Global Sustainability Summer School
Santa Fe Institute
20 Jul 2010

State of Climate Science

Professor H. J. Schellnhuber CBE

Potsdam Institute for Climate Impact Research

P I K

Outline

- How is the climate today?
- News from the poles: sea ice and ice sheets
- Sea level (projections) on the rise
- Ocean acidification beyond tropical coral reefs
- On regional and global tipping points
- Time is running out

Part 1

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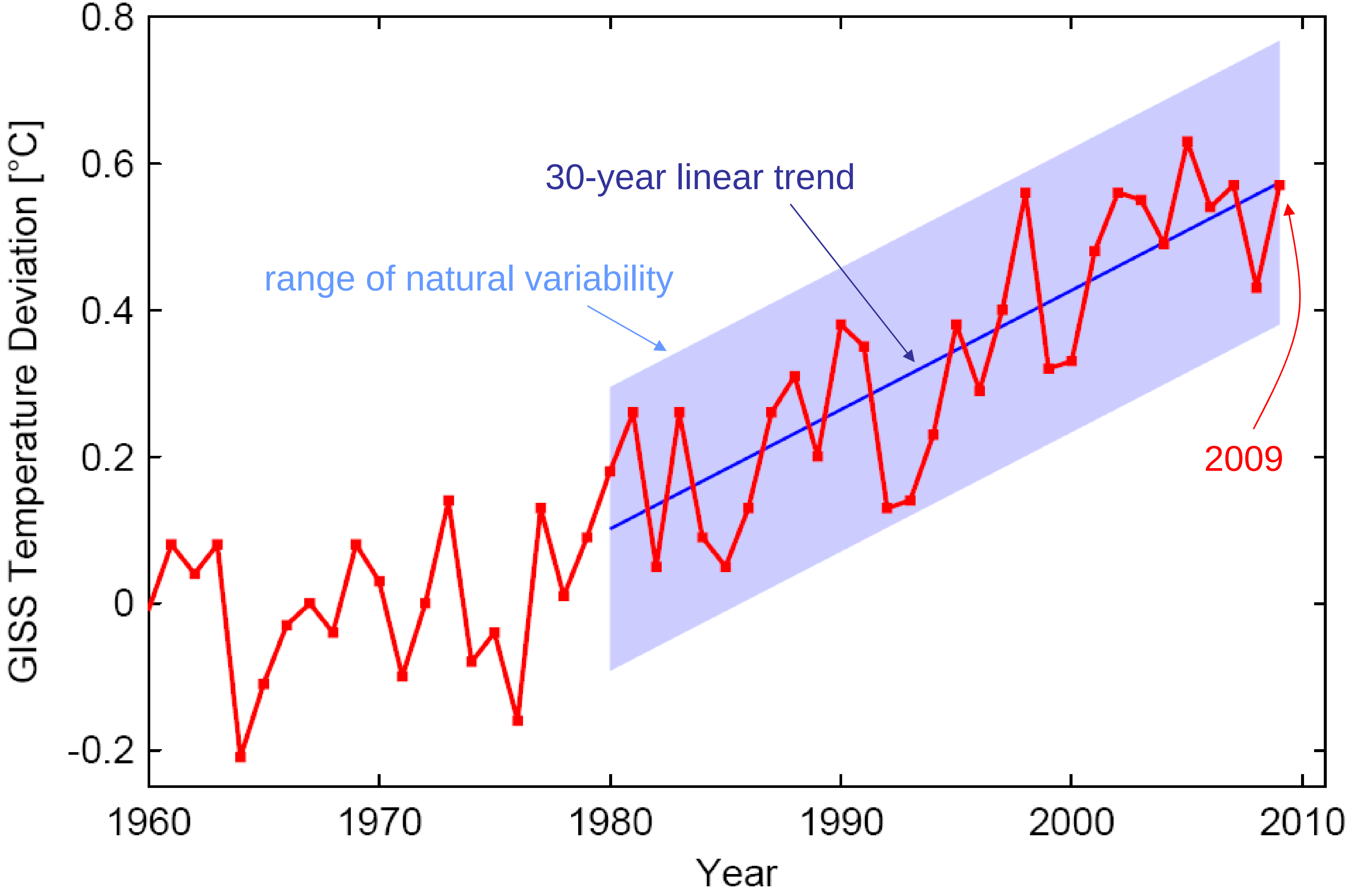
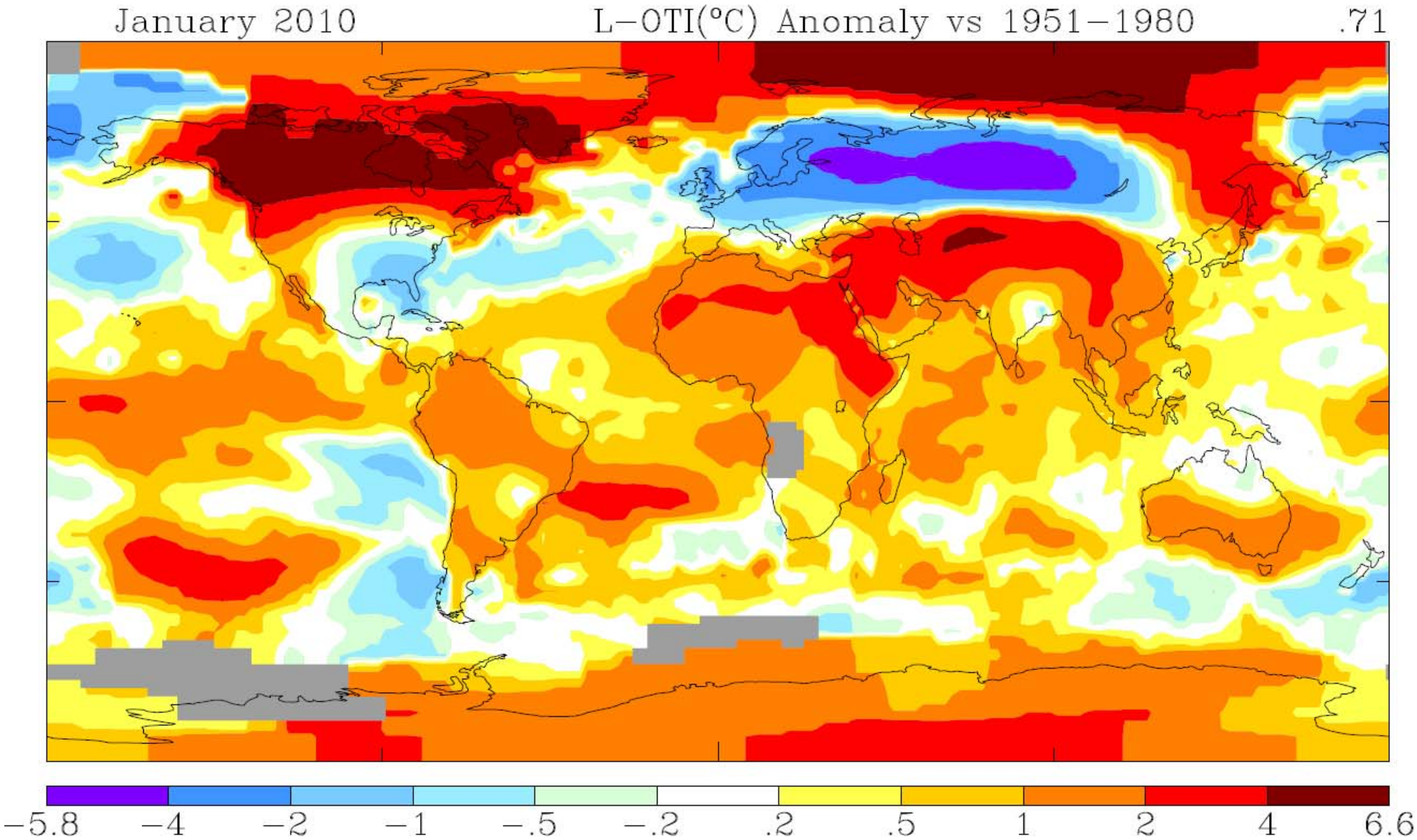
Meaningful Trends in Gobal Mean Temperature

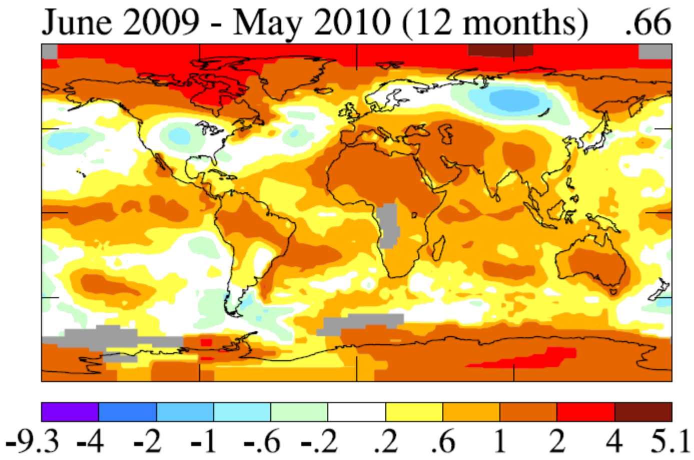


January 2010 – 'Warm' Across the Globe

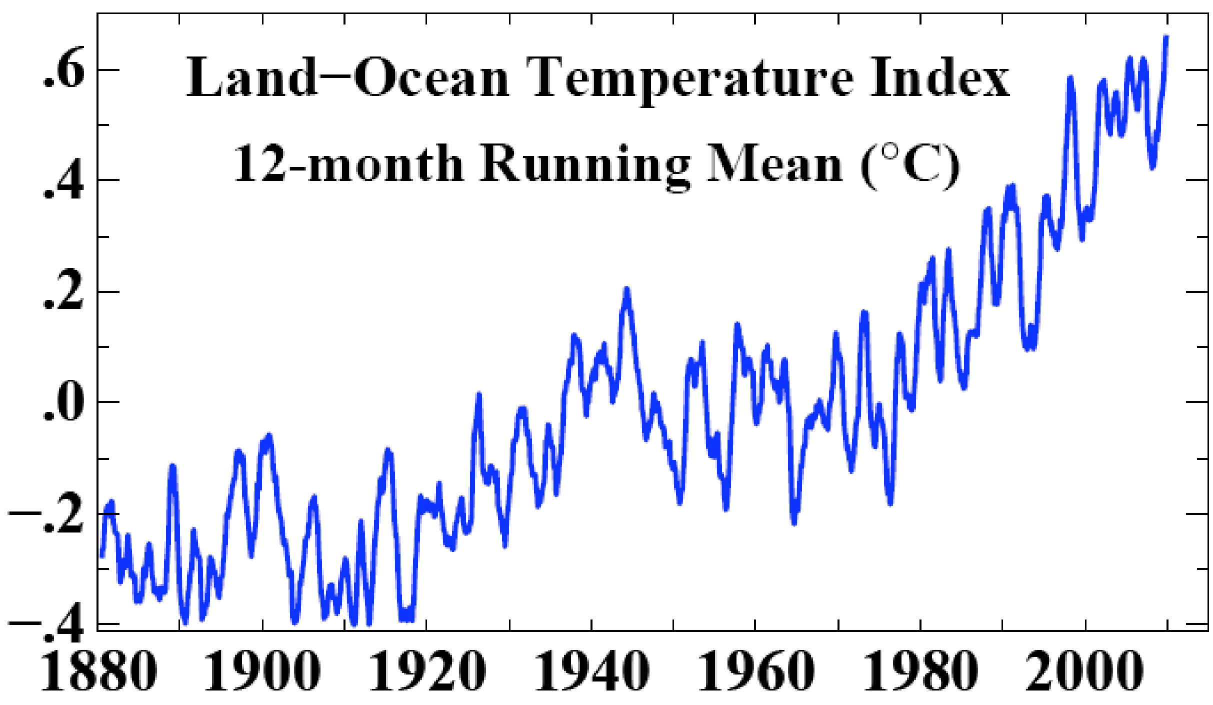


(Source: GISS NASA 2010)

Twelve Past Months Break the Record

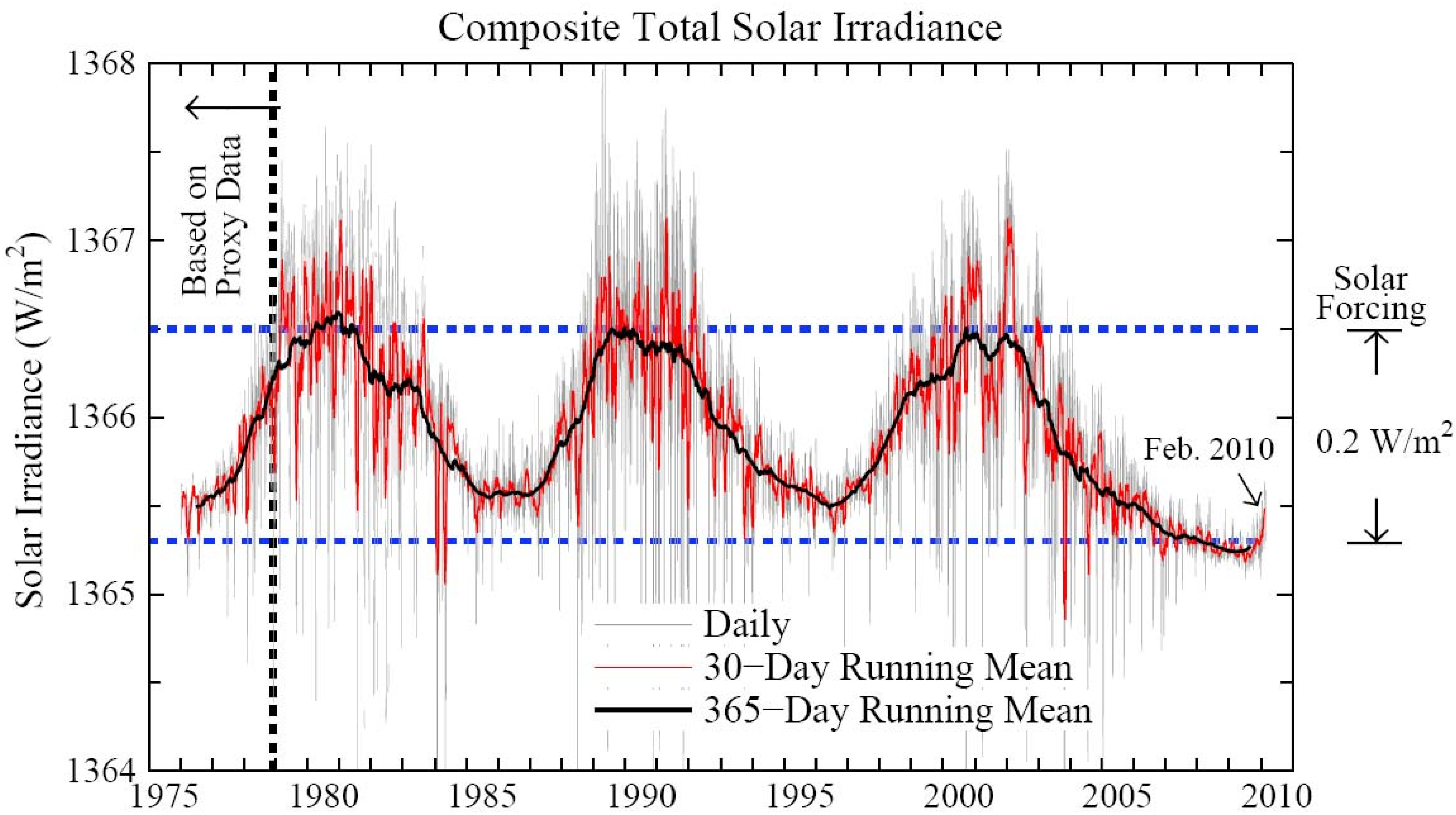


Global all-time record



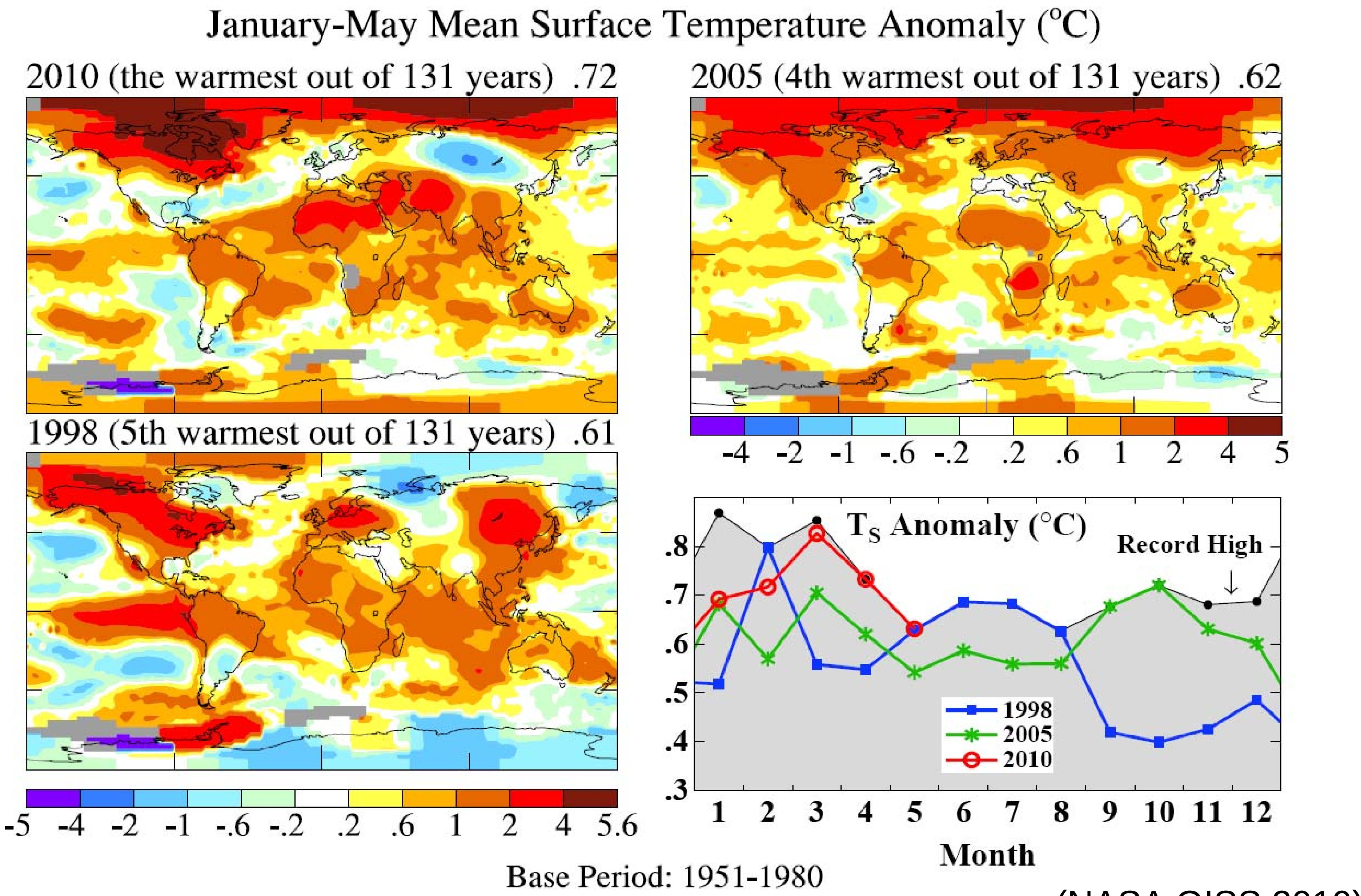
NASA GISS 2010

Global Temperature Records despite Unusual Mimimum of Solar Activity



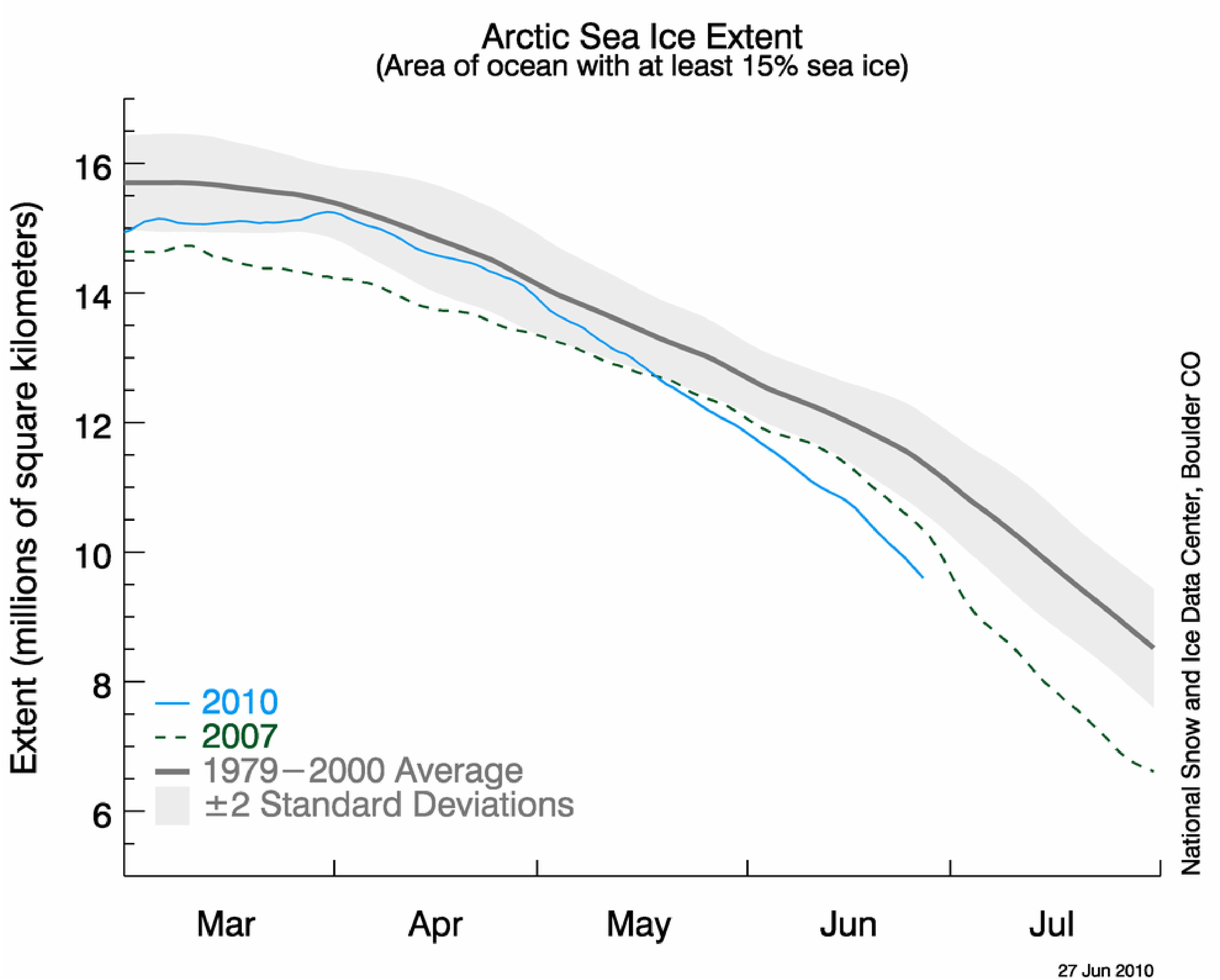
NASA GISS 2010

2010 Heading towards Temperature Records



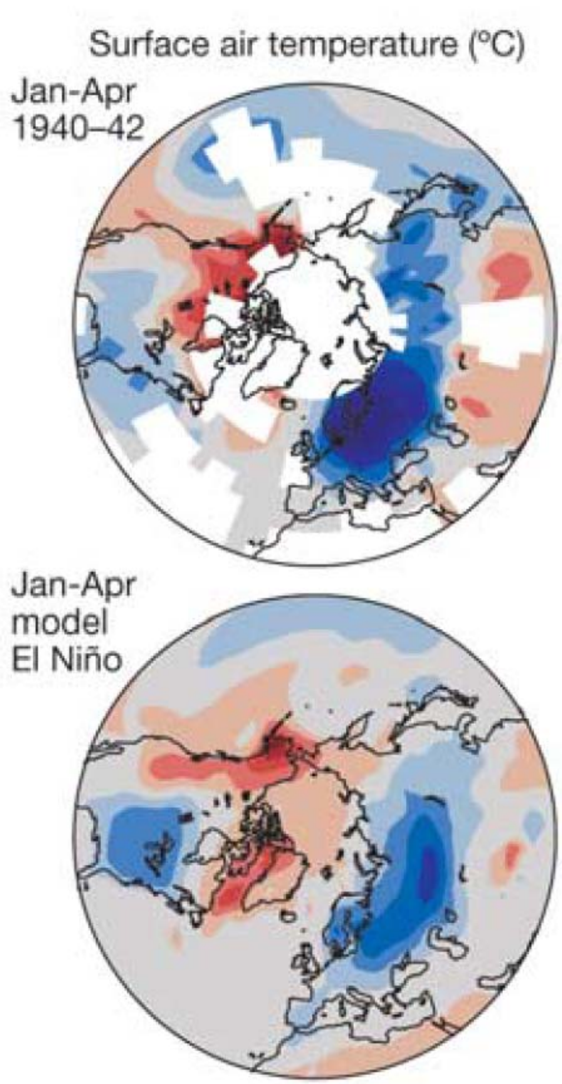
(NASA GISS 2010)

2010 Heading towards Arctic Ice Loss Record

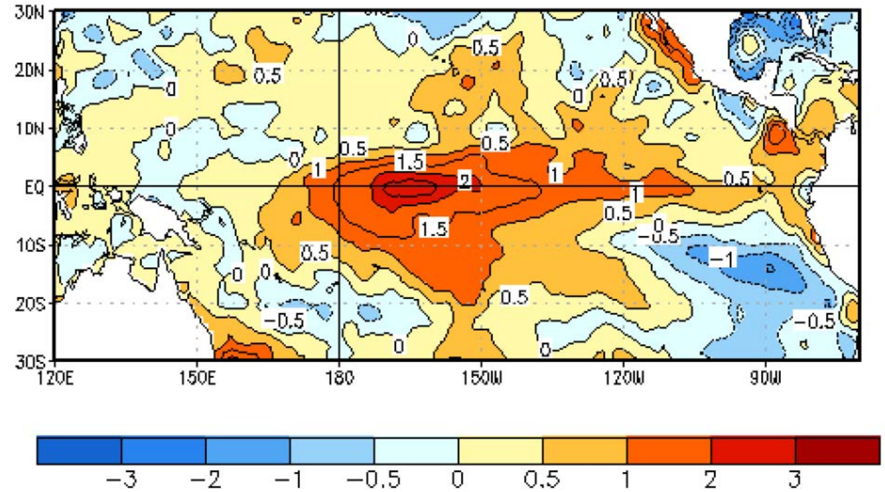


European Winter Climate Related to El-Niño

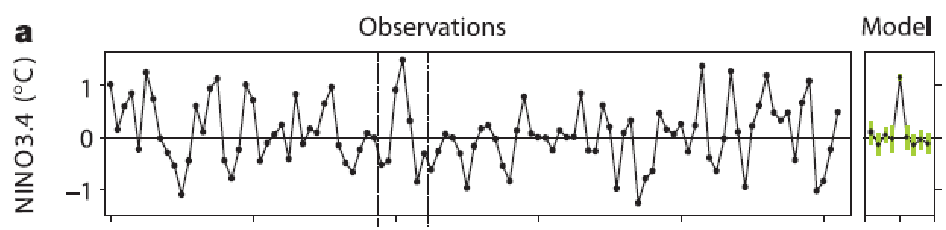
Winter
1940-1942



Average SST Anomalies
3 Jan 2010 – 30 Jan 2010



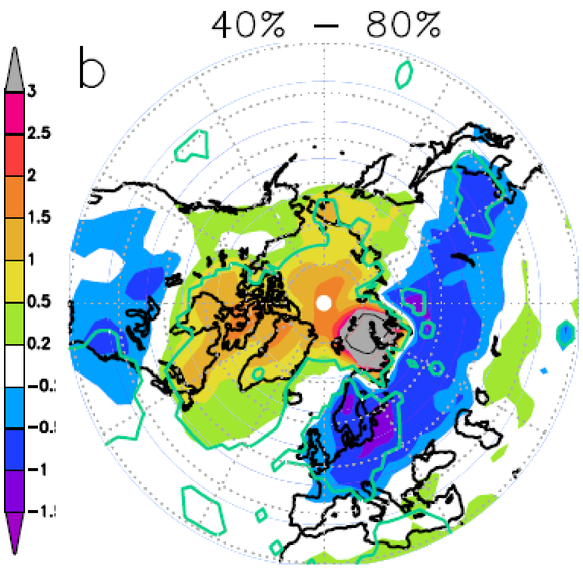
El-Niño pattern January 2010
(NOAA 2010)



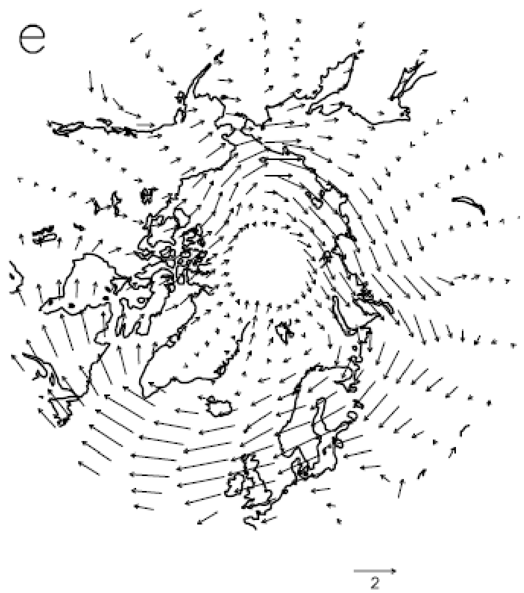
(Brönnimann et al. 2004 Nature)

Loss of Arctic Sea Ice May Cool Northern Continents in Winter

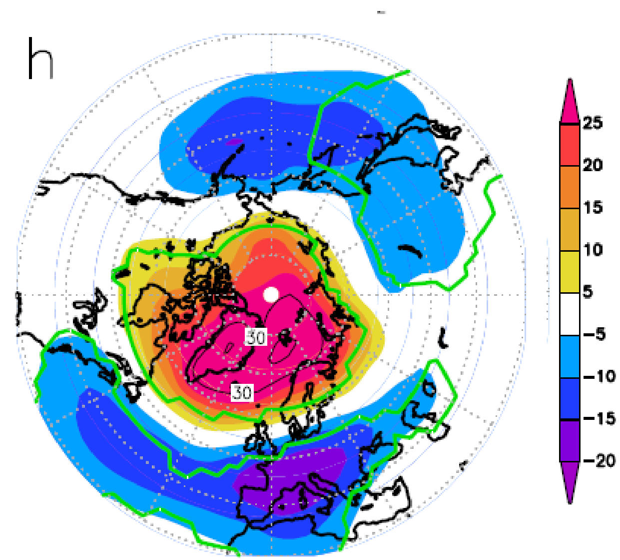
Simulated (ECHAM5) responses to decrease in the Barents-Kara sea ice concentration from 80% to 40% for February



Monthly surface air temperature (in °C)



Vector of the horizontal wind at 850 hPa (in m/s);



Geopotential height at 850 hPa (Z850, in gpm);

(Petoukhov & Semenov *submitted*)

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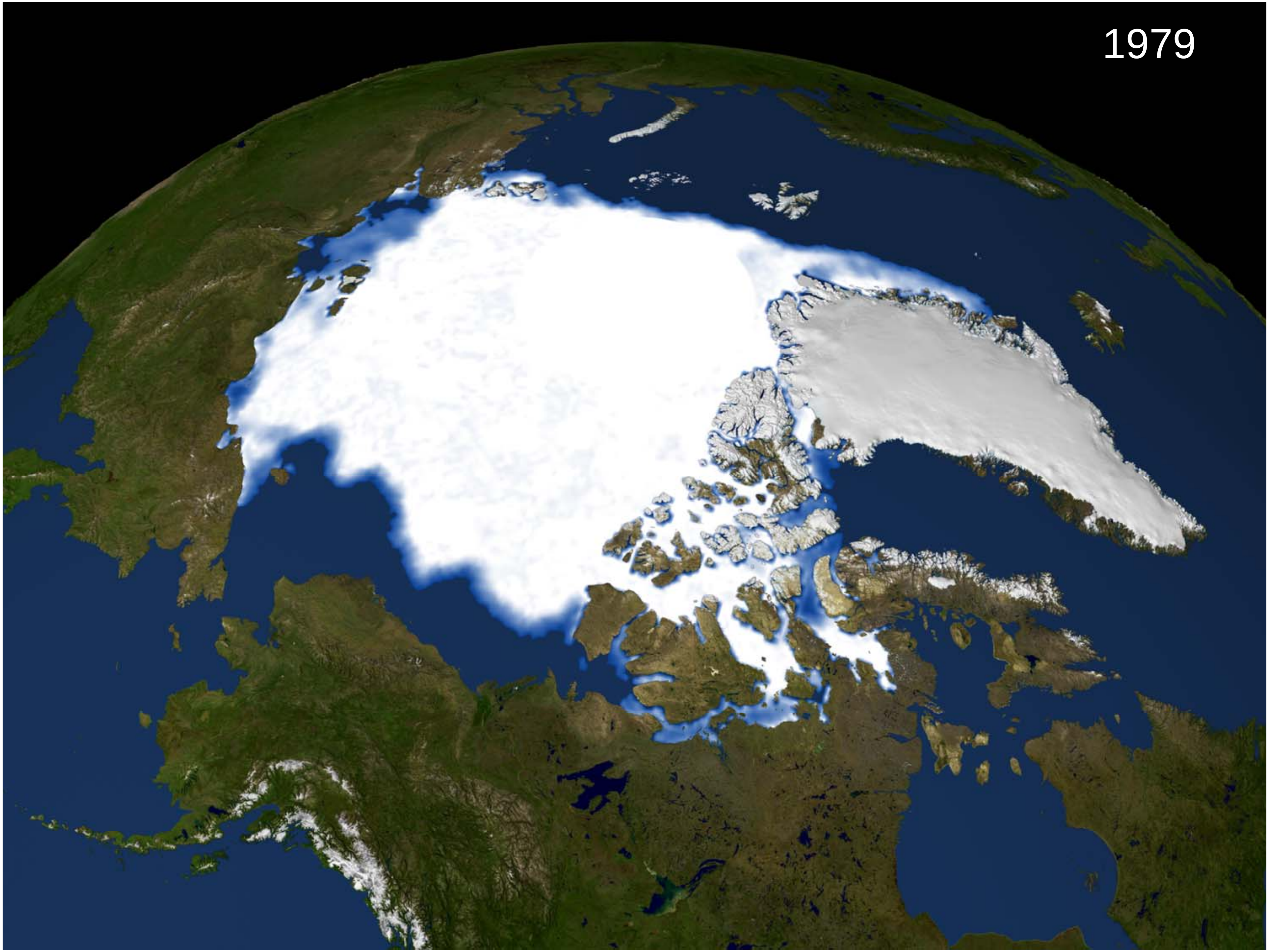
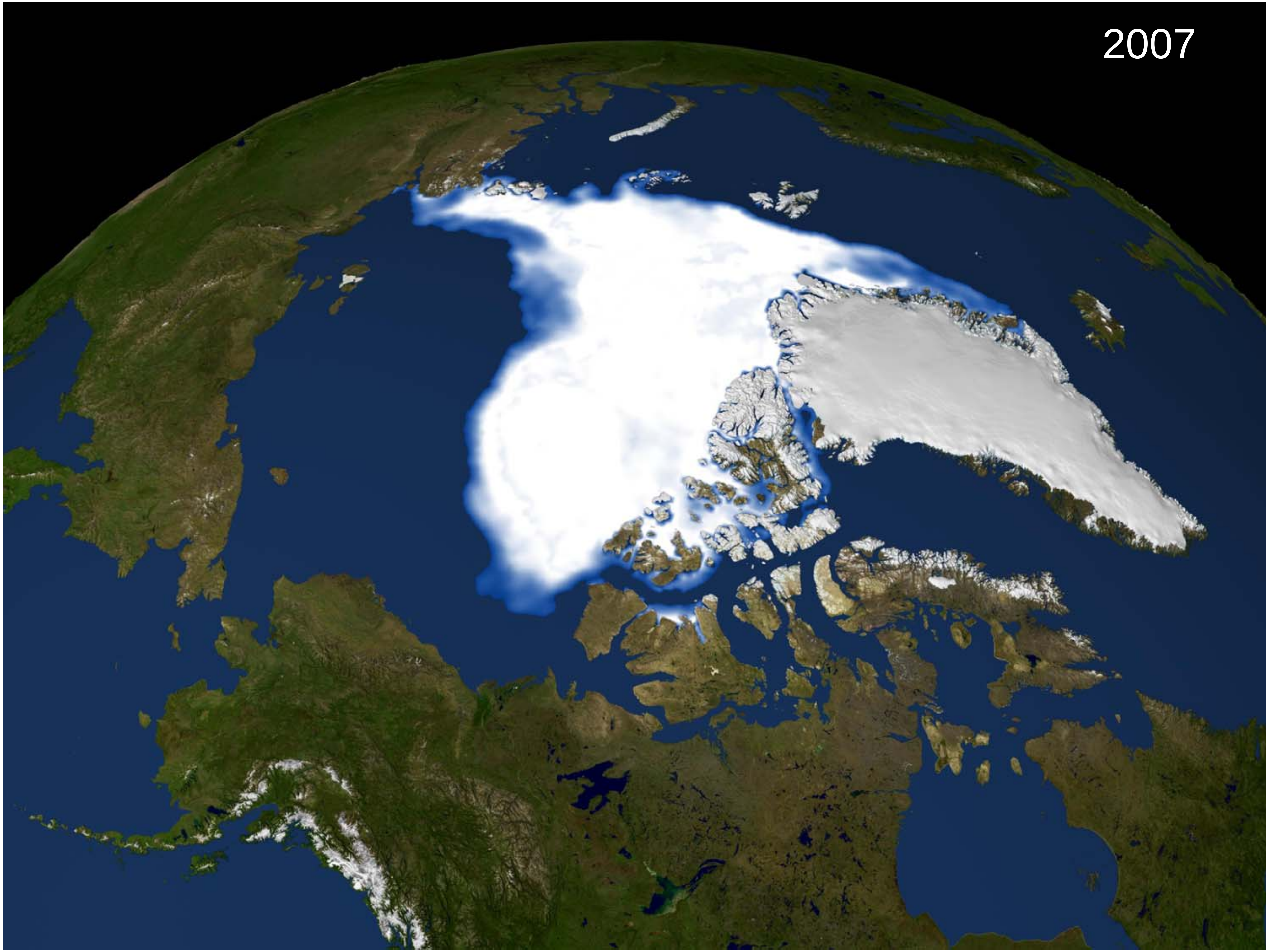
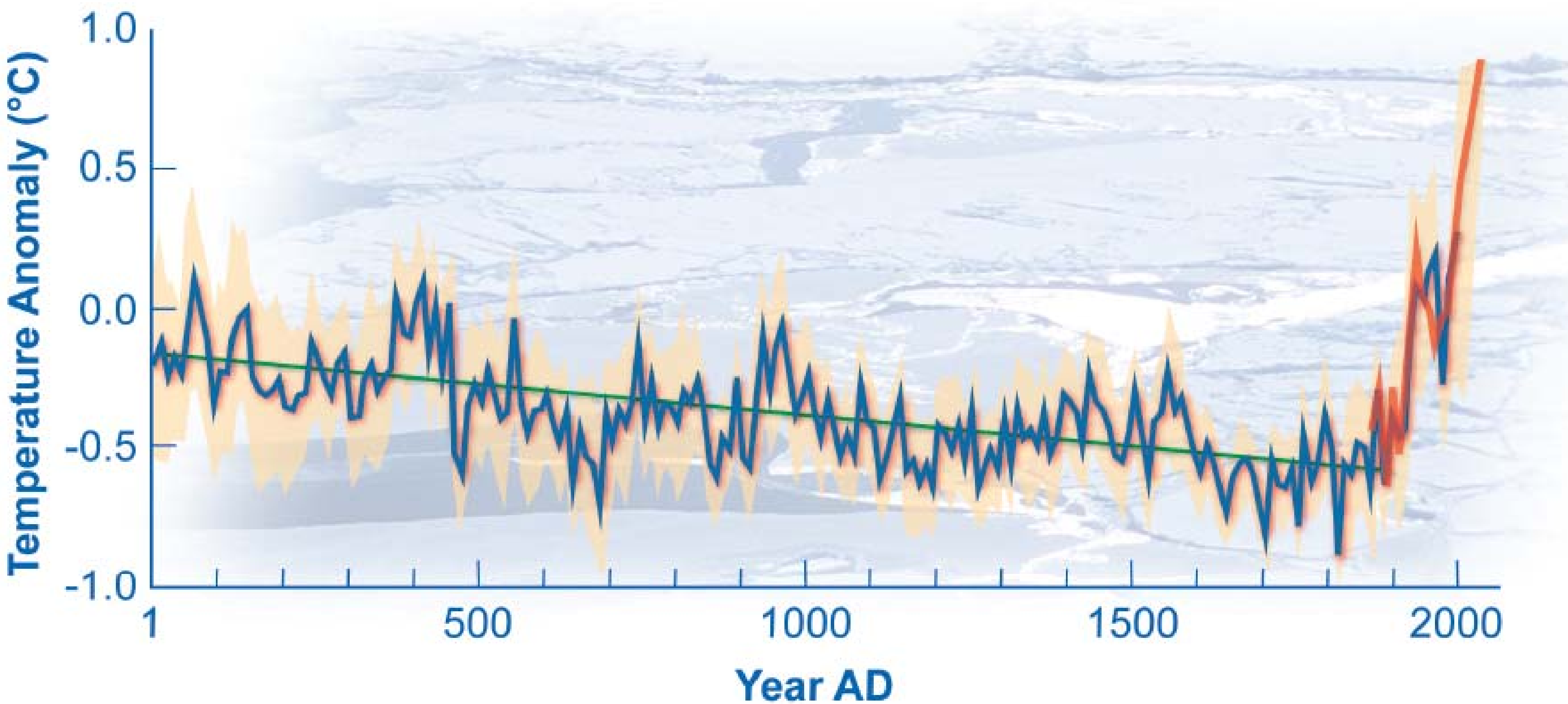

1979


2007

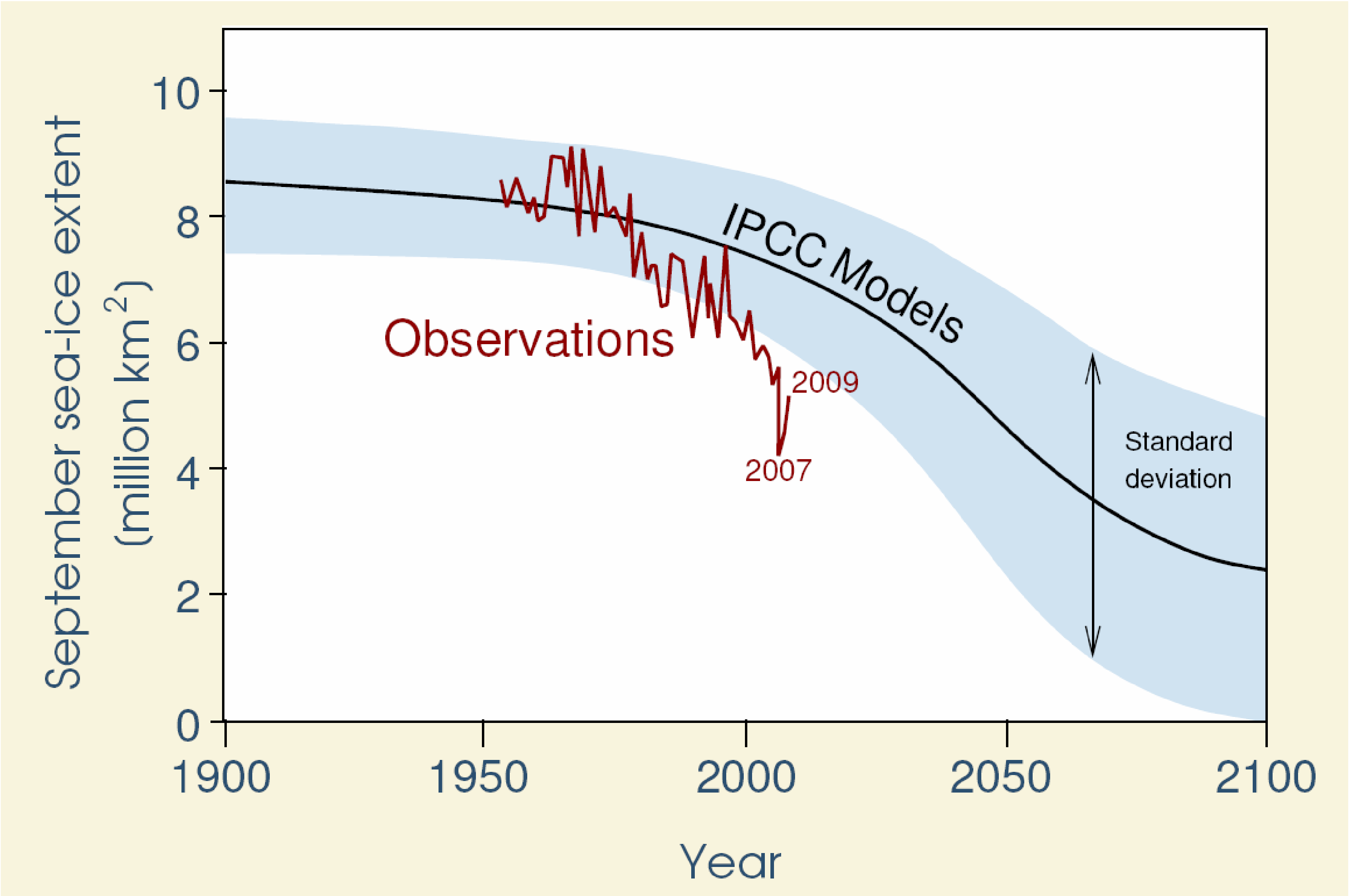
Strong Anomaly of Arctic Temperatures

Proxy-based estimates of Arctic air temperature



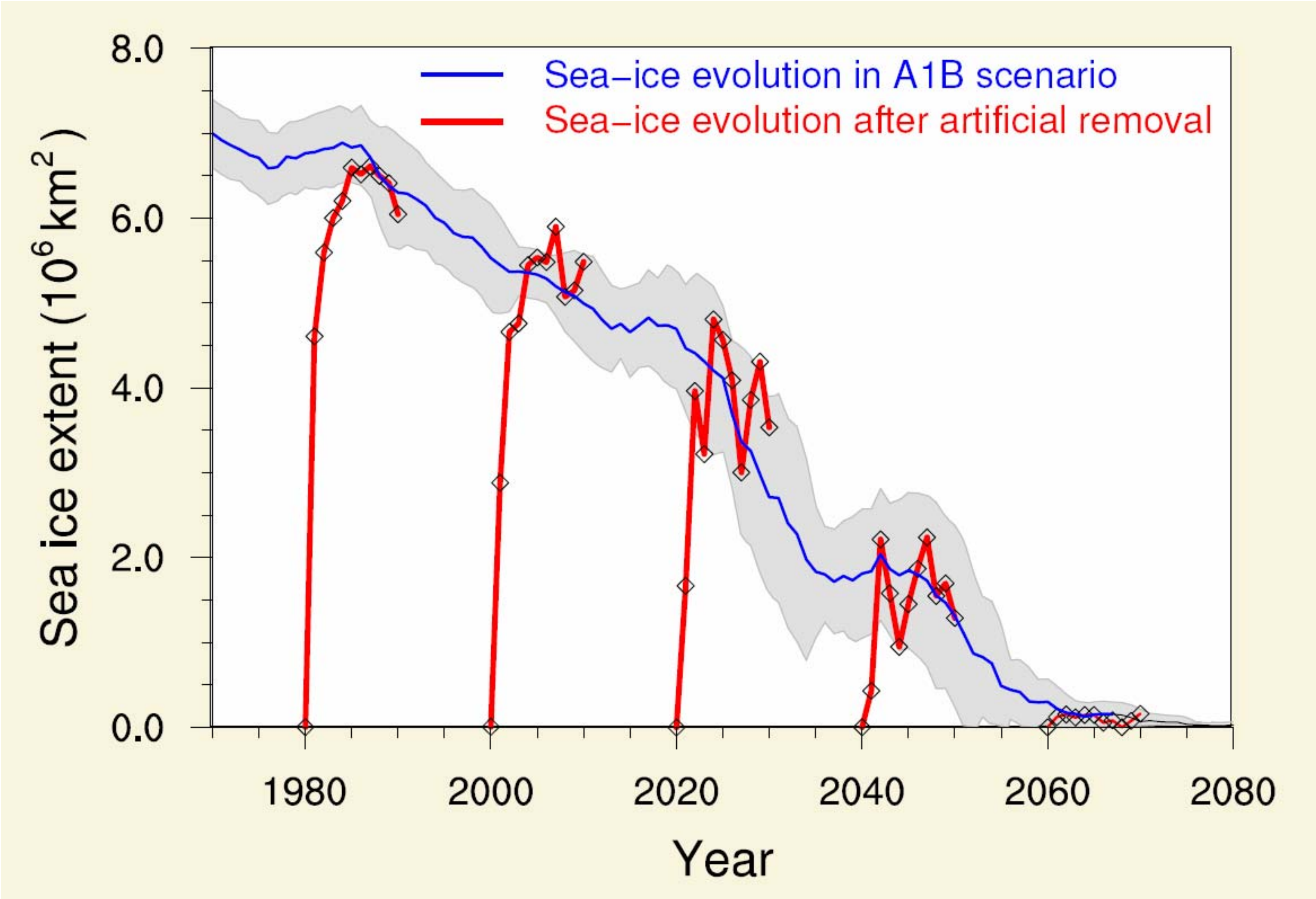
(from Kaufman et al. 2009 Science)

Rapid Arctic Sea-Ice Decline



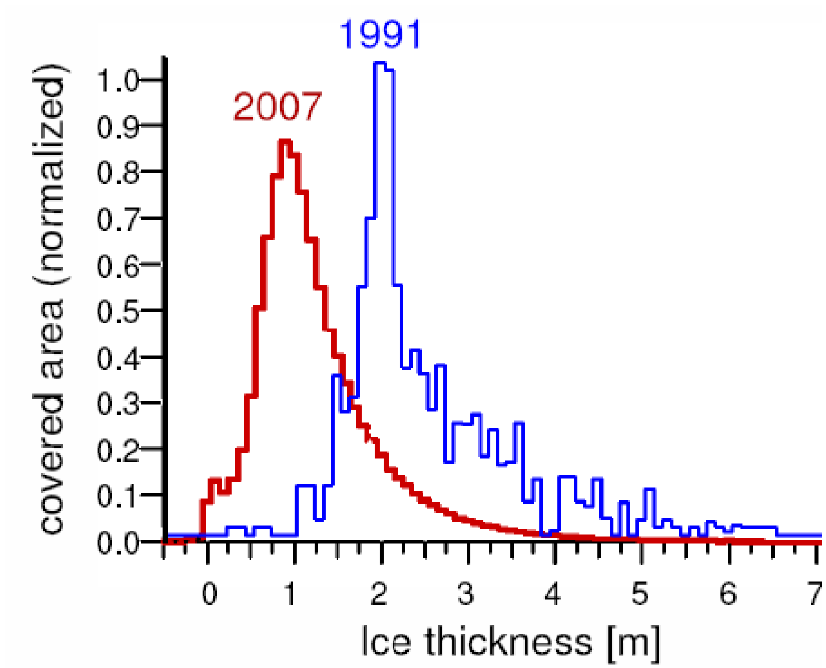
(Notz 2010 after Stroeve et al. 2007 GRL)

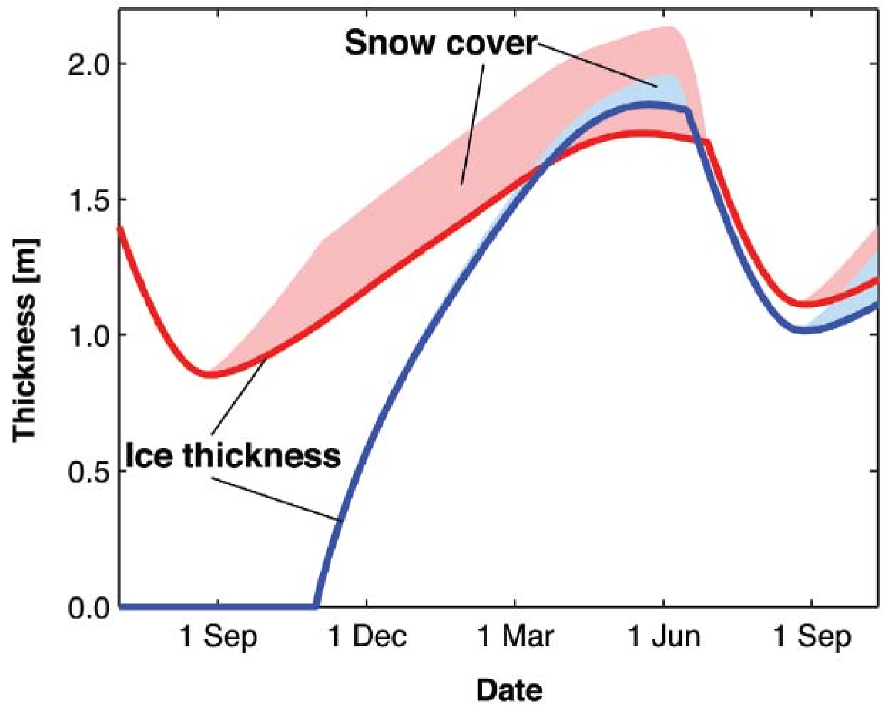
Arctic Summer Sea Ice – No Tipping Point?



(Notz 2010 after Tietsche et al. submitted)

Stabilizing Feedbacks Affecting Arctic Sea Ice

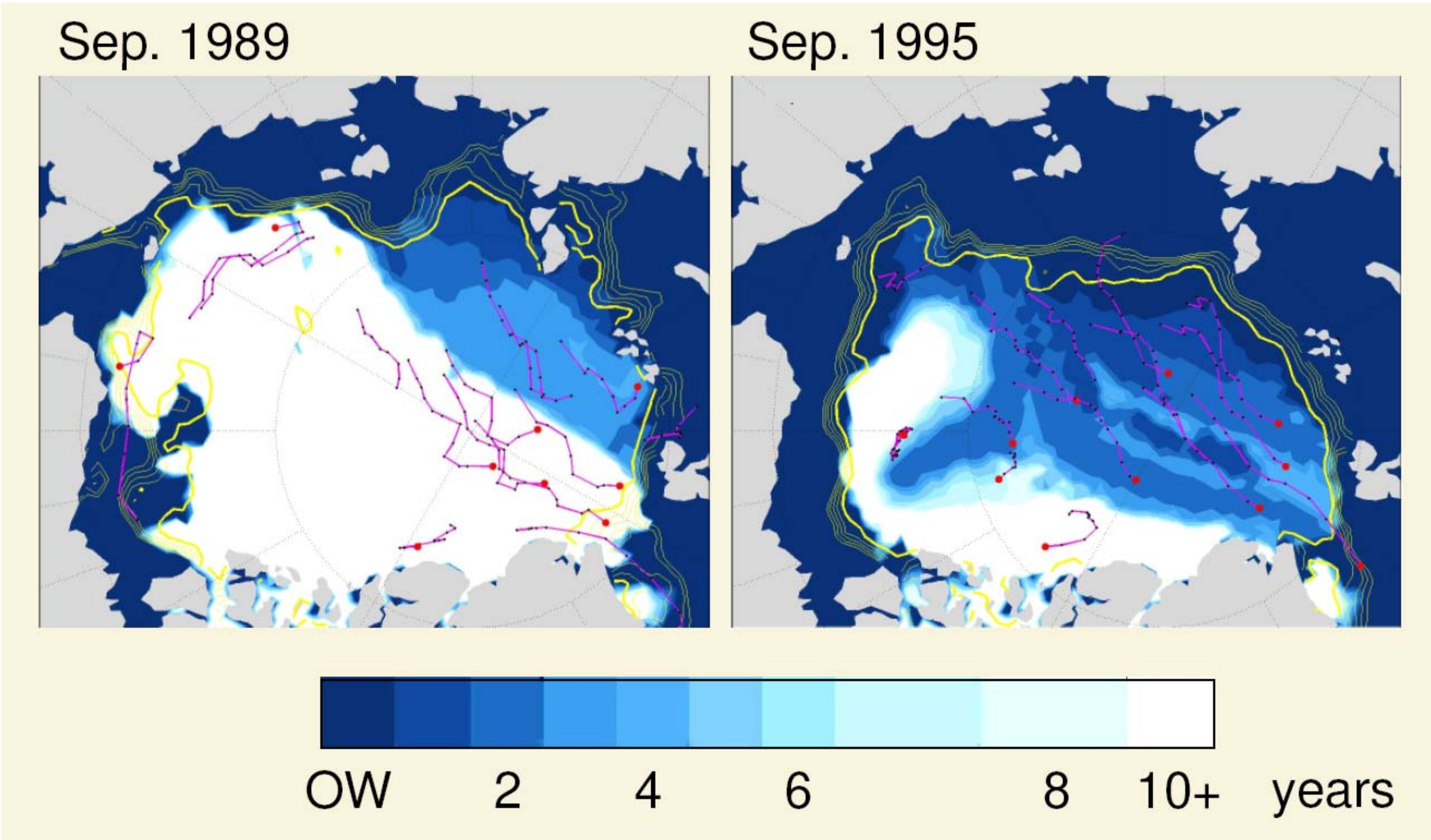




- Thin ice grows faster
- Enhanced heat release from uncovered ocean in winter
- Later ice formation leads to less insulation snow on the ice

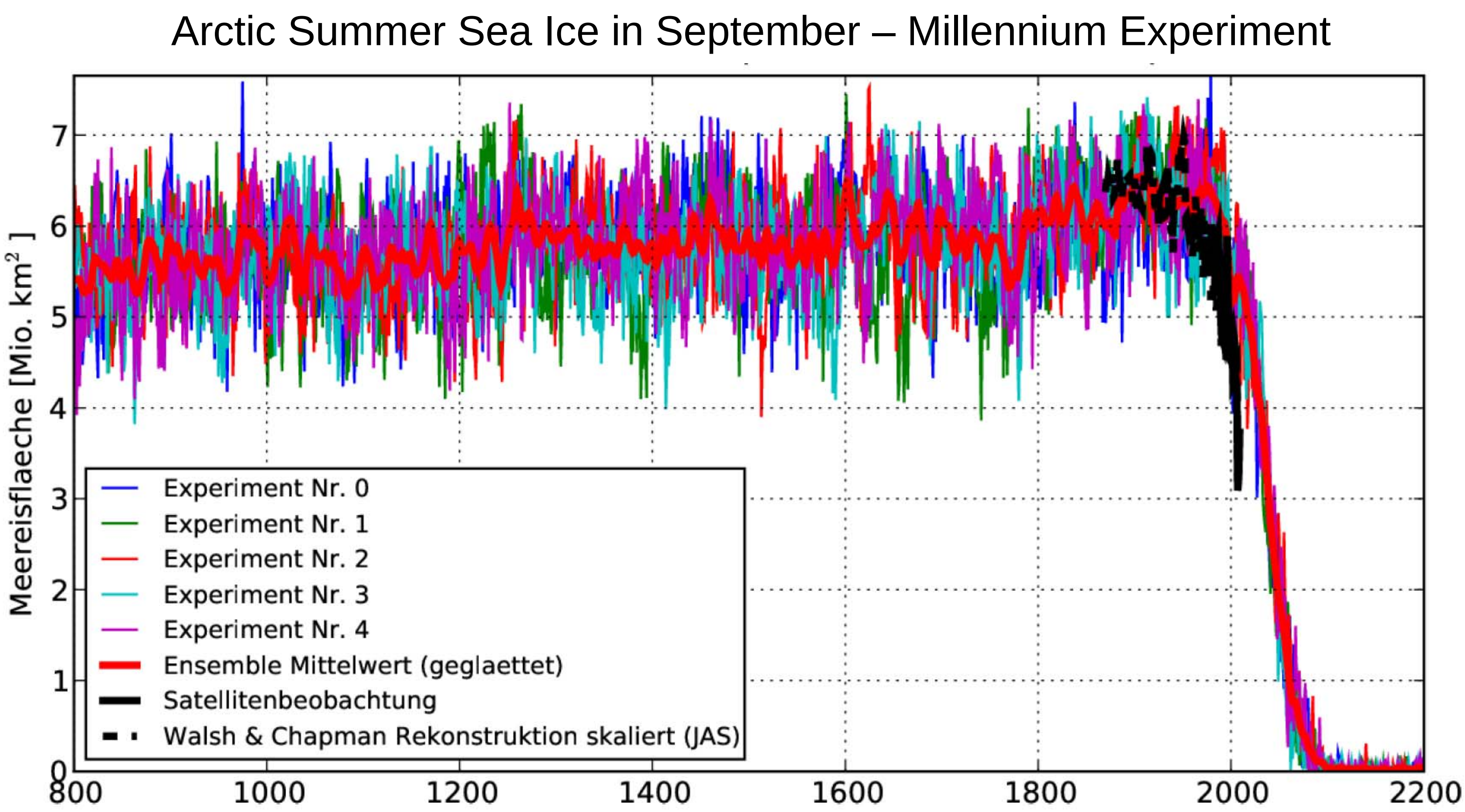
(Notz 2010 after Haas et al. 2008 GRL; Notz 2009 PNAS)

Age Structure of Arctic Ice Has Tipped



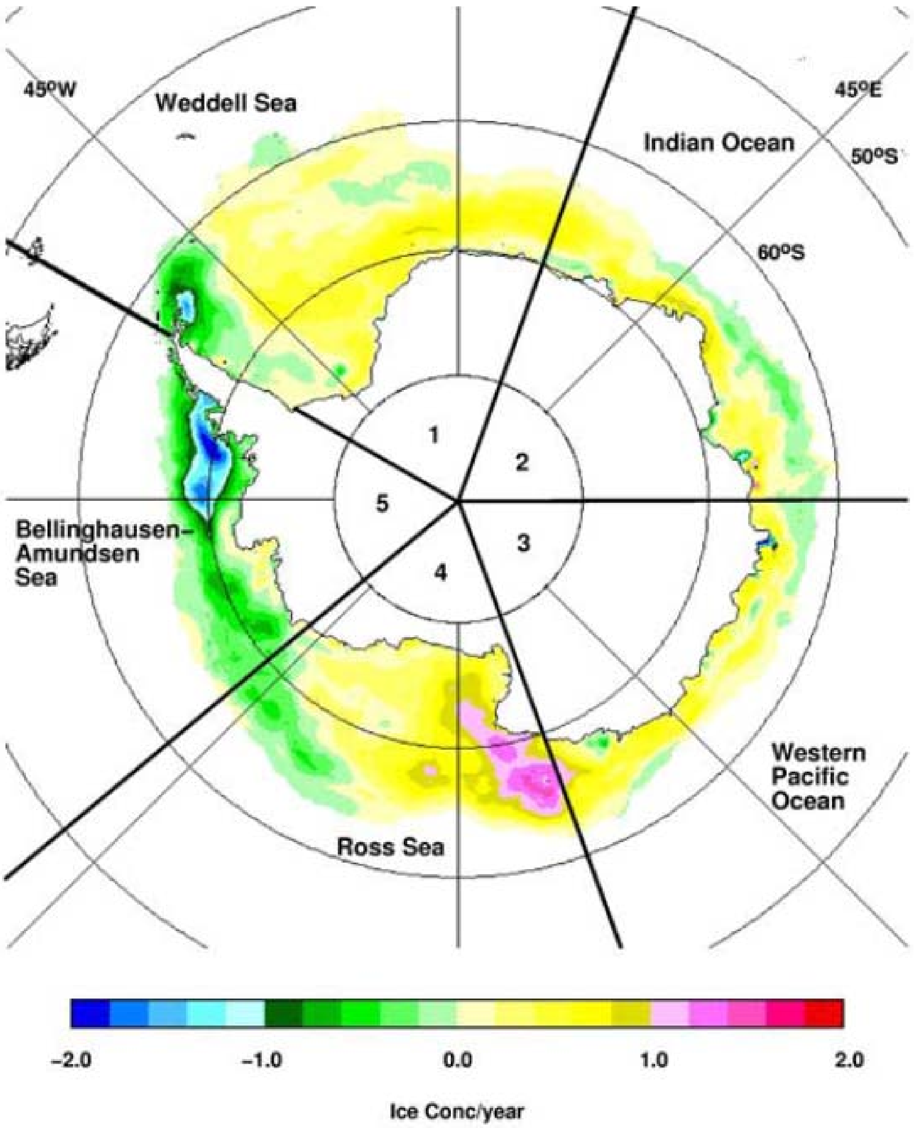
(Wallace & Rigor 2004 GRL)

Ice-Free Summer to be Expected Before 2100



Simulation with COSMOS Earth System Model
(MPI Hamburg, Coordination Johann Jungclaus, A1B-Scenario)

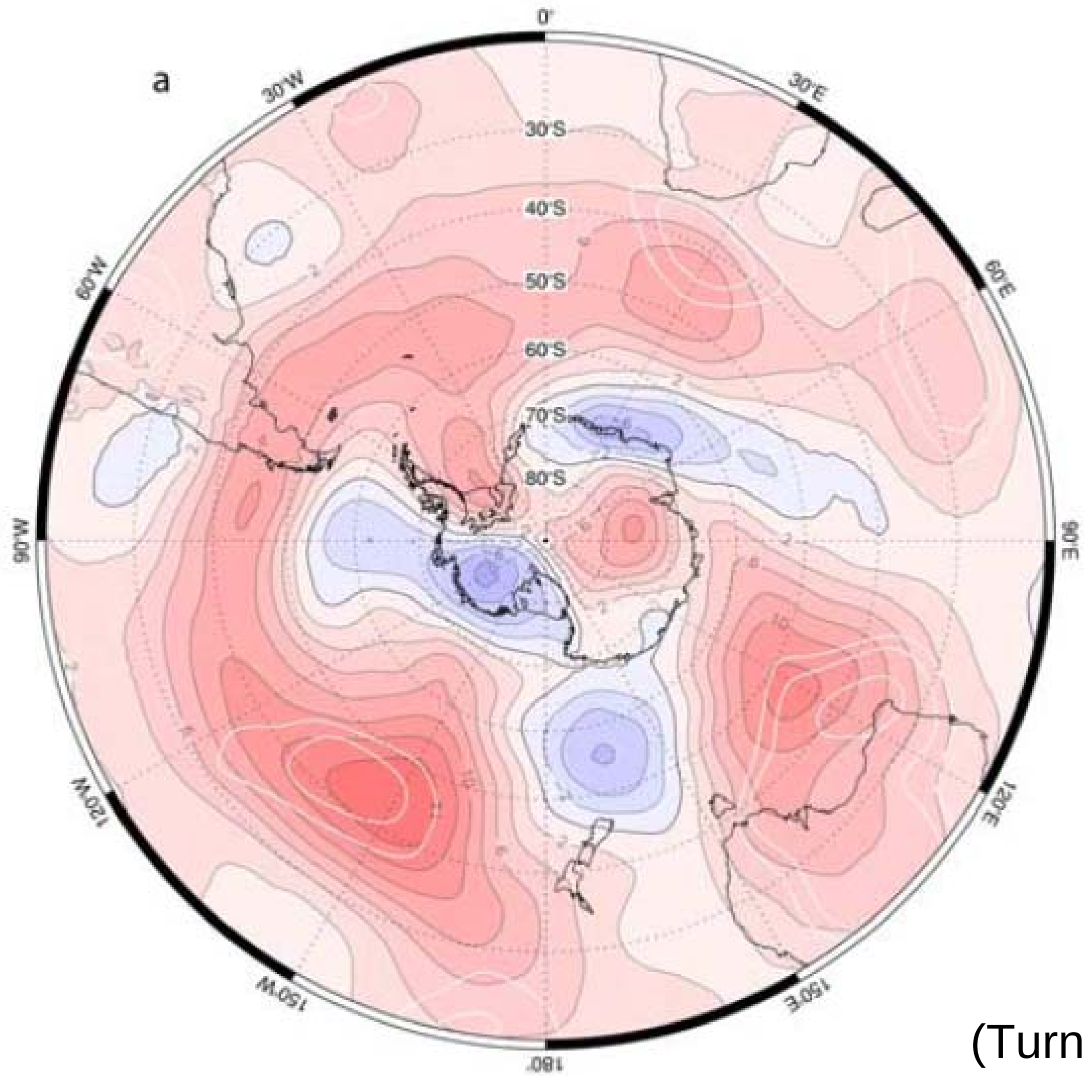
Slight Increase in Antarctic Sea-Ice Extent



(Turner et al. 2009 GRL)

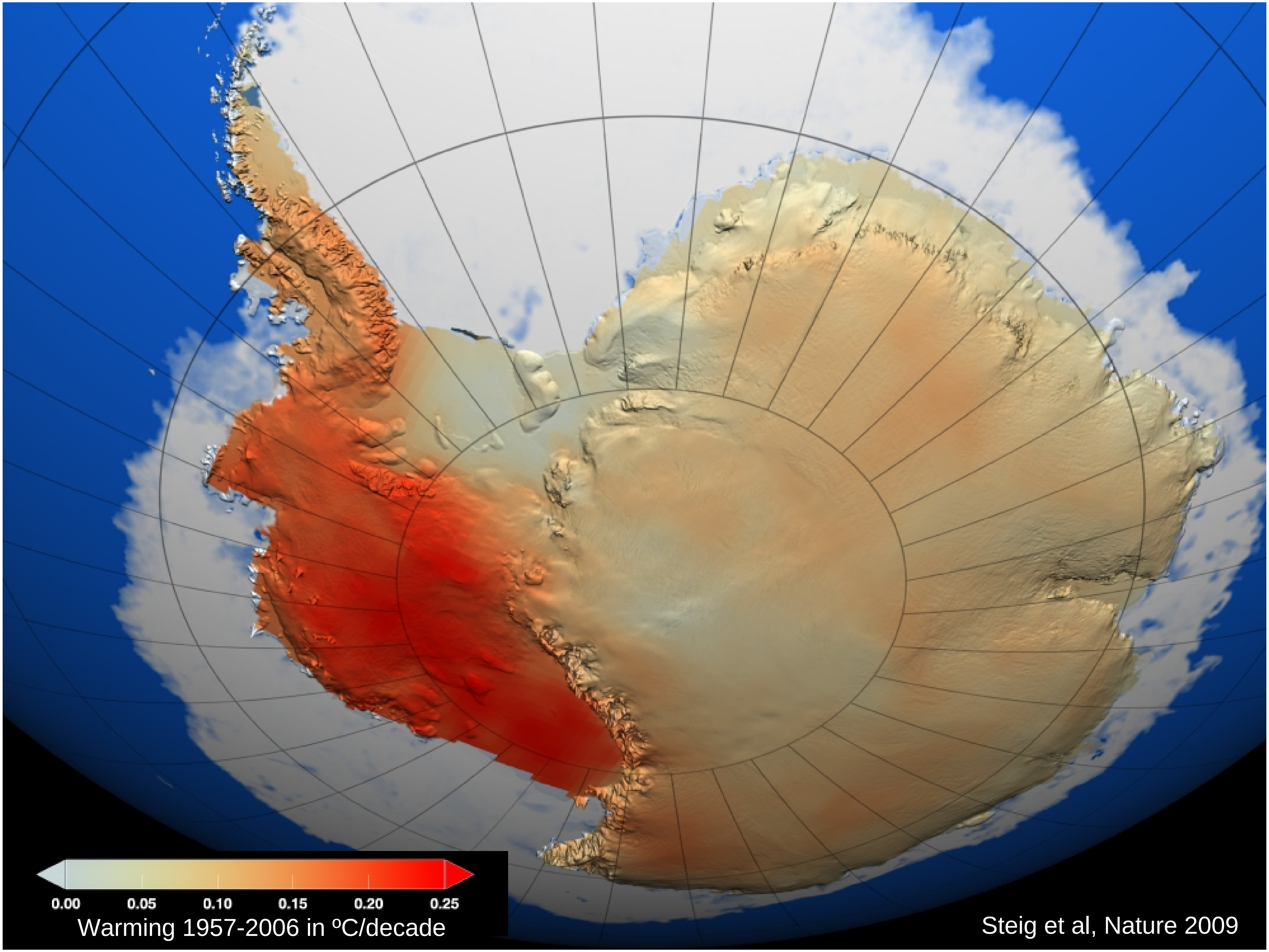
Southern Hemisphere Ice Concentration Trends, Autumn 1979-2007

Influence of the Ozone Hole on Antarctic Climate

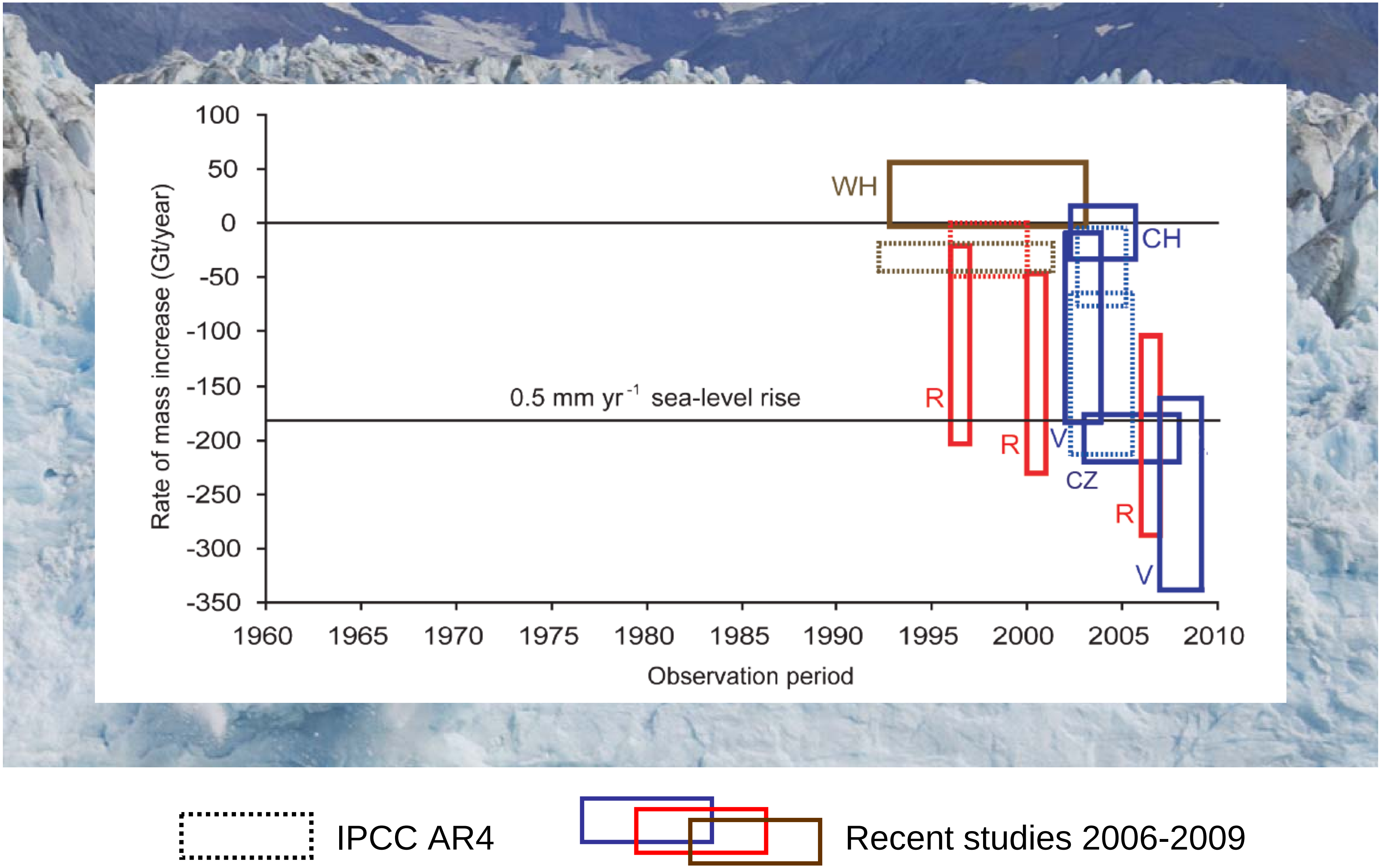


(Turner et al. 2009 GRL)

Trend in Autumn 500 hPa geopotential height for 1979–2006

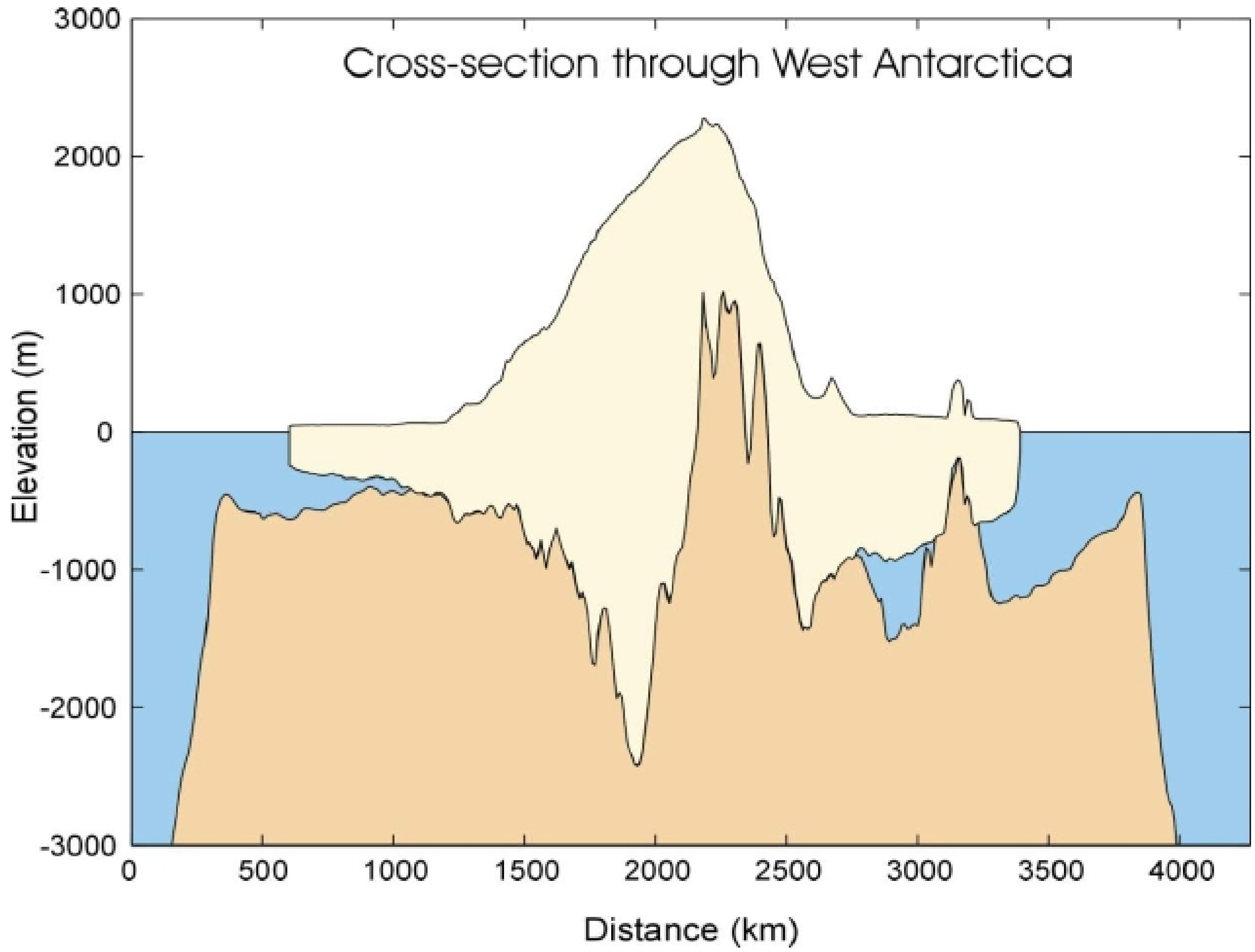

0.00
0.05
0.10
0.15
0.20
0.25
Warming 1957-2006 in ºC/decade
Steig et al, Nature 2009

Accelerating Loss of Antarctic Ice-Sheets



West Antarctic Ice Sheet

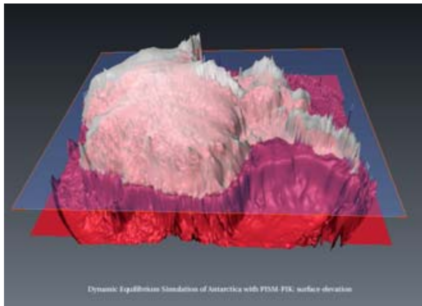
is a ‘marine ice sheet’ and thereby potentially unstable



WAIS contains 5m sea level rise

by Adrian Jenkins

Slides on WAIS courtesy of A. Levermann



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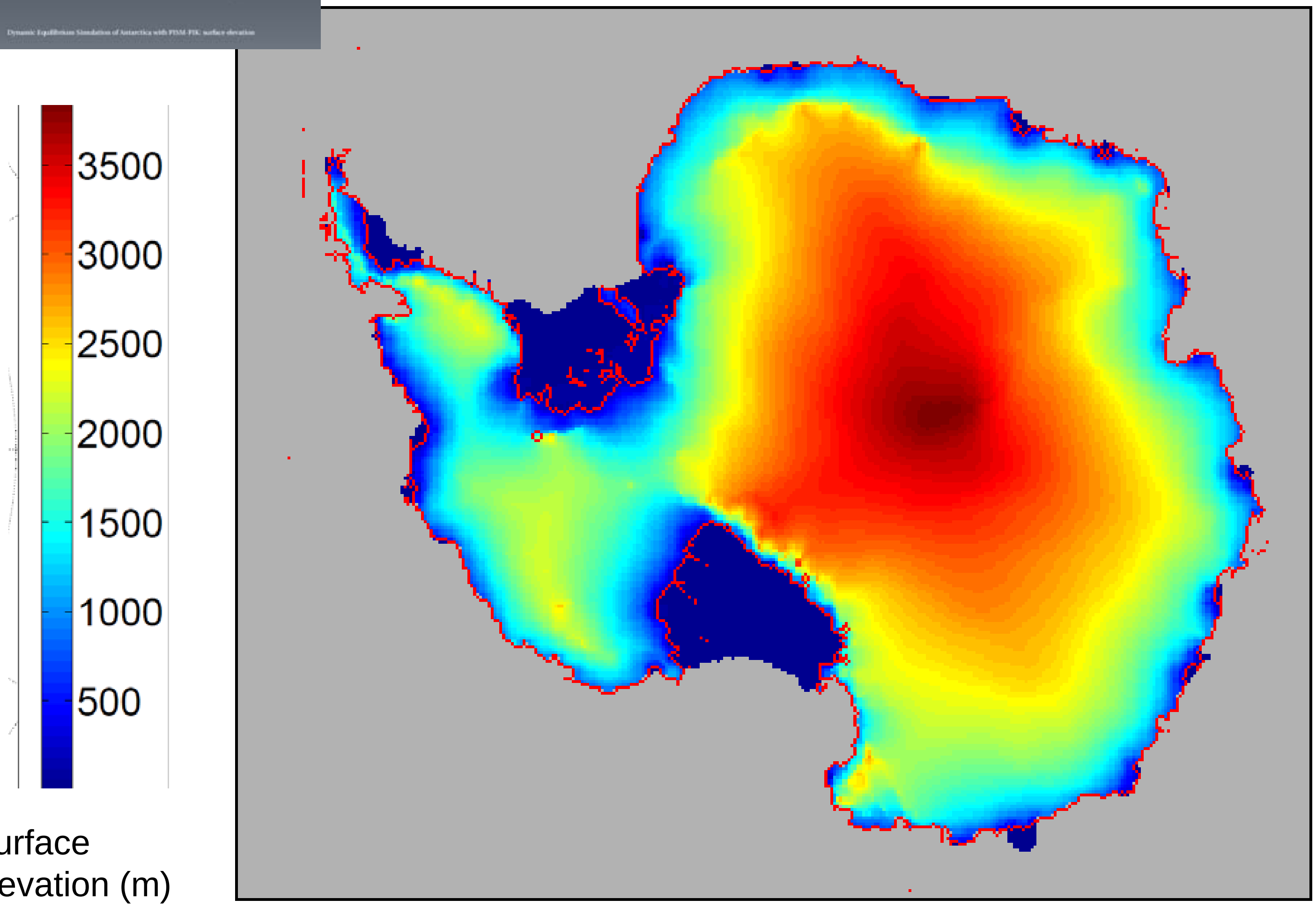
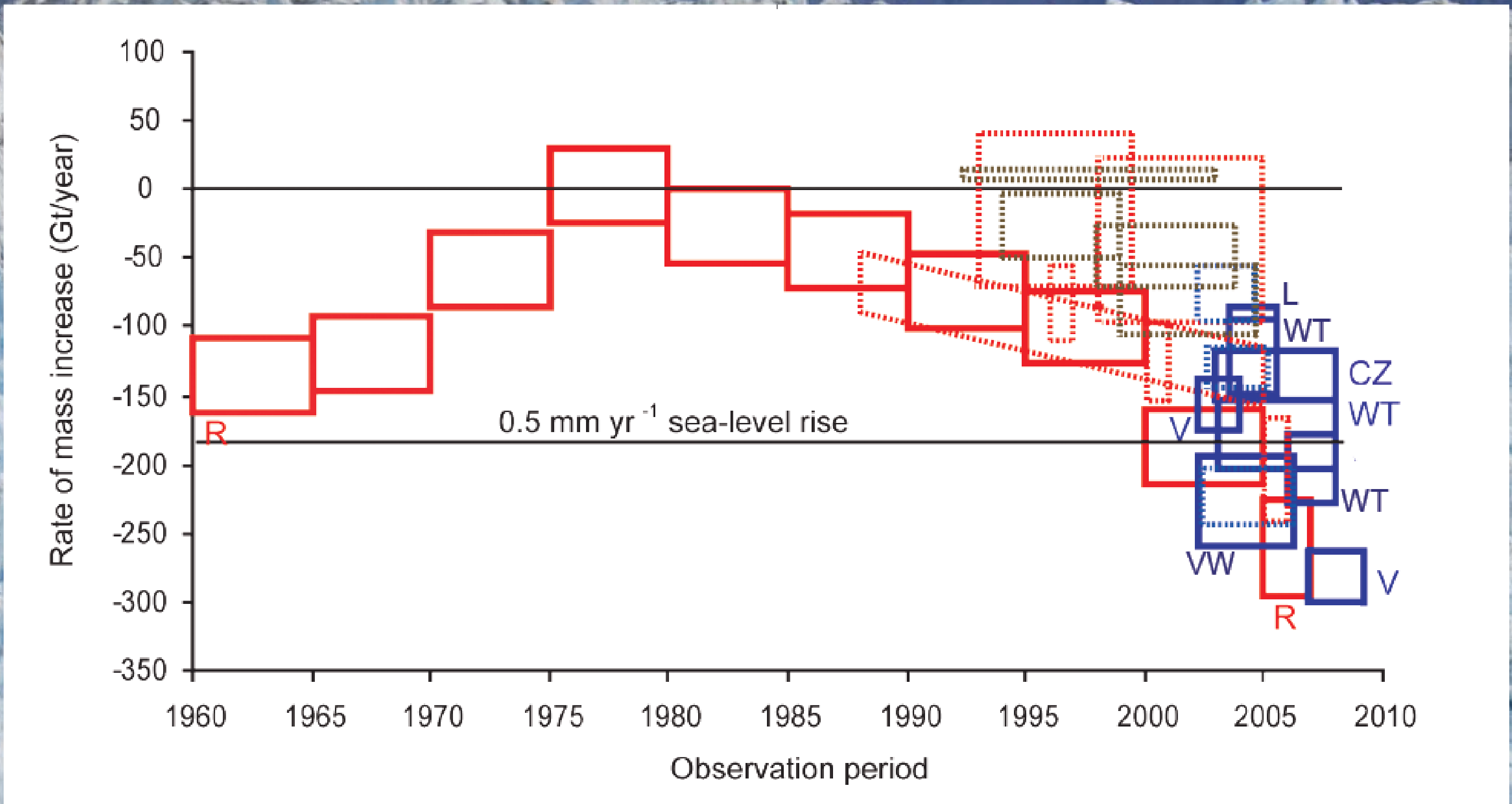


Collapse would lead to 3.5 m sea level rise

Minimal collapse time in the model ~500 years.

Martin, Levermann, Winkelmann, in preparation.

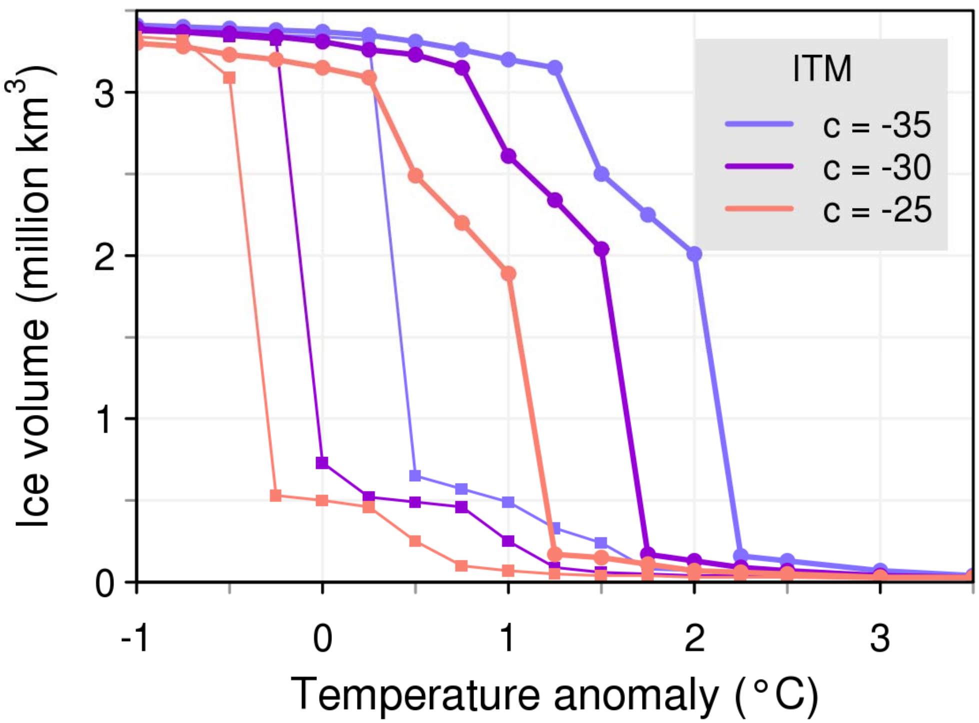
Accelerating Loss of Greenland Ice-Sheets

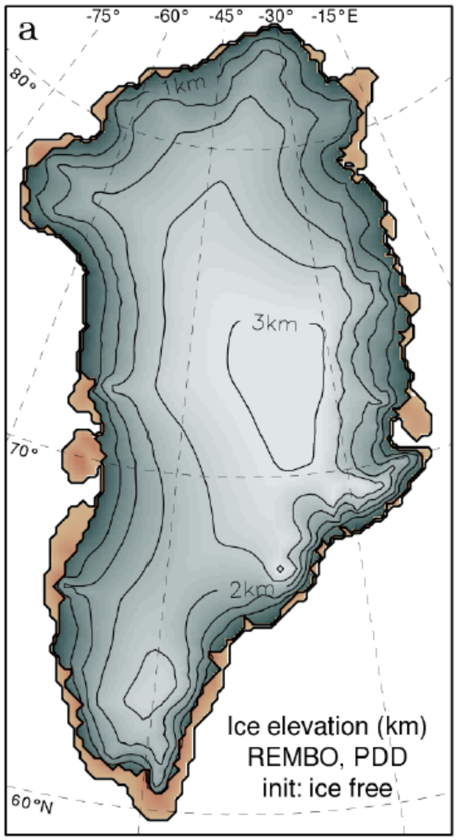


IPCC AR4

Recent studies 2006-2009

Greenland Ice Sheet – Risk of Irreversible Loss



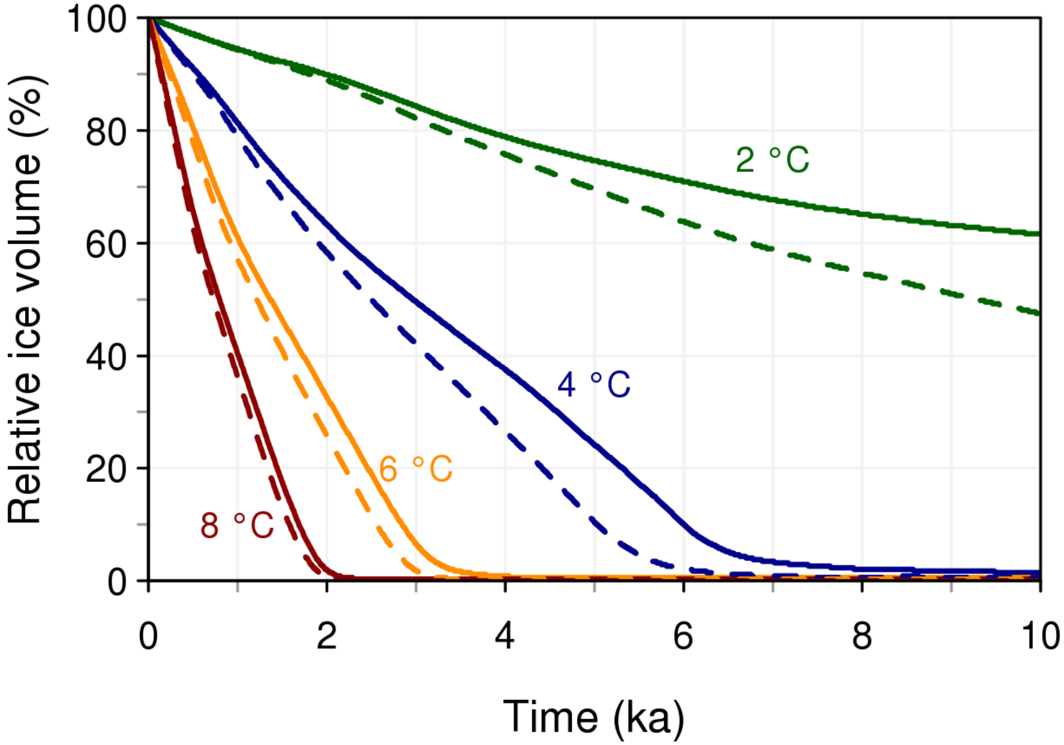


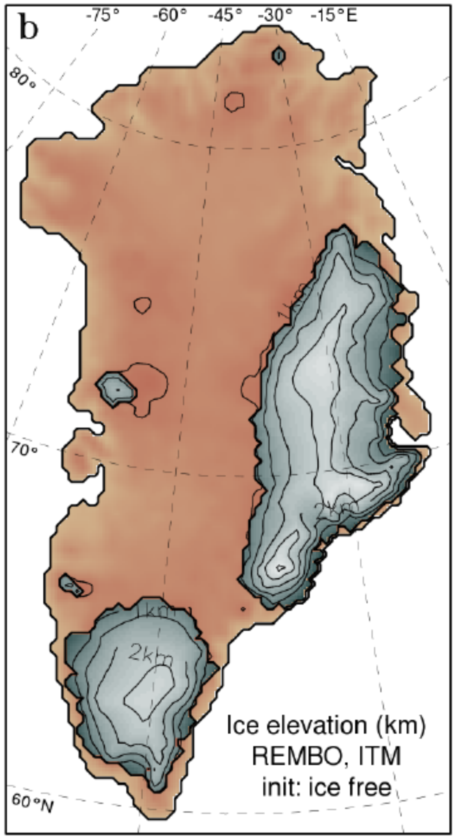
The loss of the Greenland ice sheet may be triggered at 1.5 - 2.5°C additional global warming.

Hysteresis: The ice sheet does not regrow until lower temperatures are reached again.

(Robinson, Calov, Ganopolski, in prep.)

Greenland Ice Sheet – Timescales of Melting





Greenland Ice Sheet contains 7m sea level rise

Melting may take hundreds to thousands of years.

(Robinson, Calov, Ganopolski, in prep.)

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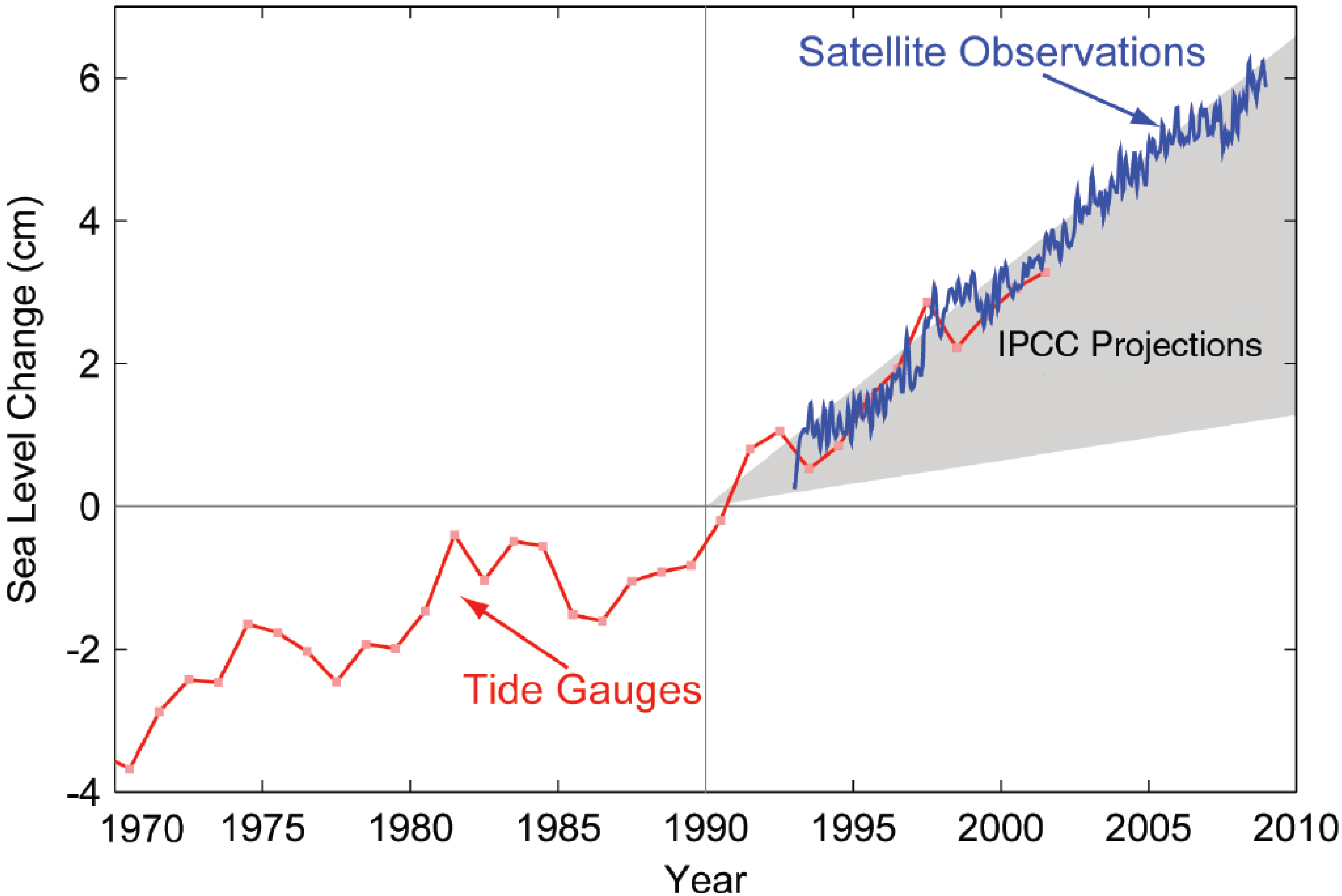
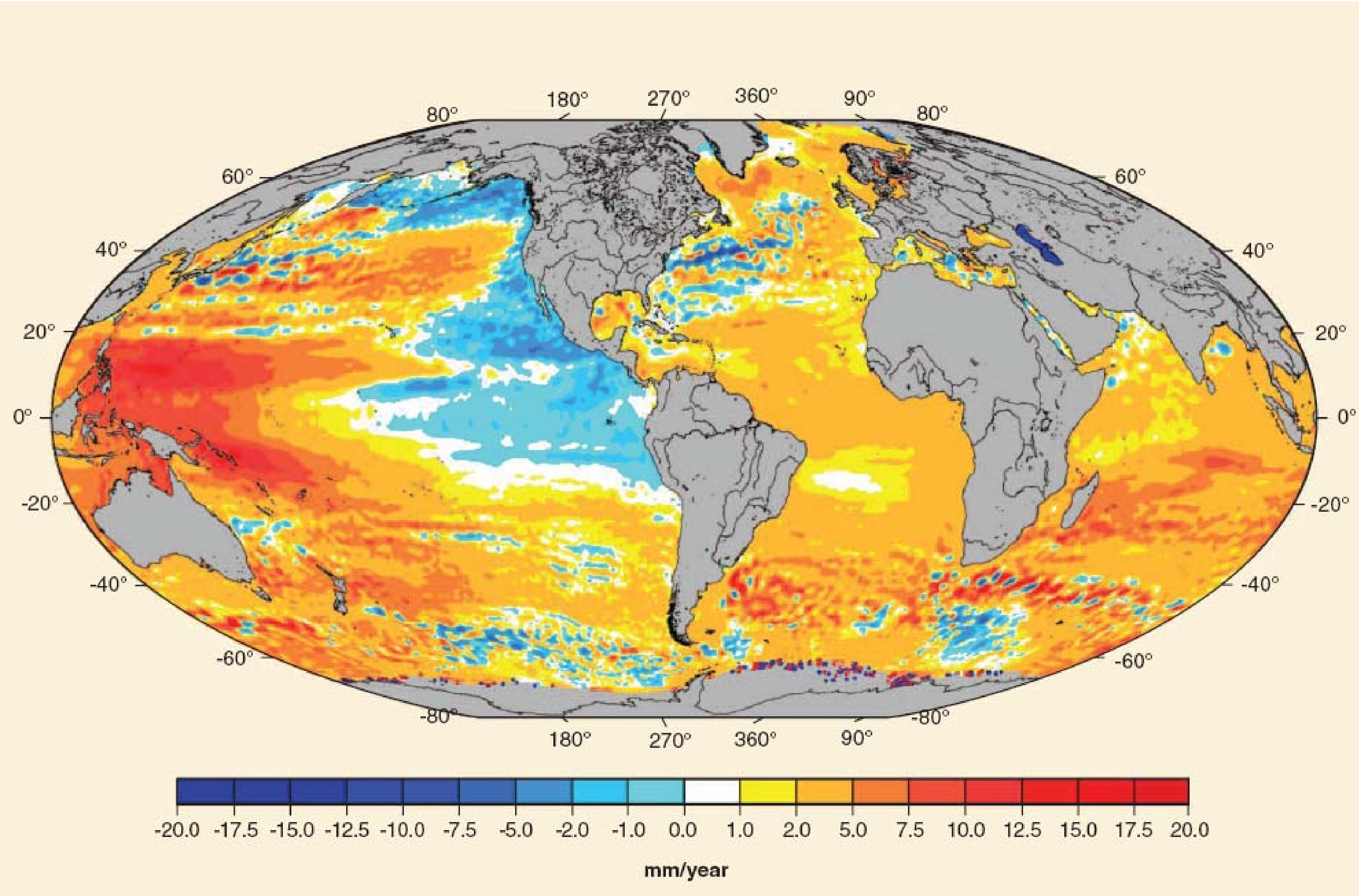
Sea-Level Rise Faster than Expected



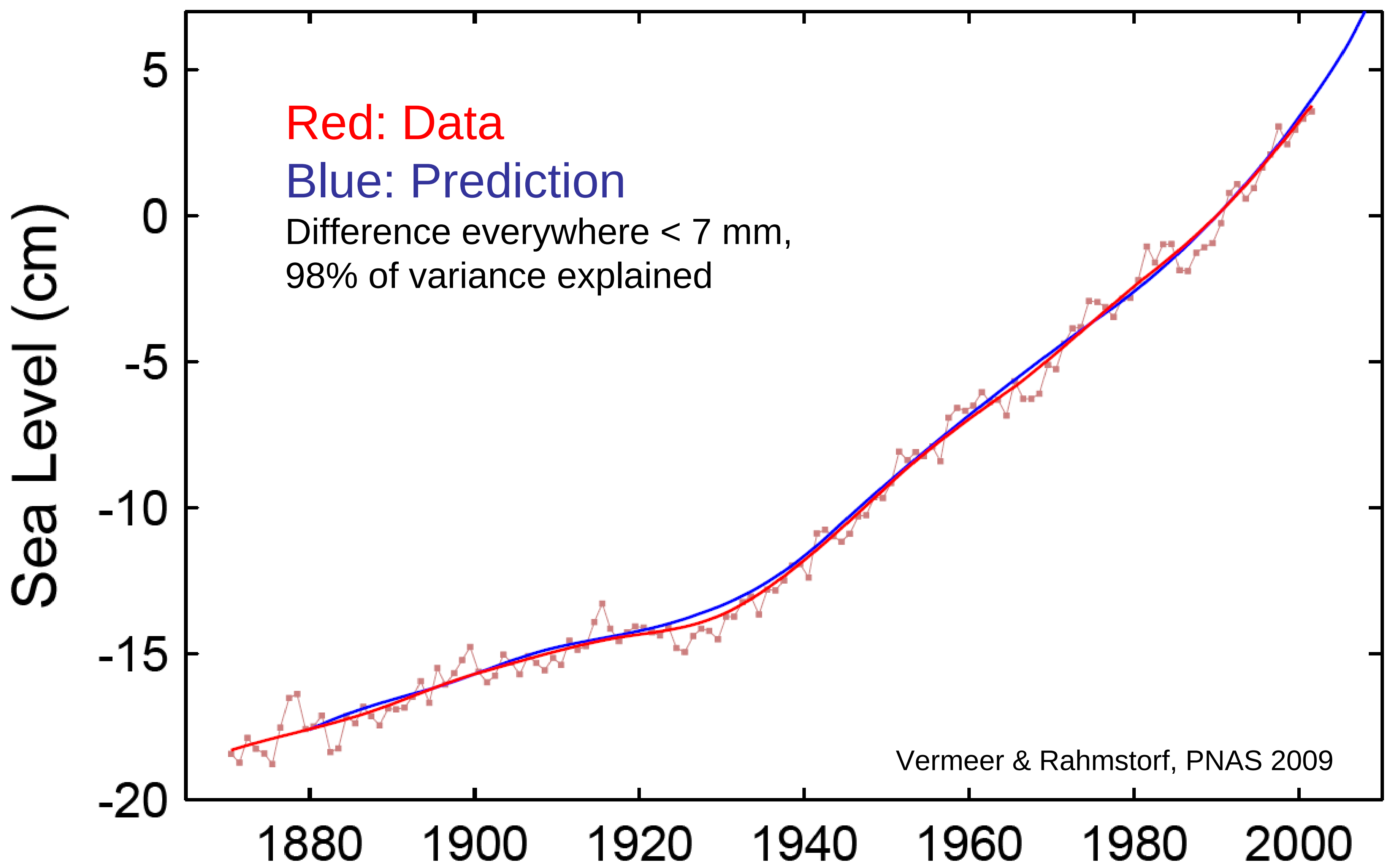
Regional Heterogeneity of Sea-Level Rise



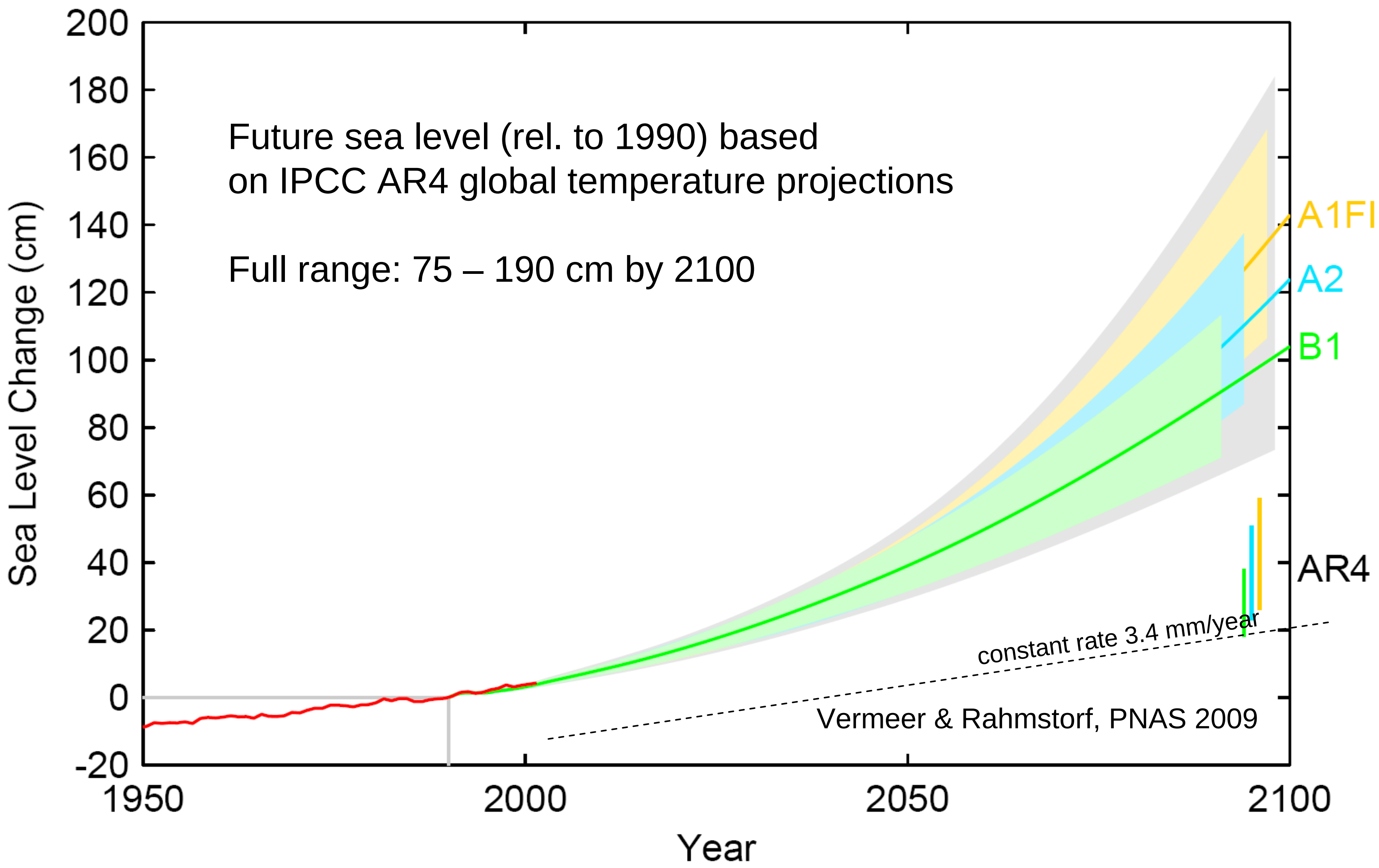
Regional sea-level trends from satellite altimetry for the period October 1992 to July 2009

(Nicholls and Cazenave 2010 Science)

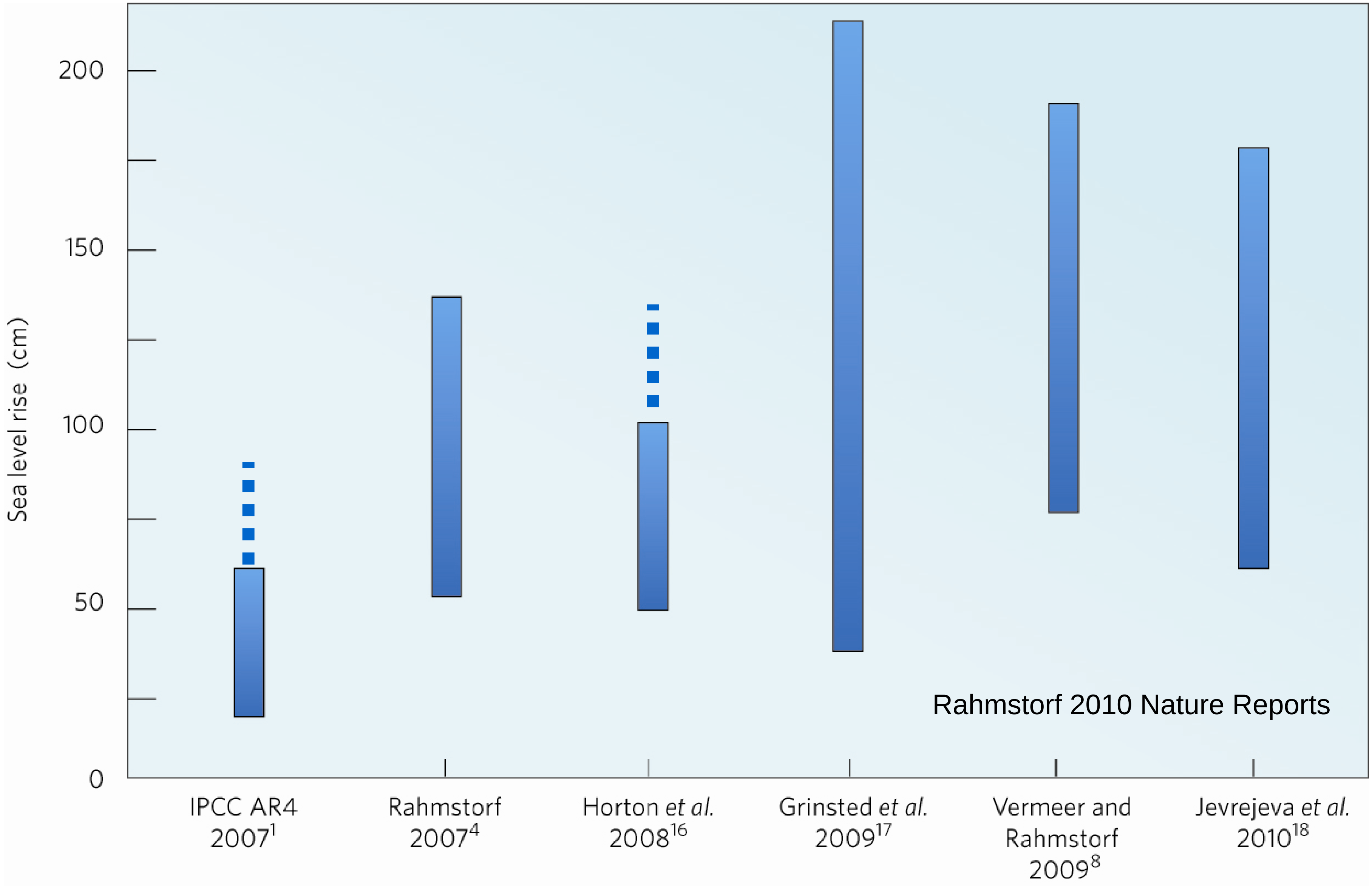
Semi-Empirical Model to Predict Sea-Level Rise Based on Temperature



Sea-Level Projections on the Rise



Has the IPCC Underestimated the Risk of Sea-Level Rise?



SLR Impact Assessment "In its Infancy"

Aggregated absolute exposure for 2 m sea-level rise:

Land Area:

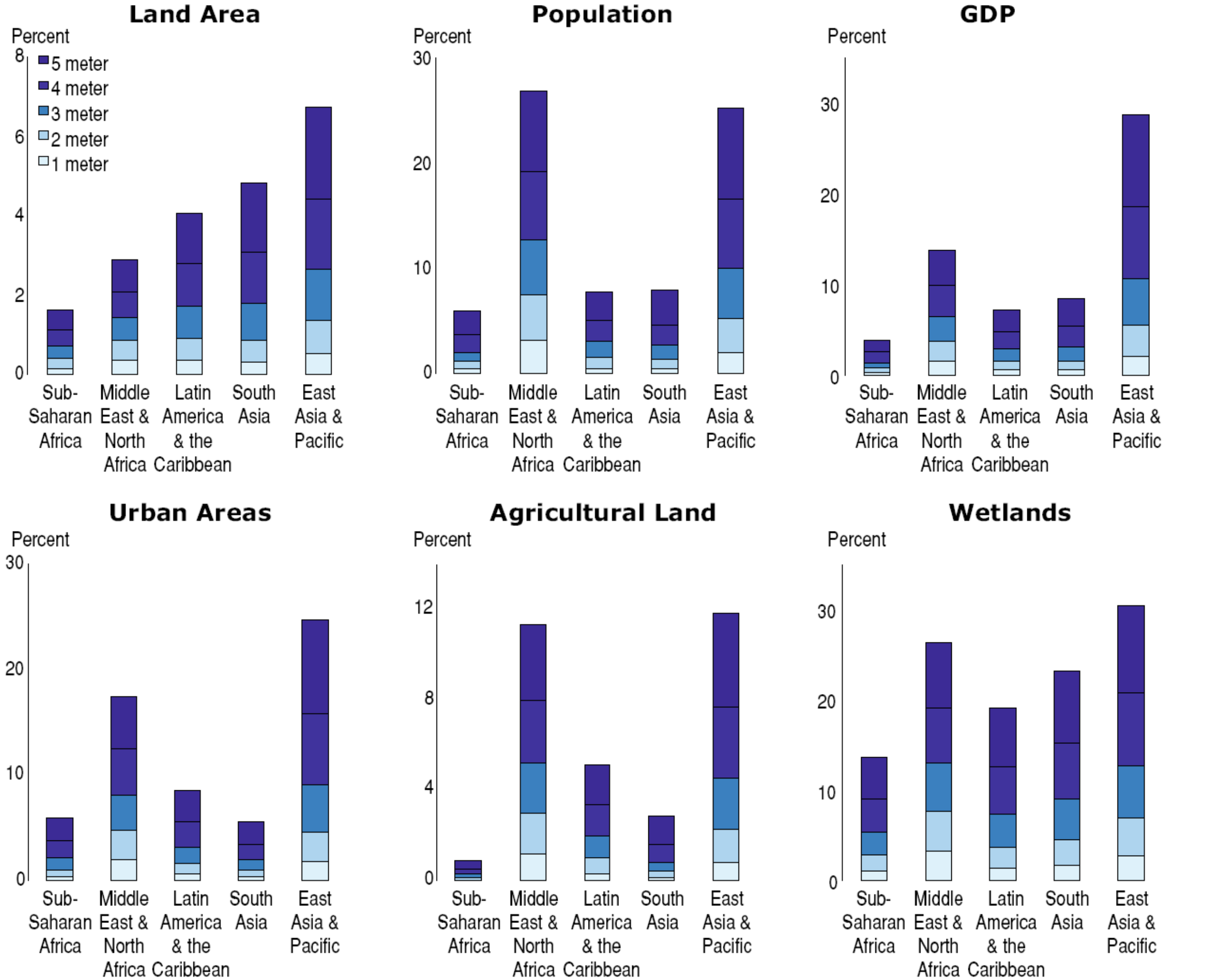
300 000 km^2 (~0.5%)

Population:

89 million (~2%)

GDP:

USD 350 billion (~2%)



Based on 84 coastal developing countries

(Dasgupta et al. 2009 Climatic Change)

How Much Does the ‘Gold Coast‘ Cost?

Long Island at 7m sea level rise (Source: http://flood.firetree.net/)

Part 4

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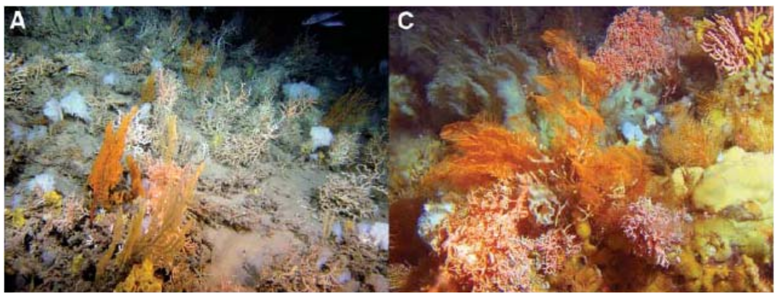
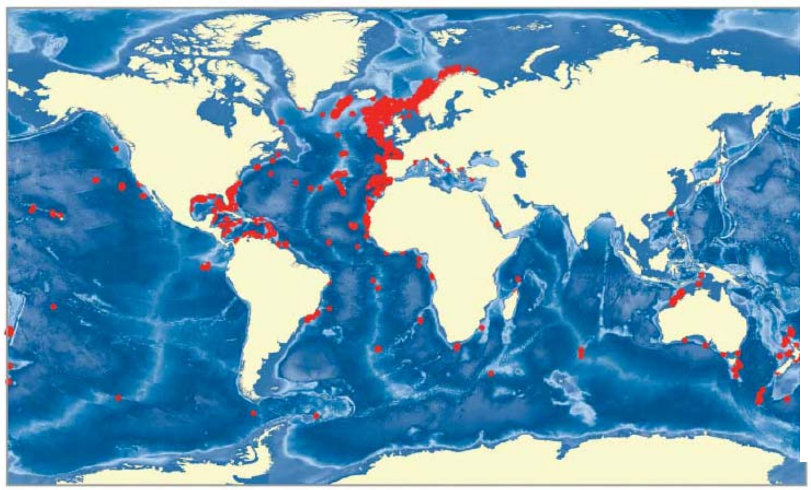
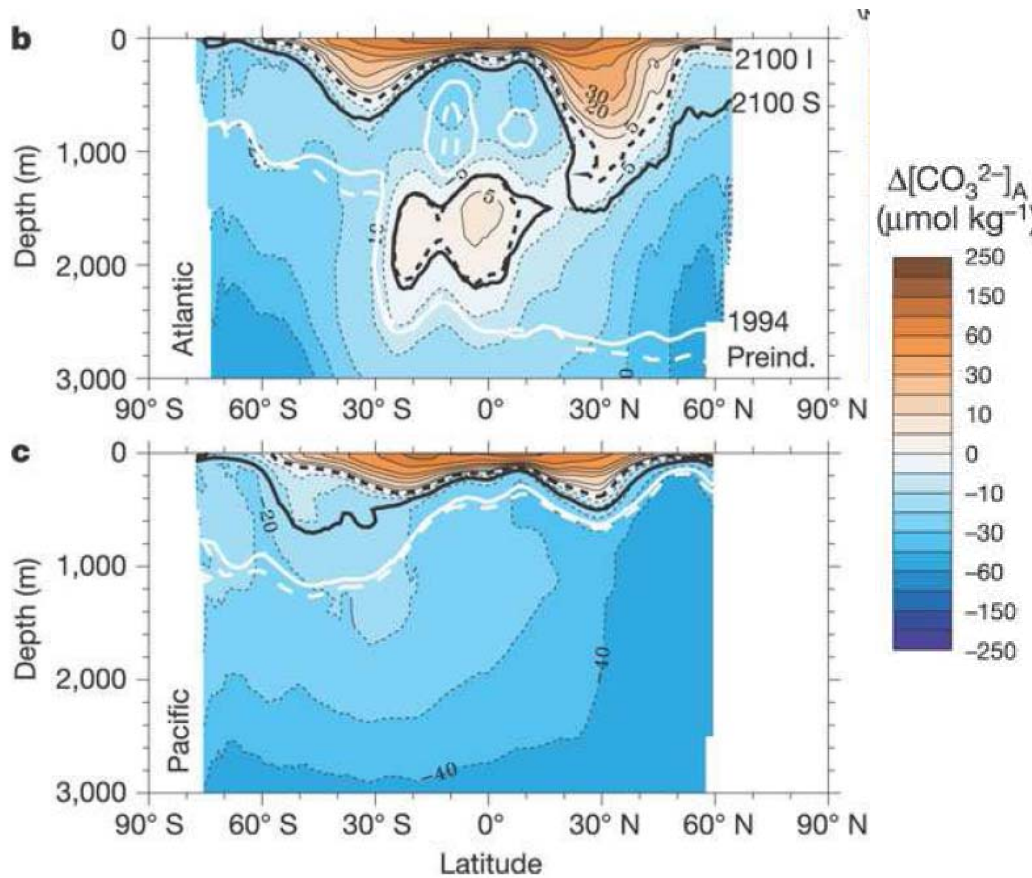
Cold-Water Coral Reefs Soon Bathed in Corrosive Waters?



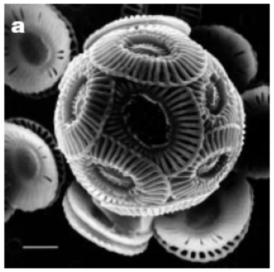


(Roberts et al. 2006 *Science*)

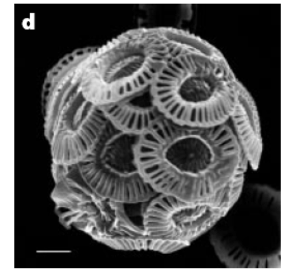


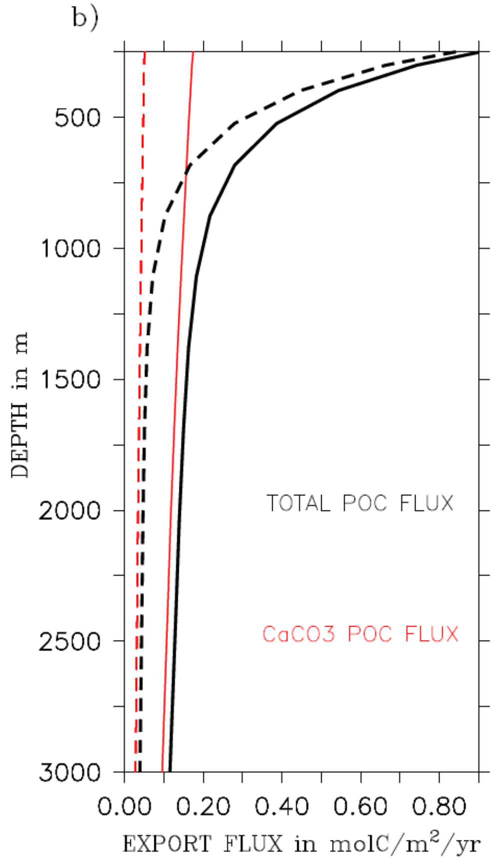
Aragonite saturation horizon is projected to move upwards by 2100

(Orr et al. 2005 *Nature*; Hofmann & Schellnhuber *submitted*)



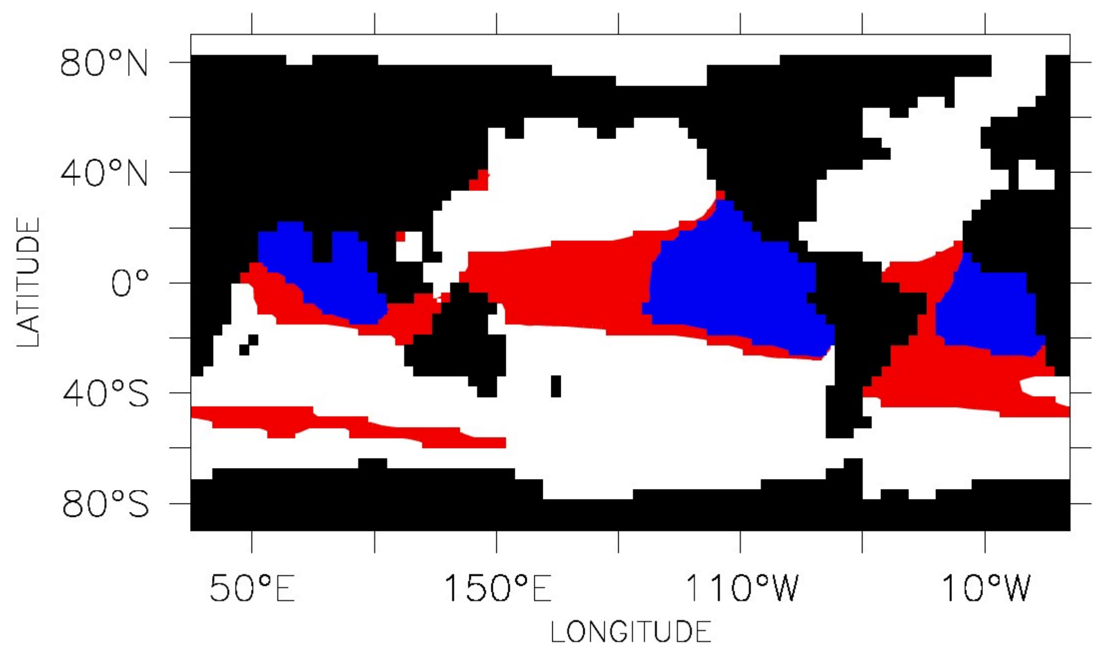
Ocean Acidification Affects Marine Carbon Pump and Triggers Extended Marine Oxygen Holes





preindustrial export flux

year 2300 export flux
(CO_2 peak : 1750 ppm)



(Hofmann *unpublished* 2009)

Oxygen depleted (< 120 μmol L^{-1}) zones at 400 m depth

preindustrial extent

year 3000 extent

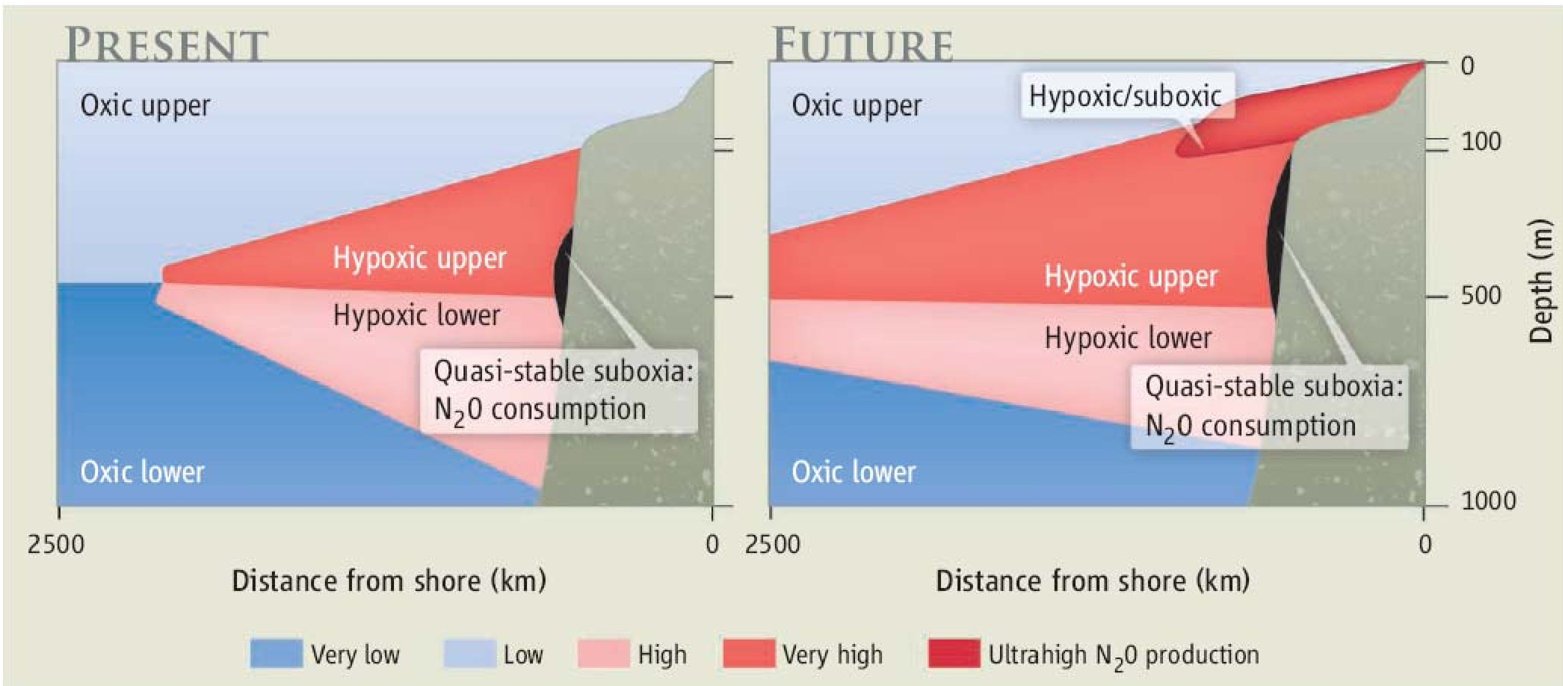
(Hofmann & Schellnhuber 2009 PNAS)

OCEANS

Interesting Times for Marine N_2O

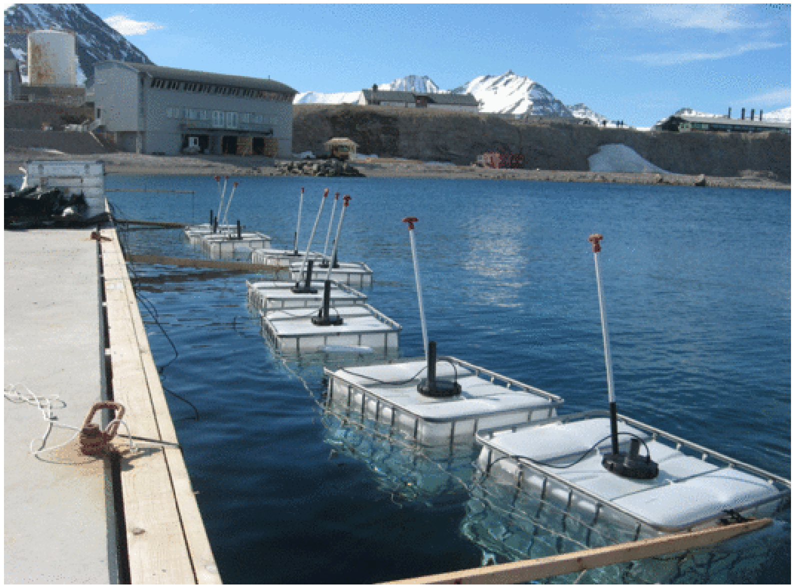
Louis A. Codispoti

Changes in ocean chemistry could exacerbate global warming by raising the atmospheric concentration of nitrous oxide, a potent greenhouse gas.

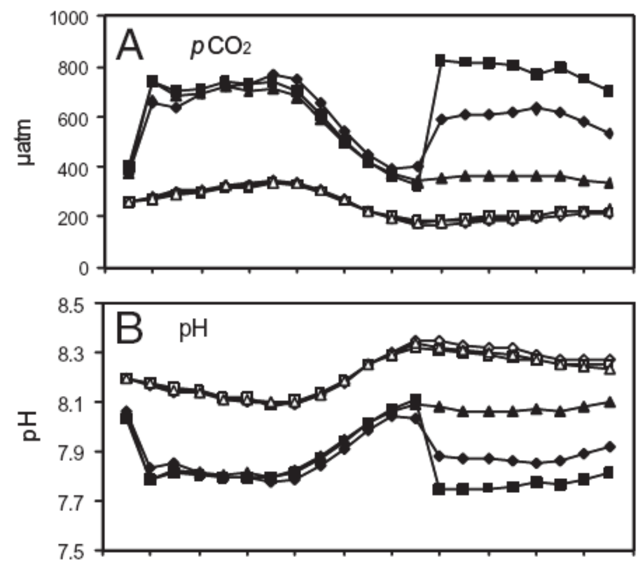


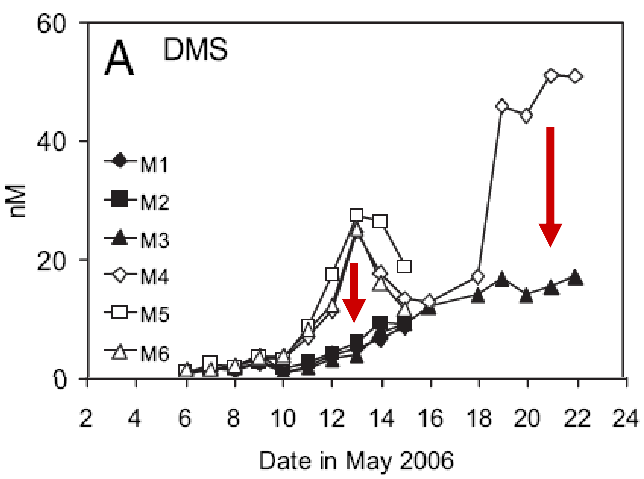
A generic eastern boundary in present-day and future oceans. Suboxia can extend further offshore than shown here, but is absent from a large portion of the oceanic eastern boundary.

Ocean Acidification and Marine Trace Gas Emissions



Mesocoms in Norvegian fjord





Decreased Dimethylsulfide (DMS) emissions of marine phytoplankton blooms grown under elevated CO_2 (750 ppmv)

Potential positive feedback on global warming

(Hopkins et al. 2010 PNAS)

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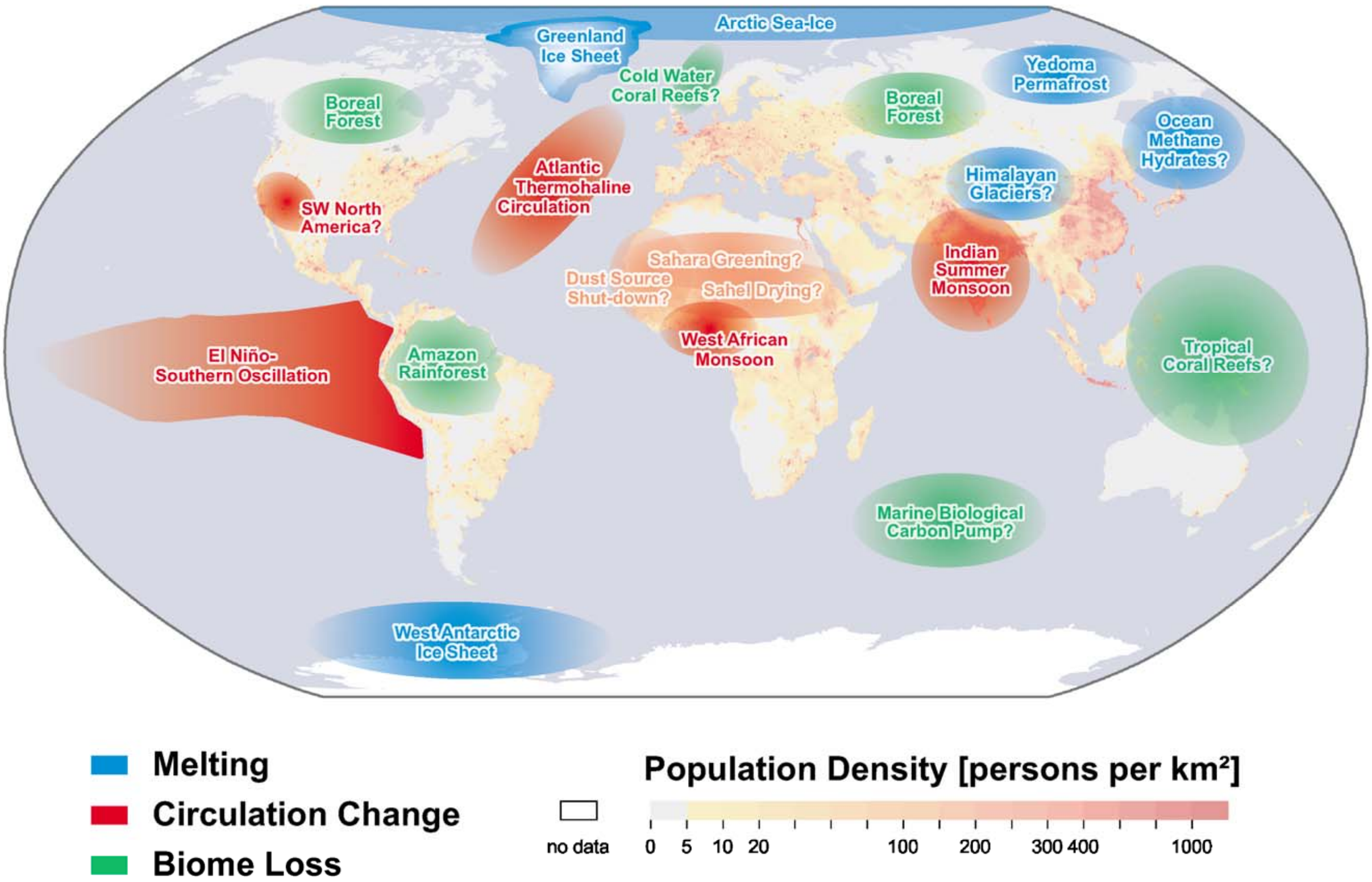
Updated Map of Tipping Elements in the Earth System



(Source: after Lenton et al. 2008)

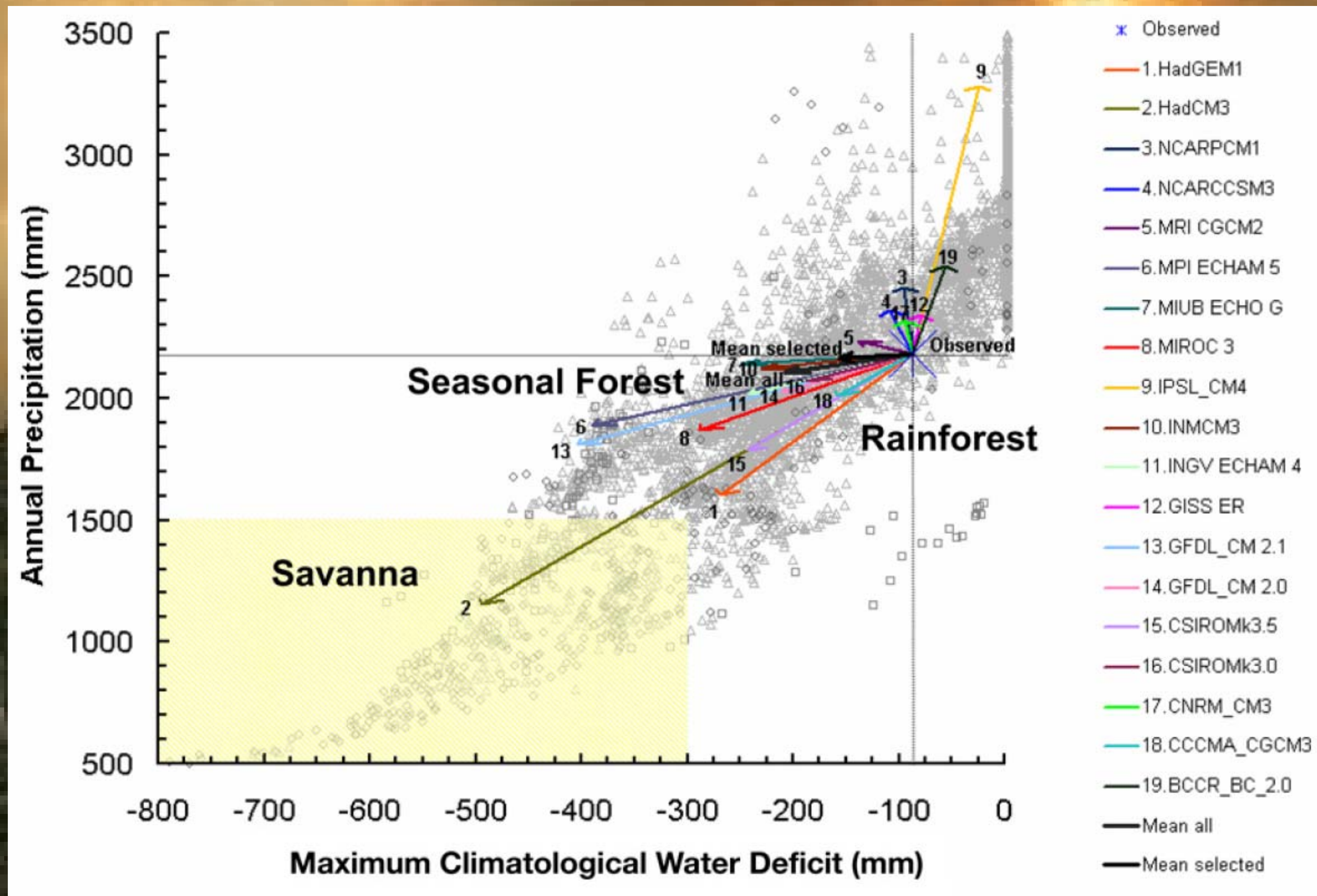
Editor Hans Joachim Schellnhuber

Special Feature: Tipping elements in the Earth System

- Hans Joachim Schellnhuber
Tipping Elements in Earth Systems
- Ulf Riebesell, Arne Körtzinger, and Andreas Oschlies
Sensitivities of marine carbon fluxes to ocean change
- Richard Washington, Christel Bouet, Guy Cautenet, Elisabeth Mackenzie, Ian Ashpole, Sebastian Engelstaedter, Gil Lizcano, Gideon M. Henderson, Kerstin Schepanski, and Ina Tegen
Tipping Elements in Earth Systems Special Feature: Dust as a tipping element: The Bodélé Depression, Chad
- Anders Levermann, Jacob Schewe, Vladimir Petoukhov, and Hermann Held
Basic mechanism for abrupt monsoon transitions
- M. Latif and N. S. Keenlyside
Tipping Elements in Earth Systems Special Feature: El Niño/Southern Oscillation response to global warming
- Matthias Hofmann and Stefan Rahmstorf
On the stability of the Atlantic meridional overturning circulation
- Dirk Notz
The future of ice sheets and sea ice: Between reversible retreat and unstoppable loss
David Archer,
- Bruce Buffett, and Victor Brovkin
Ocean methane hydrates as a slow tipping point in the global carbon cycle
- Yadvinder Malhi, Luiz E. O. C. Aragão, David Galbraith, Chris Huntingford, Rosie Fisher, Przemyslaw Zelazowski, Stephen Sitch, Carol McSweeney, and Patrick Meir
Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest
- Mario Molina, Durwood Zaelke, K. Madhava Sarma, Stephen O. Andersen, Veerabhadran Ramanathan, and Donald Kaniaru
Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO2 emissions

Large-Scale Dieback of the Amazon Rainforest

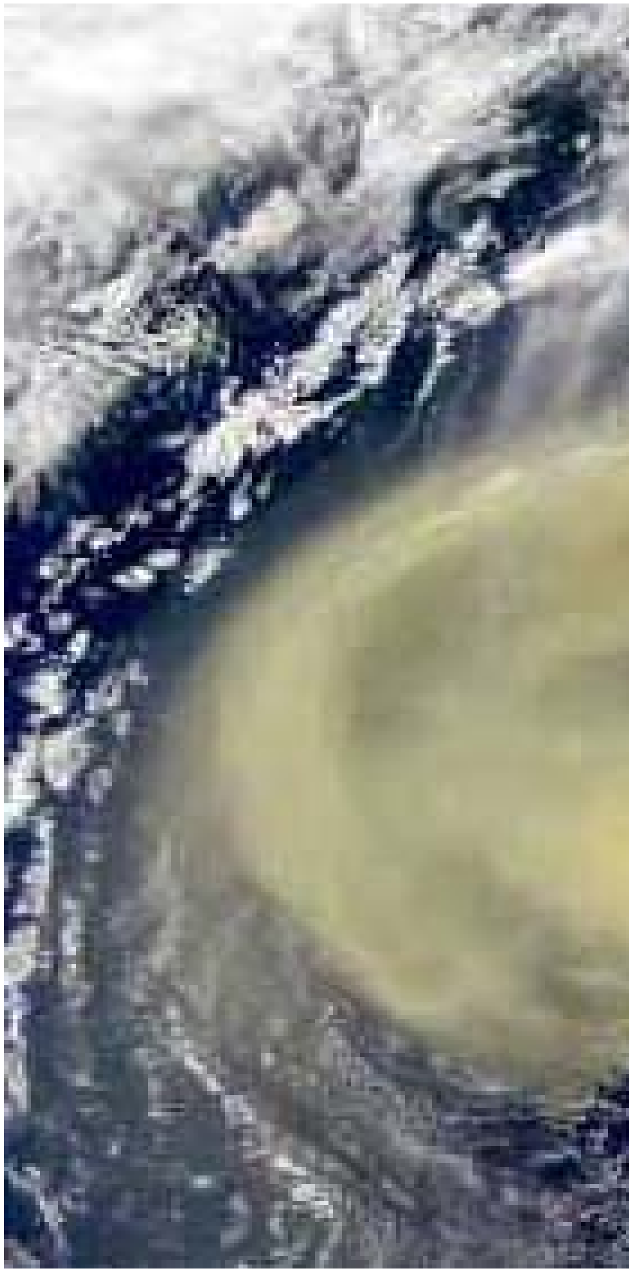
Simulated future rainfall regime in Amazonia



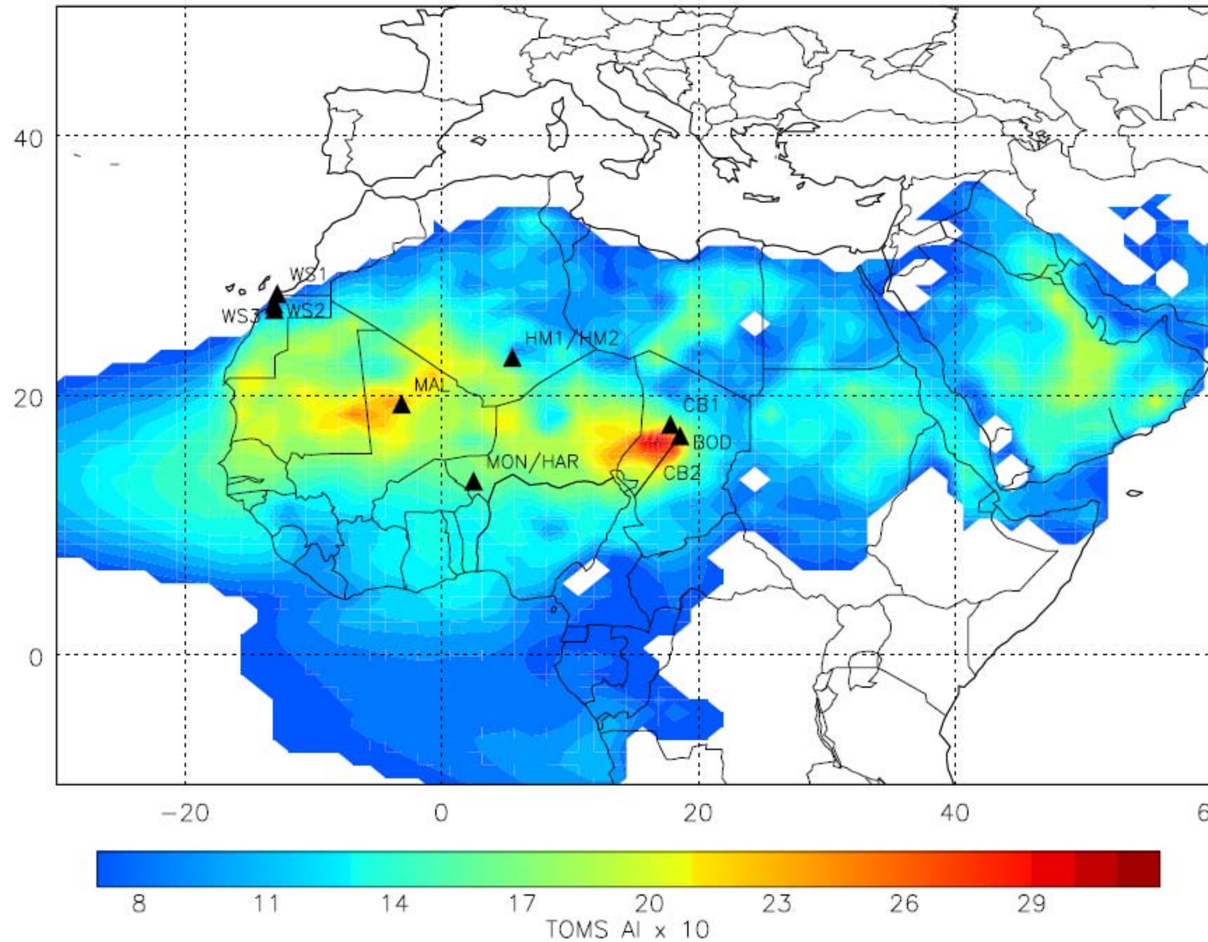
Tropical Rainfall Monitoring Mission satellite data (1998-2006) and data of 19 GCMs (SRES A2, 2070-2099)

(Malhi et al. 2009 PNAS)

The Biggest Dust Source on our Planet



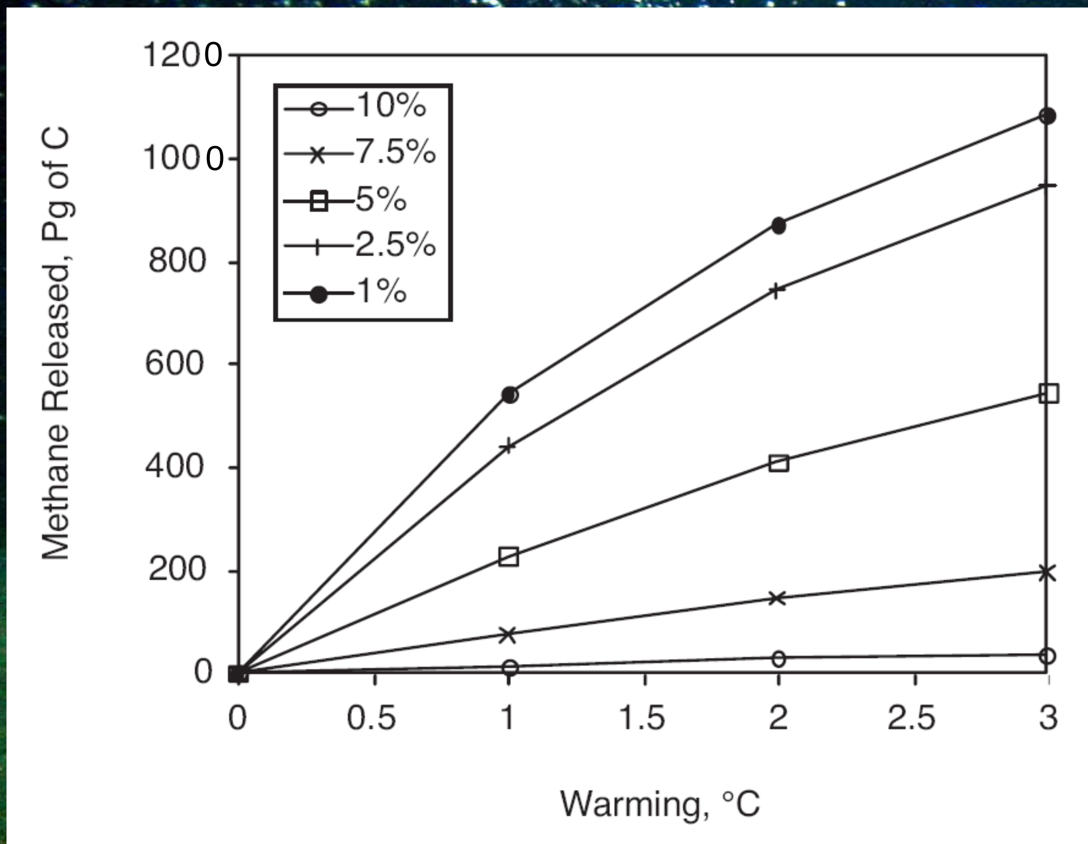
Bodélé Depression in Chad

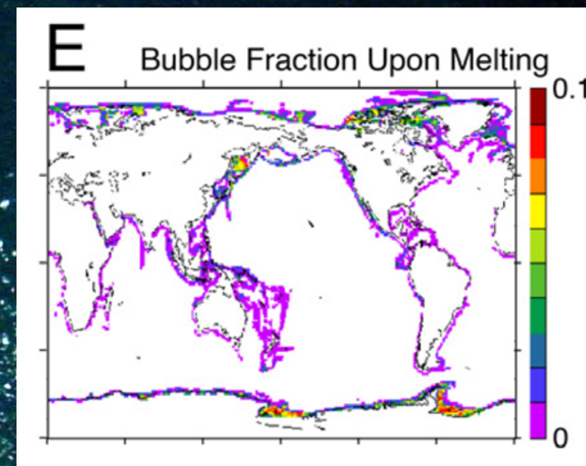


Satellite derived dust emissions data (1979-1992)

(Washington et al. 2009 PNAS)

Methane Hydrates – A Slow Tipping Element

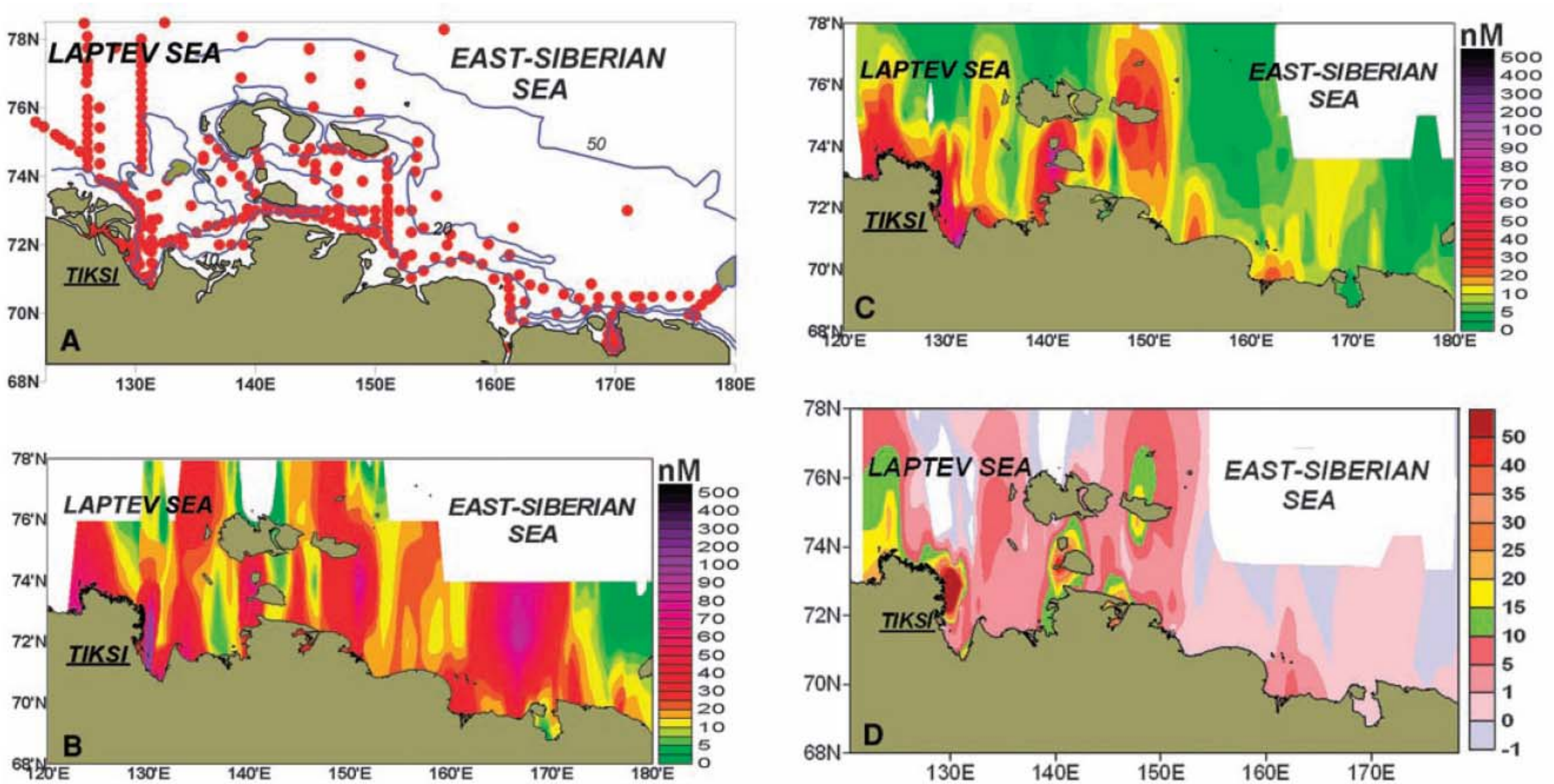




Methane release as a function of simulated ocean temperature

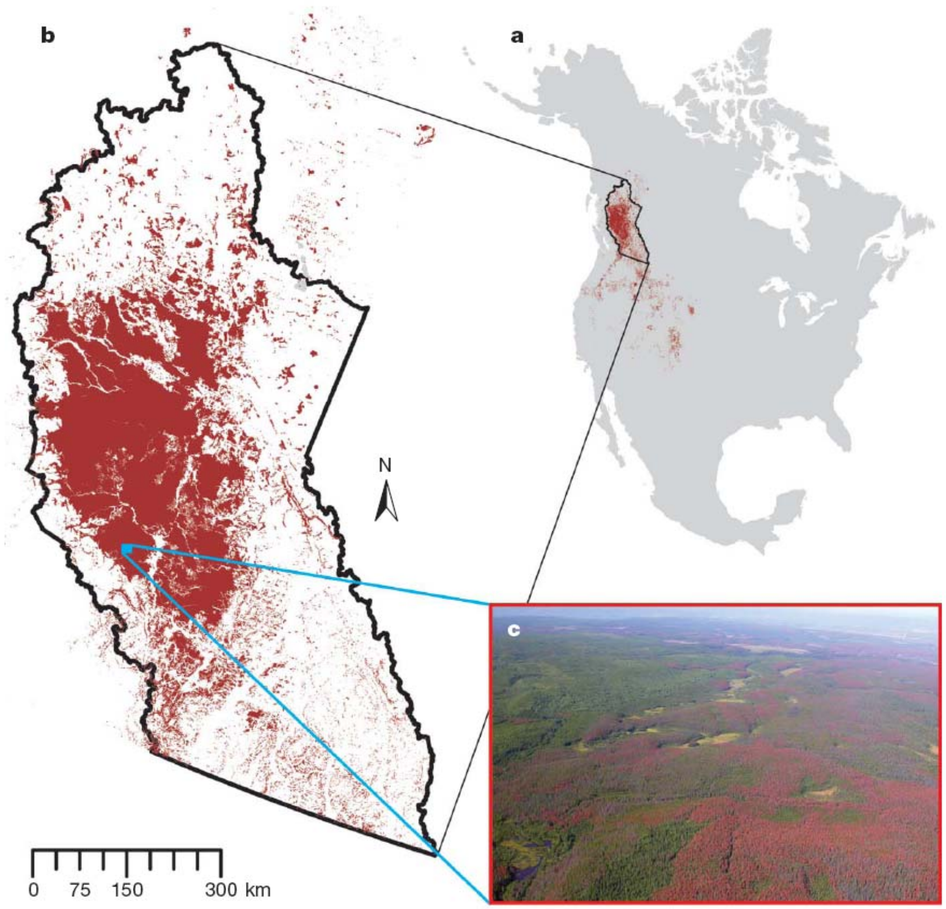
(Archer et al. 2009 PNAS)

Methane Venting to the Atmosphere from the East Siberian Arctic Shelf

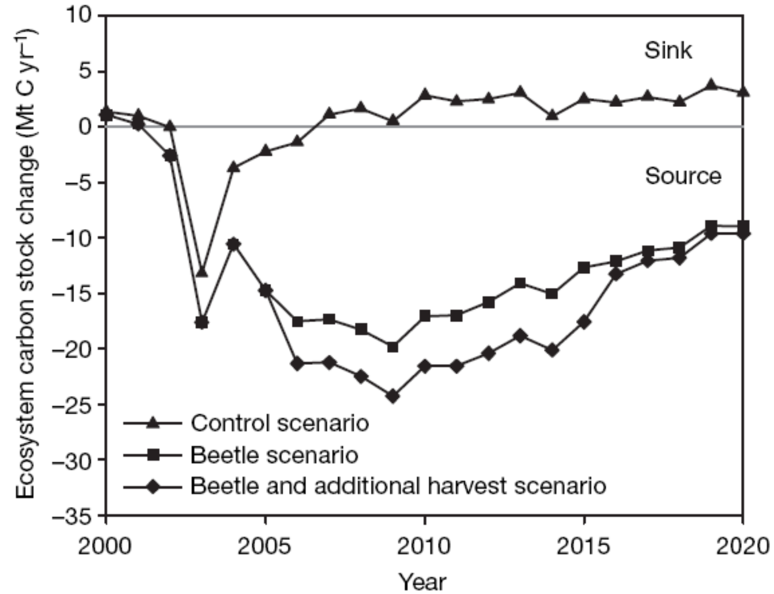


(Shakhova et al. 2010 Science)

Mountain Pine Beetle and Forest Carbon Feedback to Climate Change



Geographic extent of recent Mountain pine beetle outbreak in North America

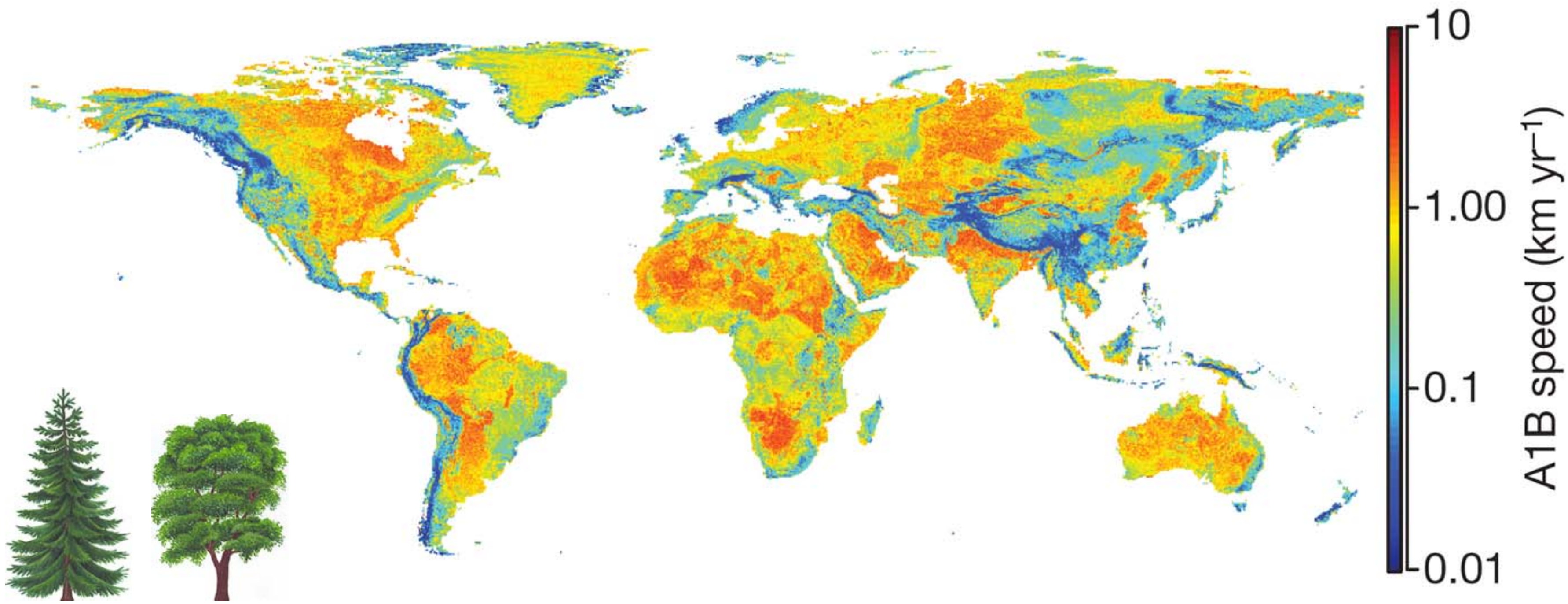


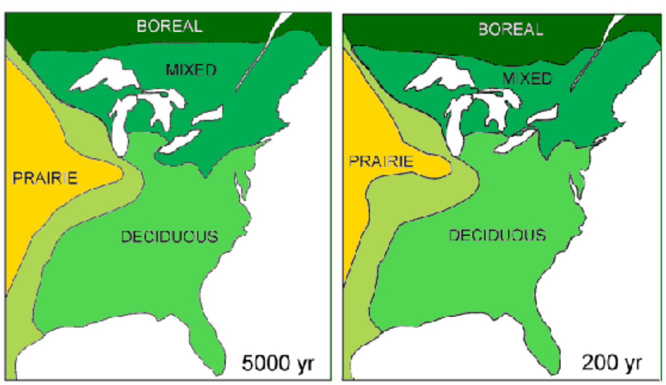
Cumulative impact of the beetle outbreak in the affected region during 2000–2020 might amount to 270 megatonnes (Mt) carbon loss.

(Kurz et al. 2008 Nature)

The Velocity of Anthropogenic Climate Change

Instantaneous local velocity along Earth's surface needed to maintain constant temperatures for SRES A1B emission scenario (2050-2100)

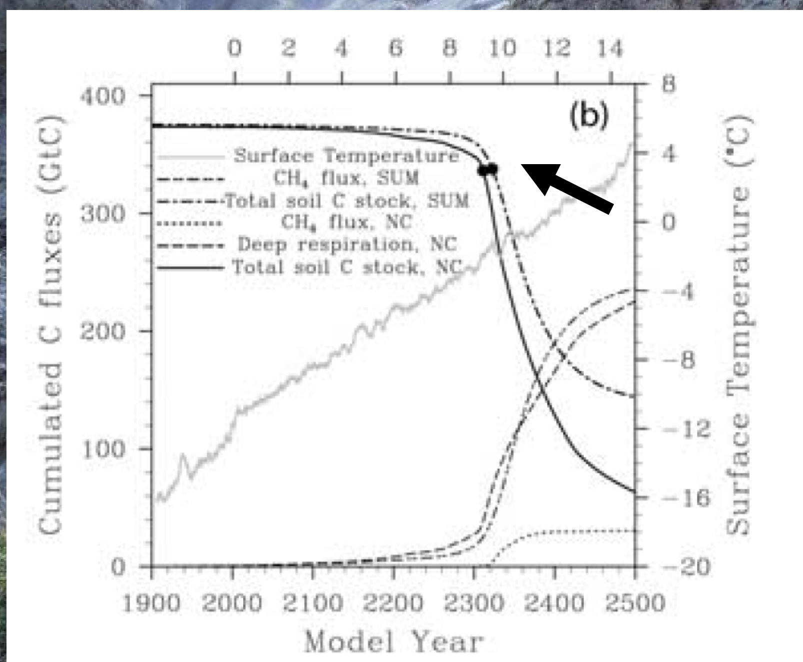




Large areas of the globe will require velocities faster than the more optimistic plant migration estimates from a landscape before anthropogenic fragmentation.

(Loarie et al. 2009 Nature)

Yedoma Permafrost

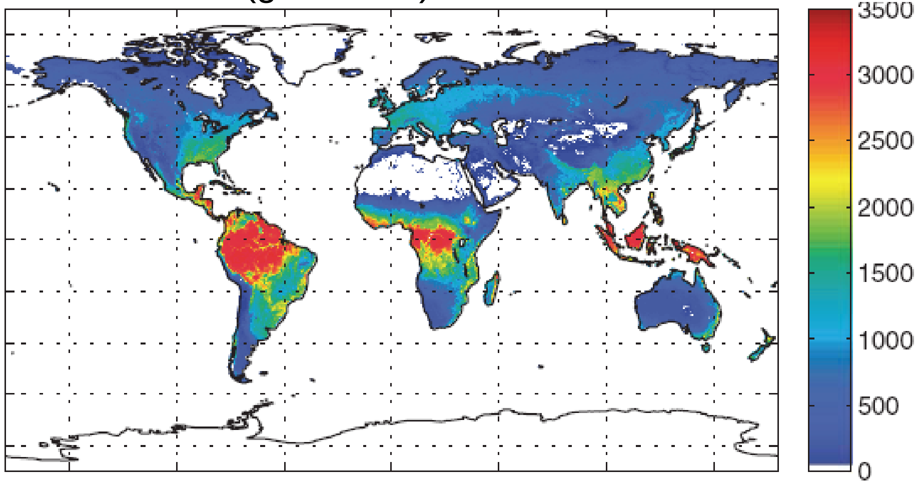


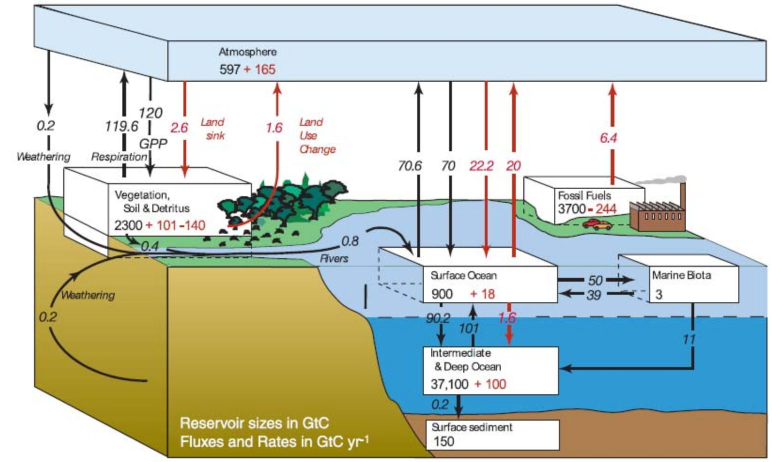
„[…] once active layer deepening in response to atmospheric warming is enough to trigger deep-soil respiration, and soil microorganisms are activated to produce enough heat, the mobilization of soil carbon can be very strong and self-sustainable.“

(Khvorostyanov et al. 2008 GRL)

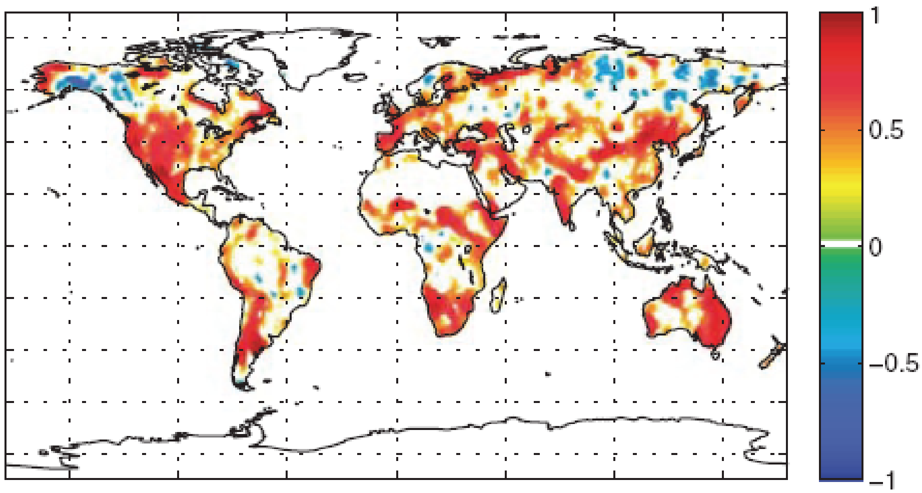
Estimates of Global Gross Primary Production Constrained by Observations

Median GPP (gC m^{-2} a^{-1})

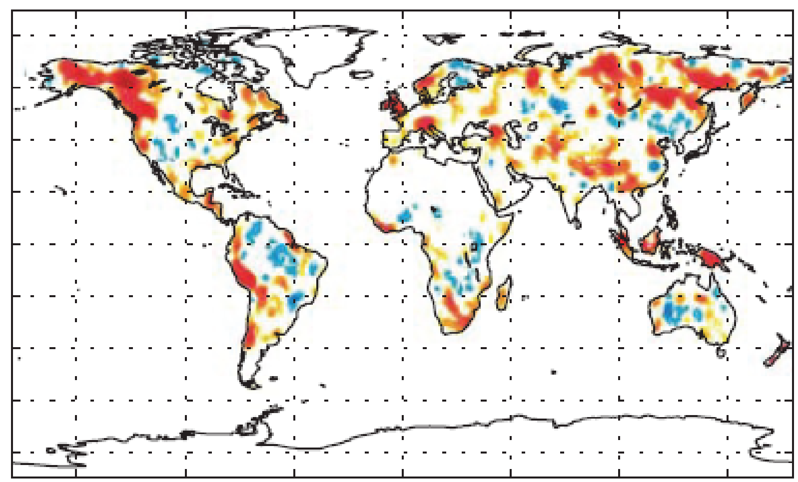




Partial correlation median GPP and precipitation

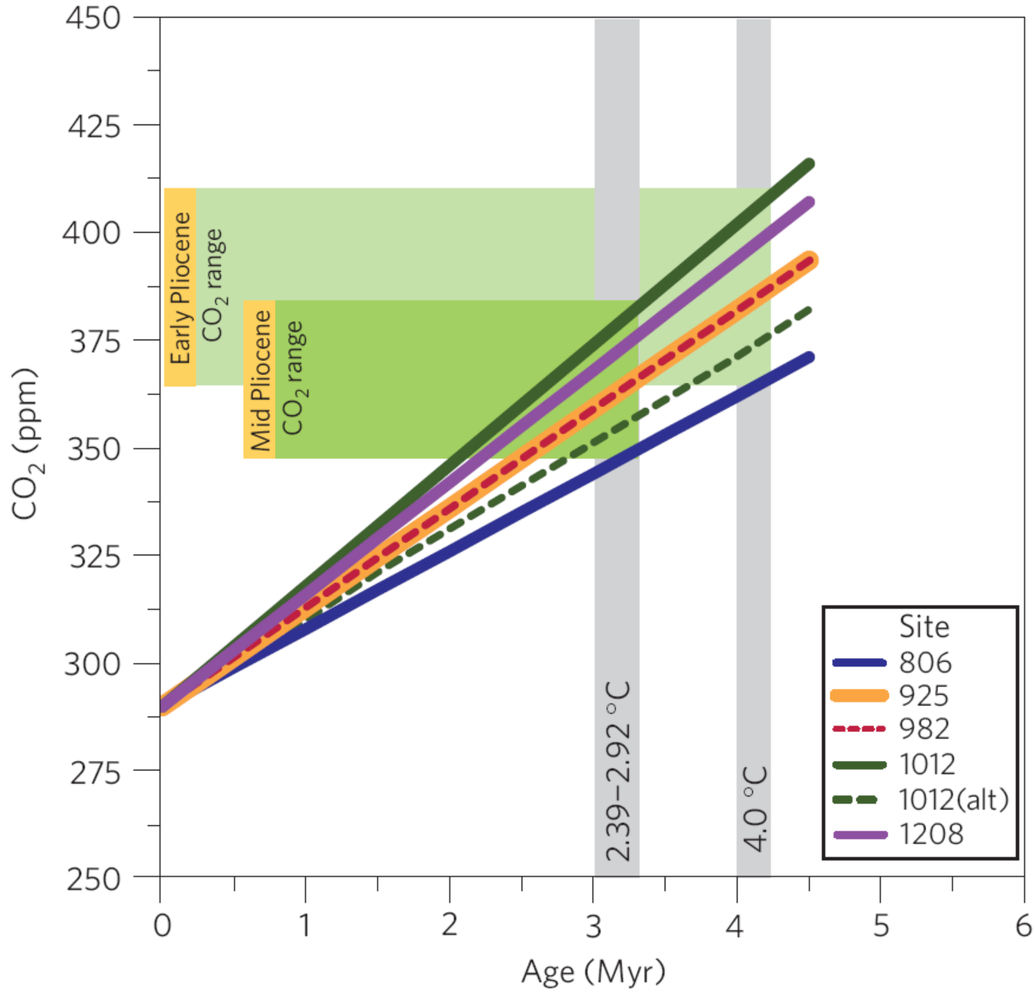


Partial correlation median GPP and air temperature



(Beer et al. 2010 Science Express)

Lessons from the Pliocene?



IPCC climate sensitivity (fast feedbacks):

1.5 - 4 °C per CO_2 doubling

Earth-system sensitivity (fast+slow feedbacks) estimates based on Pliocene data:

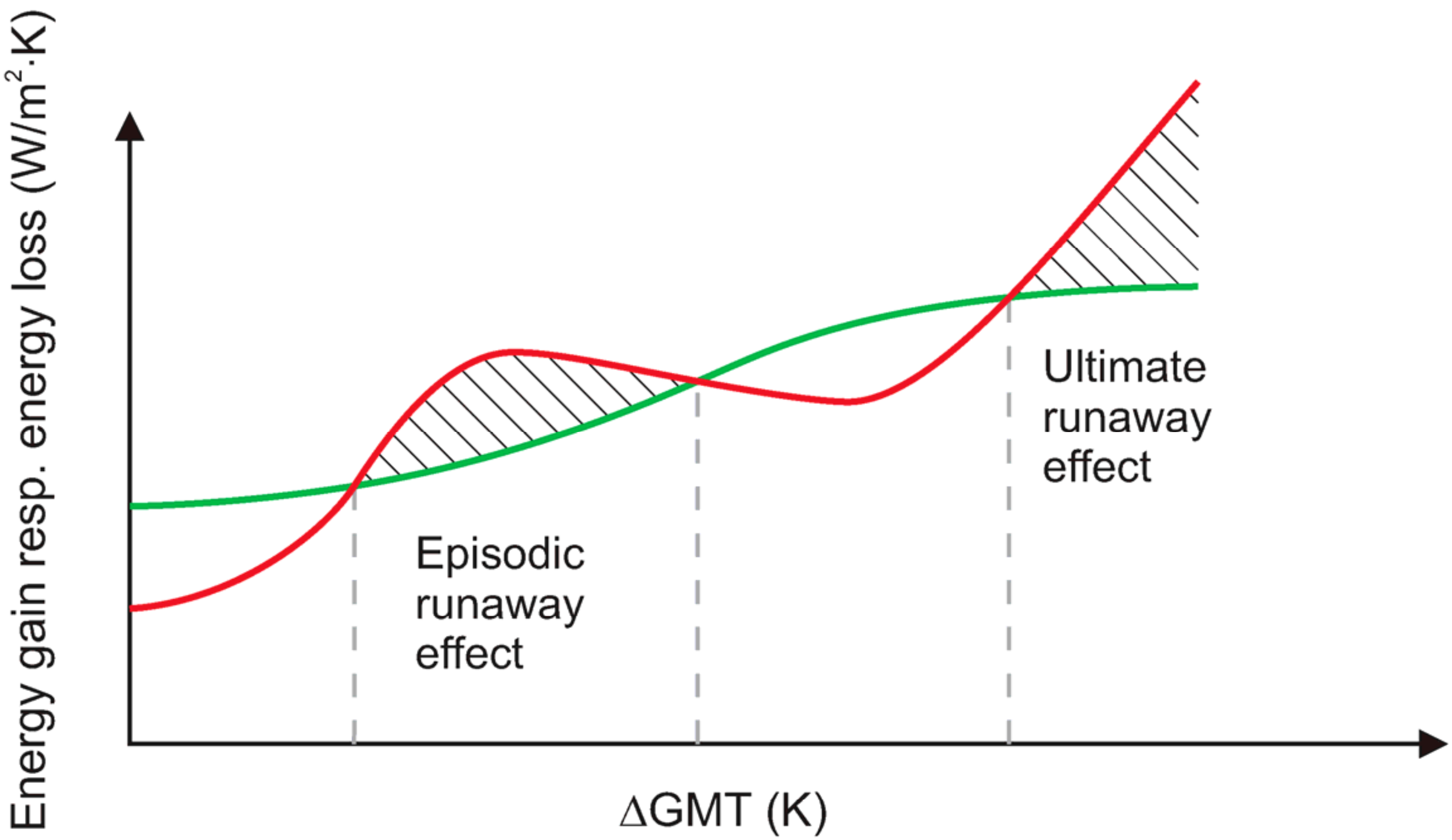
up to 9.6 ± 1.4 °C per CO_2 doubling

(Pagani et al. 2009)

Slow feedbacks: e.g., large ice-sheets, vegetation changes, GHGs other than CO_2

Fast feedbacks: e.g., water vapor, sea ice, clouds, aerosols

Limited Runaway Greenhouse Effect



Energy gain determined by positive feedbacks

Energy loss determined by Stefan-Boltzmann radiative damping and negative feedbacks

(Schellnhuber *in press,* after Schneider v. Deimling, Levermann)

Energy Gain, Energy Loss – Factors Considered

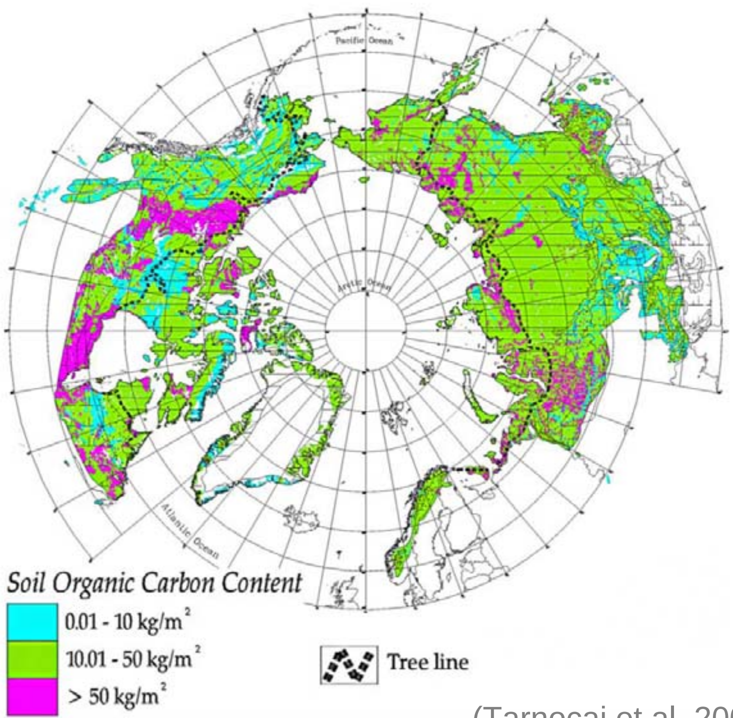
Stefan Boltzmann radiation (Soden 2006)

Charney feedbacks (water vapor, lapse rate, clouds, surface albedo) (Soden 2006)

Ocean heat uptake (CLIMBER 2)

Carbon cycle feedback — Carbon concentration feedback (Archer et al. 2009)

Carbon climate feedback (Frank et al. 2010)



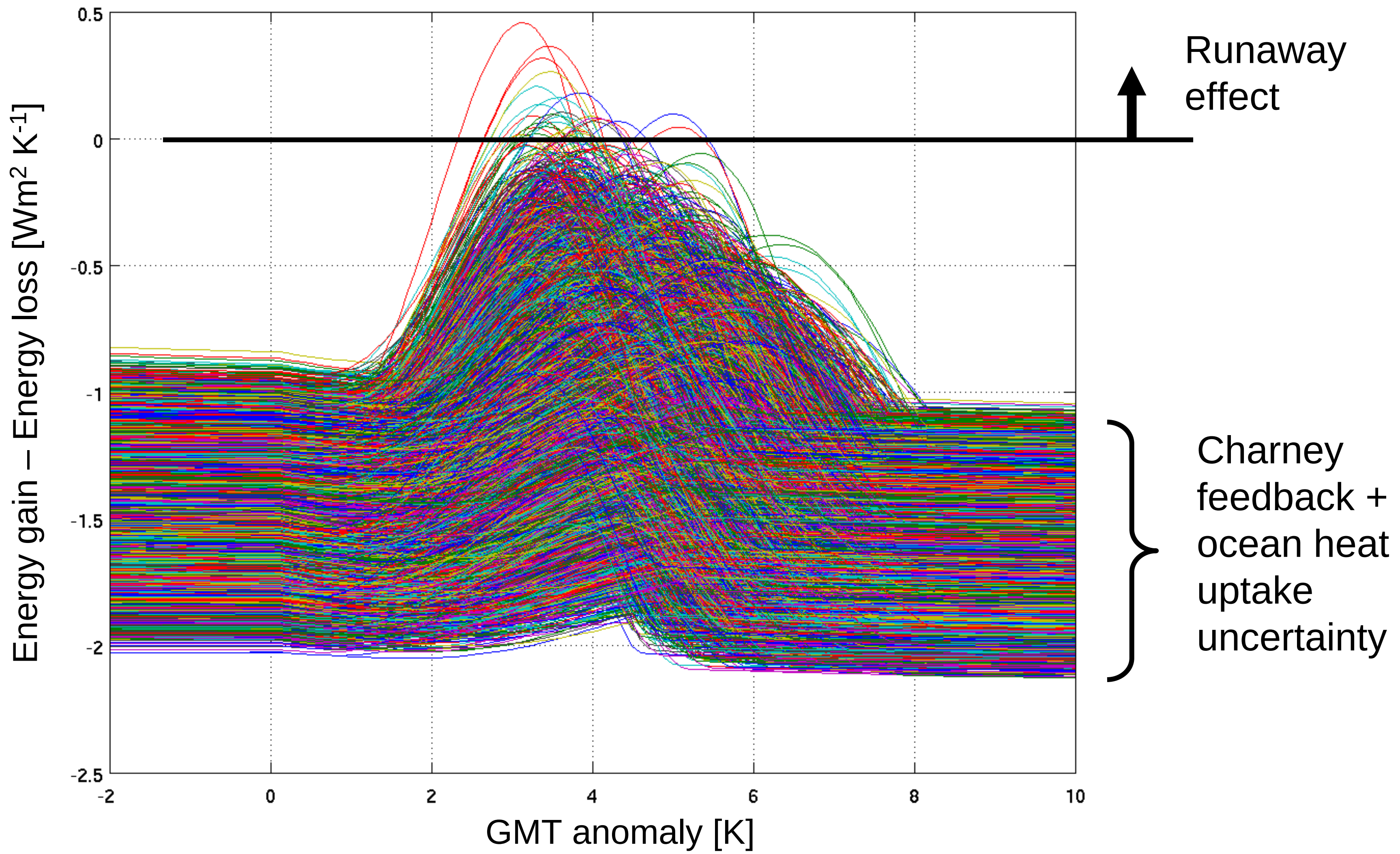
(Tarnocai et al. 2009)

Focus on Permafrost

- Total carbon pool
- Releasable carbon
- Fraction CH_4 release
- Lifetime CH_4
- Time for carbon release
- Polar amplification
- Maximum Arctic temperature anomaly for complete thawing

(Schneider v. Deimling et al. *in prep*.)

On the Edge - Preliminary Runaway Assessment



Timescale: 500 years

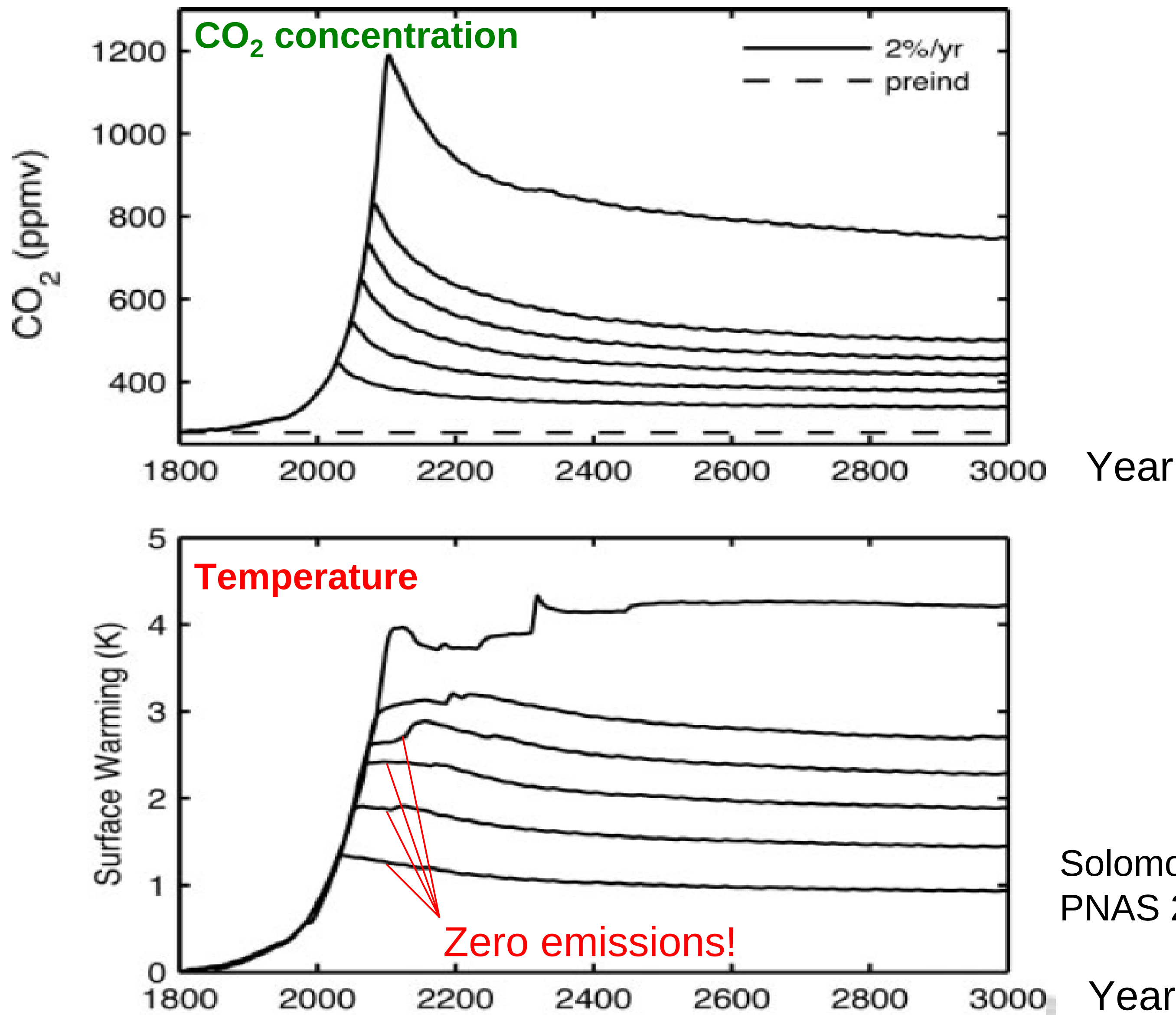
Monte Carlo parameter sampling n = 10000

(Schneider v. Deimling et al. *in prep*.)

Part 6

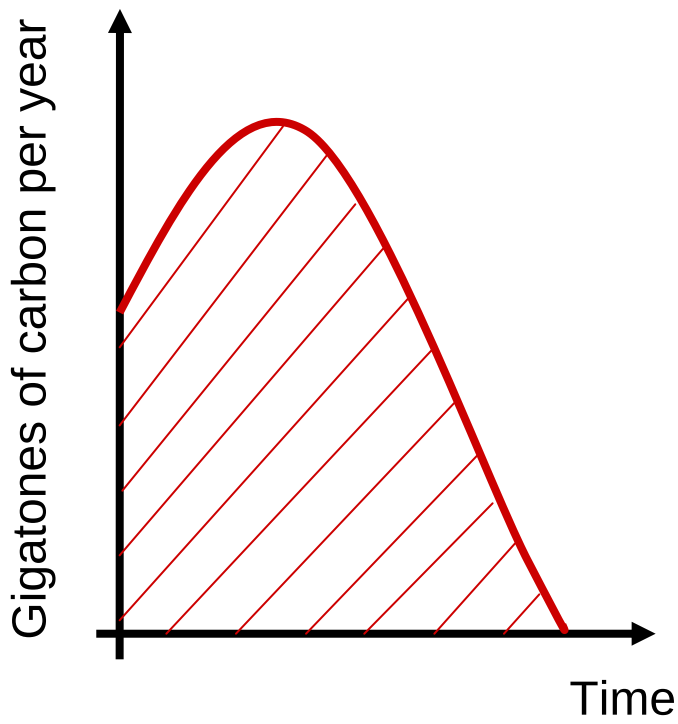
- How is the climate today?
- News from the poles: sea ice and ice sheets
- Sea level (projections) on the rise
- Ocean acidification beyond tropical coral reefs
- On regional and global tipping points
- Time is running out

Global Warming is Practically Irreversible



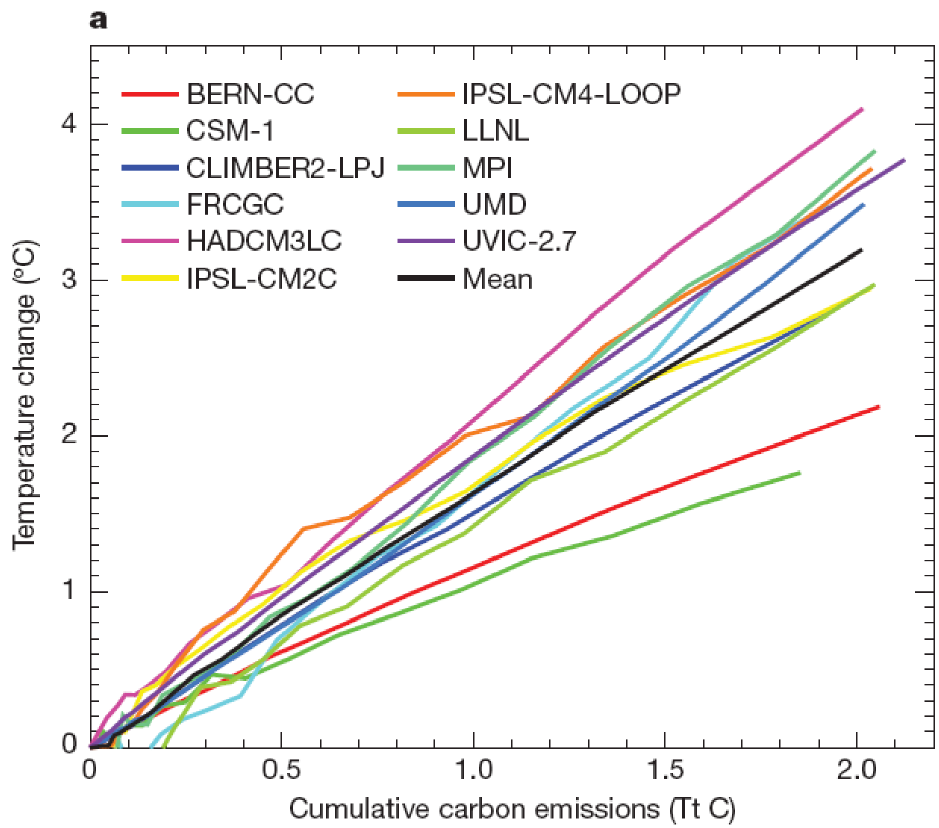
Solomon et al., PNAS 2009

The Proportionality of Global Warming to Cumulative Carbon Emissions



$$\Delta GMT \Big|_{t_1}^{t_2} \approx k \int_{t_1}^{t_2} E_{glob}(t)dt$$

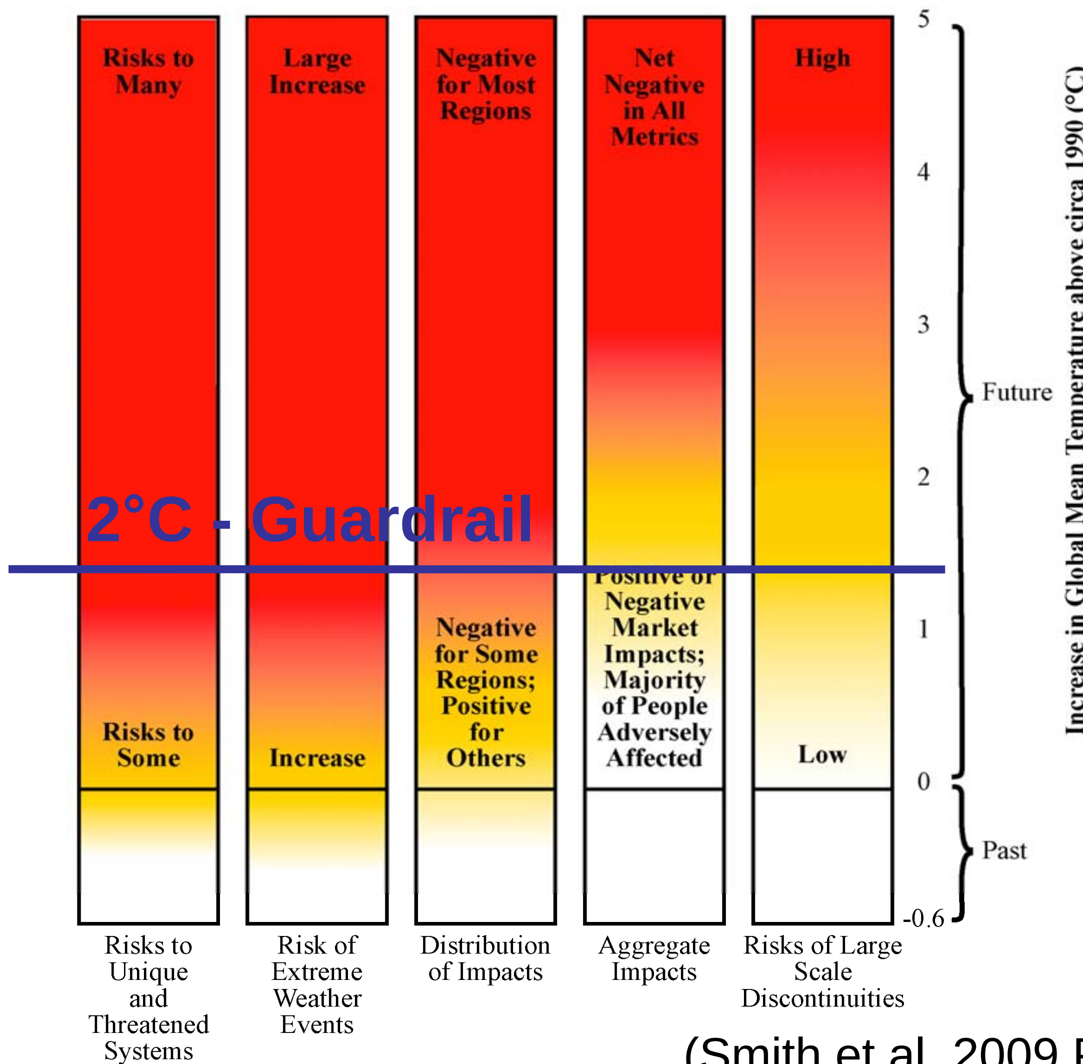
i.e., quasi-linear relationship



(Matthews et al. 2009 Nature)

Burning Embers

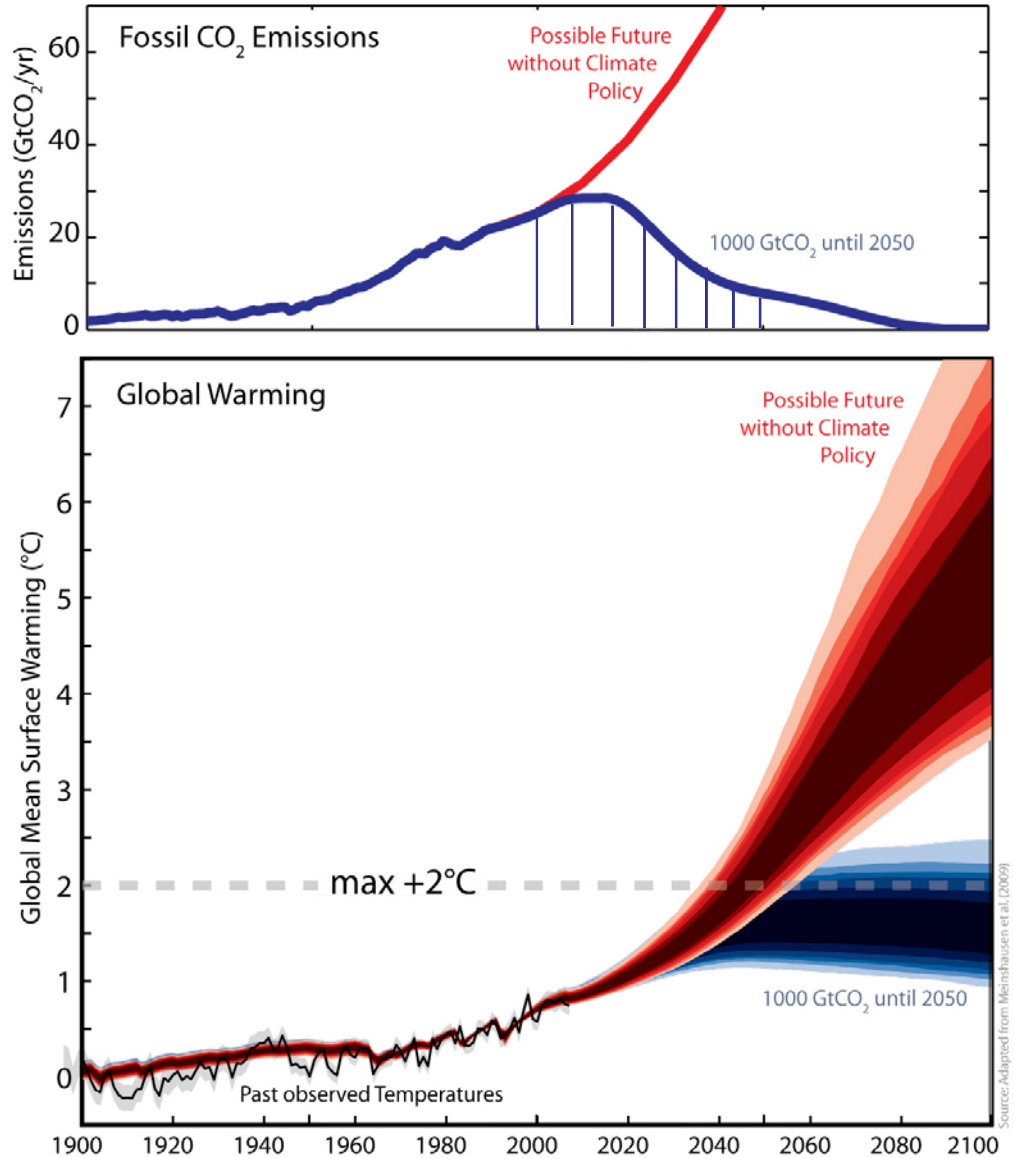
Global Damage is a Highly Non-Linear Function of ΔGMT



(Smith et al. 2009 PNAS)

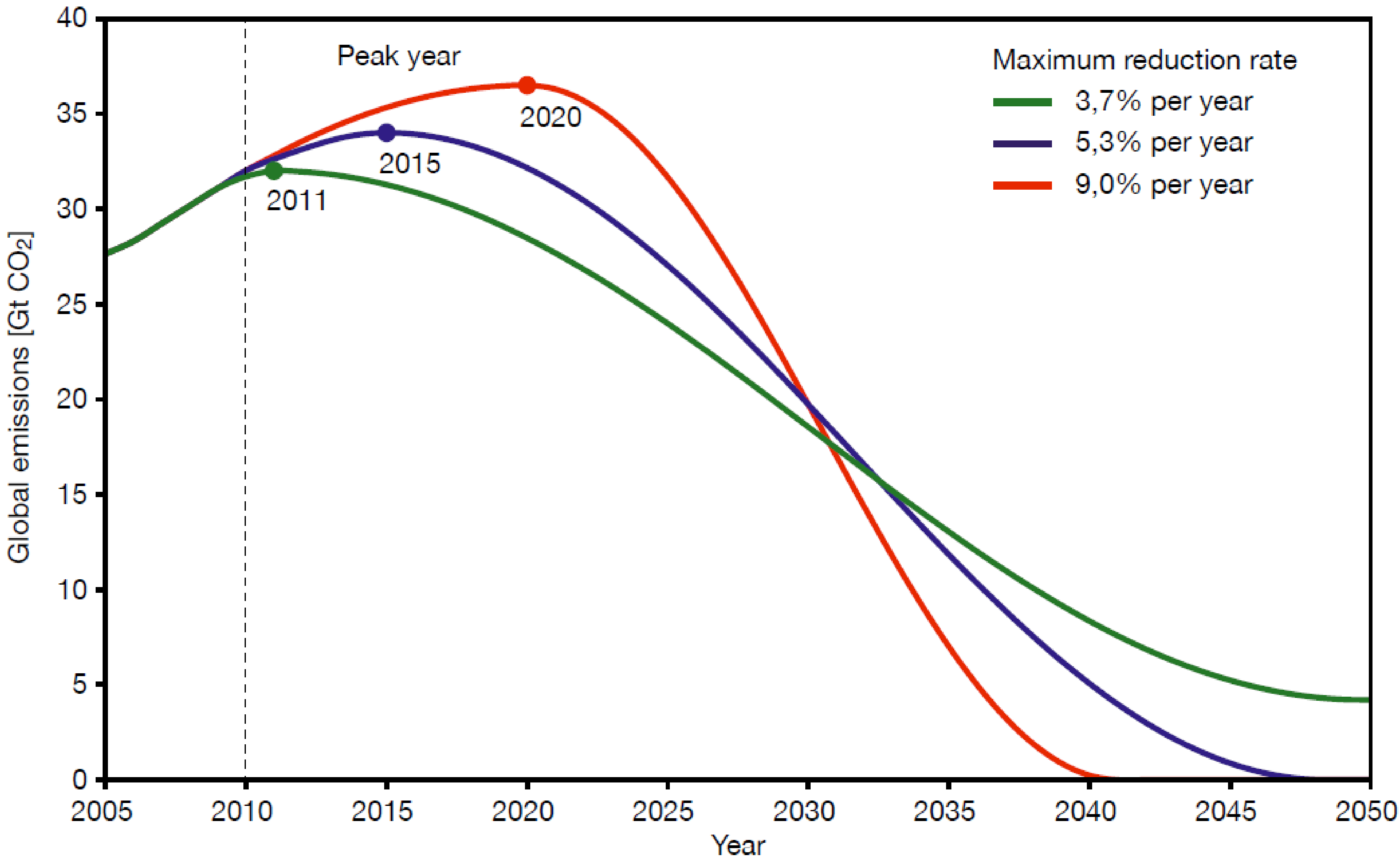
2°C-Limit and the 1 Trillion Tonne Challenge

Limiting cumulative CO_2 emissions to **1000 Gt** (1150 Gt) over 2000–50 gives a 75% (67%) probability to stay below 2°C global warming



(Meinshausen et al. 2009)

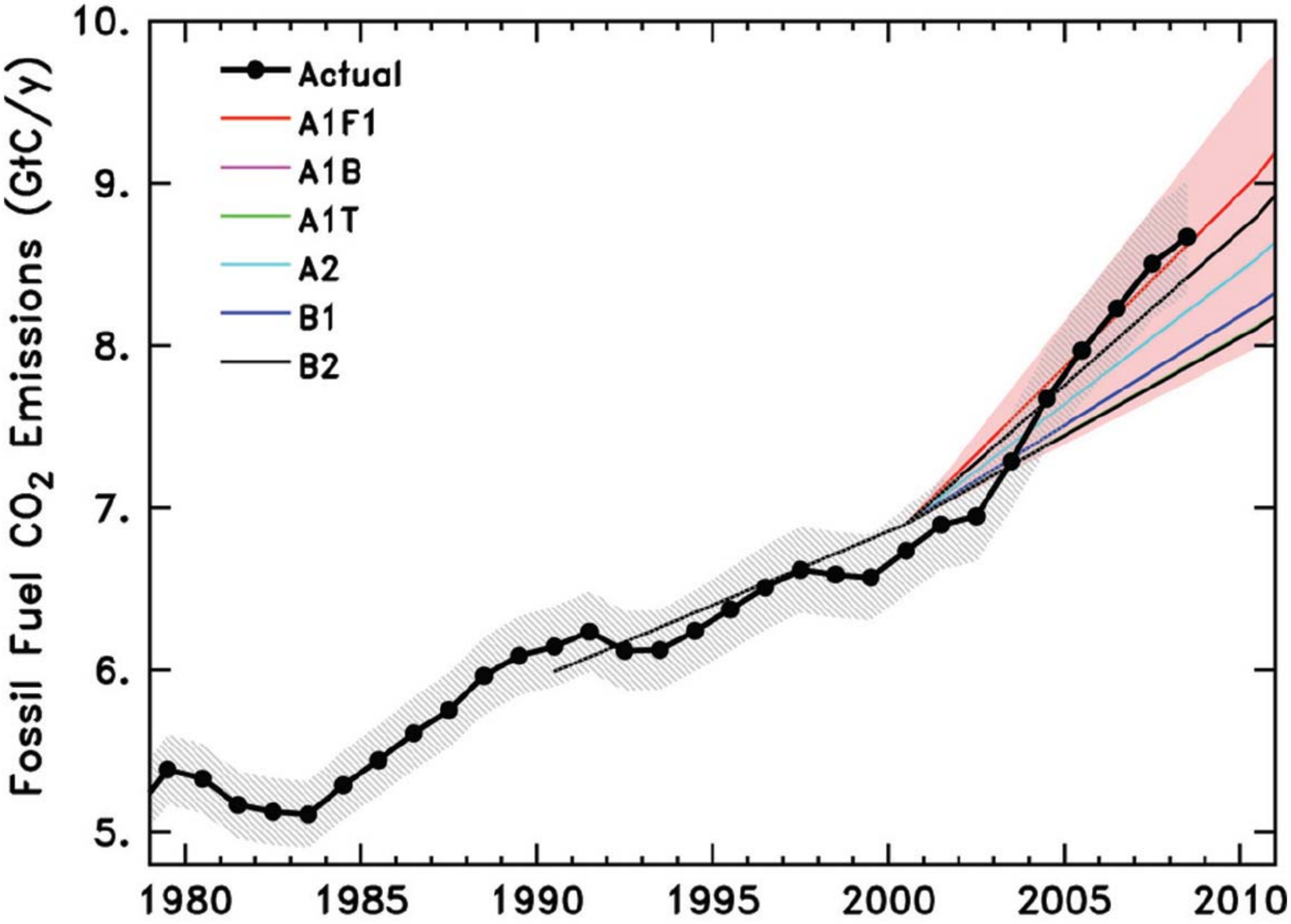
Time is of the Essence



Exemplary emission pathways in order to remain within a budget of 750 Gt between 2010 and 2050. At this level, there is a 67% probability of staying below a warming of 2 °C.

(WBGU Special Report, 2009)

Surging Greenhouse Gas Emissions



(Le Quéré et al. 2009 Nature Geoscience)

Global CO_2 emissions from fossil fuel burning in 2008 were 40% higher than those in 1990 […] tracking near the highest scenarios considered so far by the IPCC.


Questions?
Comments?