2017年(第26回)　ブループラネット賞
受賞者記念講演会

2017 Blue Planet Prize
Commemorative Lectures

ハンス・J・シェルンフーバー教授
講演スライド集

「Out of the Ice, into the Fire?」

Professor Hans J. Schellnhuber

Slides for the Lecture

" Out of the Ice, into the Fire? "

Blue Planet Prize 2017, Commemorative Lecture,
Tokyo, 19 October 2017

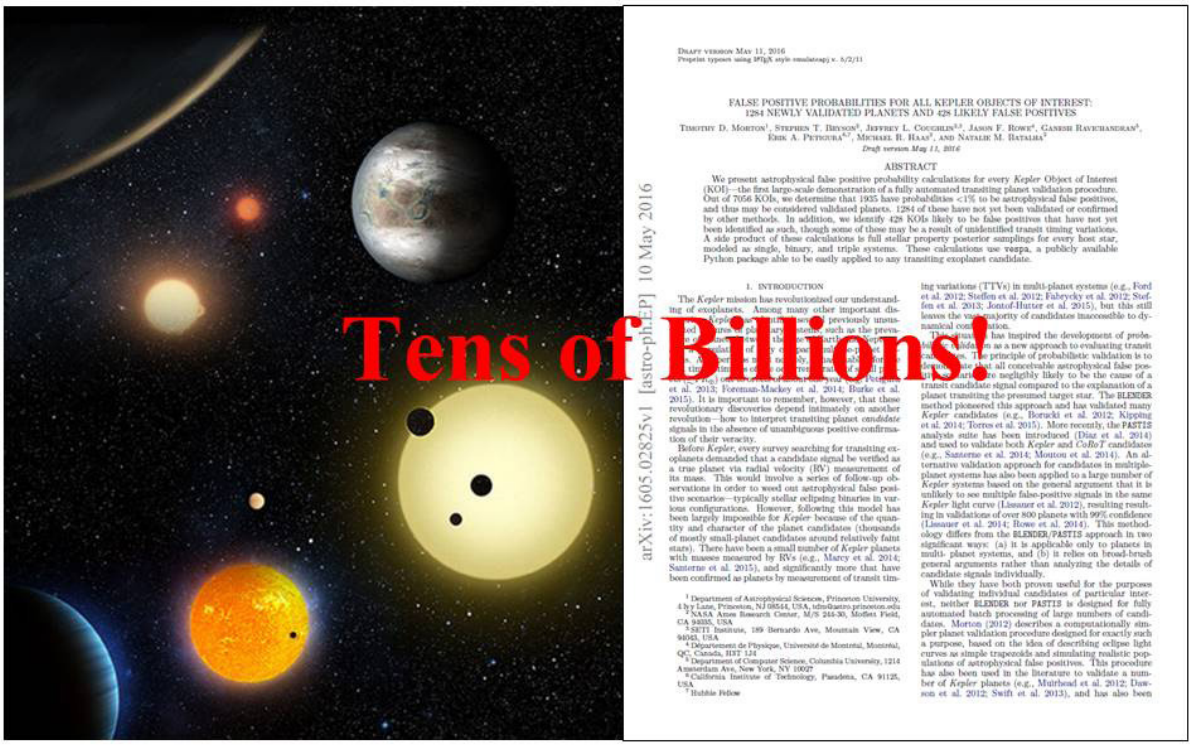
Out of the Ice – into the Fire?

Hans Joachim Schellnhuber

Director, Potsdam Institute for Climate Impact Research;
Professor for Theoretical Physics, University of Potsdam;
Senior Research Fellow, Stockholm Resilience Centre

PIK

How Many Earth-like Planets Are There?



Tens of Billions!

DRAFT VERSION MAY 11, 2016
Preprint typeset using LaTeX style emulateapj v. 5/2/11

FALSE POSITIVE PROBABILITIES FOR ALL KEPLER OBJECTS OF INTEREST:
1284 NEWLY VALIDATED PLANETS AND 428 LIKELY FALSE POSITIVES

TIMOTHY D. MORTON[1], STEPHEN T. BRYSON[2], JEFFREY L. COUGHLIN[2,3], JASON F. ROWE[4], GANESH RAVICHANDRAN[5],
ERIK A. PETIGURA[6,7], MICHAEL R. HAAS[2], AND NATALIE M. BATALHA[2]
Draft version May 11, 2016

arXiv:1605.02825v1 [astro-ph.EP] 10 May 2016

ABSTRACT

We present astrophysical false positive probability calculations for every *Kepler* Object of Interest (KOI)—the first large-scale demonstration of a fully automated transiting planet validation procedure. Out of 7056 KOIs, we determine that 1935 have probabilities <1% to be astrophysical false positives, and thus may be considered validated planets. 1284 of these have not yet been validated or confirmed by other methods. In addition, we identify 428 KOIs likely to be false positives that have not yet been identified as such, though some of these may be a result of unidentified transit timing variations. A side product of these calculations is full stellar property posterior samplings for every host star, modeled as single, binary, and triple systems. These calculations use `vespa`, a publicly available Python package able to be easily applied to any transiting exoplanet candidate.

1. INTRODUCTION

The *Kepler* mission has revolutionized our understanding of exoplanets. Among many other important dis- [illegible] previously unsus- [illegible] such as the preva- [illegible] et al. 2013; Foreman-Mackey et al. 2014; Burke et al. 2015). It is important to remember, however, that these revolutionary discoveries depend intimately on another revolution—how to interpret transiting planet *candidate* signals in the absence of unambiguous positive confirmation of their veracity.

Before *Kepler*, every survey searching for transiting exoplanets demanded that a candidate signal be verified as a true planet via radial velocity (RV) measurement of its mass. This would involve a series of follow-up observations in order to weed out astrophysical false positive scenarios—typically stellar eclipsing binaries in various configurations. However, following this model has been largely impossible for *Kepler* because of the quantity and character of the planet candidates (thousands of mostly small-planet candidates around relatively faint stars). There have been a small number of *Kepler* planets with masses measured by RVs (e.g., Marcy et al. 2014; Santerne et al. 2015), and significantly more that have been confirmed as planets by measurement of transit timing variations (TTVs) in multi-planet systems (e.g., Ford et al. 2012; Steffen et al. 2012; Fabrycky et al. 2012; Steffen et al. 2013; Jontof-Hutter et al. 2015), but this still leaves the vast majority of candidates inaccessible to dynamical confirmation.

This situation has inspired the development of probabilistic validation as a new approach to evaluating transit candidates. The principle of probabilistic validation is to demonstrate that all conceivable astrophysical false positive scenarios are negligibly likely to be the cause of a transit candidate signal compared to the explanation of a planet transiting the presumed target star. The `BLENDER` method pioneered this approach and has validated many *Kepler* candidates (e.g., Borucki et al. 2012; Kipping et al. 2014; Torres et al. 2015). More recently, the `PASTIS` analysis suite has been introduced (Díaz et al. 2014) and used to validate both *Kepler* and *CoRoT* candidates (e.g., Santerne et al. 2014; Moutou et al. 2014). An alternative validation approach for candidates in multiple-planet systems has also been applied to a large number of *Kepler* systems based on the general argument that it is unlikely to see multiple false-positive signals in the same *Kepler* light curve (Lissauer et al. 2012), resulting resulting in validations of over 800 planets with 99% confidence (Lissauer et al. 2014; Rowe et al. 2014). This methodology differs from the `BLENDER`/`PASTIS` approach in two significant ways: (a) it is applicable only to planets in multi- planet systems, and (b) it relies on broad-brush general arguments rather than analyzing the details of candidate signals individually.

While they have both proven useful for the purposes of validating individual candidates of particular interest, neither `BLENDER` nor `PASTIS` is designed for fully automated batch processing of large numbers of candidates. Morton (2012) describes a computationally simpler planet validation procedure designed for exactly such a purpose, based on the idea of describing eclipse light curves as simple trapezoids and simulating realistic populations of astrophysical false positives. This procedure has also been used in the literature to validate a number of *Kepler* planets (e.g., Muirhead et al. 2012; Dawson et al. 2012; Swift et al. 2013), and has also been

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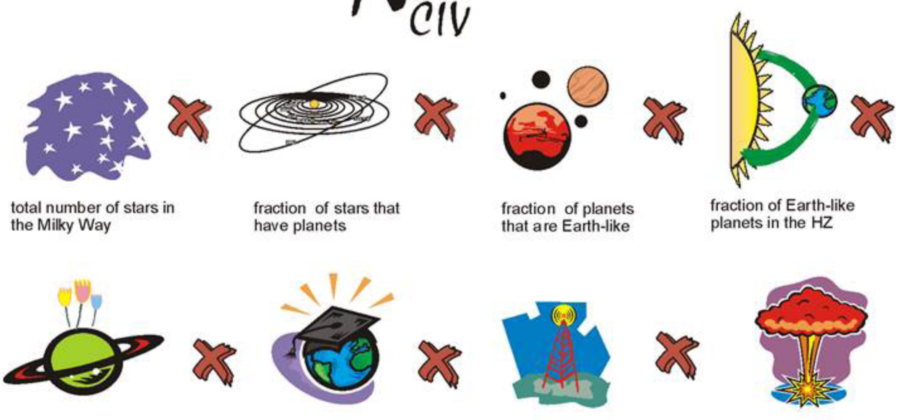
[4] Département de Physique, Université de Montréal, Montréal, QC, Canada, H3T 1J4
[5] Department of Computer Science, Columbia University, 1214 Amsterdam Ave, New York, NY 10027
[6] California Institute of Technology, Pasadena, CA 91125, USA
[7] Hubble Fellow

How Many Technical Civilizations Are There?

$N_{civ} =$



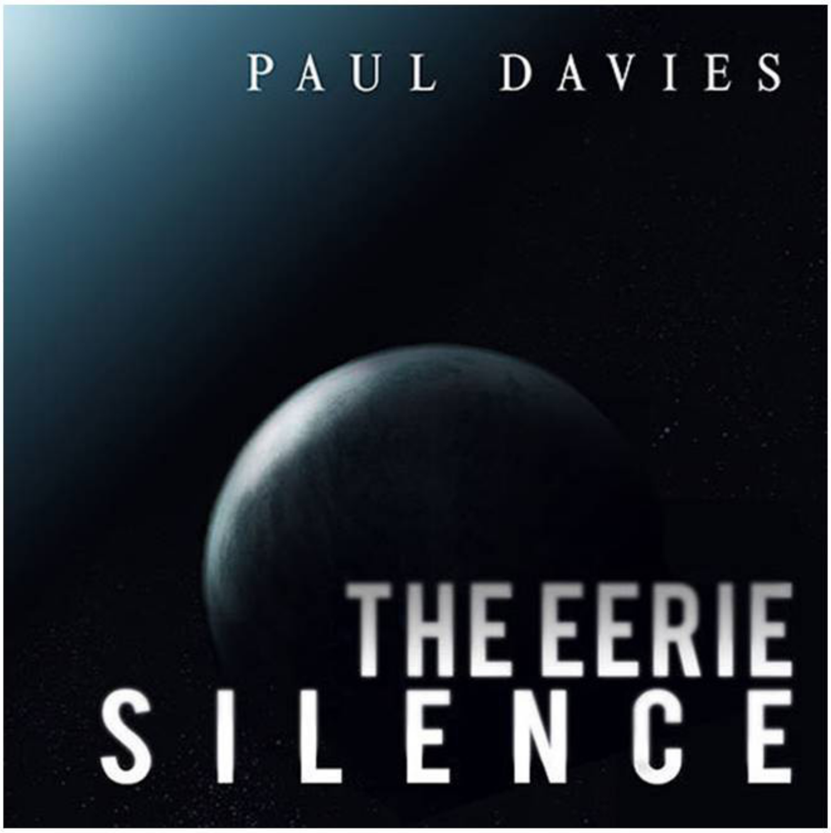
total number of stars in the Milky Way × fraction of stars that have planets × fraction of planets that are Earth-like × fraction of Earth-like planets in the HZ ×

fraction of habitable planets that develop life × fraction of habitable planets that develop intelligent life × fraction of intelligent life that develops radio technology × normalized mean life time of an intelligent civilisation

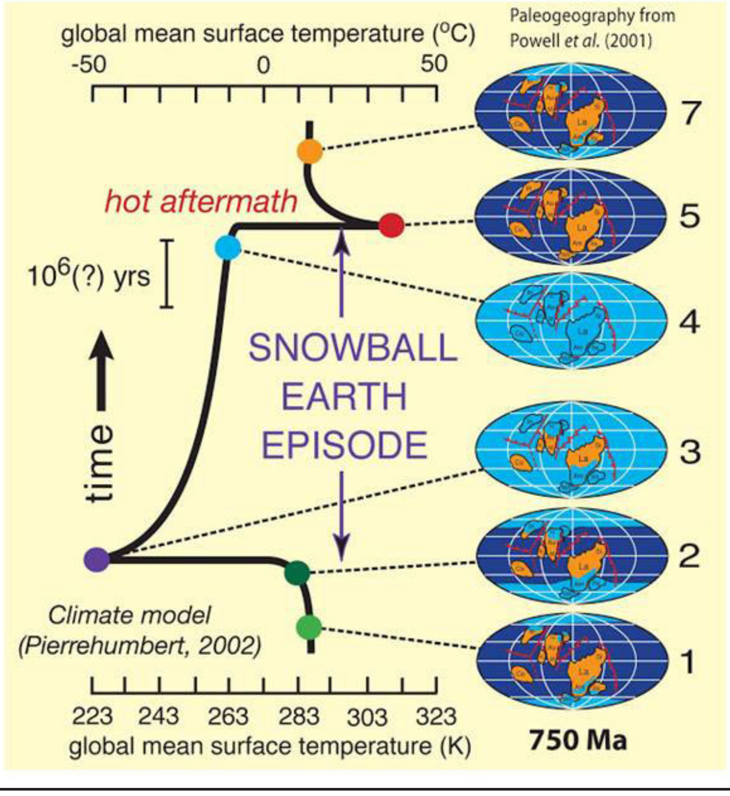
Drake's Equation

„It would be a tragedy of literally cosmic proportions if we succeeded in annihilating (…), the one truly intelligent species in the entire universe.“

Paul Davies,
NYT, 21 April 2010



Snowball Earth



Carboniferous/Permian: Creating Coal, Cooling Earth

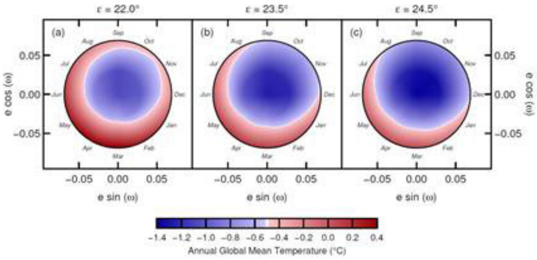
Formation of most of our coal brought Earth close to global glaciation

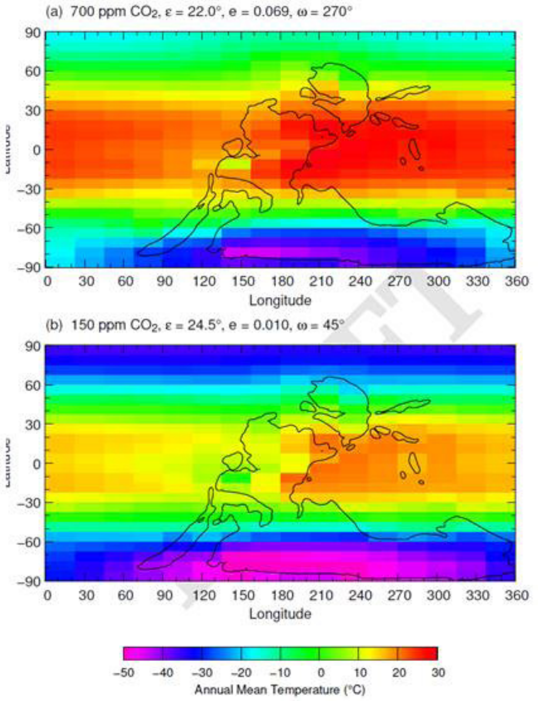
Georg Feulner[a,1]

[a]Potsdam Institute for Climate Impact Research, Leibniz Association, D-14412 Potsdam, Germany

Edited by Mark H. Thiemens, University of California, San Diego, La Jolla, CA, and approved September 5, 2017 (received for review July 7, 2017)

The bulk of Earth's coal deposits used as fossil fuel today was formed from plant debris during the late Carboniferous and early Permian periods. The high burial rate of organic carbon correlates with a significant drawdown of atmospheric carbon dioxide (CO_2) at that time. A recent analysis of a high-resolution record reveals large orbitally driven variations in atmospheric CO_2 concentration between ~150 and 700 ppm for the latest Carboniferous and very low values of 100 ± 80 ppm for the earliest Permian. Here, I explore the sensitivity of the climate around the Carboniferous/Permian boundary to changes in Earth's orbital parameters and in atmospheric CO_2 using a coupled climate model. The coldest orbital configurations are characterized by large axial tilt and small eccentricities of Earth's elliptical orbit, whereas the warmest configuration occurs at minimum tilt, maximum eccentricity, and a perihelion passage during Northern hemisphere spring. Global glaciation occurs at CO_2 concentrations <40 ppm, suggesting a rather narrow escape from a fully glaciated Snowball Earth state given the low levels and large fluctuations of atmospheric CO_2. These findings highlight the importance of orbital cycles for the climate and carbon cycle during the late Paleozoic ice age and the climatic significance of the fossil carbon stored in Earth's coal deposits.





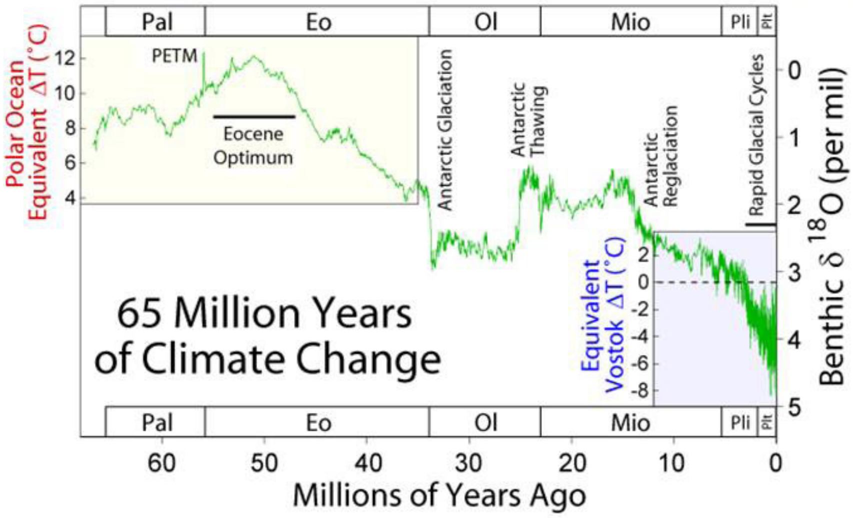
Feulner 2017, PNAS (accepted)

Carbon Levels …

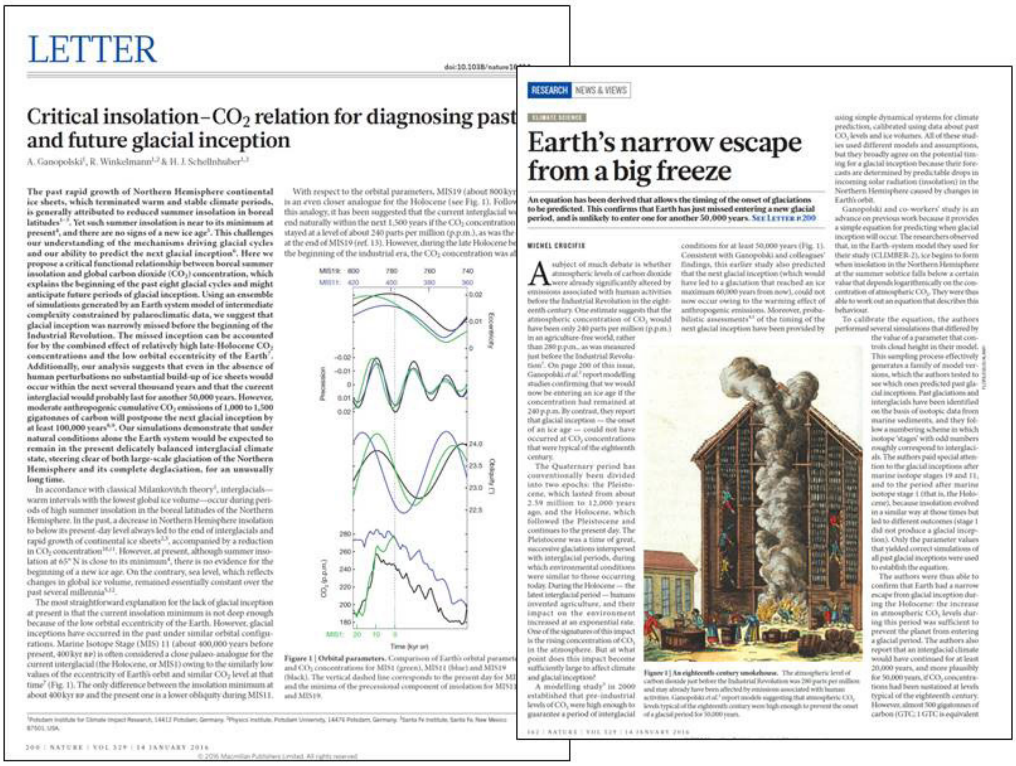
… a main dial in forming the Antarctic Ice Sheet in the past

… and triggering a potential future loss ?

By possible interactions with
- Opening / deepenng of the Drake passage
- Reorganization in ocean circulation, e.g. AMOC, Circumpolar current
- Changes in hydrological cycle, weathering, and carbon cycle



Solving the Riddle of the Ice Ages



LETTER

doi:10.1038/nature16494

Critical insolation–CO_2 relation for diagnosing past and future glacial inception

A. Ganopolski[1], R. Winkelmann[1,2] & H. J. Schellnhuber[1,3]

RESEARCH NEWS & VIEWS

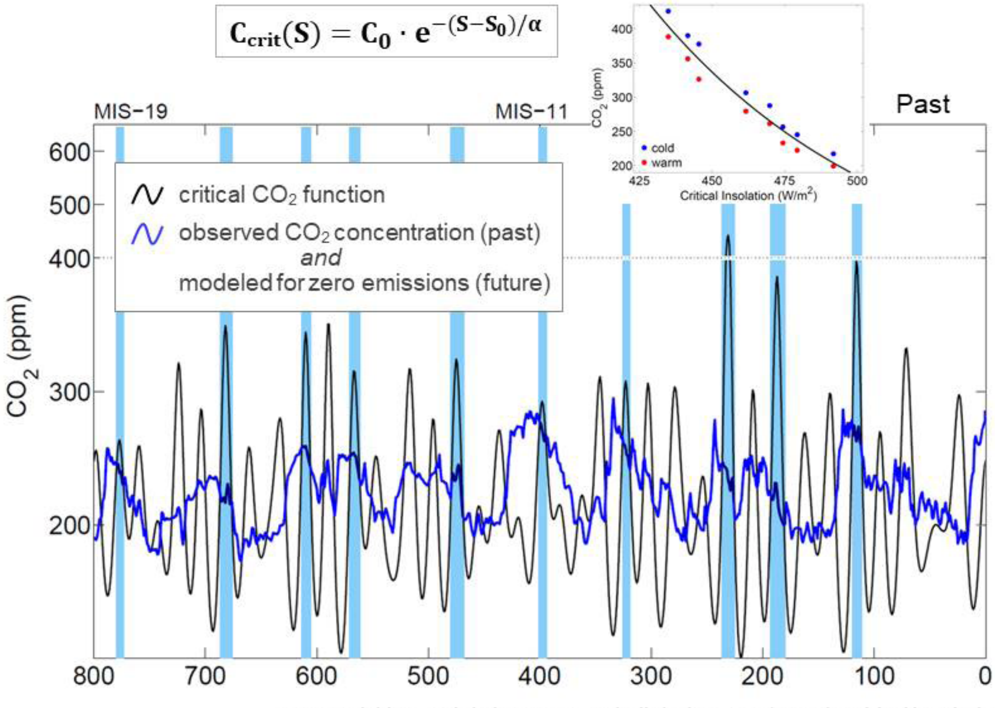
Earth's narrow escape from a big freeze

An equation has been derived that allows the timing of the onset of glaciations to be predicted. This confirms that Earth has just missed entering a new glacial period, and is unlikely to enter one for another 50,000 years. See Letter p.200

MICHEL CRUCIFIX

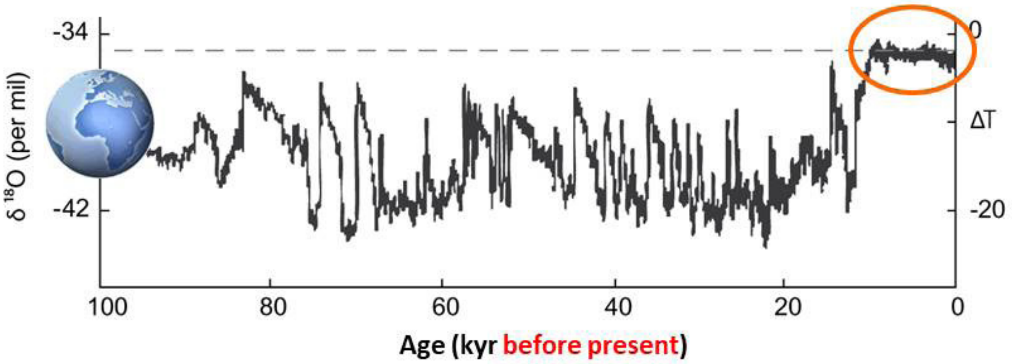
Critical CO_2 Concentration-Insolation Function

$$C_{crit}(S) = C_0 \cdot e^{-(S-S_0)/\alpha}$$



Ganopolski, A., Winkelmann, R., Schellnhuber, H.J. (2016): Critical insolation-CO_2 relation for diagnosing past and future glacial inception. Nature

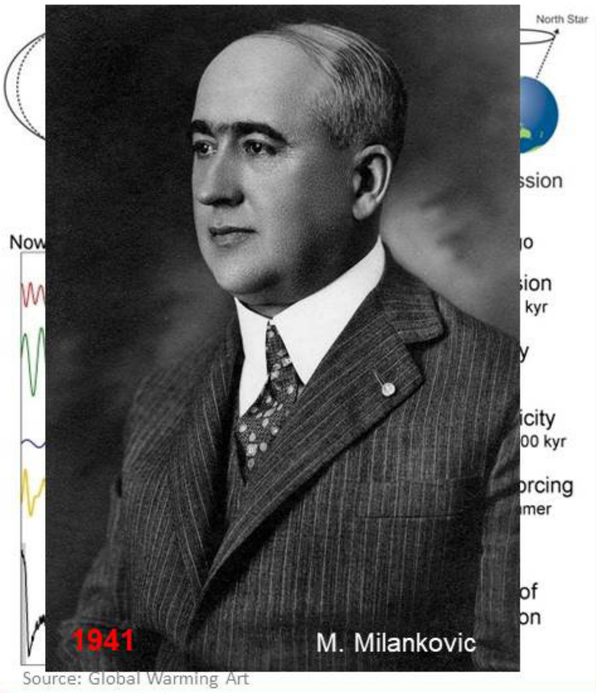
The Holocene: *From Glacial Chaos to Climate Paradise*



Source: Johan Rockström

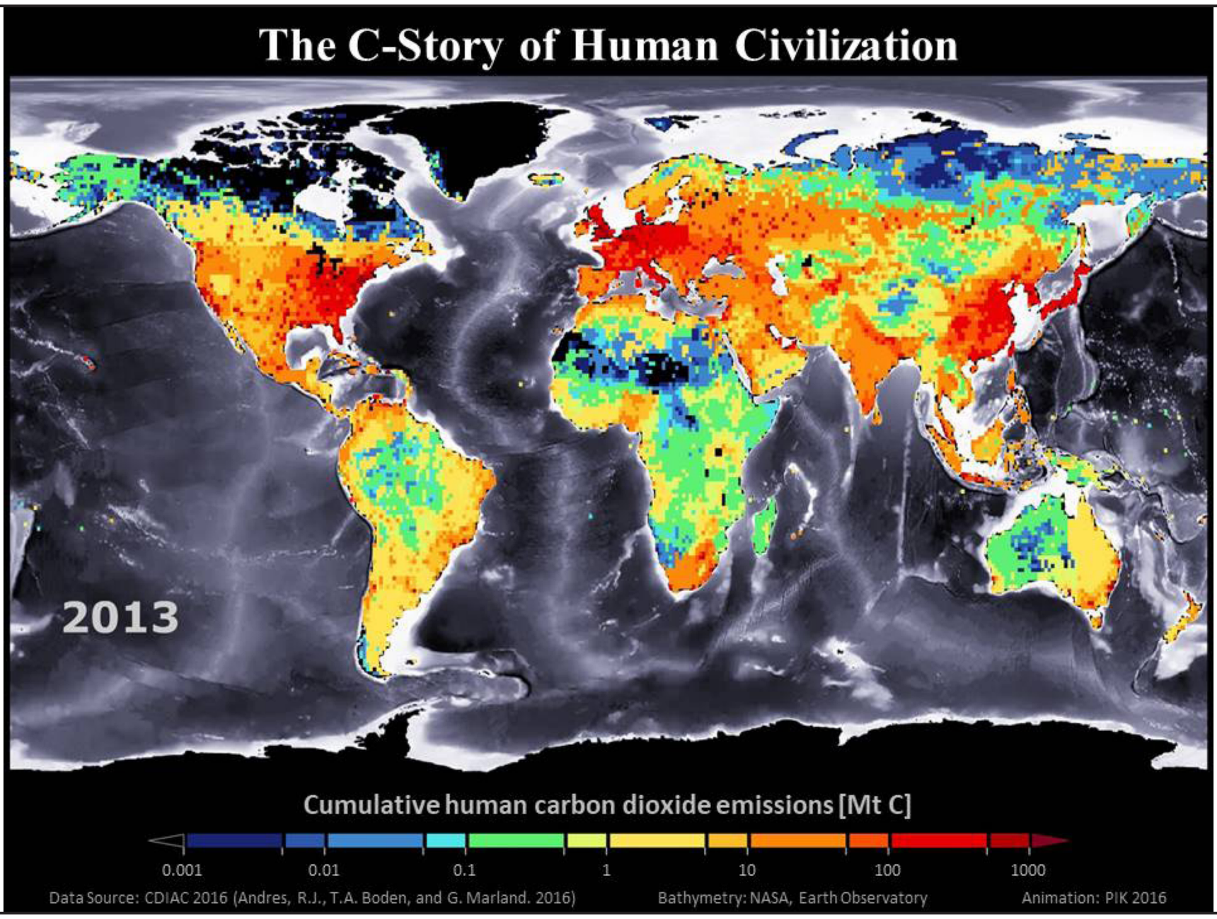
Why Does the Climate Change at All? Longer-Term Factors:

Milankovic Cycles



Source: Global Warming Art

The Greenhouse Effect



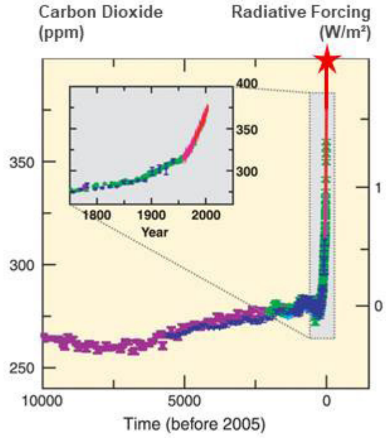
The C-Story of Human Civilization

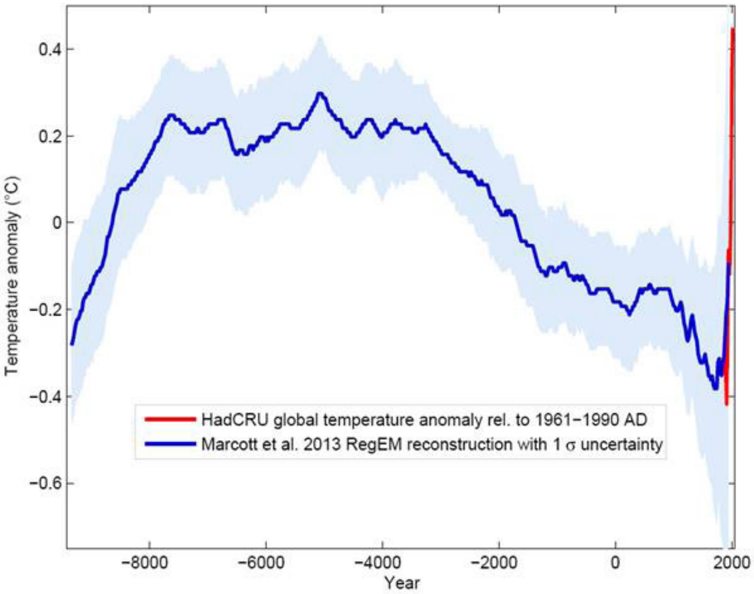
Data Source: CDIAC 2016 (Andres, R.J., T.A. Boden, and G. Marland. 2016) Bathymetry: NASA, Earth Observatory Animation: PIK 2016

Rising CO_2 Concentration

Global Reconstruction of Holocene Temperature

2014: 400 ppm



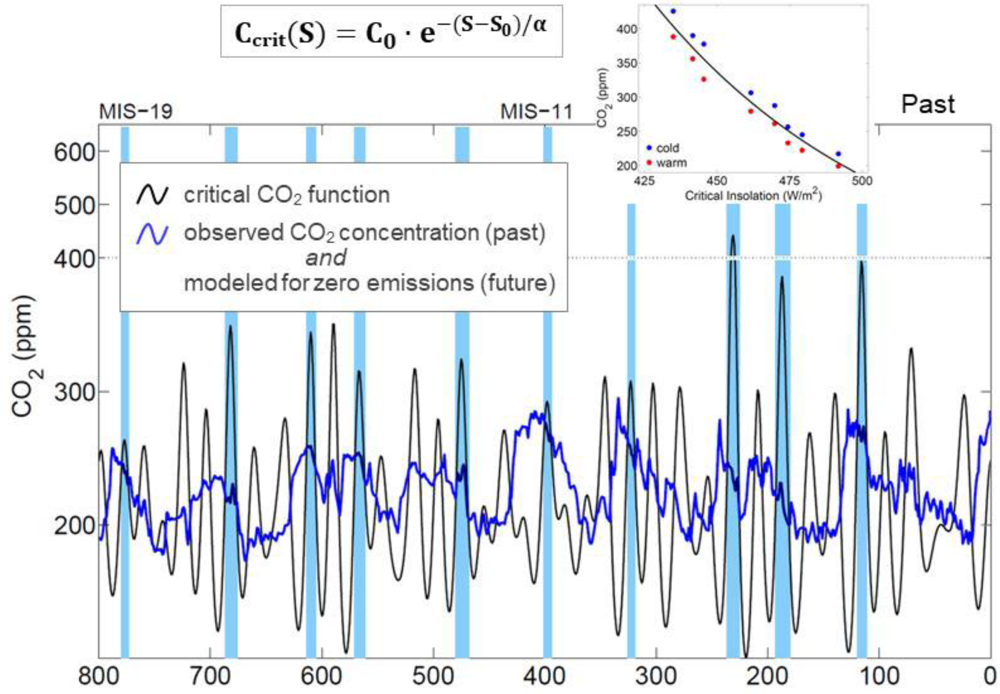


IPCC 2007

Marcott *et al.* 2013, Science

Critical CO_2 Concentration-Insolation Function

$$C_{crit}(S) = C_0 \cdot e^{-(S-S_0)/\alpha}$$



Ganopolski, A., Winkelmann, R., Schellnhuber, H.J. (2016): Critical insolation-CO_2 relation for diagnosing past and future glacial inception. Nature

Critical CO_2 Concentration-Insolation Function

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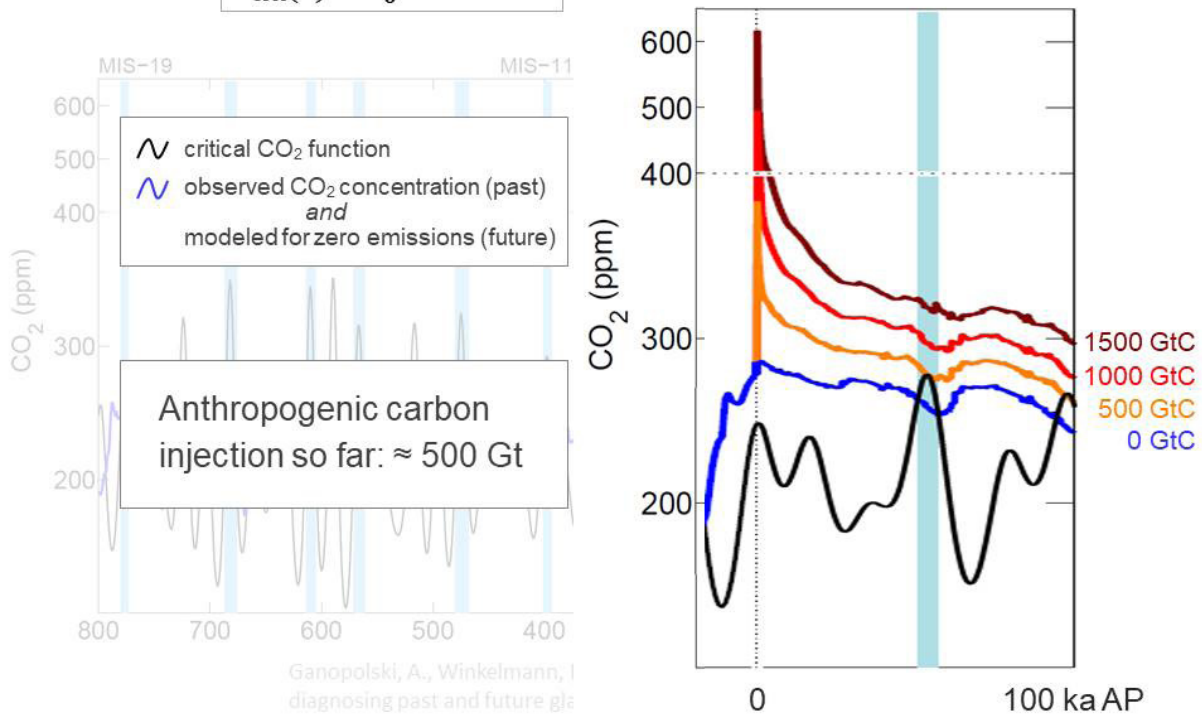
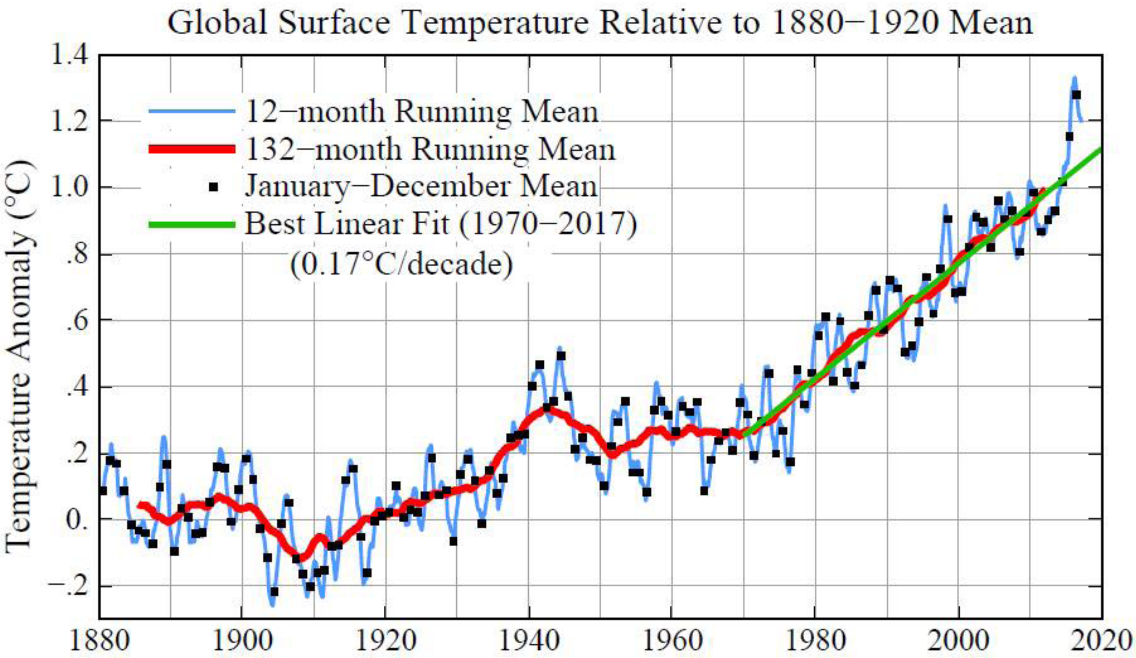


Anthropogenic carbon injection so far: ≈ 500 Gt

Current Development of Global Warming

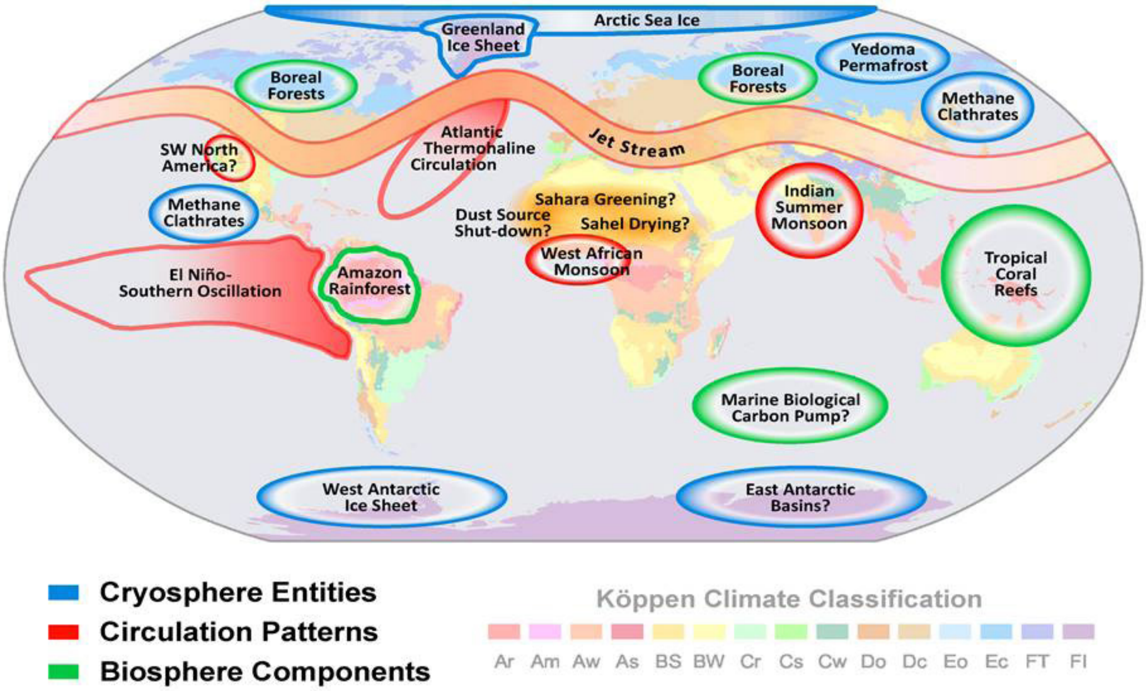


The Paris Agreement

Bildquelle: https://www.wmo.int/media/

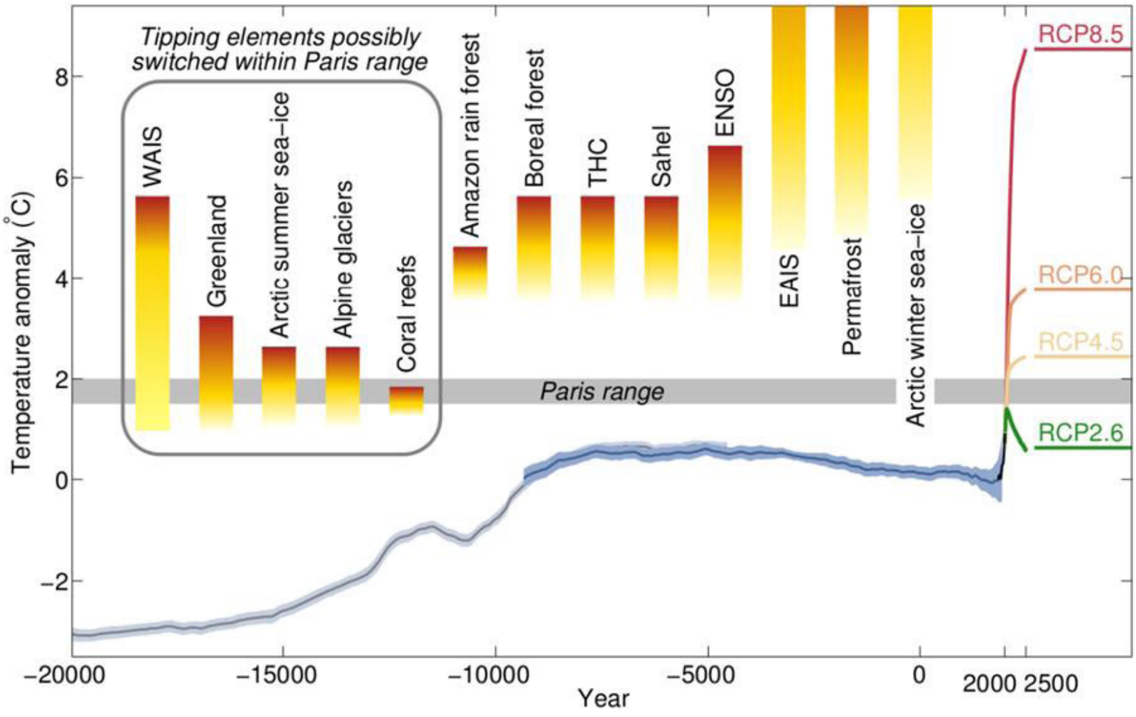
Limiting global warming "well below" 2 degrees Celsius	**Net-zero emissions of greenhouse gases by mid-21st century**	**National emission targets regularly reviewed and tightened**	**Developed countries provide 100 billion USD per year between 2020-2025**

Looming Risks: Tipping Elements in the Earth System



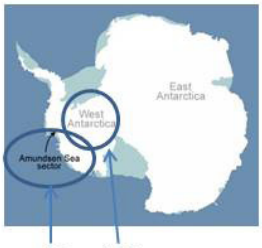
PIK 2017

Tipping Points Related to 2°C-Guardrail



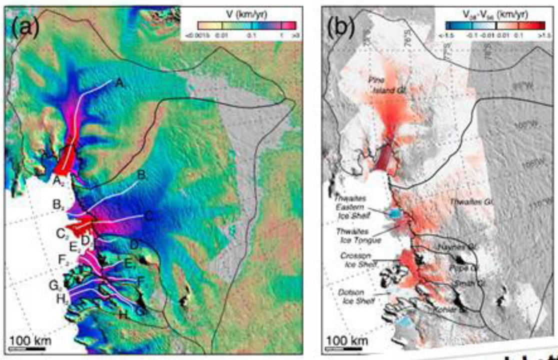
Schellnhuber et al. , Nature Climate Change, 2016

The Die is Cast!



ca. 1.2 and 3.3 m
Sea-Level Equivalent, resp.

Ice-Flow Speed →



← Acceleration of Ice Flow

nature climate change

PUBLISHED ONLINE: 12 JANUARY 2014 | DOI: 10.1038/NCLIMATE2094

LETTERS

Retreat of Pine Island Glacier controlled by marine ice-sheet instability

L. Favier[1,2], G. Durand[1,2★], S. L. Cornford[3], G. H. Gudmundsson[4,5], O. Gagliardini[1,2,6], F. Gillet-Chaulet[1,2], T. Zwinger[7], A. J. Payne[3] and A. M. Le Brocq[8]

Geophysical Research Letters

Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith, and Kohler glaciers, West Antarctica, from 1992 to 2011

E. Rignot[1,2], J. Mouginot[1], M. Morlighem[1], H. Seroussi[2], and B. Scheuchl[1]

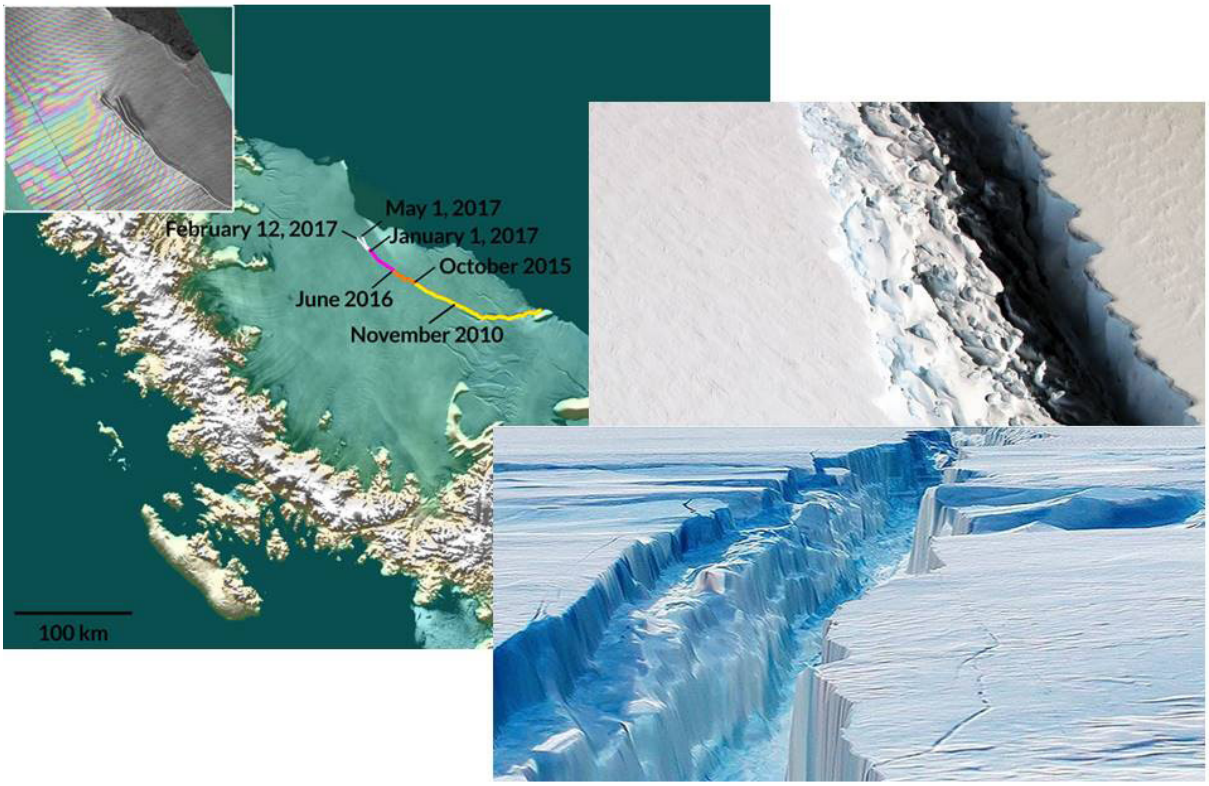
Sustained increase in ice discharge from the Amundsen Sea Embayment, West Antarctica, from 1973 to 2013

J. Mouginot[1], E. Rignot[1,2], and B. Scheuchl[1]

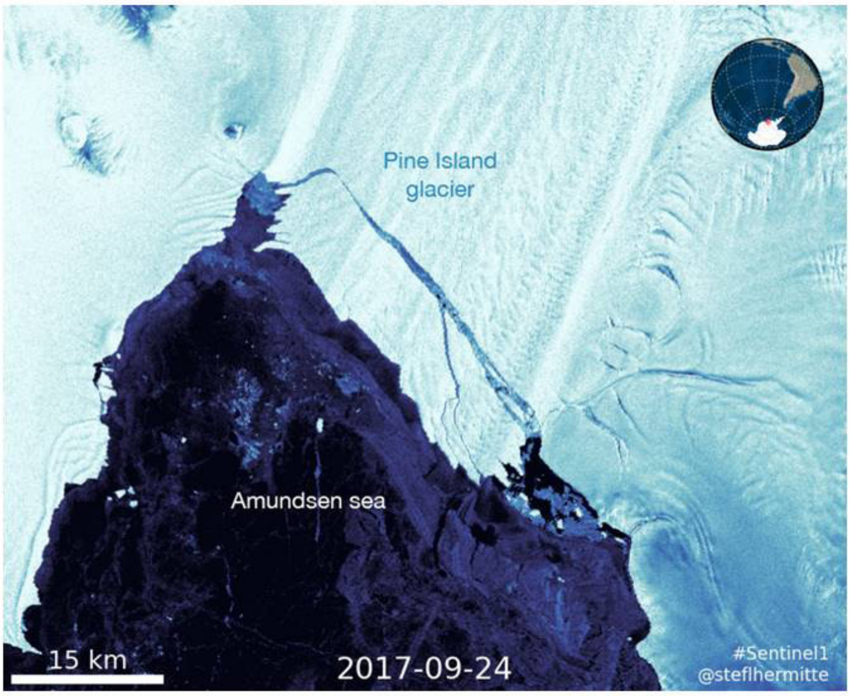
Science AAAS

Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica
Ian Joughin *et al.*
Science **344**, 735 (2014);
DOI: 10.1126/science.1249055

Crack in Antarctica's Larsen C Ice Shelf



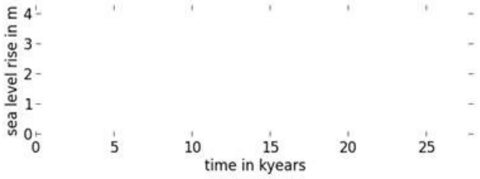
A Key Antarctic Glacier Just Lost a Huge Piece of Ice



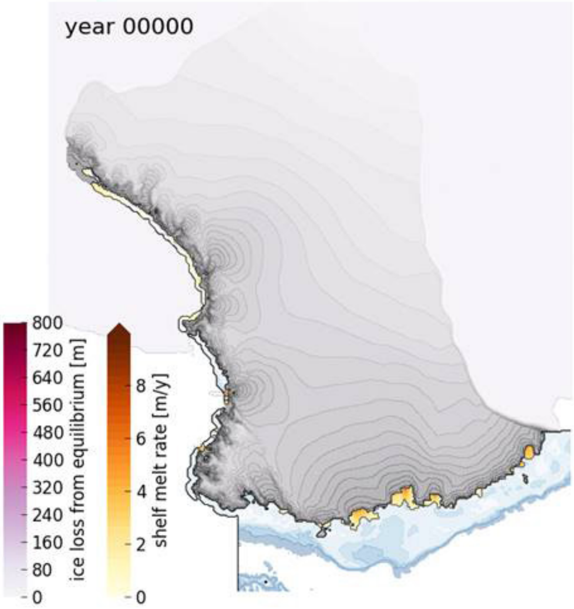
Pictures: Washington Post

Sea-level Rise After Ice Plug Removal

critical threshold
< 80 mm sea-level equiv.

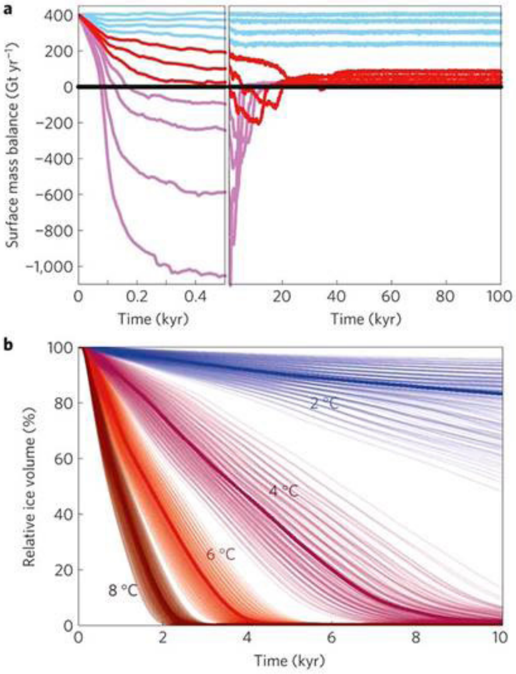


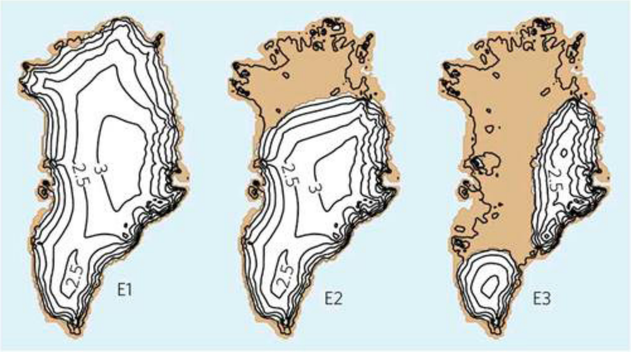
self-sustained long-term
sea-level rise of 3 - 4 m



Mengel & Levermann, Nature Climate Change, 2014.

Irreversible Loss of Greenland Ice-Sheet Could Start with 1.6°C Temperature Rise Relative to Preindustrial



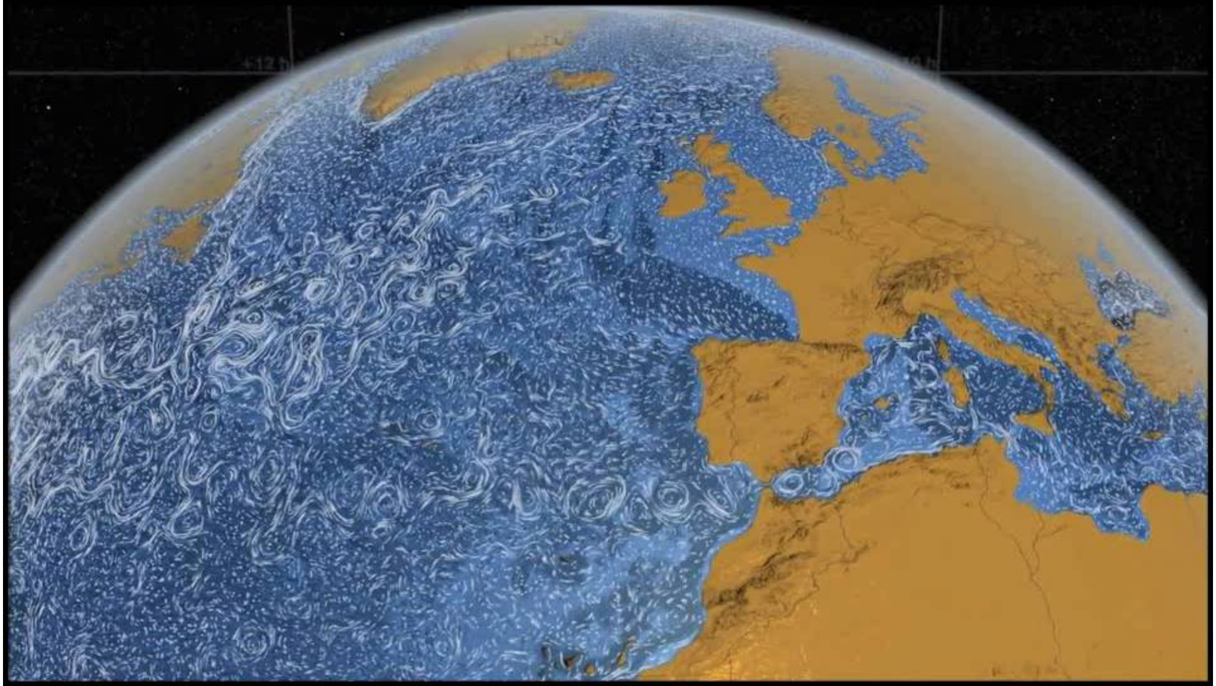


Equilibrium states of the GIS

Transient GIS evolution

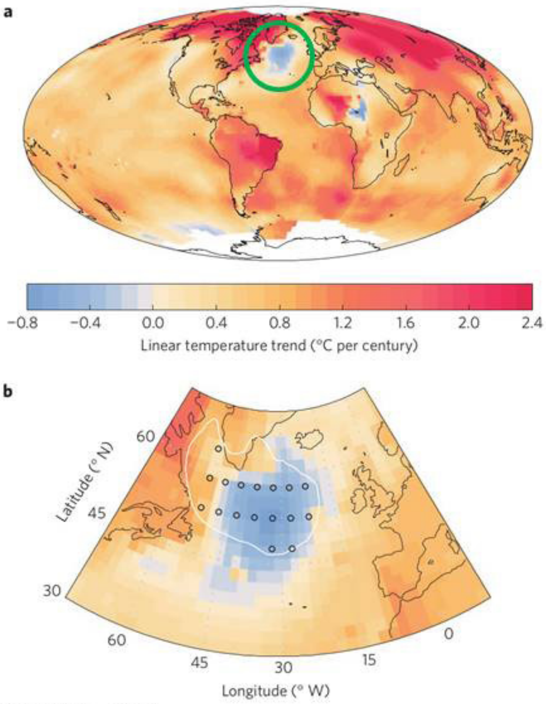
Robinson et al. 2012, Nature Climate Change

Tracing the Flow of Surface Currents

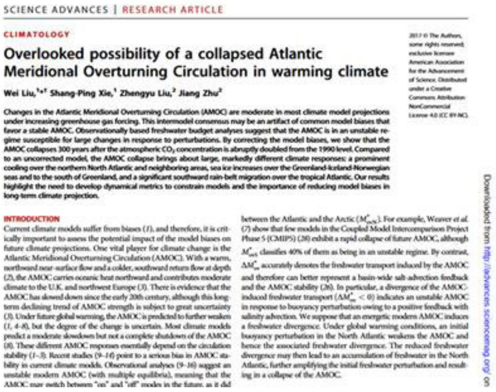


NASA'S GODDARD SPACE FLIGHT CENTER

Exceptional Slowdown and Shrinking Stability of the Atlantic Ocean Overturning Circulation



Rahmstorf et al., 2015



SCIENCE ADVANCES | RESEARCH ARTICLE

CLIMATOLOGY

Overlooked possibility of a collapsed Atlantic Meridional Overturning Circulation in warming climate

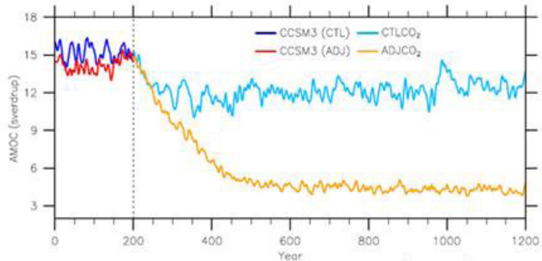
Wei Liu,[1*†] Shang-Ping Xie,[1] Zhengyu Liu,[2] Jiang Zhu[2]

Changes in the Atlantic Meridional Overturning Circulation (AMOC) are moderate in most climate model projections under increasing greenhouse gas forcing. This intermodel consensus may be an artifact of common model biases that favor a stable AMOC. Observationally based freshwater budget analyses suggest that the AMOC is in an unstable regime susceptible for large changes in response to perturbations. By correcting the model biases, we show that the AMOC collapses 300 years after the atmospheric CO_2 concentration is abruptly doubled from the 1990 level. Compared to an uncorrected model, the AMOC collapse brings about large, markedly different climate responses: a prominent cooling over the northern North Atlantic and neighboring areas, sea ice increases over the Greenland-Iceland-Norwegian seas and to the south of Greenland, and a significant southward rain-belt migration over the tropical Atlantic. Our results highlight the need to develop dynamical metrics to constrain models and the importance of reducing model biases in long-term climate projection.

INTRODUCTION

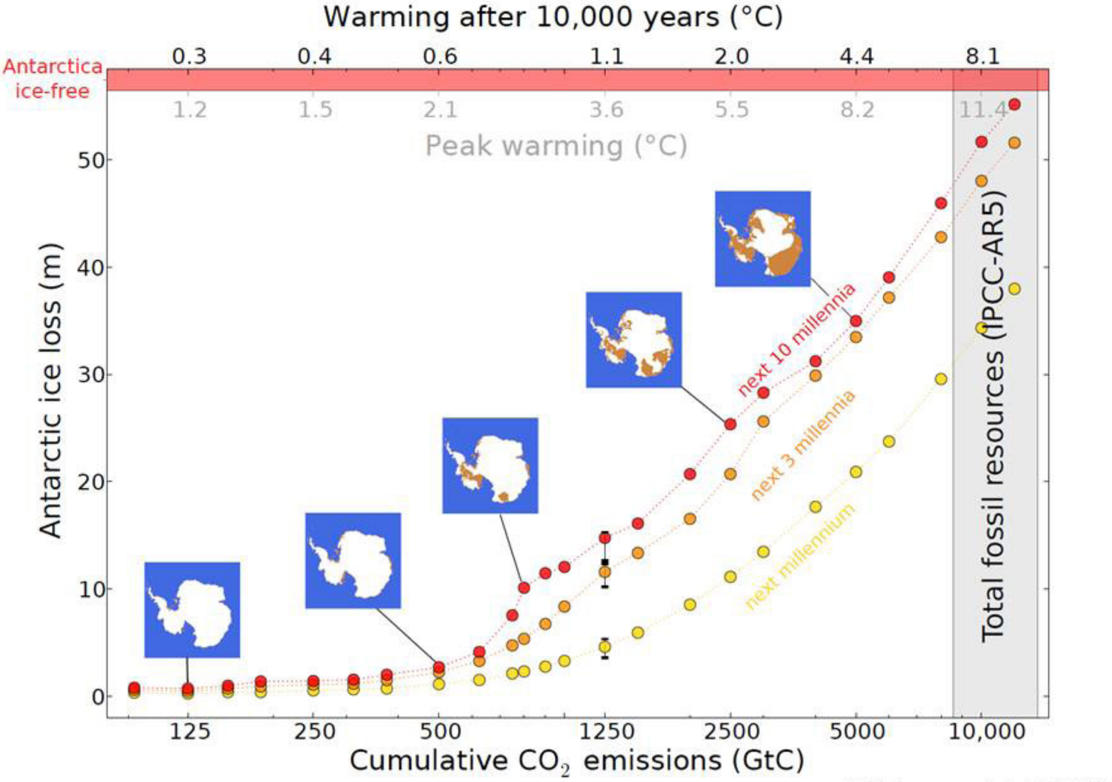
Current climate models suffer from biases (1), and therefore, it is critically important to assess the potential impact of the model biases on future climate projections. One vital player for climate change is the Atlantic Meridional Overturning Circulation (AMOC). With a warm, northward near-surface flow and a colder, southward return flow at depth (2), the AMOC carries oceanic heat northward and contributes moderate climate to the U.K. and northwest Europe (3). There is evidence that the AMOC has slowed down since the early 20th century, although this long-term declining trend of AMOC strength is subject to great uncertainty (3). Under future global warming, the AMOC is predicted to further weaken (1, 4-8), but the degree of the change is uncertain. Most climate models predict a moderate slowdown but not a complete shutdown of the AMOC (8). These different AMOC responses essentially depend on the circulation stability (1-3). Recent studies (9-14) point to a serious bias in AMOC stability in current climate models. Observational analyses (9-16) suggest an unstable modern AMOC (with multiple equilibria), meaning that the AMOC may switch between "on" and "off" modes in the future, as it did

between the Atlantic and the Arctic (M^*_{ovN}). For example, Weaver et al. (7) show that few models in the Coupled Model Intercomparison Project Phase 5 (CMIP5) (28) exhibit a rapid collapse of future AMOC, although M^*_{ovS} classifies 40% of them as being in an unstable regime. By contrast, ΔM^*_{ov} accurately denotes the freshwater transport induced by the AMOC and therefore can better represent a basin-wide salt-advection feedback and the AMOC stability (26). In particular, a divergence of the AMOC-induced freshwater transport ($\Delta M^*_{ov} < 0$) indicates an unstable AMOC in response to buoyancy perturbation owing to a positive feedback with salinity advection. We suppose that an energetic modern AMOC induces a freshwater divergence. Under global warming conditions, an initial buoyancy perturbation in the North Atlantic weakens the AMOC and hence the associated freshwater divergence. The reduced freshwater divergence may then lead to an accumulation of freshwater in the North Atlantic, further amplifying the initial freshwater perturbation and resulting in a collapse of the AMOC.



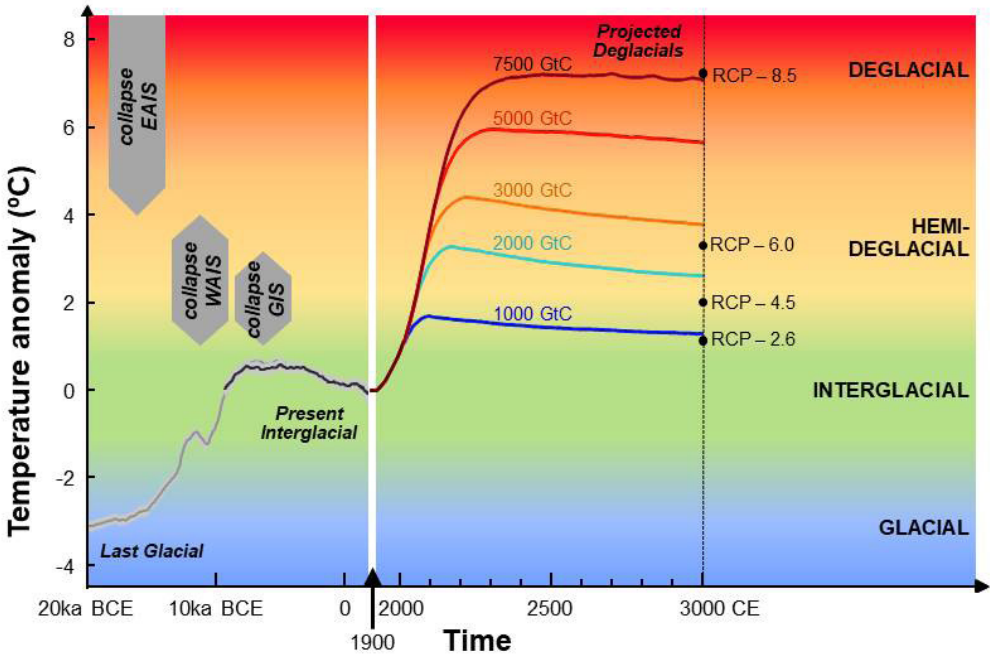
Liu et al., 2017

Sea Level Commitment from Antarctic Ice Loss



Winkelmann et al., Sci. Ad. 2015

Anthropogenic Rush through Cryo-Phase Space

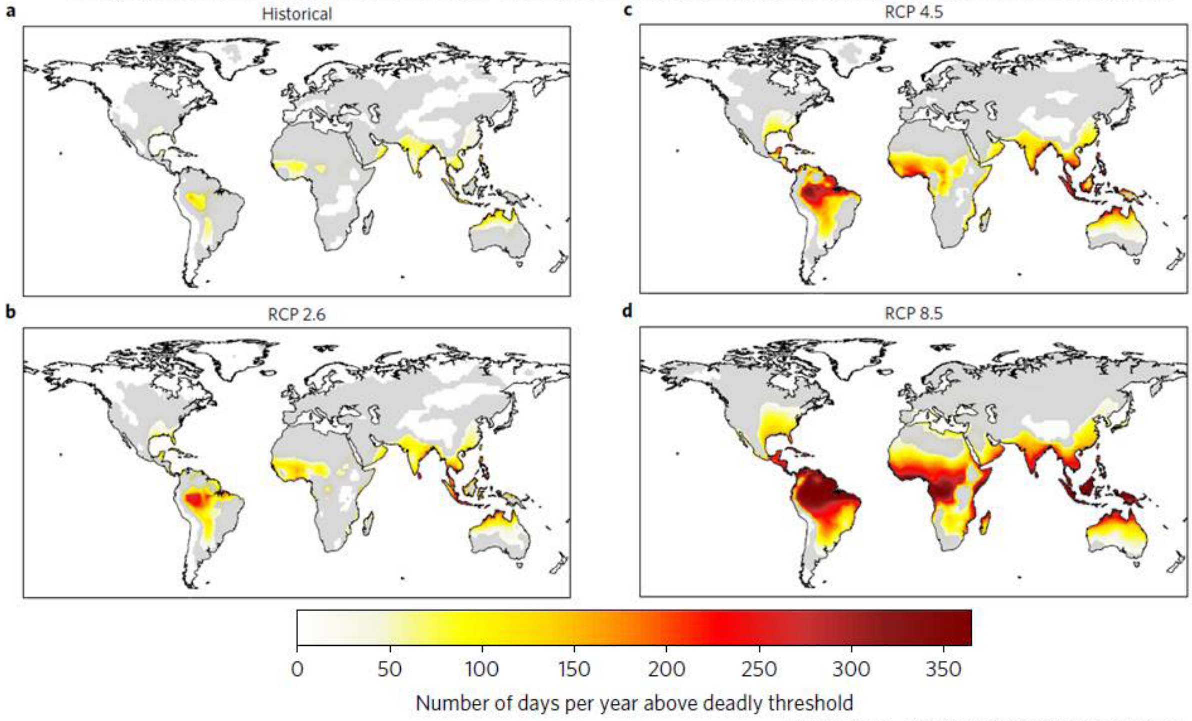


Temperature Reconstructions before 1900 based on Shakun et al. (2012), Marcott et al. (2013)

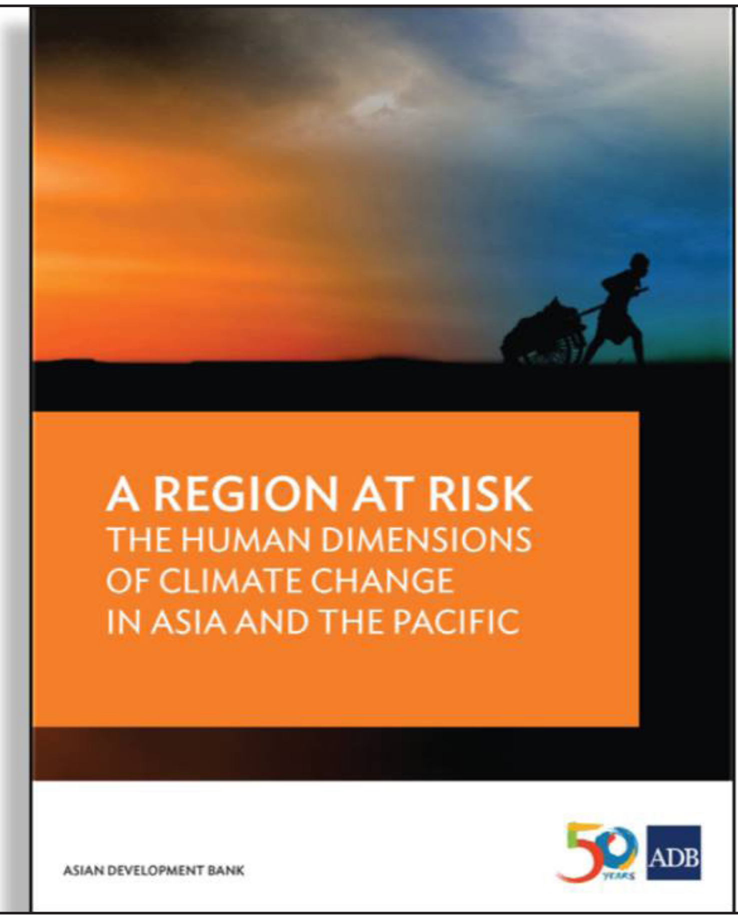
After Ganopolski et al., under review

Climate Change Can Bring about Conditions Exceeding Human Thermoregulatory Capacity

Geographical distribution of deadly climatic conditions under different emission scenarios.



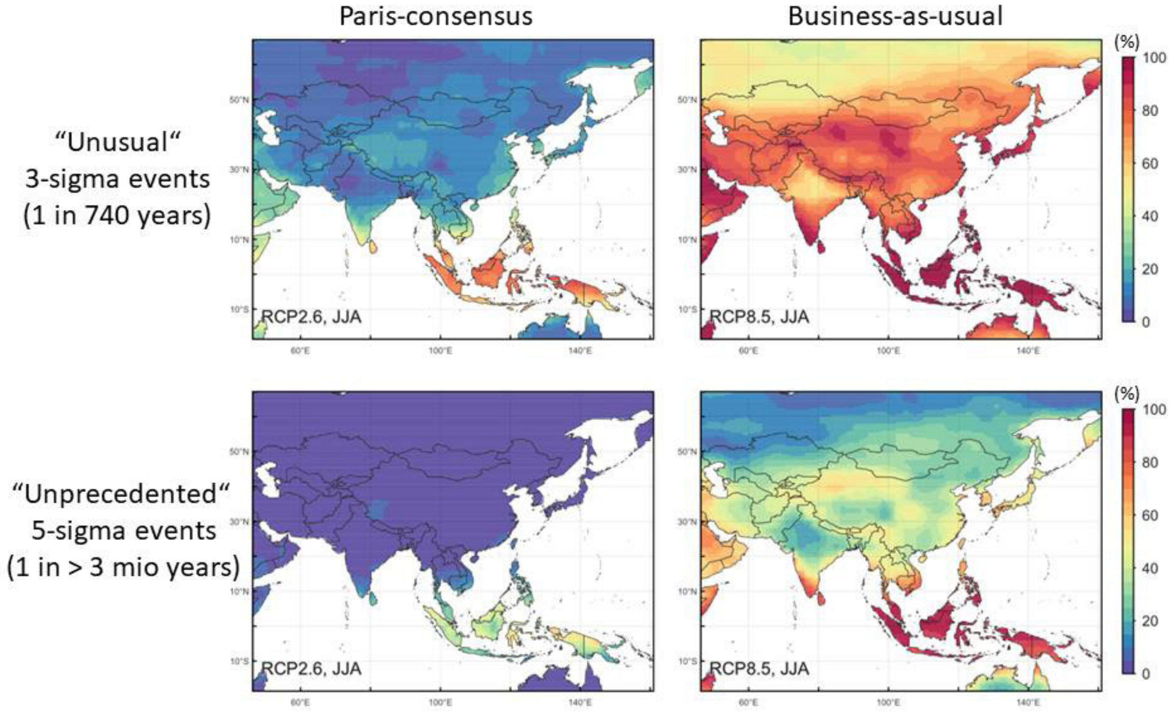
Mora et al., 2017, Nature Climate Change



A REGION AT RISK
THE HUMAN DIMENSIONS
OF CLIMATE CHANGE
IN ASIA AND THE PACIFIC

ASIAN DEVELOPMENT BANK

Summer Heat Extremes
Shift Regions into New Climate Regimes



Data source: ISI-MIP database (Warszawski et al. 2014, PNAS)

LAUDATO SI'
PAPA FRANCESCO SULLA CURA DELLA CASA COMUNE

ENCYCLICAL LAUDATO SI`
Published 18 June 2015


FRANCESCO
Laudato si'
sulla cura
della casa comune

Meeting of the Pontifical Academy of Sciences at the Vatican, November 2016

Bild: Pontifical Academy of Sciences

COMMENT

ASTROBIOLOGY A profile of the indomitable woman at the helm of SETI **p.596**

HEALTH Documentary traces the roots and legacy of a pioneering aid agency **p.598**

ENERGY Call for caution following China's gas-hydrate extraction **p.599**

TAXONOMY Rebuttals on bureaucracy, hypotheses, conservation and more **p.600**

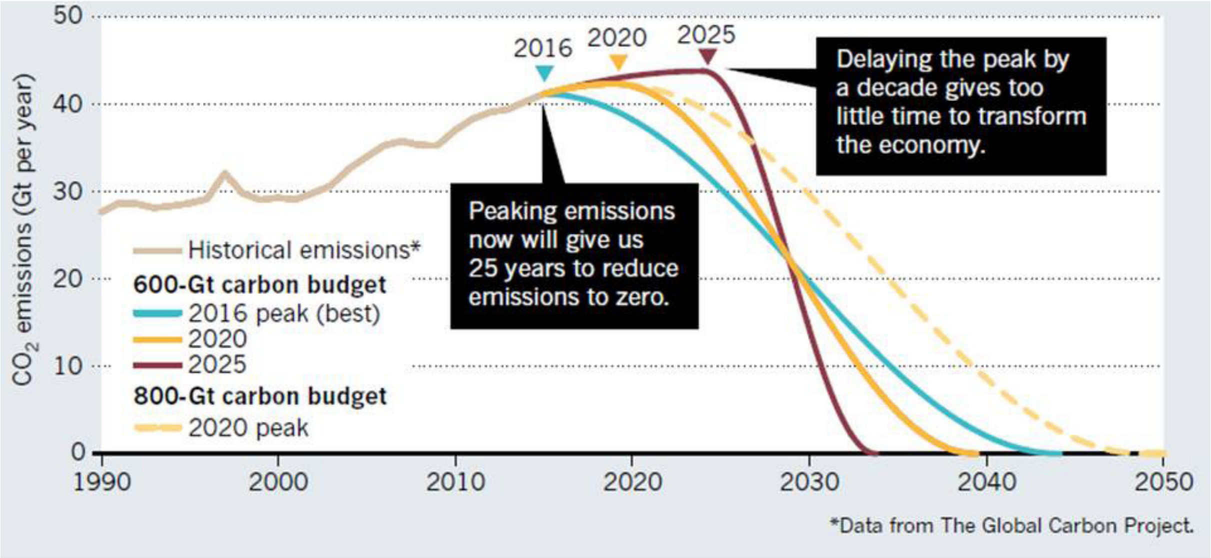
Decarbonizing the world economy will require renewable energy generation from vast solar farms, such as this one in Nevada.

Three years to safeguard our climate

Christiana Figueres and colleagues set out a six-point plan for turning the tide of the world's carbon dioxide by 2020.

Figueres, Schellnhuber et al. 2017, Nature

The Carbon Crunch



Delaying the peak by a decade gives too little time to transform the economy.

Peaking emissions now will give us 25 years to reduce emissions to zero.

*Data from The Global Carbon Project.

Figueres, Schellnhuber et al. 2017, Nature

The Blue Marble: New NASA Satellite Image

Image taken by NASA space probe "Lunar Reconnaissance Orbiter" on 12 October 2015