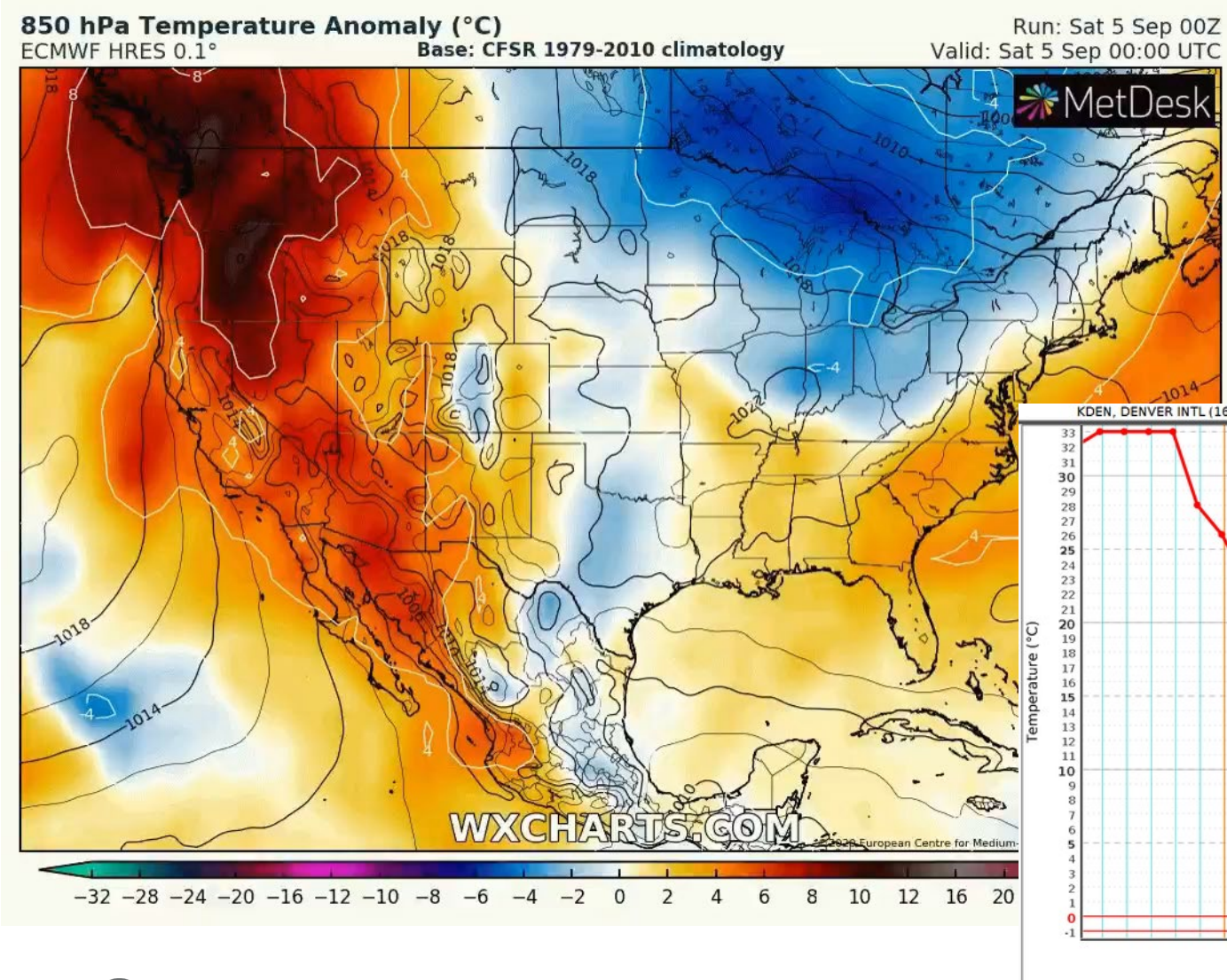
Januar
Temperatursprung
Sibirien



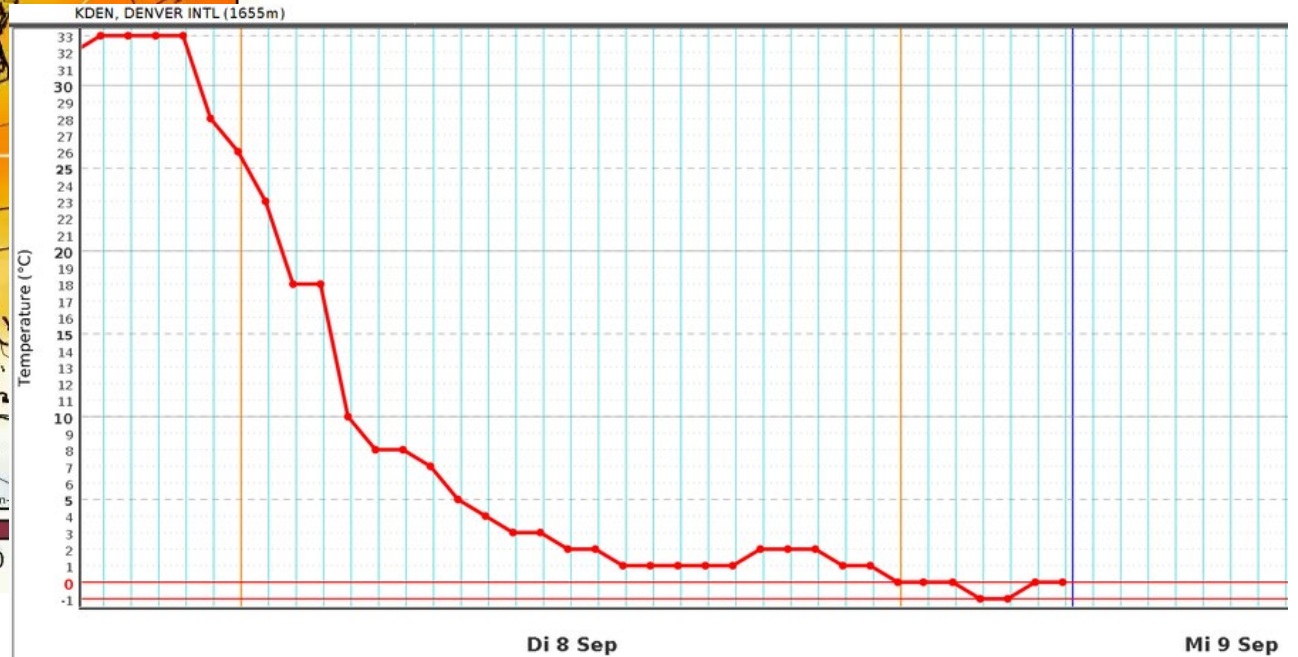
Februar
Schmelzender
Nordpol



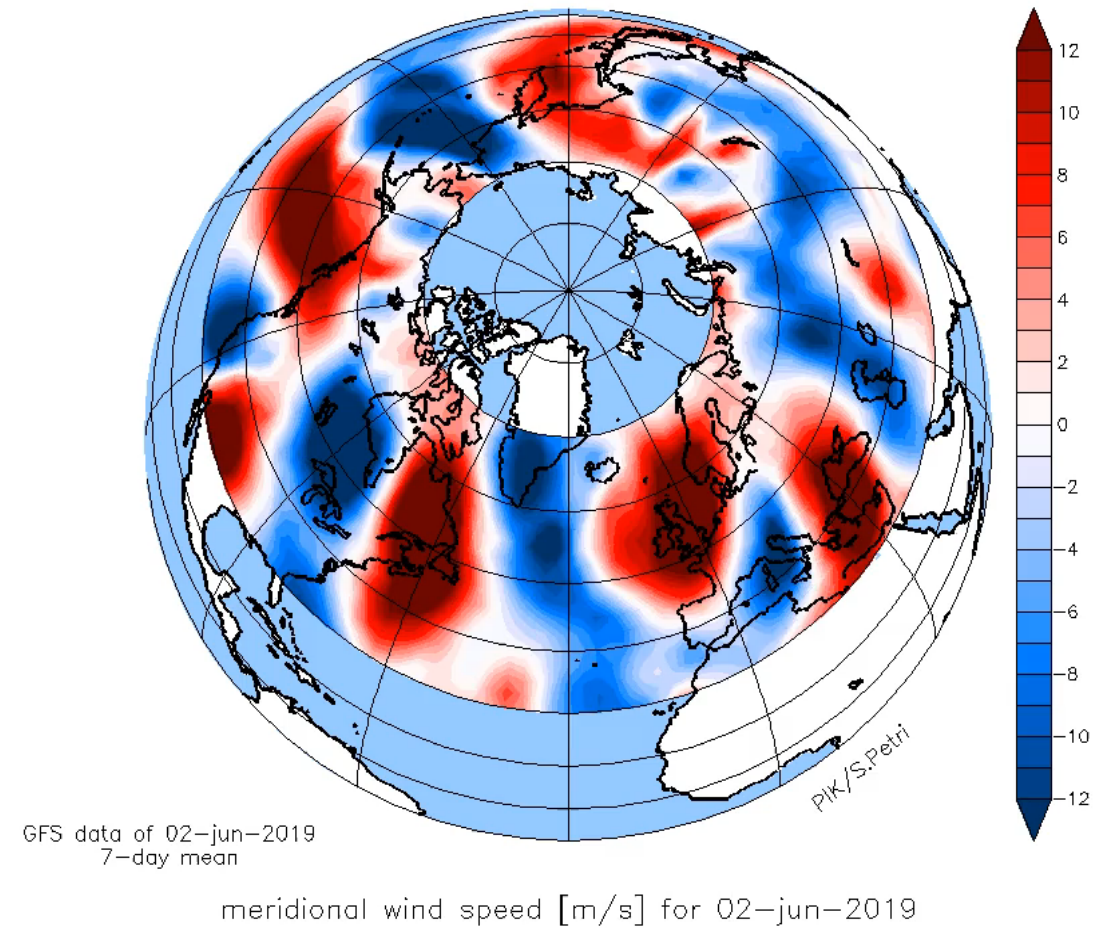
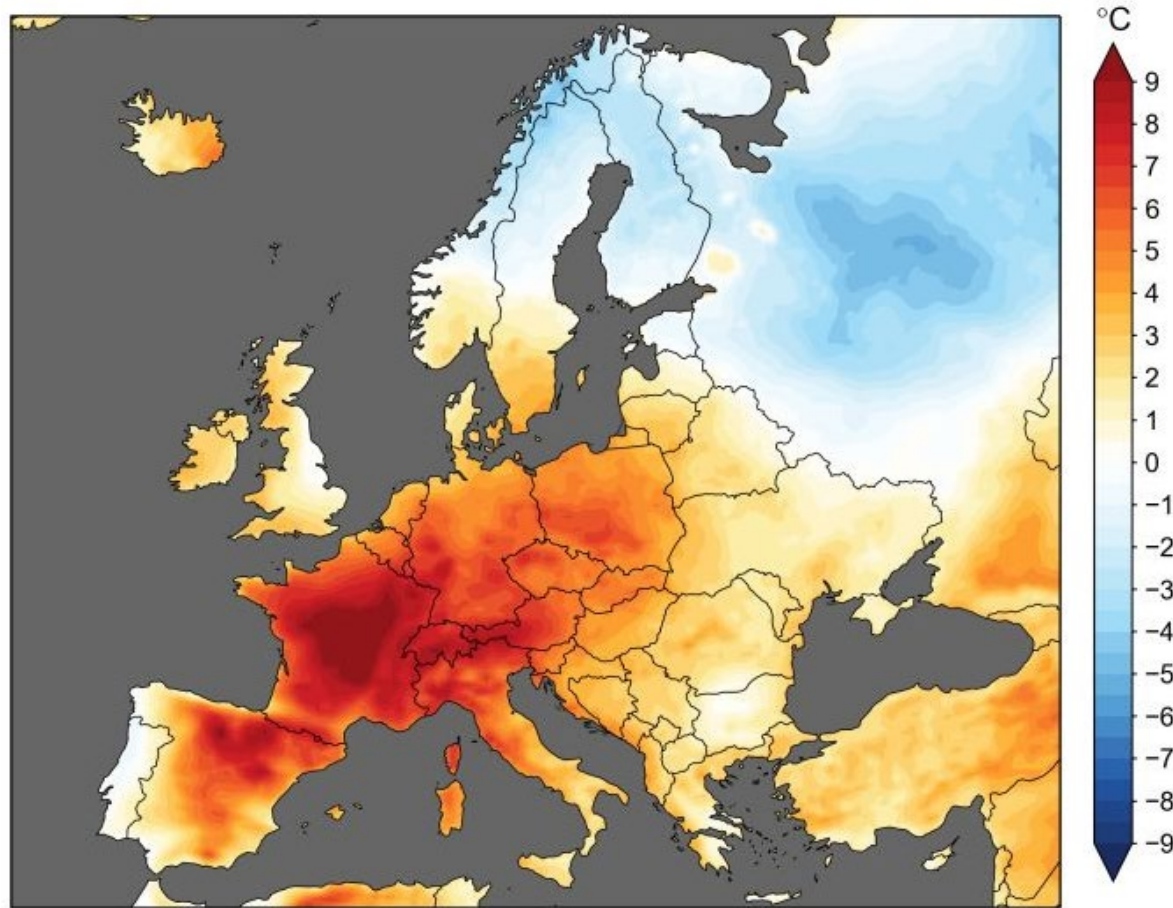
Mittlerer Westen der USA 2020



Temperatursturz:
35°C in 24h

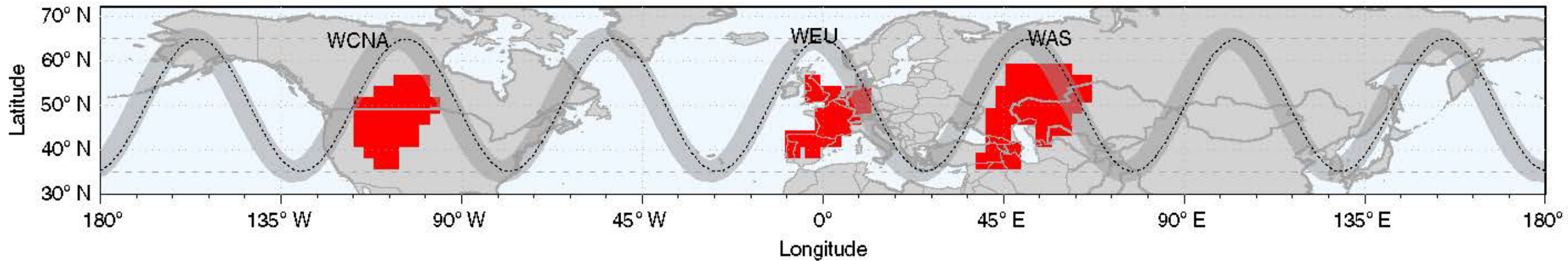


Europäischer Sommer 2019



Jet Stream Resonanz 2019

Dürre in allen drei Brotkörbe der Erde gleichzeitig.

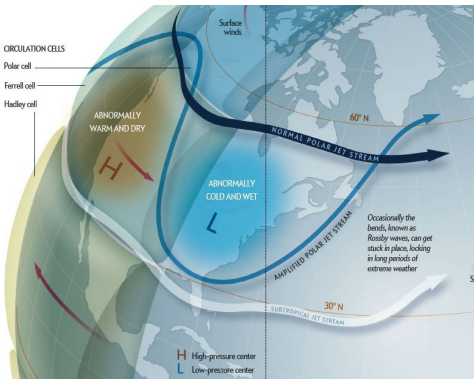


Kornhuber et al. ERL (2019).
Kornhuber et al. Nature CC (2020).

Wetterextreme: immer mehr immer heftiger

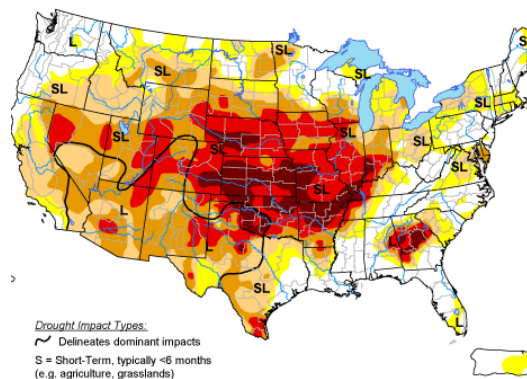
Was wenn wir keine Zeit mehr haben aufzuräumen?

Dec
2018



Schneechaos
NY-Chicago

Mar-Aug
2012



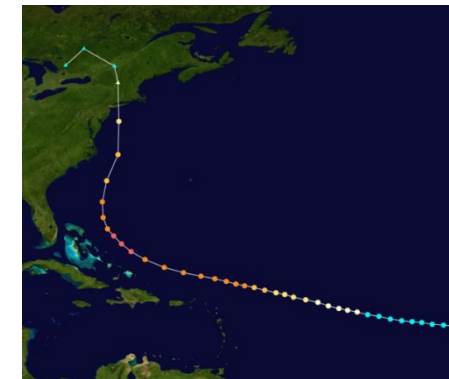
Dürre im mittleren
Westen der USA

Aug
2005



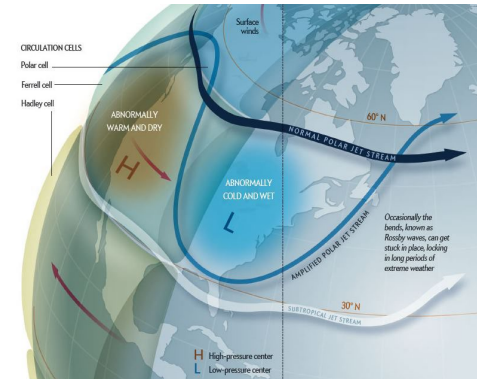
Hurricane
Katrina

Oct-Nov
2012



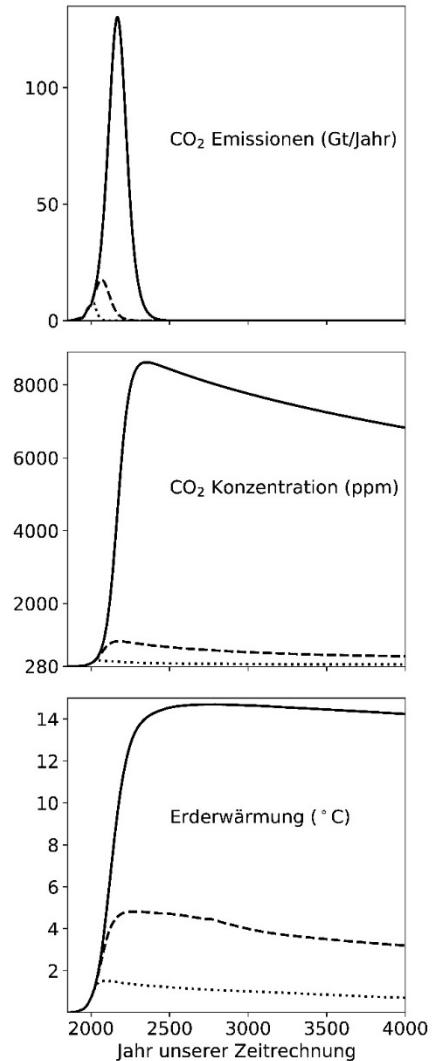
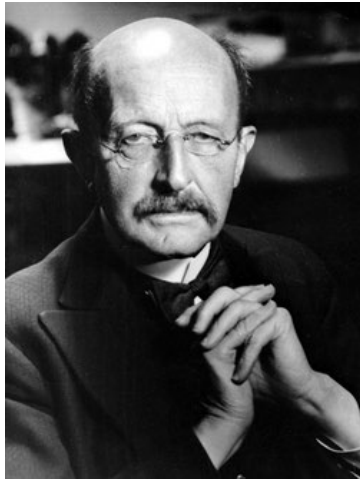
Hurricane
Sandy

Dec
2019



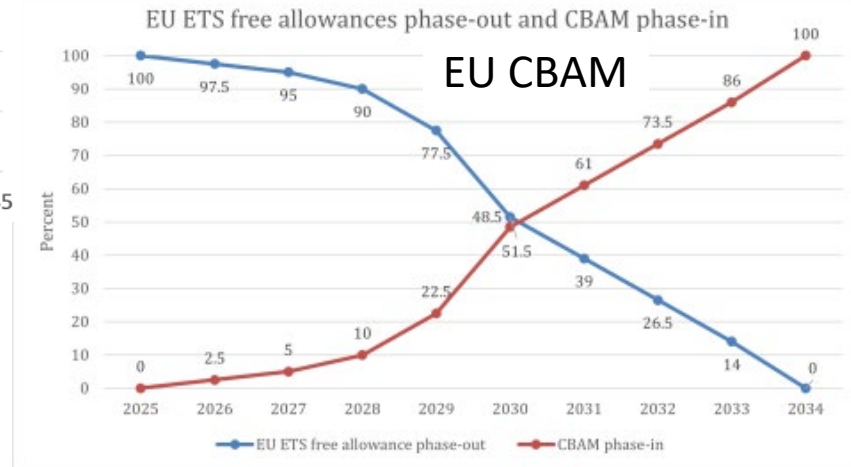
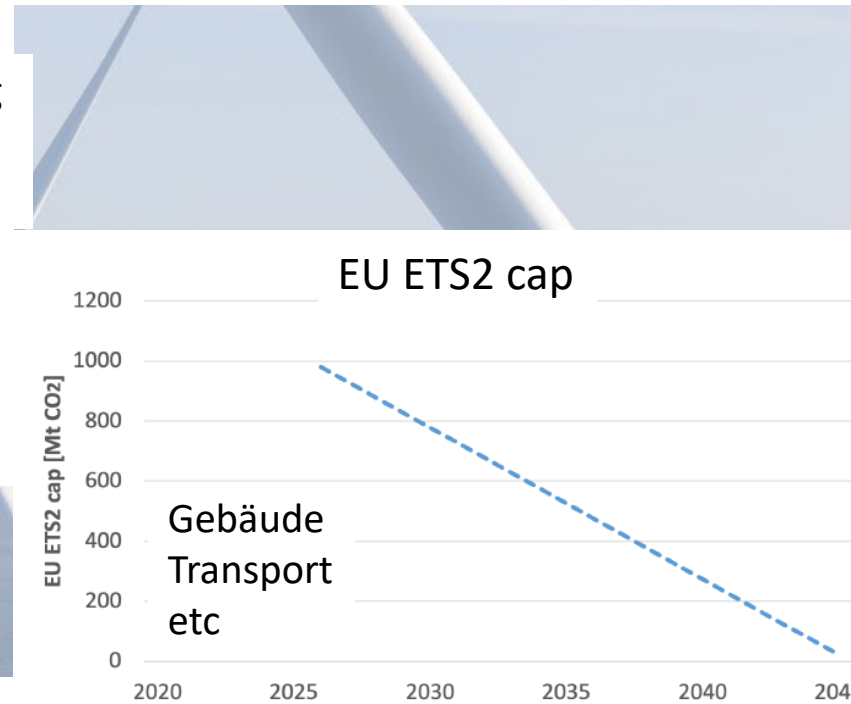
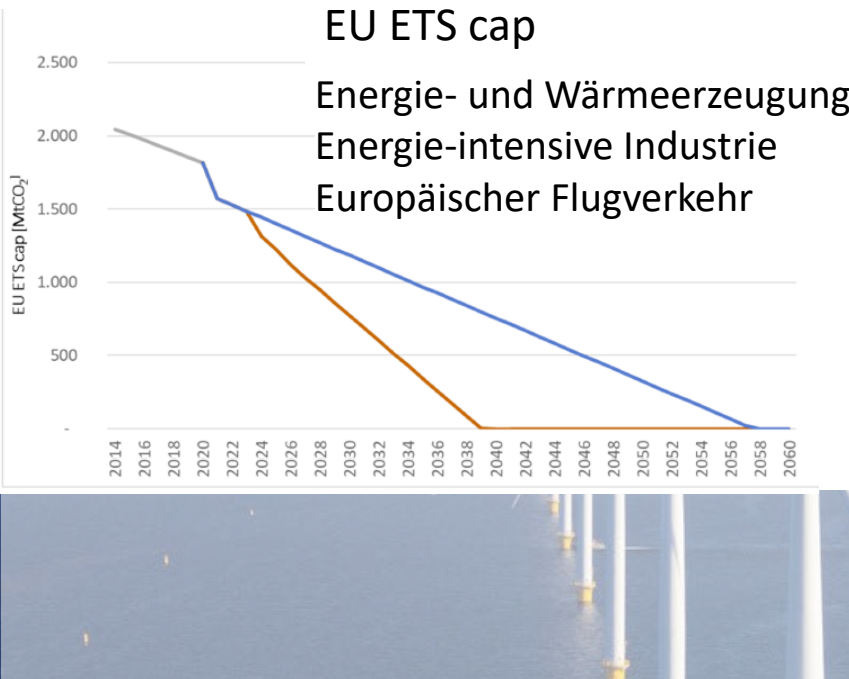
Schneechaos
NY-Chicago

Wir müssen auf Null Emissionen.



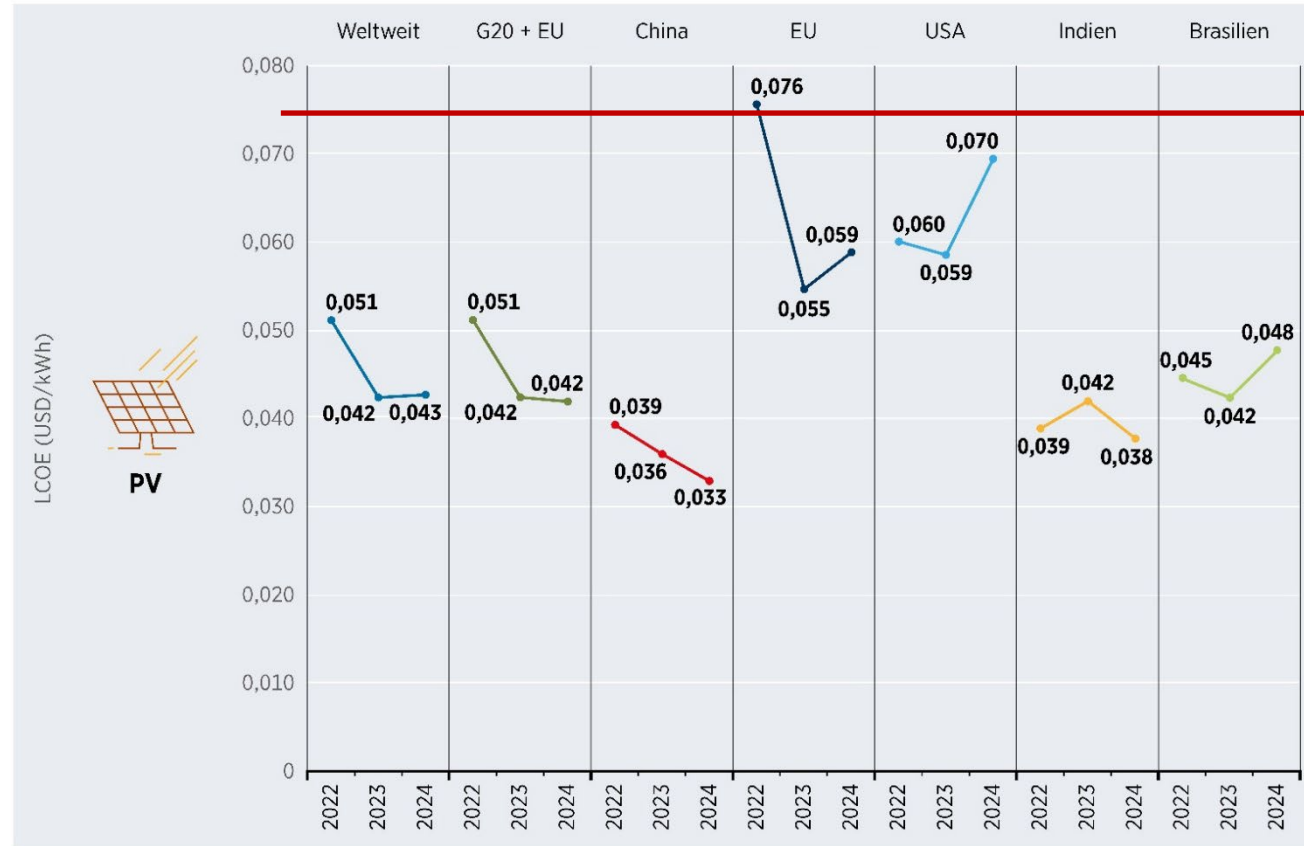
Wir haben die Lösungen

Europäischer Emissionshandel



Wir haben die Lösungen

Erneuerbare sind billiger als Kohle



Kohlepreis
(weltweiter Durchschnitt)

Anmerkung: EU = Europäische Union; G20 = Gruppe der 20; kWh = Kilowattstunde; LCOE = Stromgestehungskosten; PV = Photovoltaik; USD = US-Dollar.

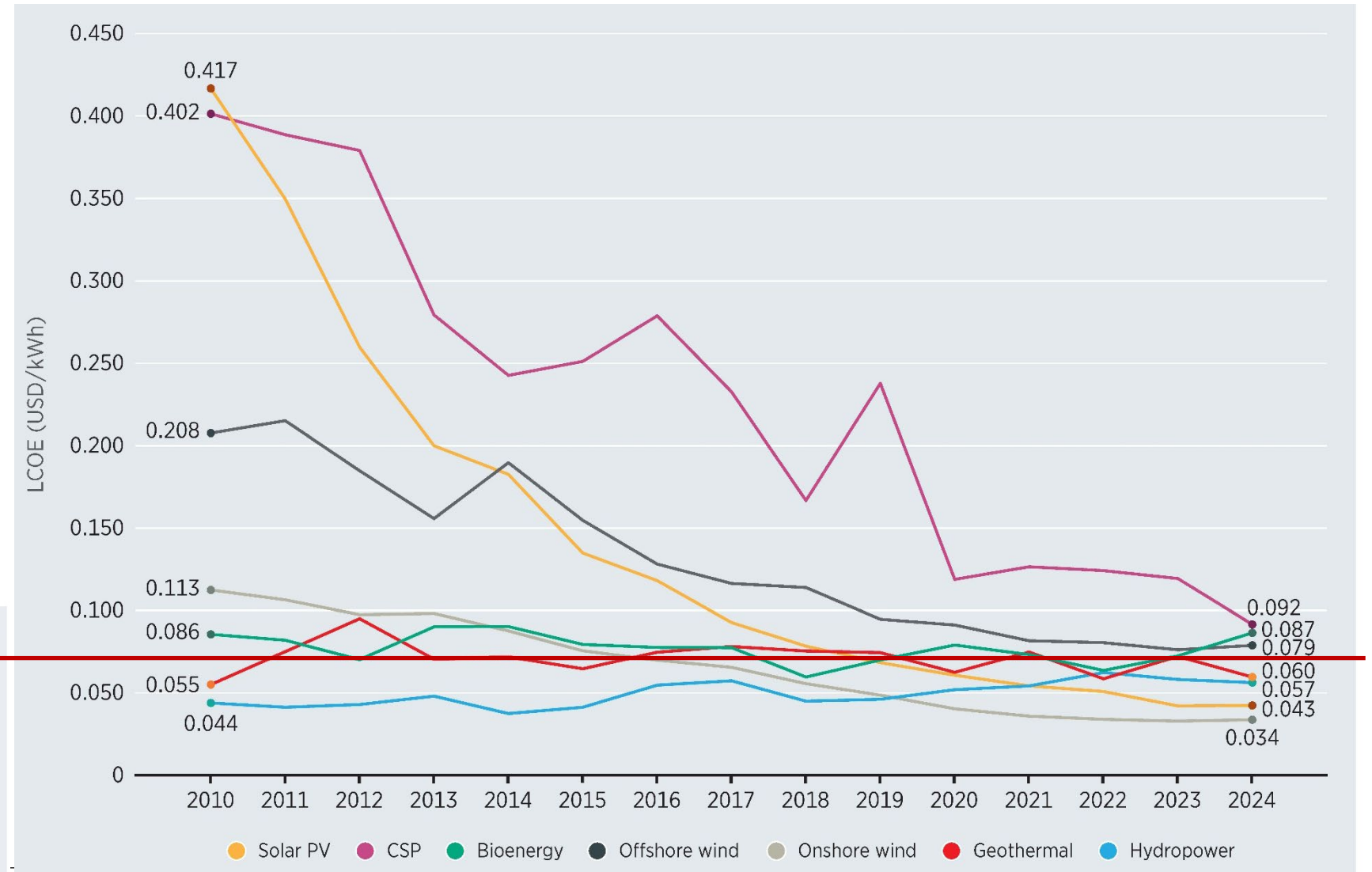
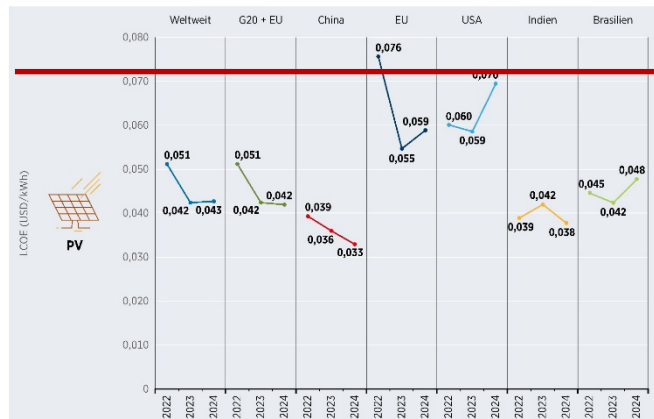
⁴ Die weltweit durchschnittlichen Stromgestehungskosten (LCOE) für Kohlekraft lagen bei 0,073 USD/kWh und für GuD-Kraftwerke bei 0,085 USD/kWh.

Wir haben die Lösungen

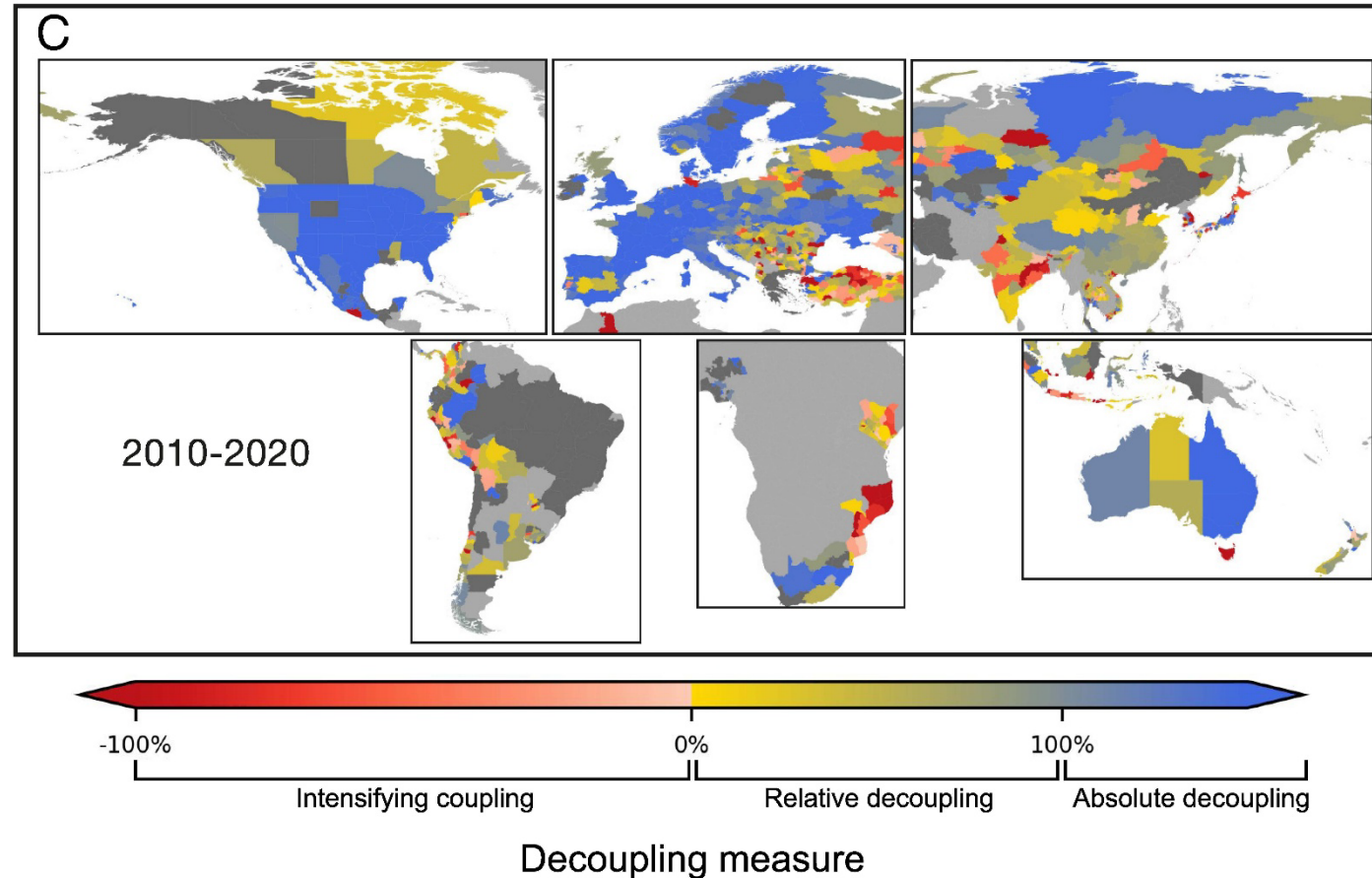
Erneuerbare sind billiger als Kohle



Kohlepreis
(weltweiter Durchschnitt)



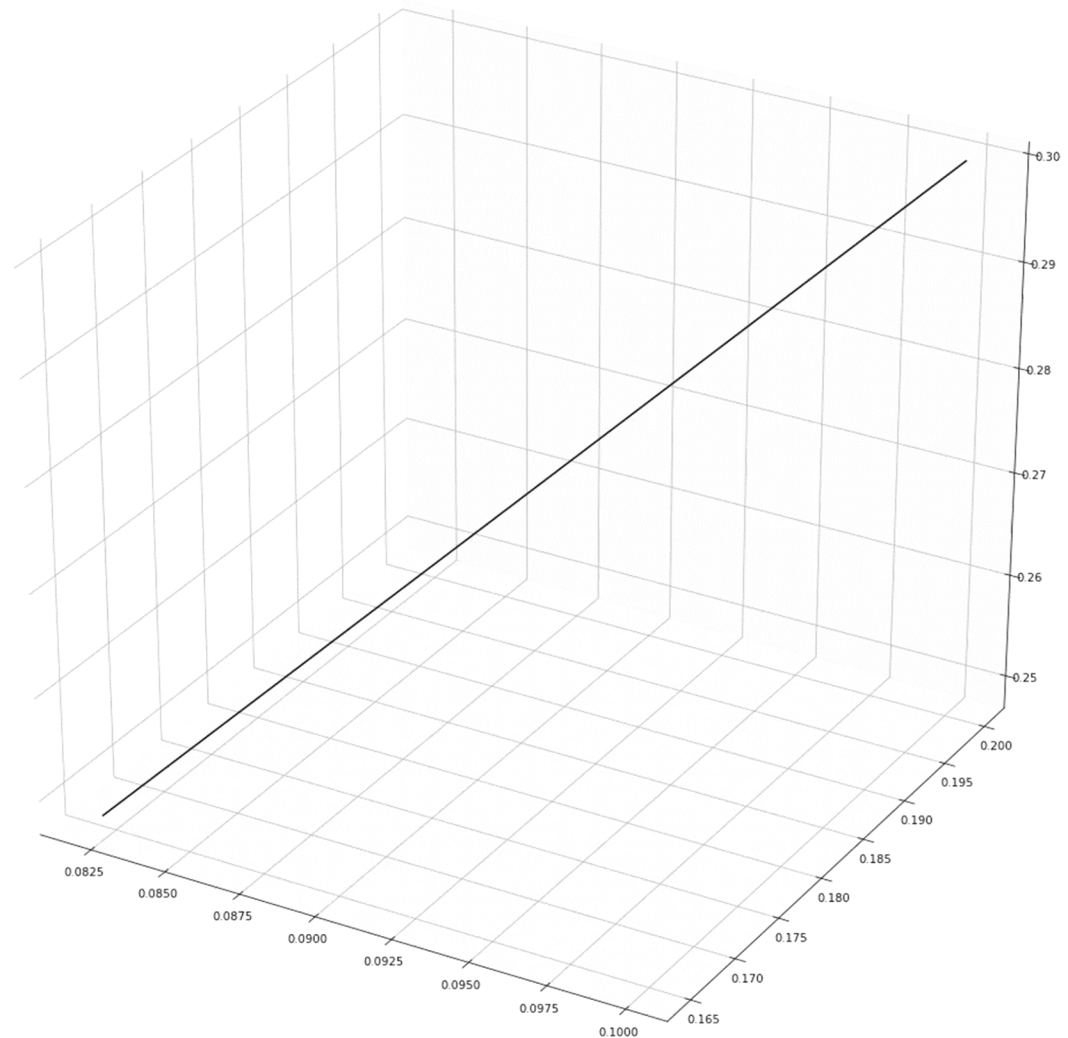
Weltwirtschaft entkoppelt von CO₂



Zioga, Kotz, Levermann
Proceedings of the National Academy of Science, 2024.

Was ist Die Faltung des Wassers ?

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





foldingtheworld.net

faltungderwelt.de



Prof. Anders Levermann, PhD