Complexity, Crisis, and Creativity:
Meeting the Challenges of the Age of Nature

CEC JPAC Conference

North America 2030: An Environmental Outlook

Ottawa, Ontario

Thomas Homer-Dixon

Trudeau Centre for Peace and Conflict Studies

University of Toronto

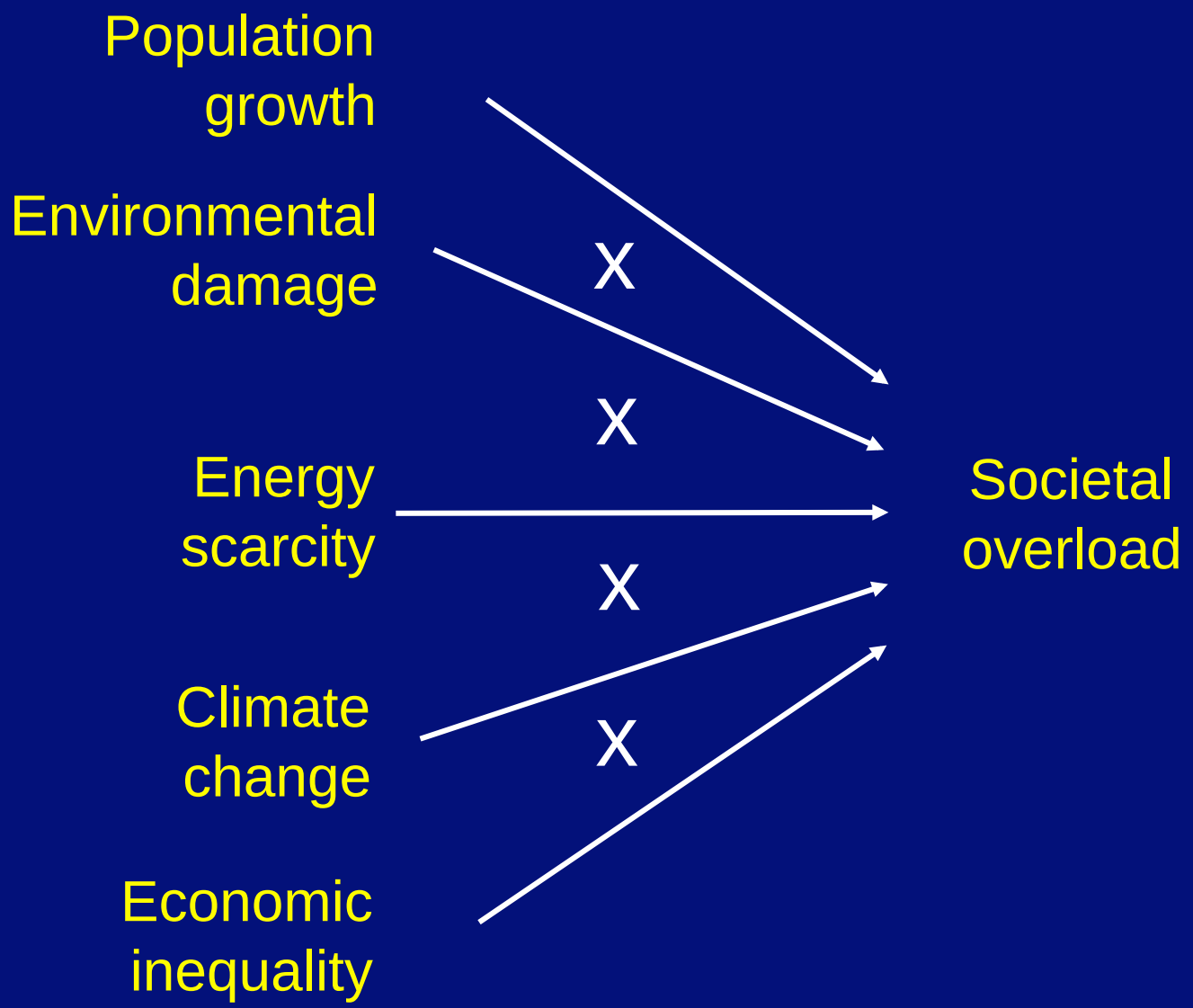
June 25 2008

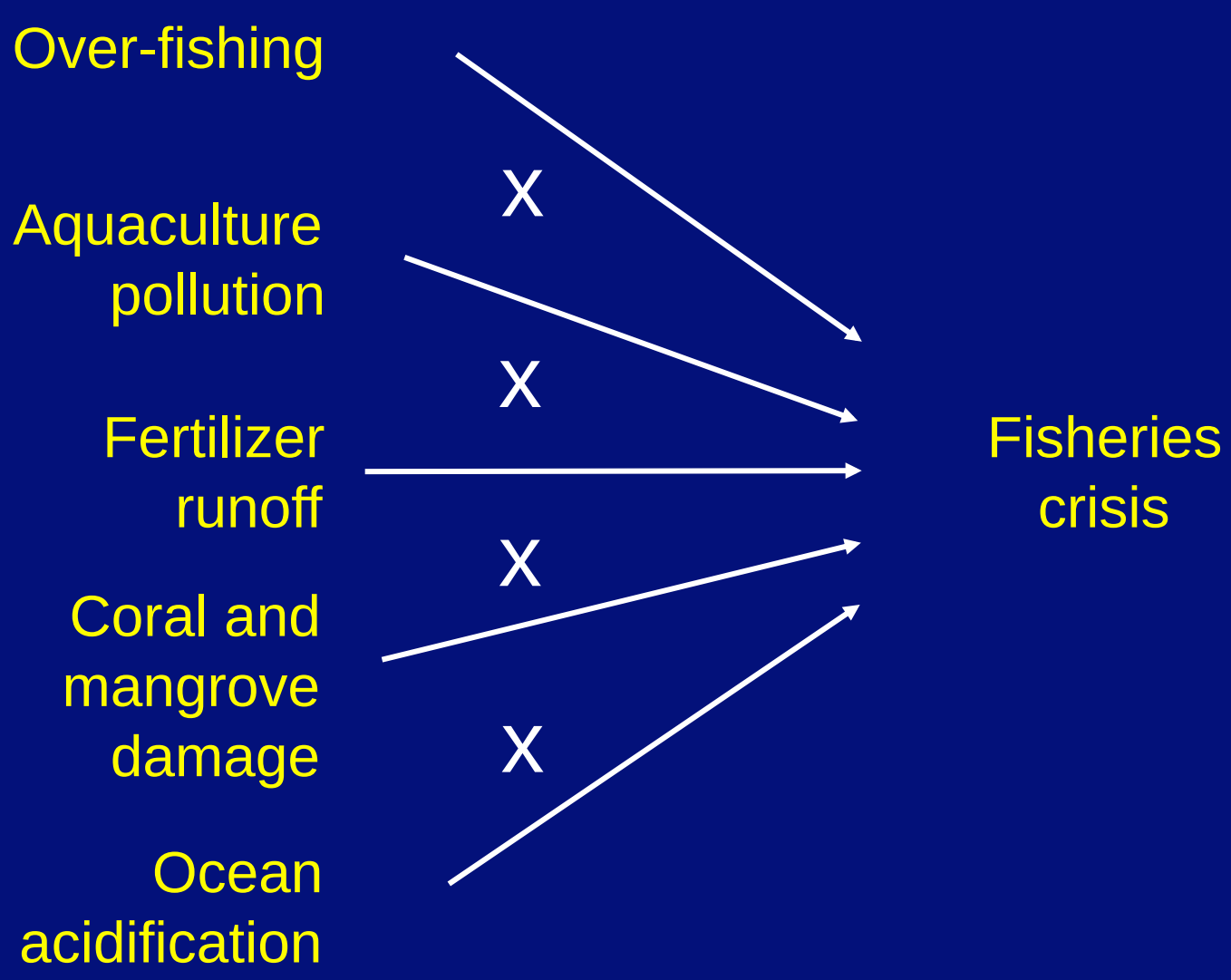
KEY CONCEPTS

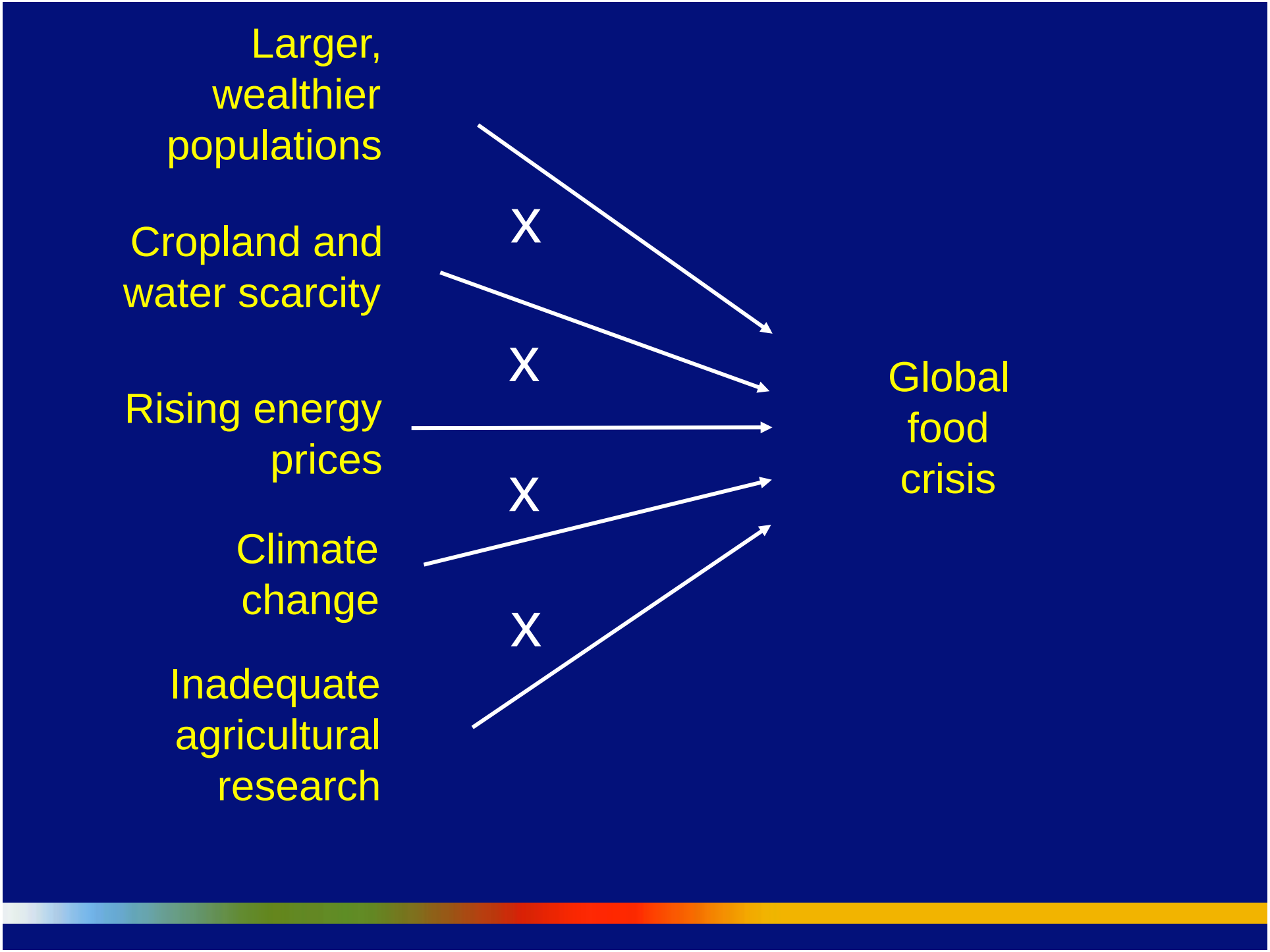
- Convergence
- Synergy
- Complexity

CONVERGENCE

SYNERGY


Population growth
Environmental damage
Energy scarcity
Climate change
Economic inequality
X
X
X
X
Societal overload


Over-fishing
Aquaculture pollution
Fertilizer runoff
Coral and mangrove damage
Ocean acidification
X
X
X
X
Fisheries crisis


Larger, wealthier populations
Cropland and water scarcity
Rising energy prices
Climate change
Inadequate agricultural research
X
X
X
X
Global food crisis

VULNERABILITY OF THE GLOBAL FOOD SYSTEM

World grain output of about 2 billion tons provides about two-thirds of humankind's protein intake

The 17 percent of arable land that is irrigated requires 75 percent of the fresh water that humans consume annually to produce 40 percent of world grain output

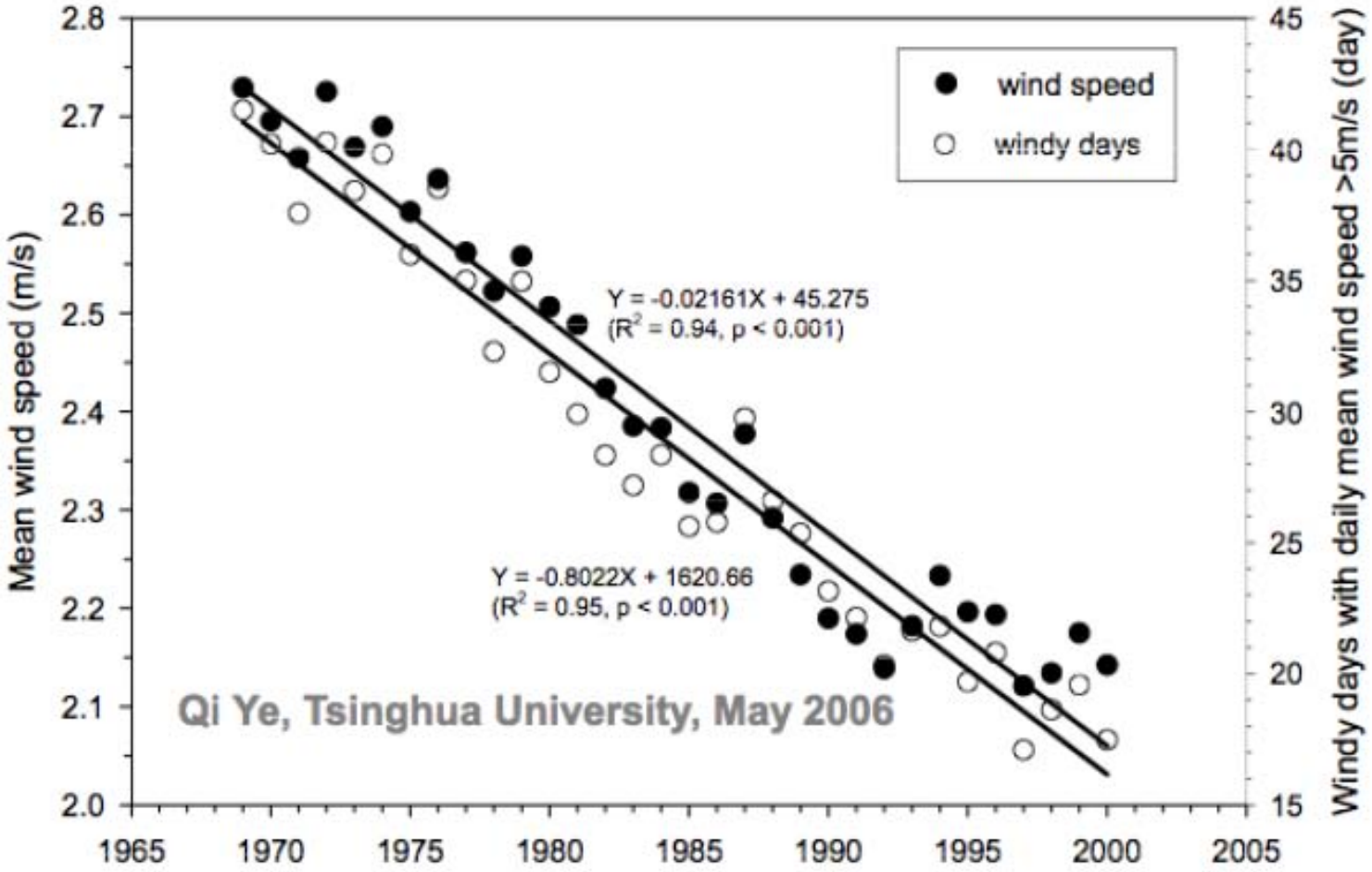
VULNERABILITY OF THE GLOBAL FOOD SYSTEM

China requires about 450 million tons of grain each year

World grain trade is about 200 million tons

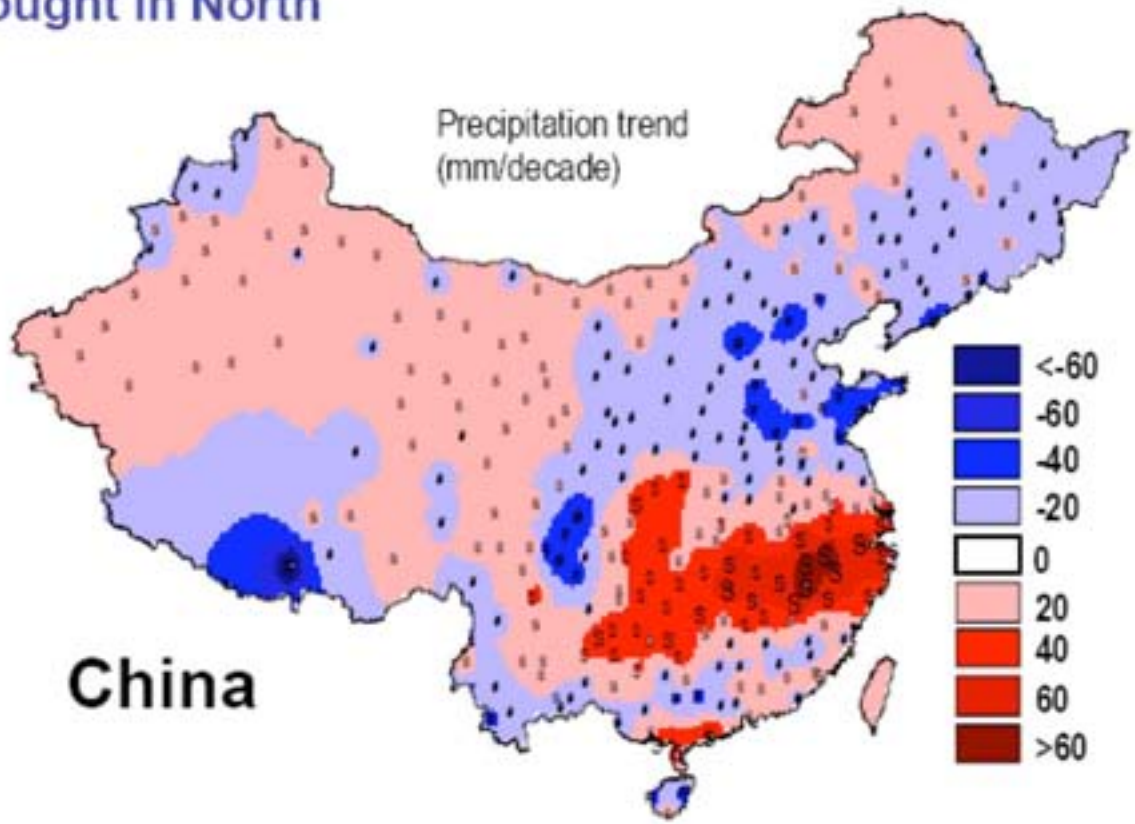
An intervention by China on world grain markets for only 10 percent of its needs would absorb 25 percent of grain on world markets

WEAKENING OF EAST ASIAN MONSOON



The observations match model predictions, by Chinese researchers, for greenhouse-gas-driven disruption .

Weakening monsoon means less moisture flow South to North, producing increased flooding in South, drought in North



Qi Ye, Tsinghua University, May 2006

COMPLEXITY

We need to shift from seeing the world as composed mainly of

MACHINES

to seeing it as composed mainly of

COMPLEX SYSTEMS

Whereas MACHINES

- can be taken apart, analyzed, and fully understood (they are no more than the sum of their parts)
- show proportionality of cause and effect
- exhibit “normal” or equilibrium patterns of behavior, and
- can be managed because their behavior is predictable . . .

COMPLEX SYTEMS

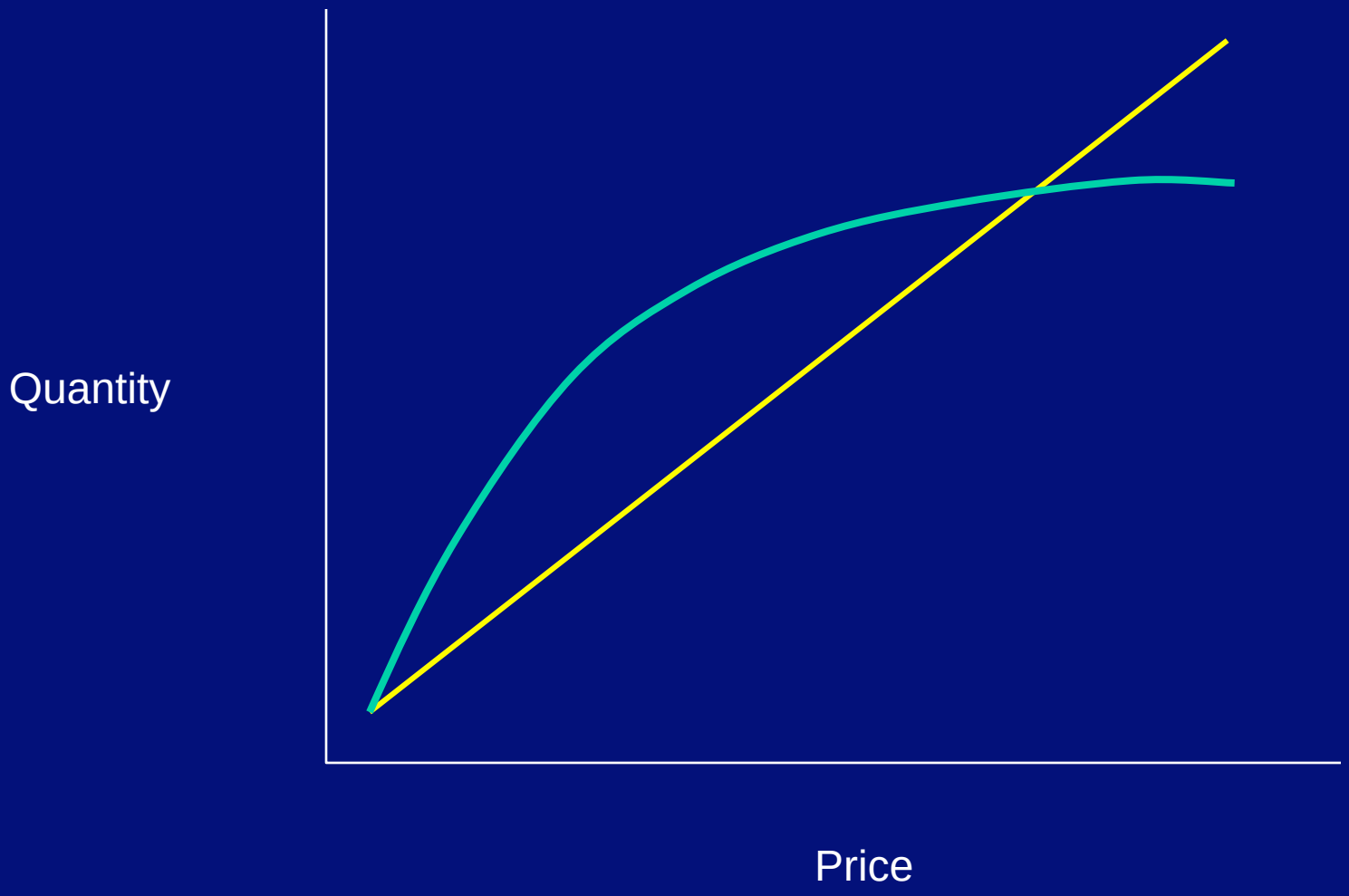
- are more than the sum of their parts (they have *emergent* properties)
- show disproportionality of cause and effect (their behavior is often *nonlinear*, because of *feedbacks* and *synergies*)
- can flip from one pattern of behavior to another (they have *multiple equilibriums*), and
- cannot be easily *managed* because their behavior is often *unpredictable*.

A MECHANISTIC “ONTOLOGY” CONTRIBUTES TO:

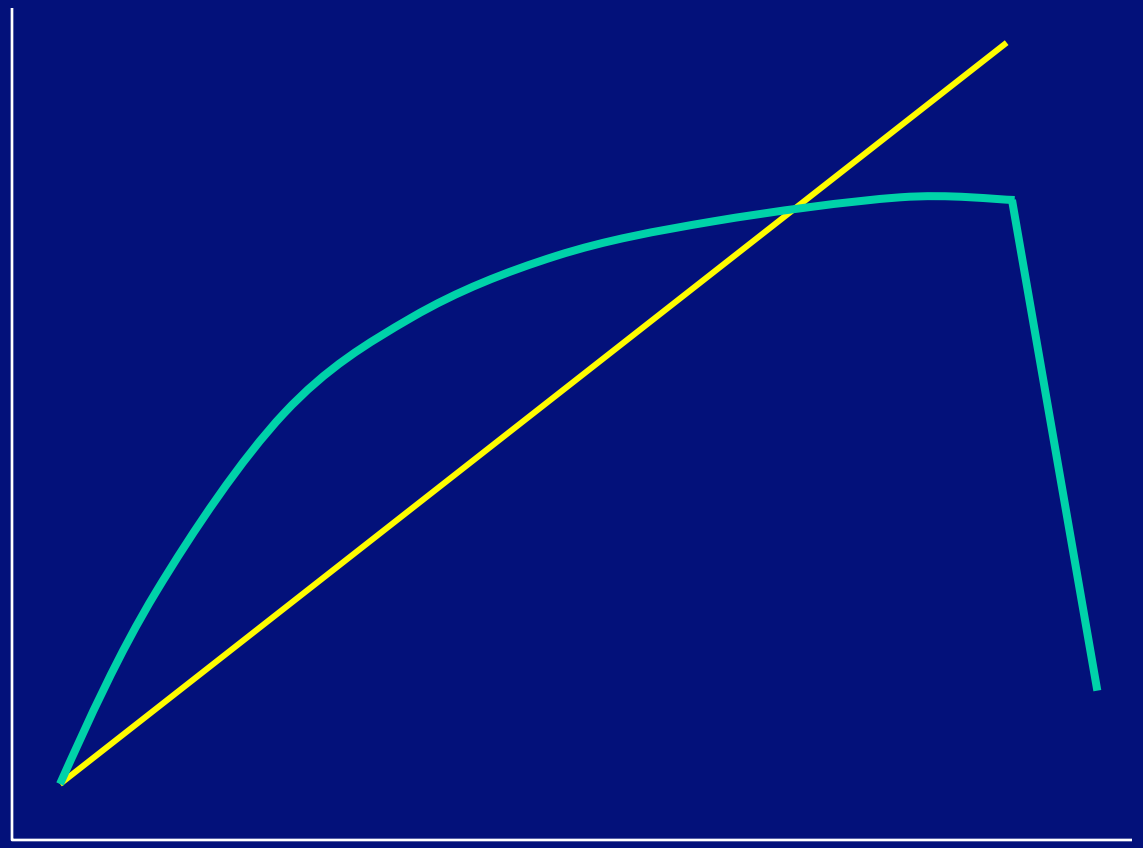
- the belief that natural “resources” can be “managed” sustainably; and
- the belief the resource availability is a linear function of price

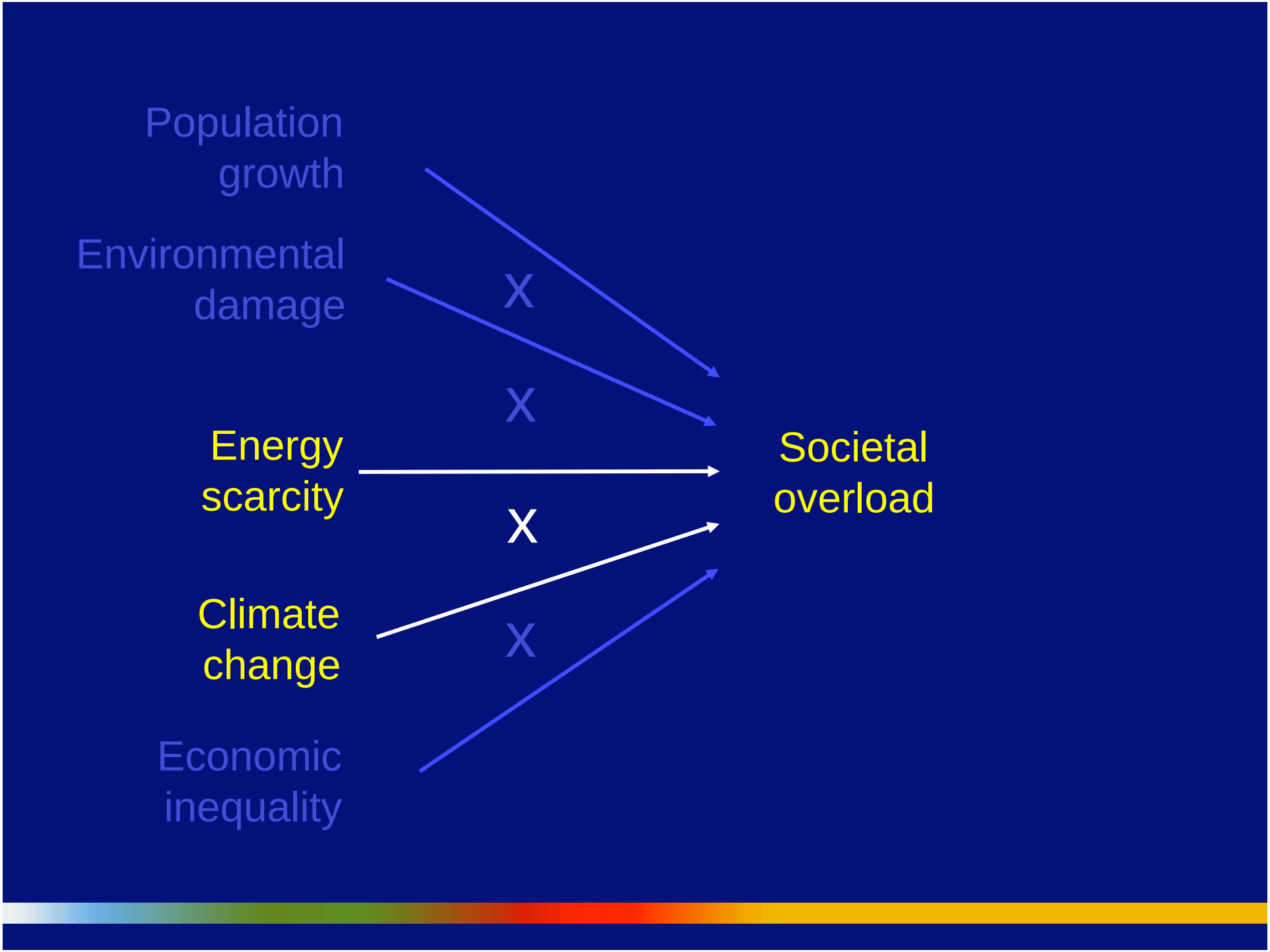
Functional form of price-quantity relationship

Functional form of price-quantity relationship



Functional form of price-quantity relationship




Population growth
Environmental damage
Energy scarcity
Climate change
Economic inequality
X
X
X
X
Societal overload

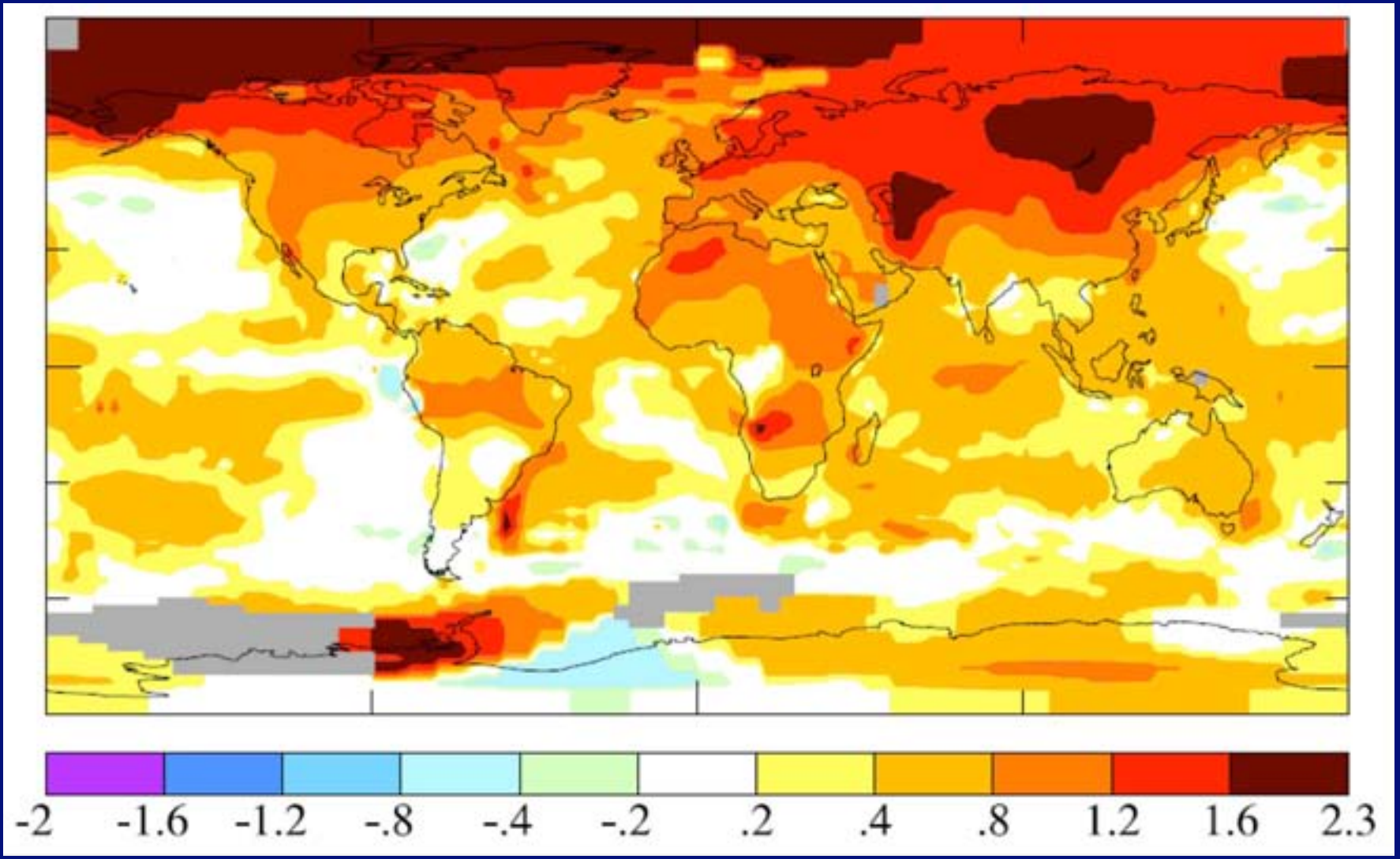
CLIMATE

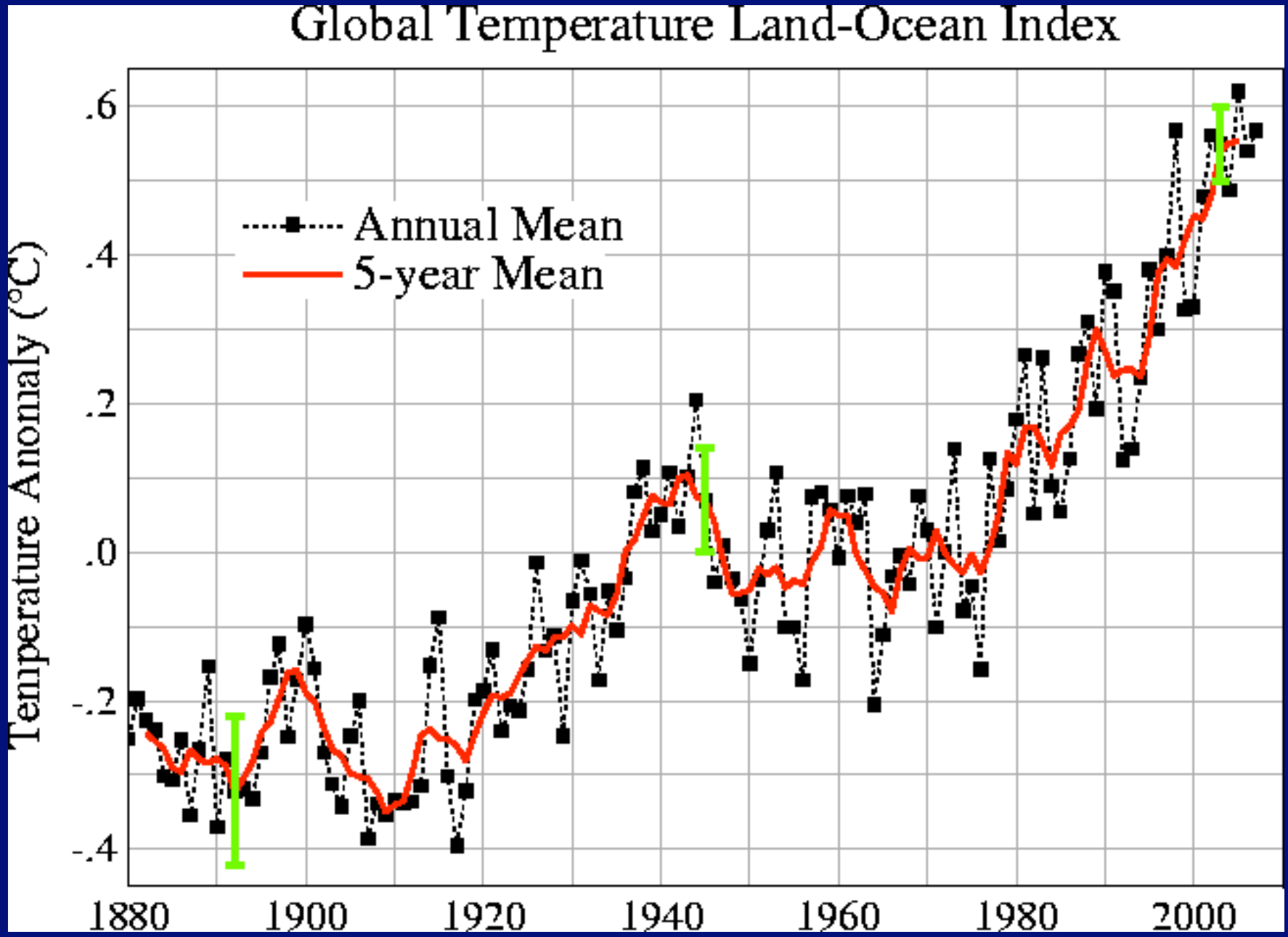
Positive feedbacks appear to be developing enormous force

Ice-sheet melting appears to be occurring far faster than expected because of dynamic processes

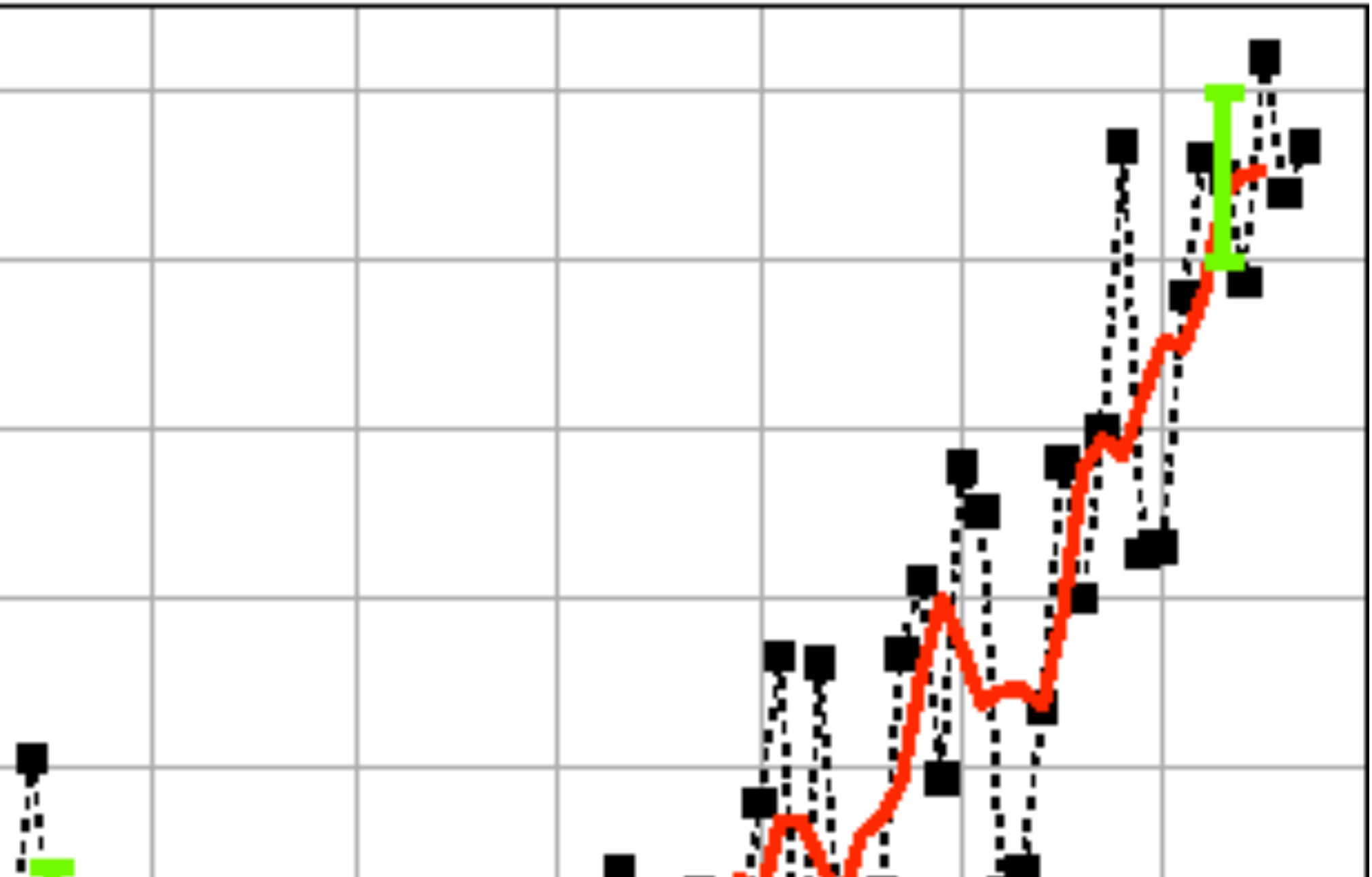
2001-2007 Mean Surface Temperature Anomaly (◦C)

Base Period = 1951-80, Global Mean = 0.54

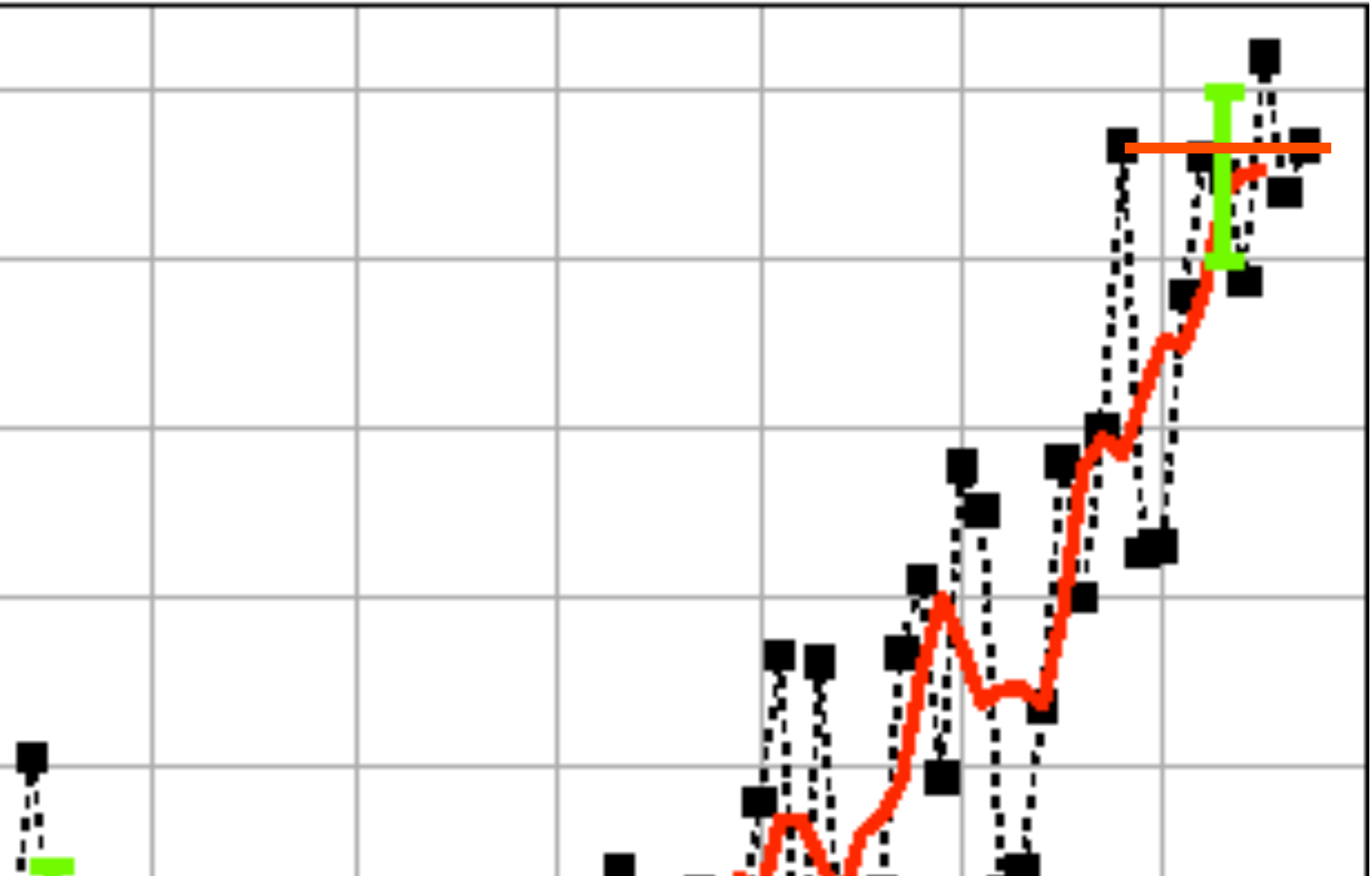



Global Temperature Land-Ocean Index
Annual Mean
5-year Mean
Temperature Anomaly (°C)
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000

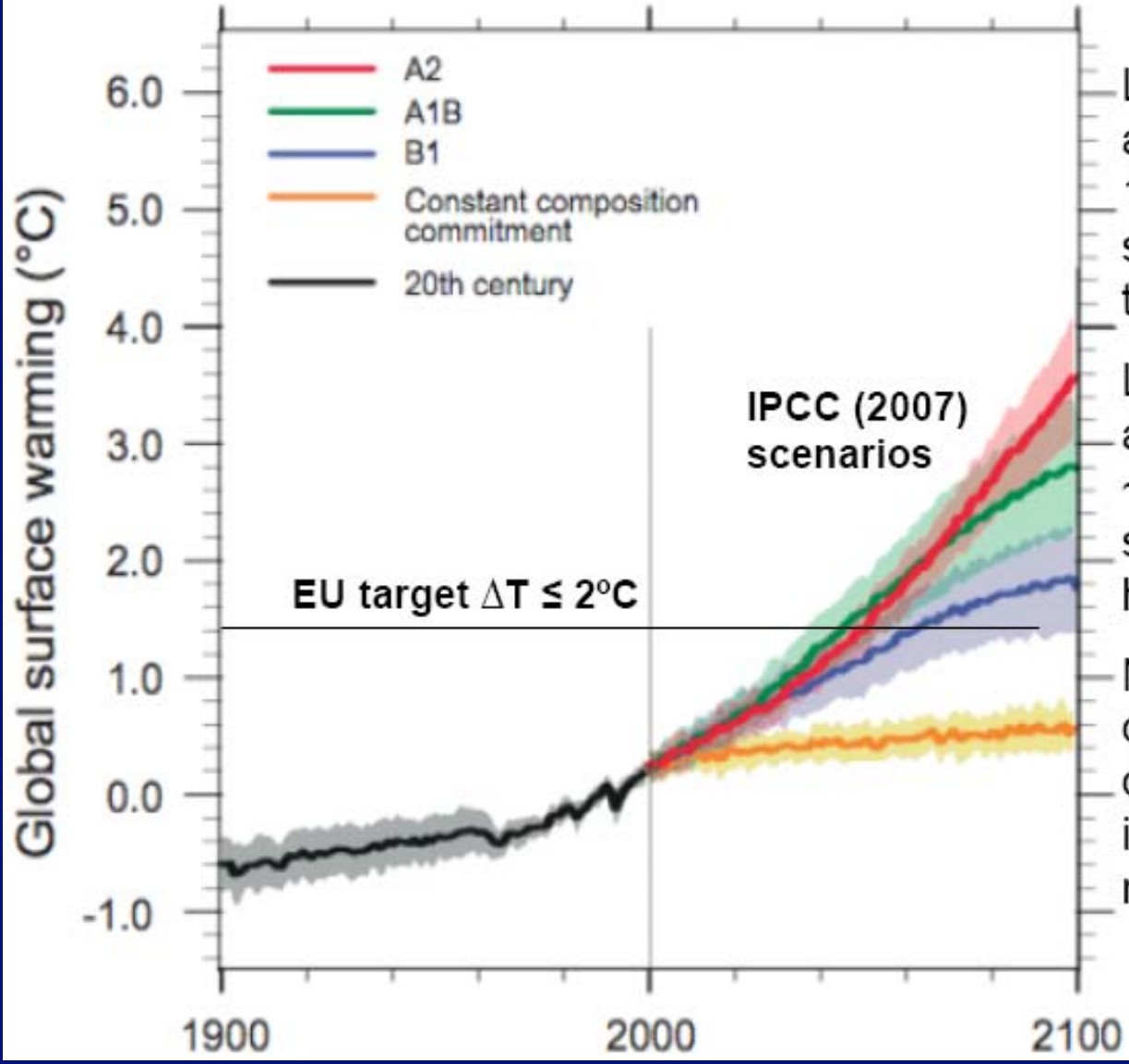
re Land-Ocean Index



re Land-Ocean Index



Under BAU much bigger disruption is coming



Last time T was 2°C above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

Last time T was 3°C above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

Note: Shaded bands denote 1 standard deviation from mean in ensembles of model runs

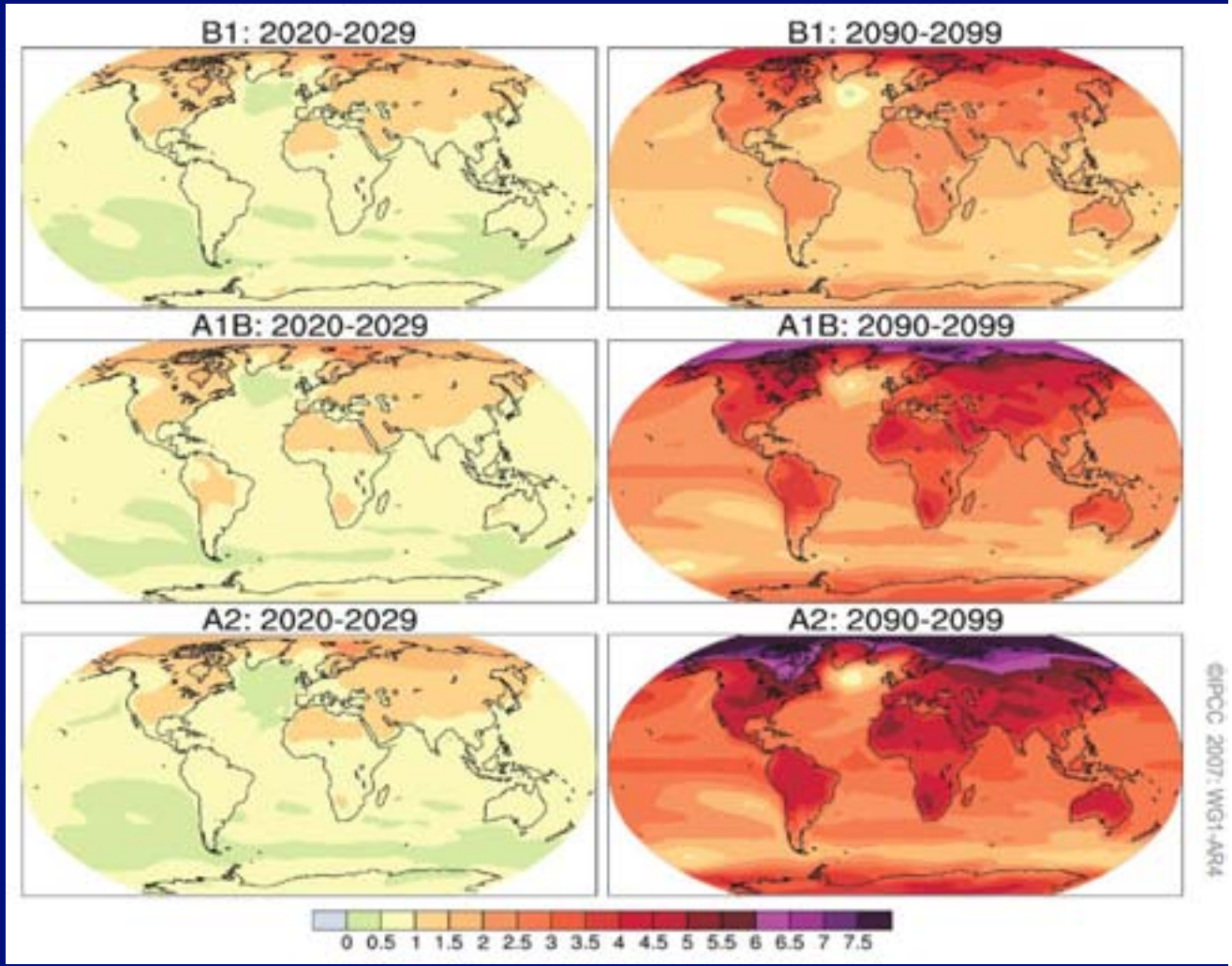
IPCC 2007

Projections of Future Changes in Climate

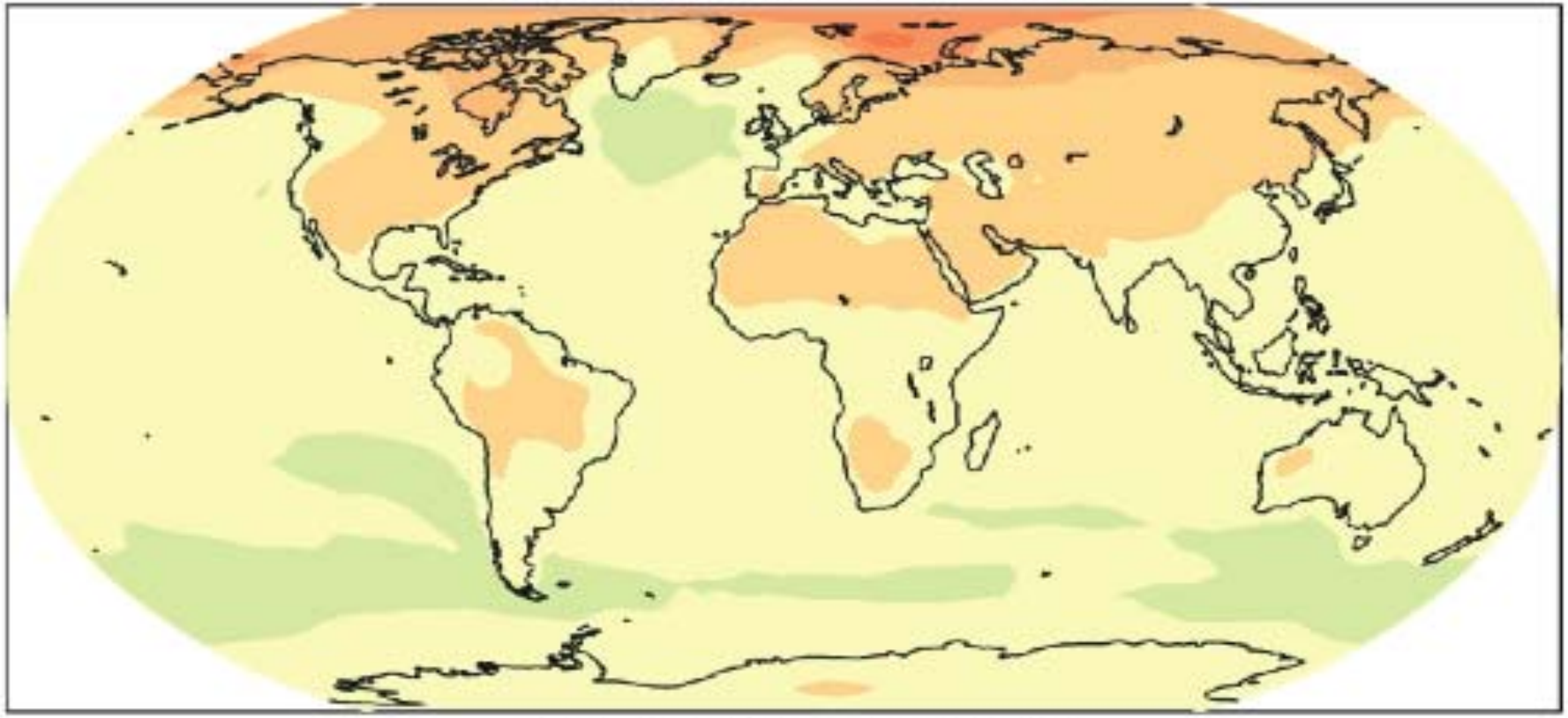
Projected warming in 21st century expected to be

greatest over land and at most high northern latitudes

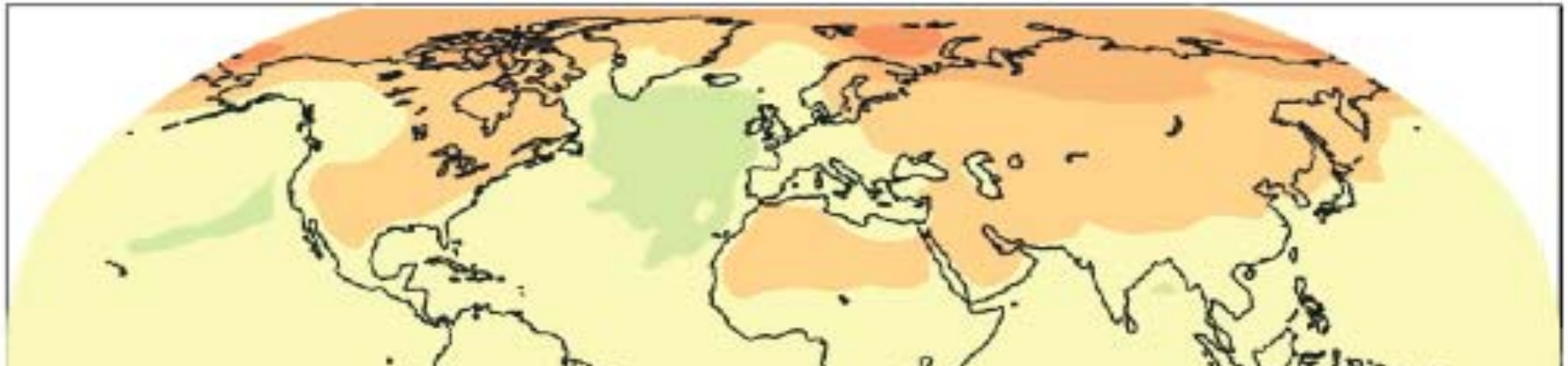
and least over the Southern Ocean and parts of the North Atlantic Ocean



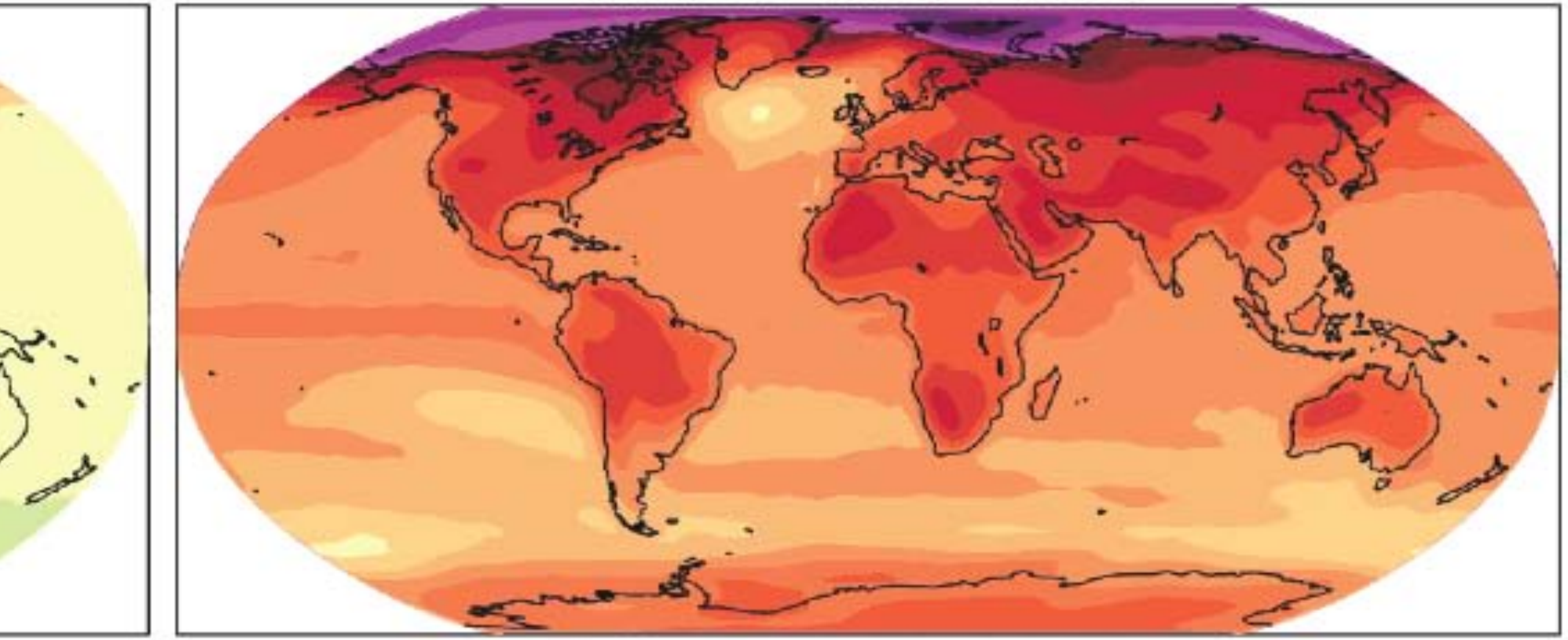
A1B: 2020-2029



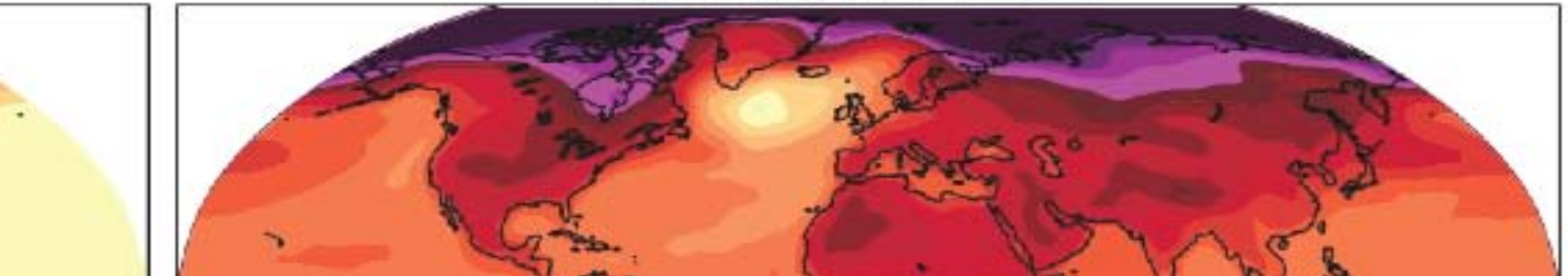
A2: 2020-2029



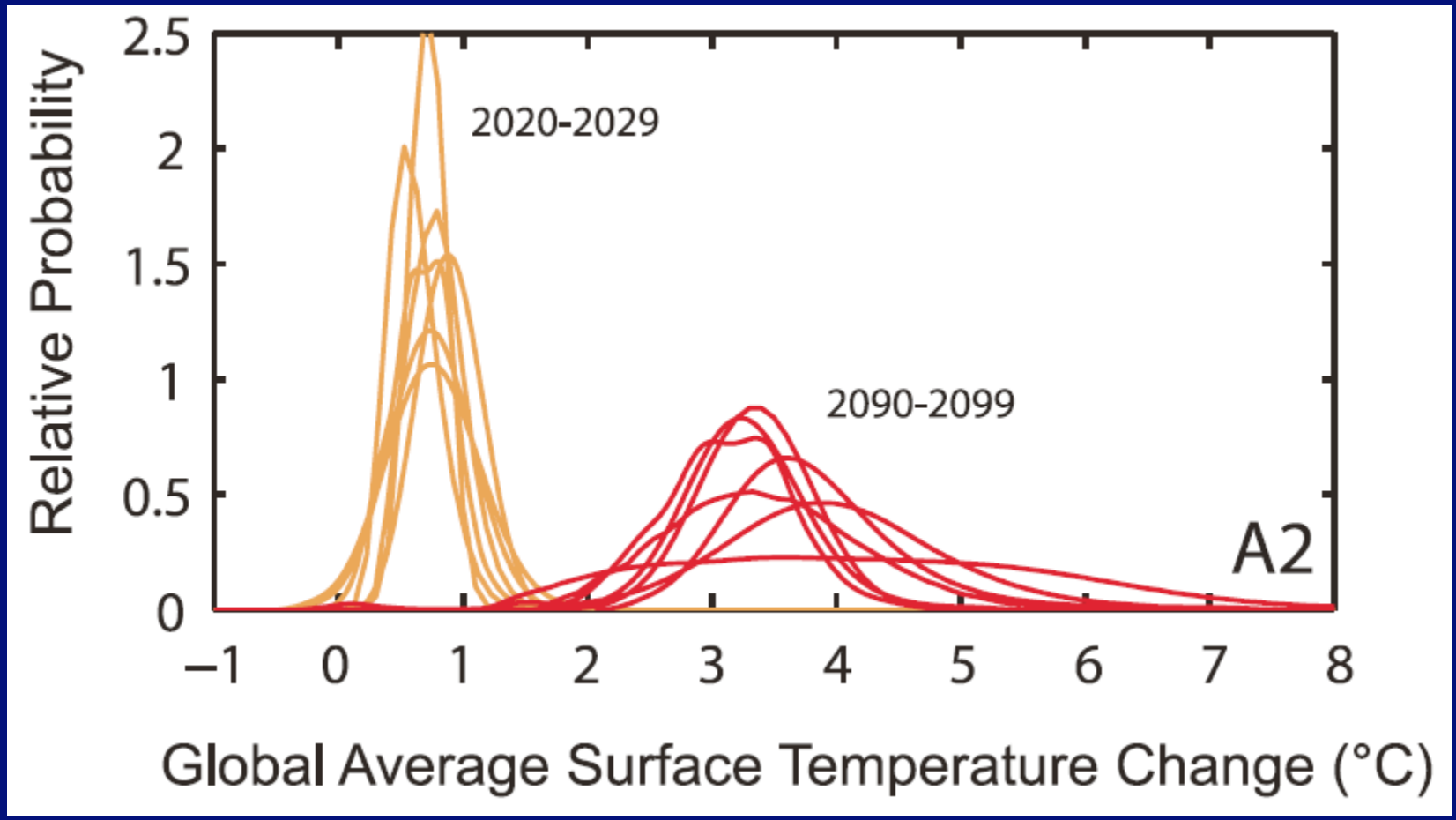
A1B: 2090-2099



A2: 2090-2099



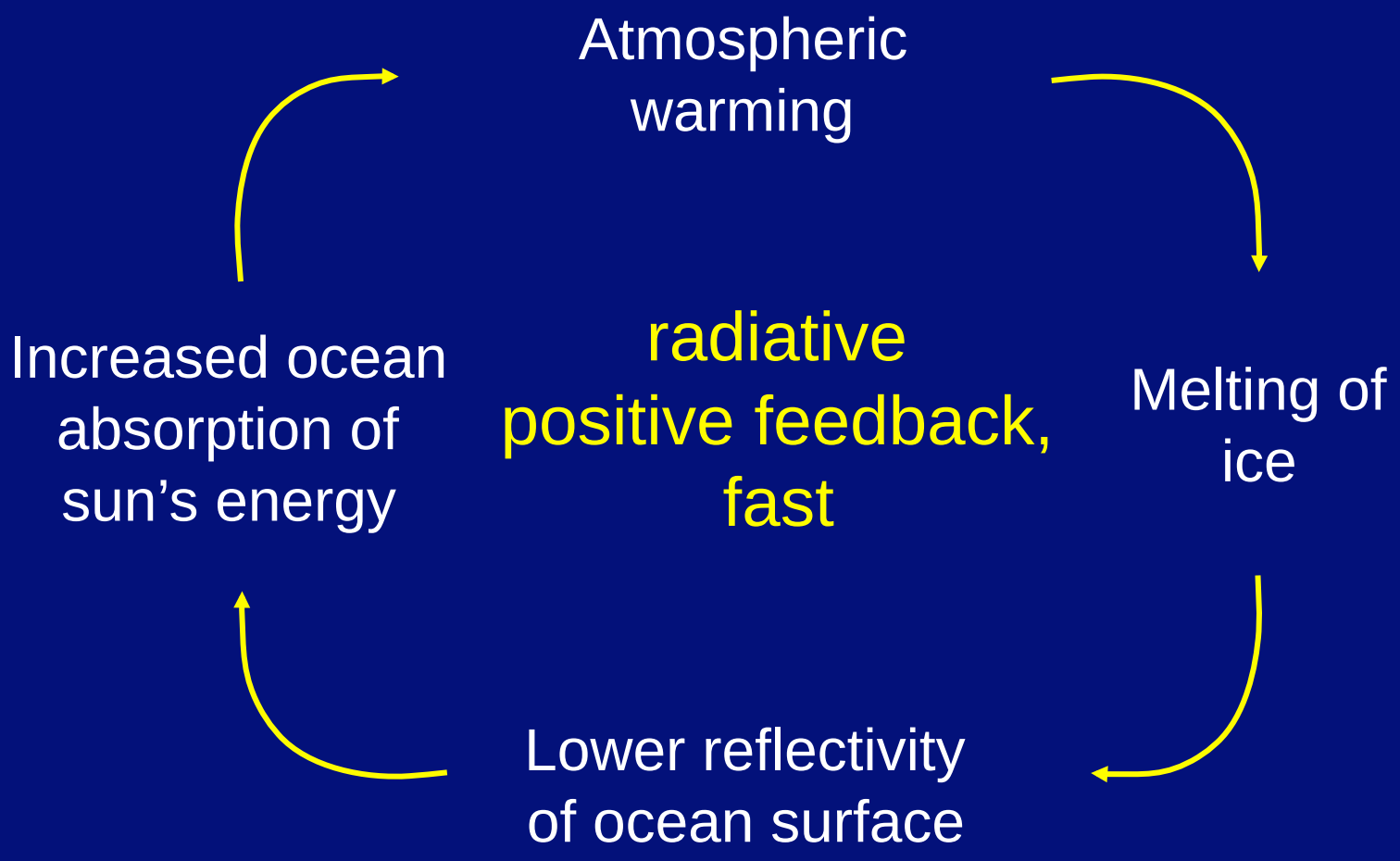
©IPCC 2

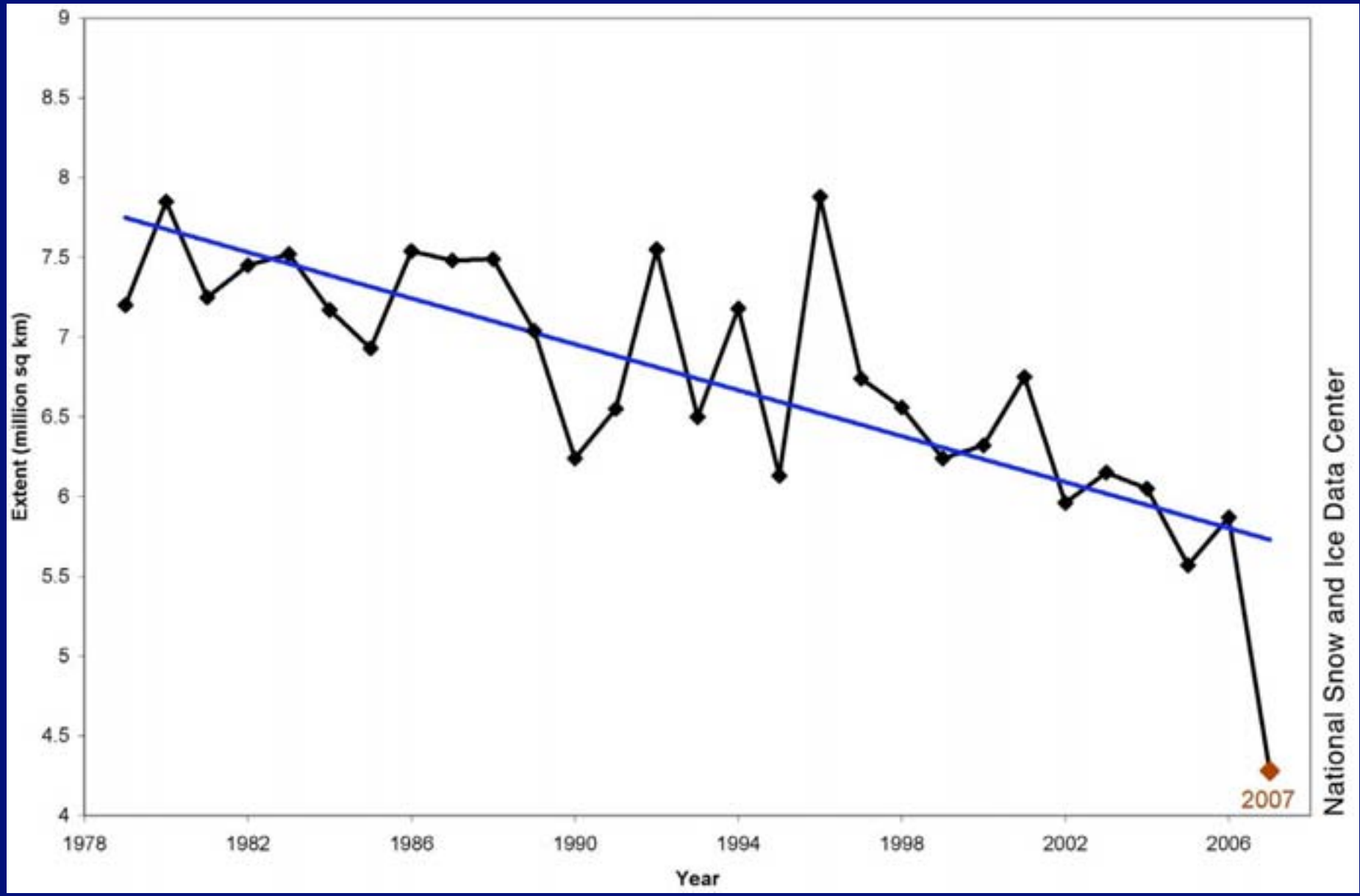

Relative Probability
2.5
2
1.5
1
0.5
0
2020-2029
2090-2099
A2
–1
0
1
2
3
4
5
6
7
8
Global Average Surface Temperature Change (°C)

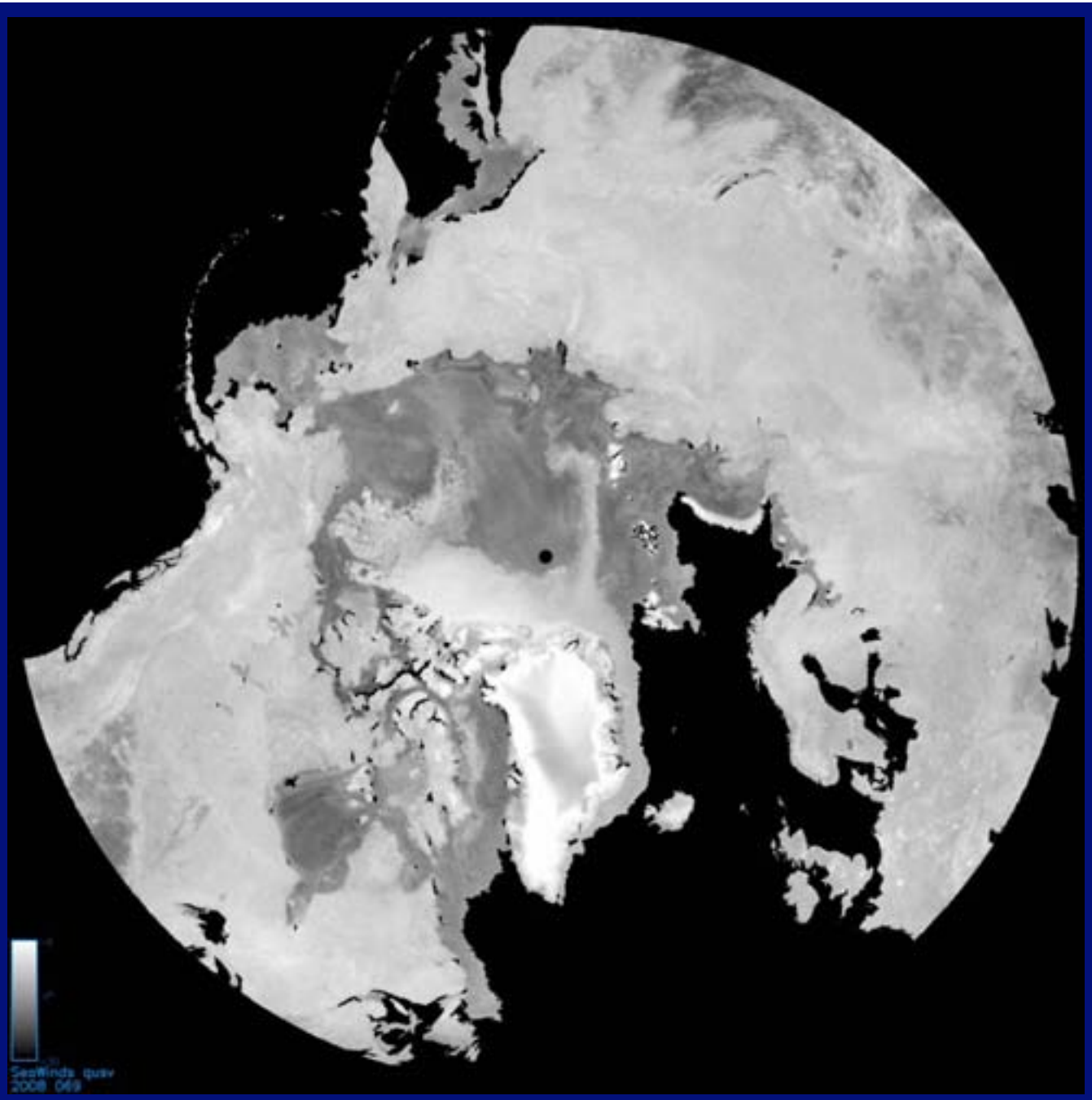
IPCC 2007

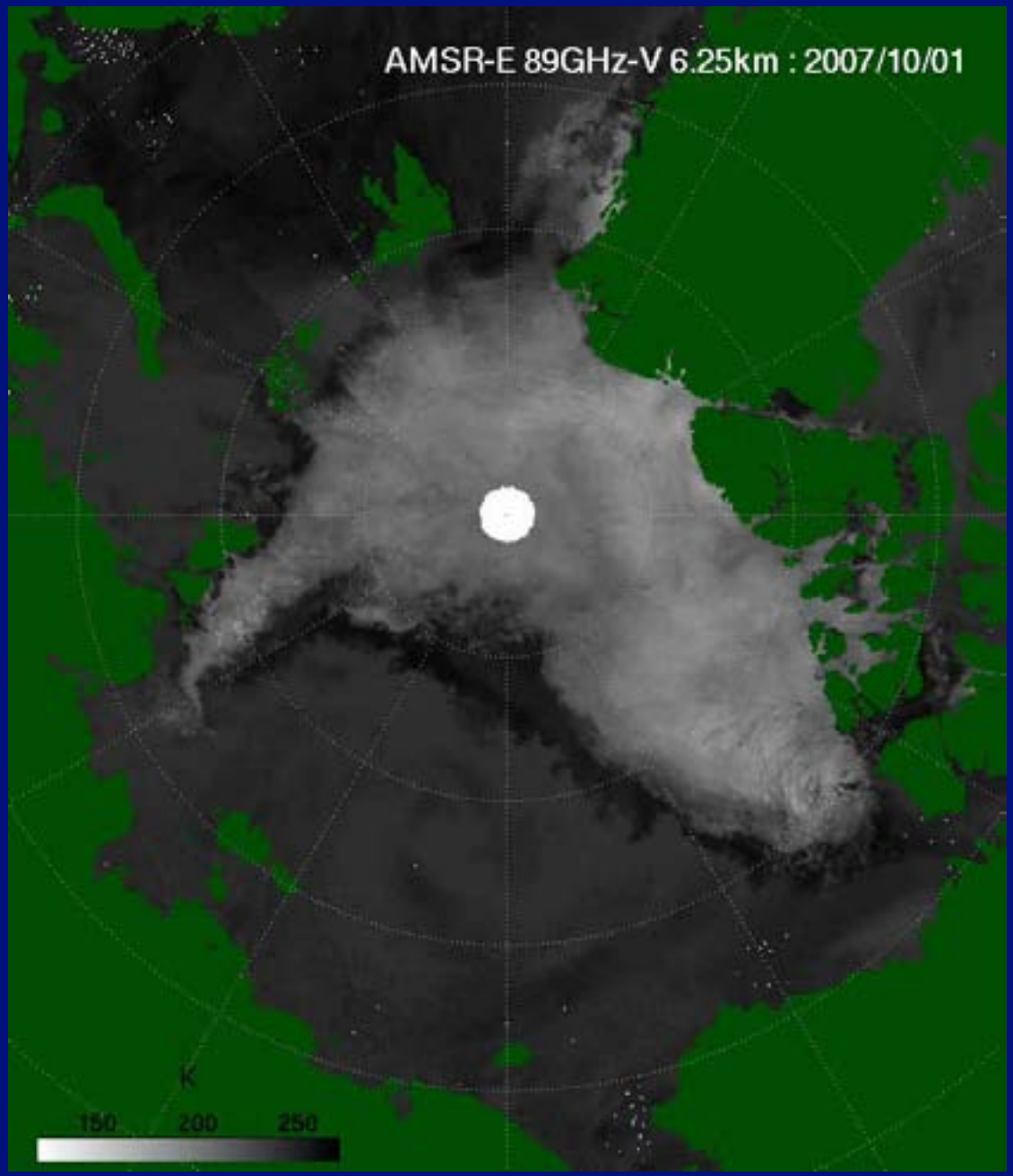
POSITIVE FEEDBACKS

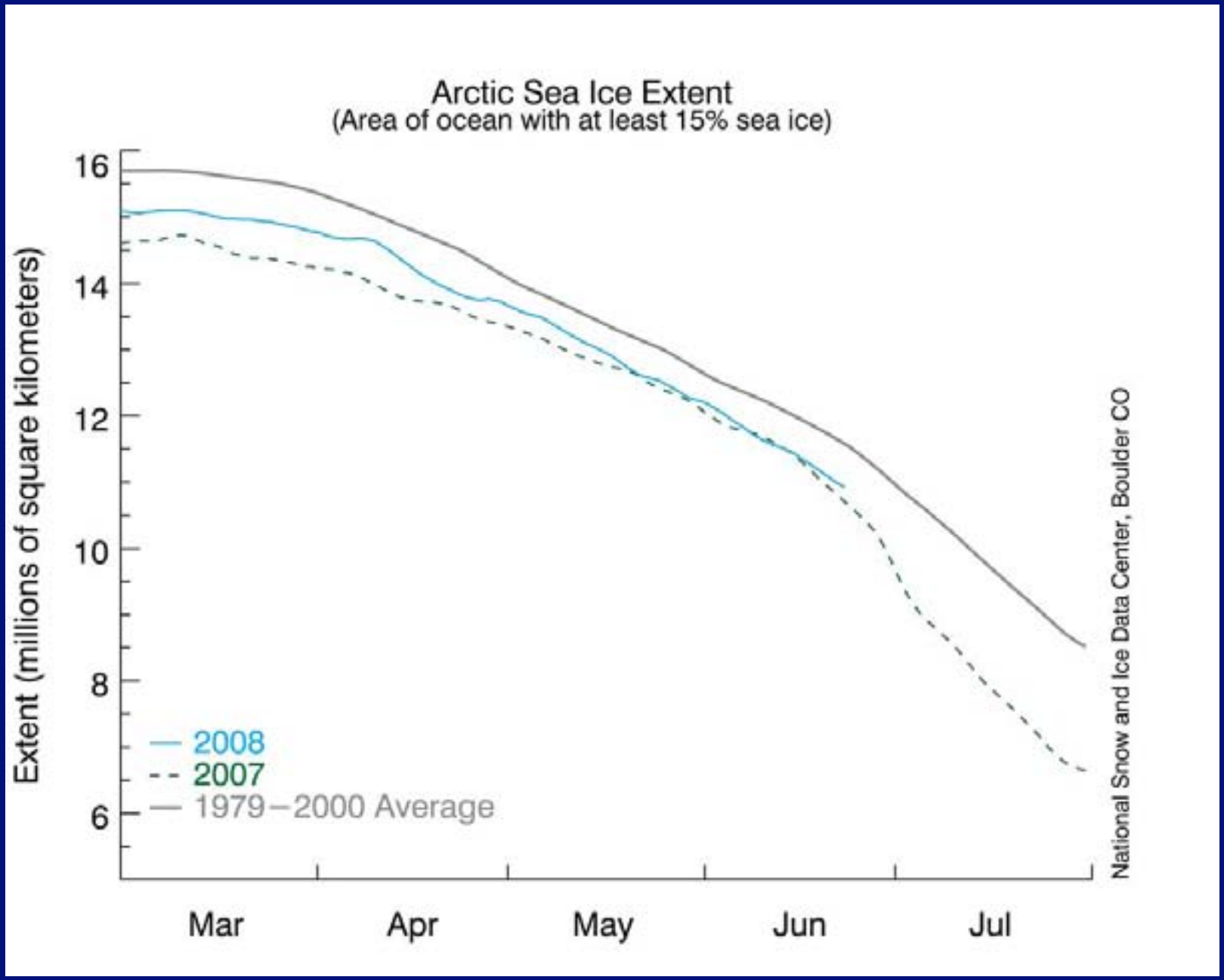
More rapid warming at poles
One reason: Ice-albedo feedback

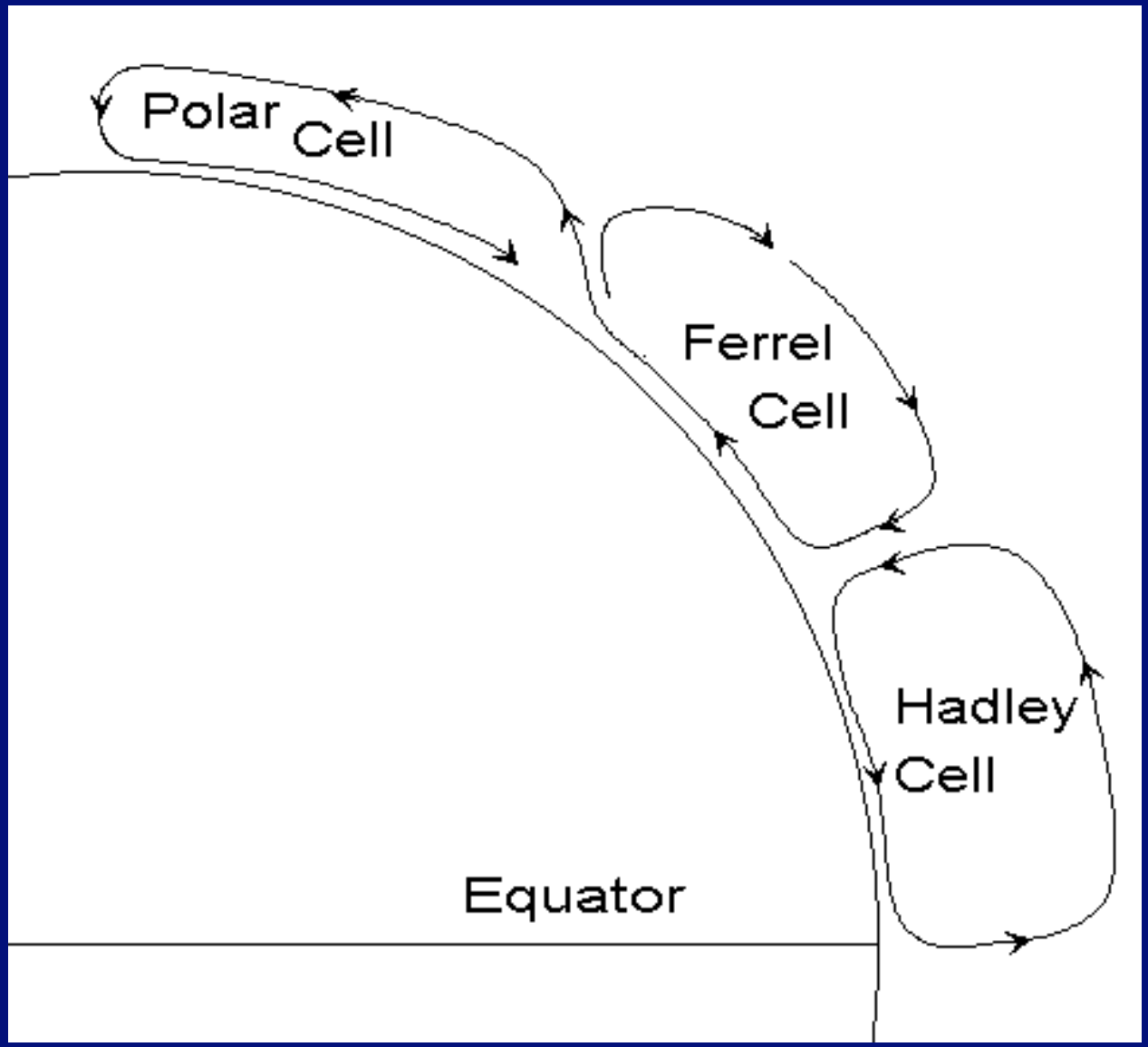


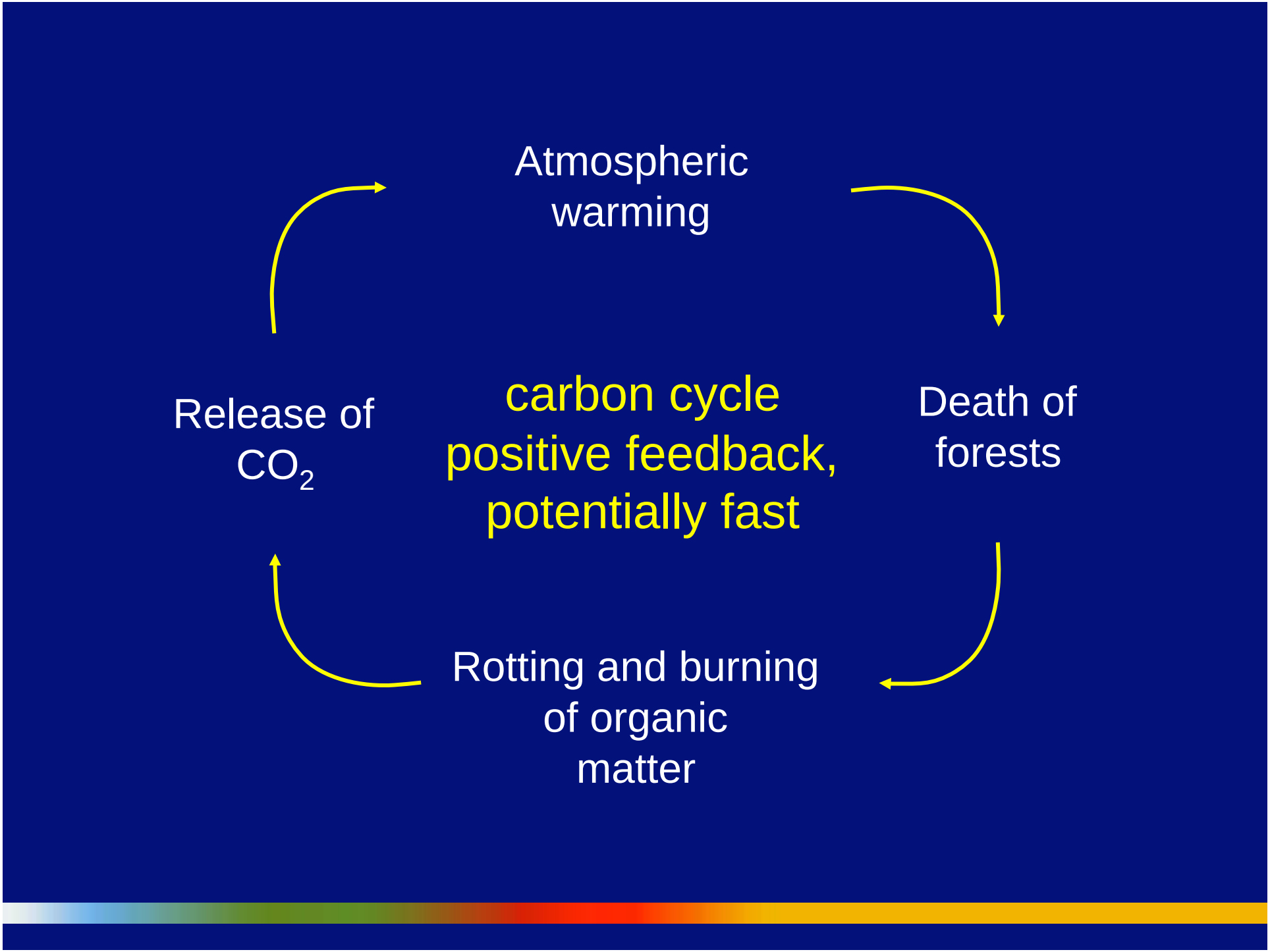

Extent (million sq km)
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
1978
1982
1986
1990
1994
1998
2002
2006
Year
2007
National Snow and Ice Data Center

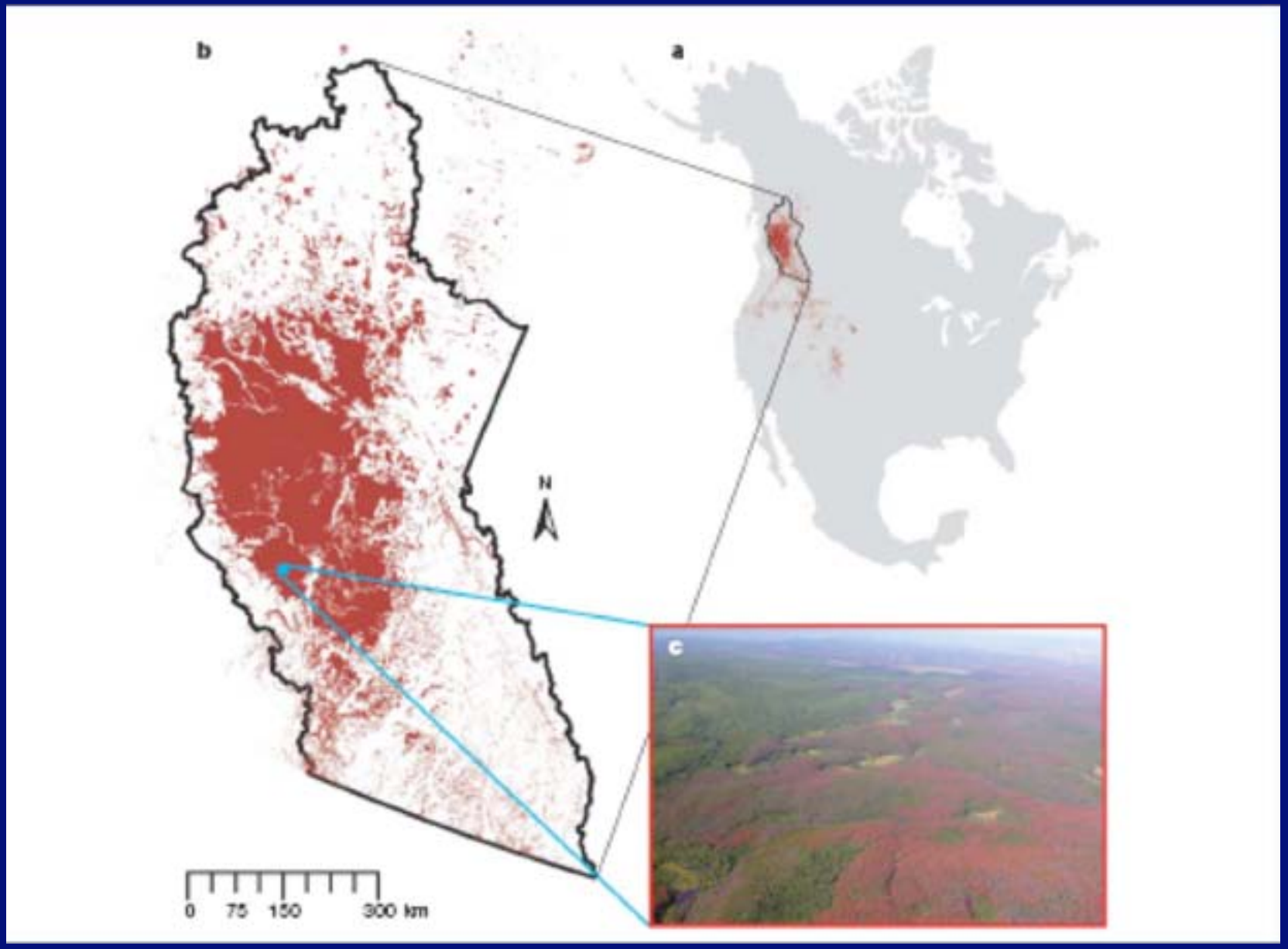

SeaWinds quav
2008 069


AMSR-E 89GHz-V 6.25km : 2007/10/01
K
150
200
250


Arctic Sea Ice Extent
(Area of ocean with at least 15% sea ice)
Extent (millions of square kilometers)
16
14
12
10
8
6
2008
2007
1979–2000 Average
Mar
Apr
May
Jun
Jul
National Snow and Ice Data Center, Boulder CO


Polar Cell
Ferrel Cell
Hadley Cell
Equator


Atmospheric warming
Death of forests
Rotting and burning of organic matter
Release of CO_2
carbon cycle positive feedback, potentially fast


b
a
N
c
0 75 150 300 km

LETTERS

Mountain pine beetle and forest carbon feedback to climate change

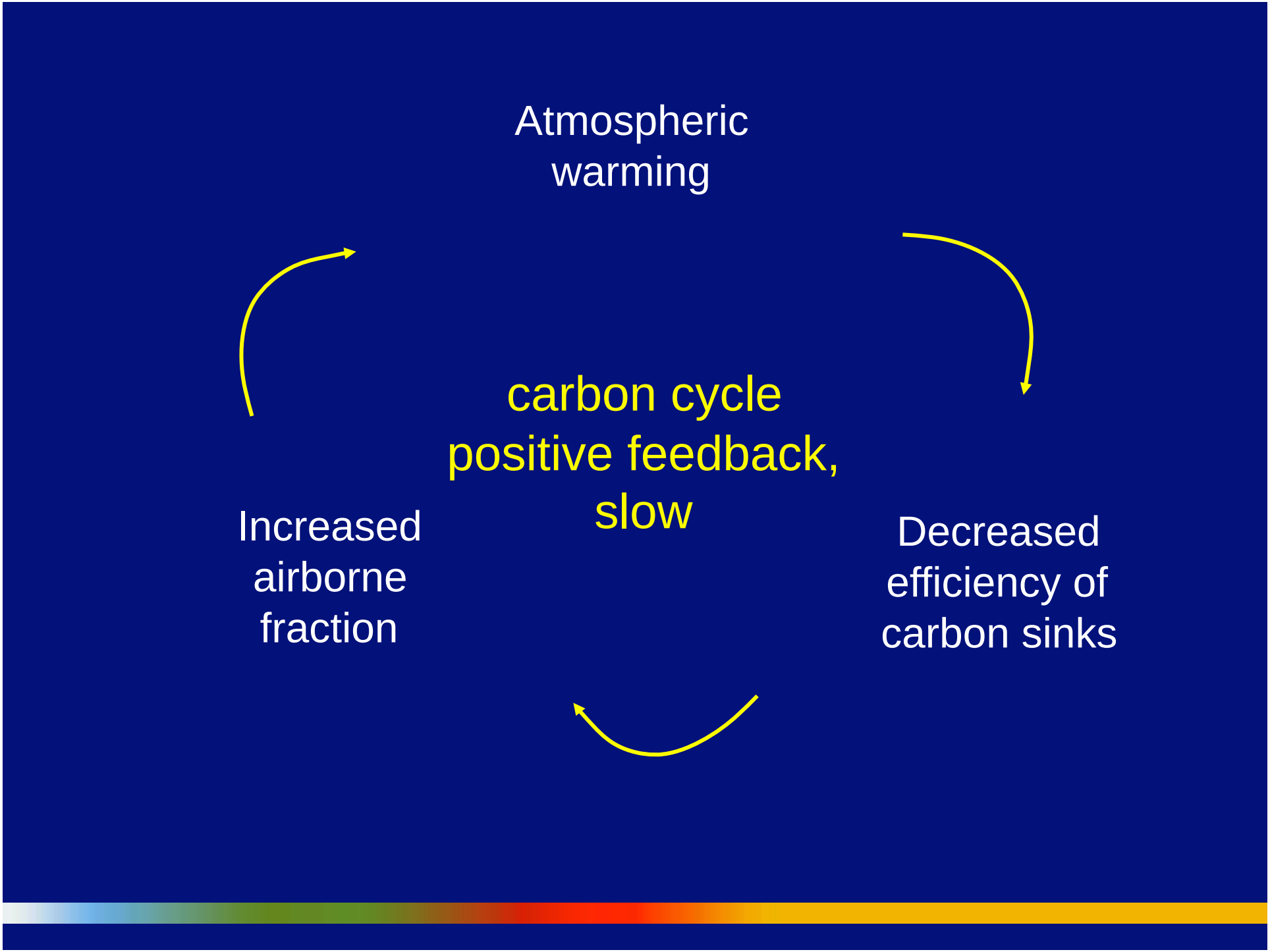
W. A. Kurz[1], C. C. Dymond[1], G. Stinson[1], G. J. Rampley[1], E. T. Neilson[1], A. L. Carroll[1], T. Ebata[2] & L. Safranyik[1]

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Curculionidae, Scolytinae) is a native insect of the pine forests of western North America, and its populations periodically erupt into large-scale outbreaks[1–3]. During outbreaks, the resulting widespread tree mortality reduces forest carbon uptake and increases future emissions from the decay of killed trees. The impacts of insects on forest carbon dynamics, however, are generally ignored in large-scale modelling analyses. The current outbreak in British Columbia, Canada, is an order of magnitude larger in area and severity than all previous recorded outbreaks[4]. Here we estimate that the cumulative impact of the beetle outbreak in the affected region during 2000–2020 will be 270 megatonnes (Mt) carbon (or 36 g carbon $m^{-2} yr^{-1}$ on average over 374,000 km^2 of forest). This impact converted the forest from a small net carbon sink to a large net carbon source both during and

stand in a single year[11]. Timber losses are estimated to be more than 435 million m^3, with additional losses outside the commercial forest[12]. The forest sector has responded by increasing harvest rates and reallocating some harvest, increasing the pine portion of the provincial total volume harvested from 31% to 45% over four years (2001–2004).

We estimated the combined impact of the beetle, forest fires and harvesting on forest productivity and carbon balance from 2000 until 2020 for the south-central region of British Columbia (Fig. 1). This area includes 374,000 km^2 of productive forest, largely dominated by pine (*Pinus*) and spruce (*Picea*) species. We used a Monte Carlo design for simulating future net biome production (NBP) using a forest ecosystem model (the Carbon Budget Model of the Canadian Forest Sector, CBM-CFS3). This model accounts for annual tree growth, litterfall, turnover and decay, and it explicitly simulates

Nature, April 24, 2008

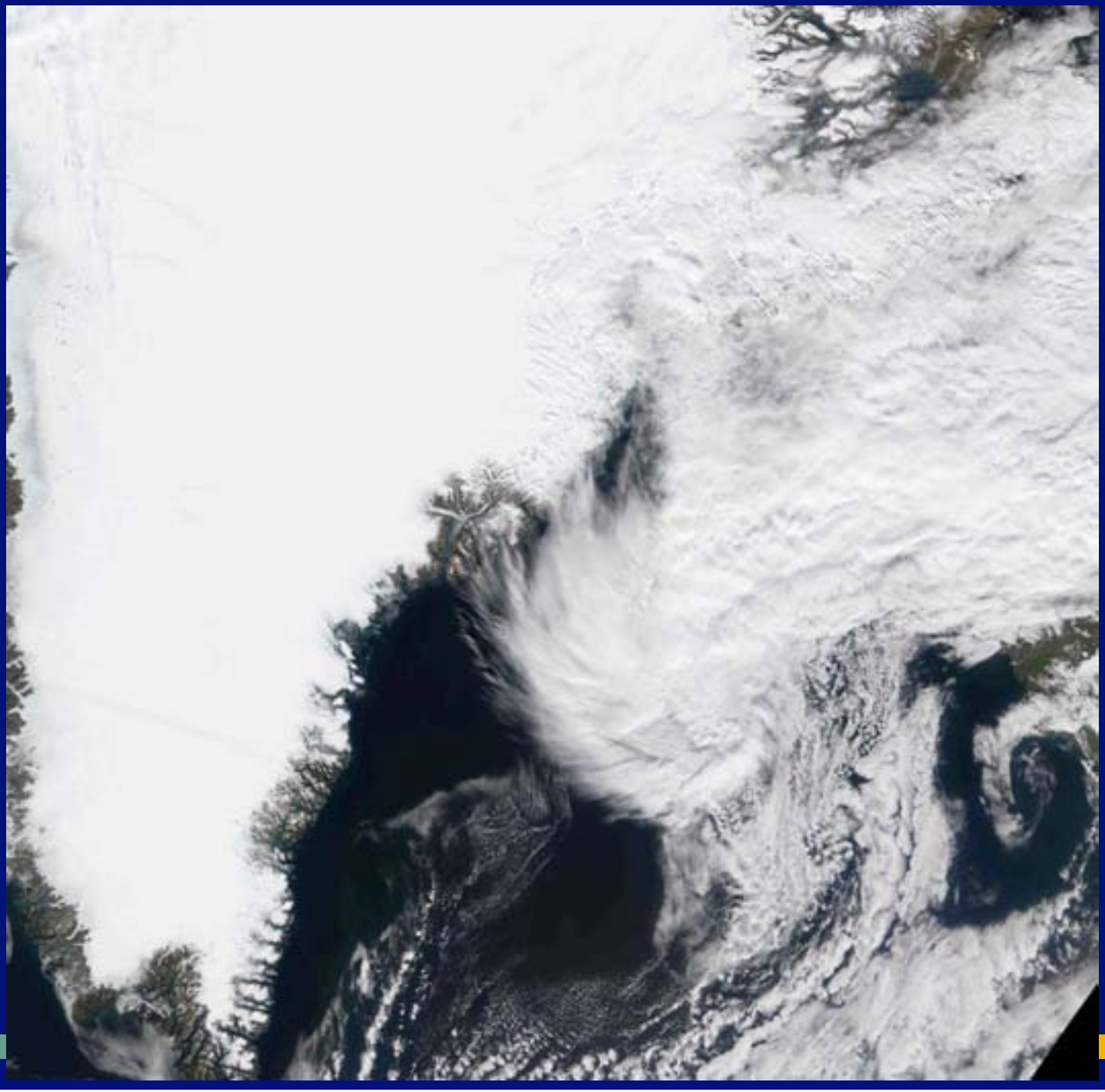

Atmospheric warming
carbon cycle positive feedback, slow
Decreased efficiency of carbon sinks
Increased airborne fraction

Declining efficiency of the ocean sink

- Up to 30 percent decrease in the efficiency of the Southern Ocean sink over the last 20 years
- Strengthening of the winds around Antarctica increases exposure of carbon-rich deep waters
- Strengthening of the winds due to global warming and the ozone hole

Le Quéré et al. 2007, Science

DYNAMIC ICE SHEETS

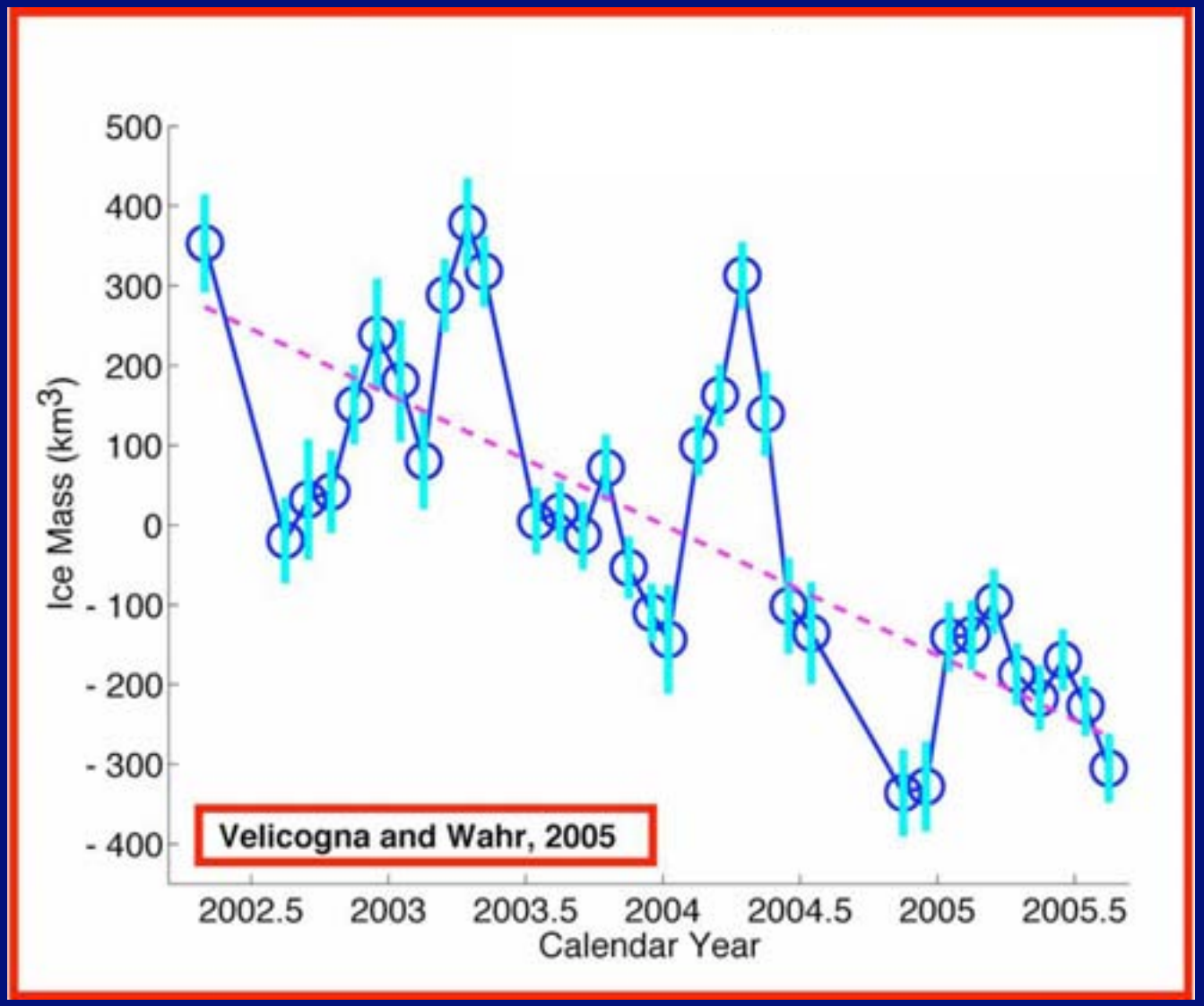


Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado

Greenland Mass Loss – From Gravity Satellite



ENERGY

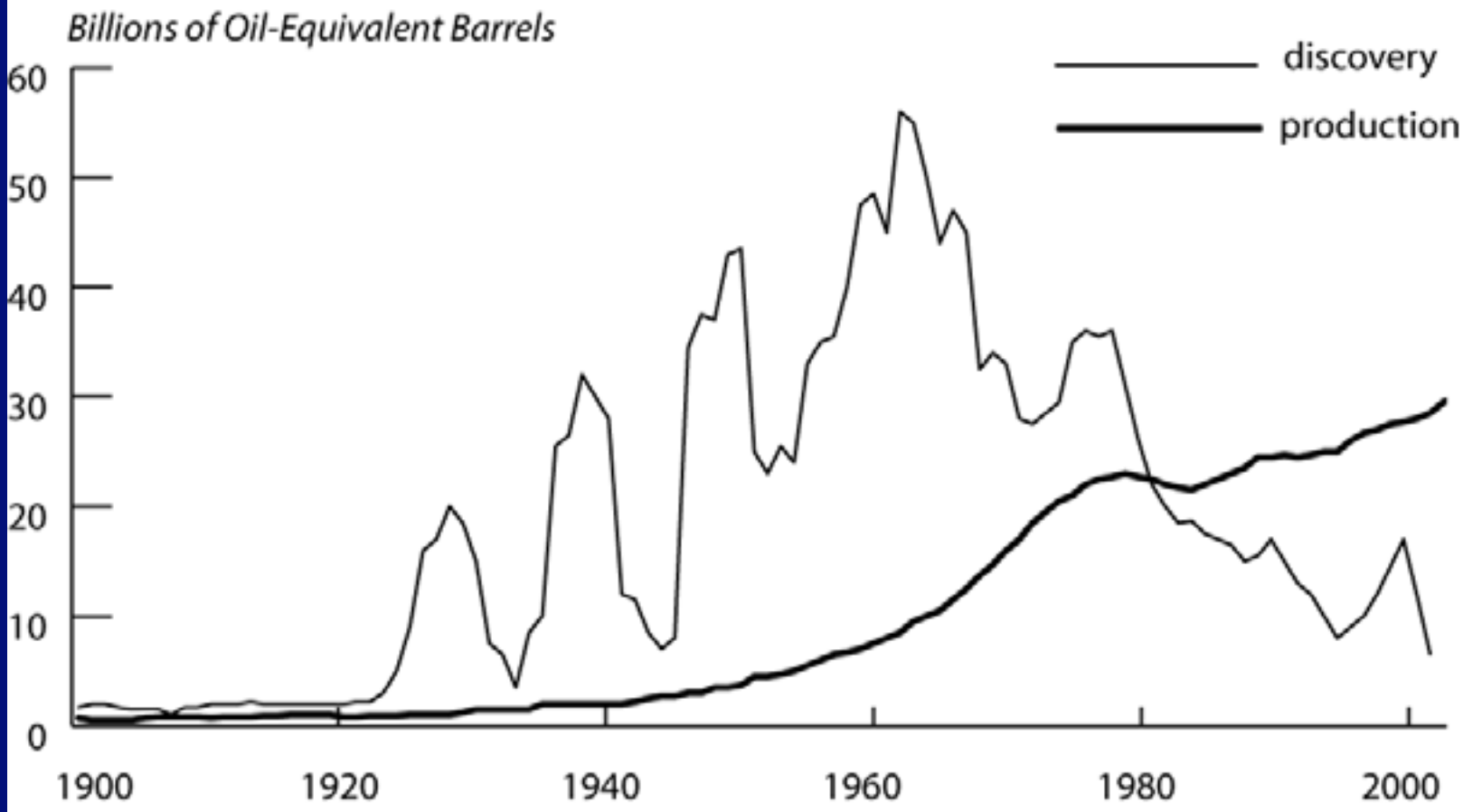
We are probably near peak global output of conventional oil

The “energy cost” of conventional oil is rising fast

This trend appears to be is driving a shift to more carbon-intensive fuels

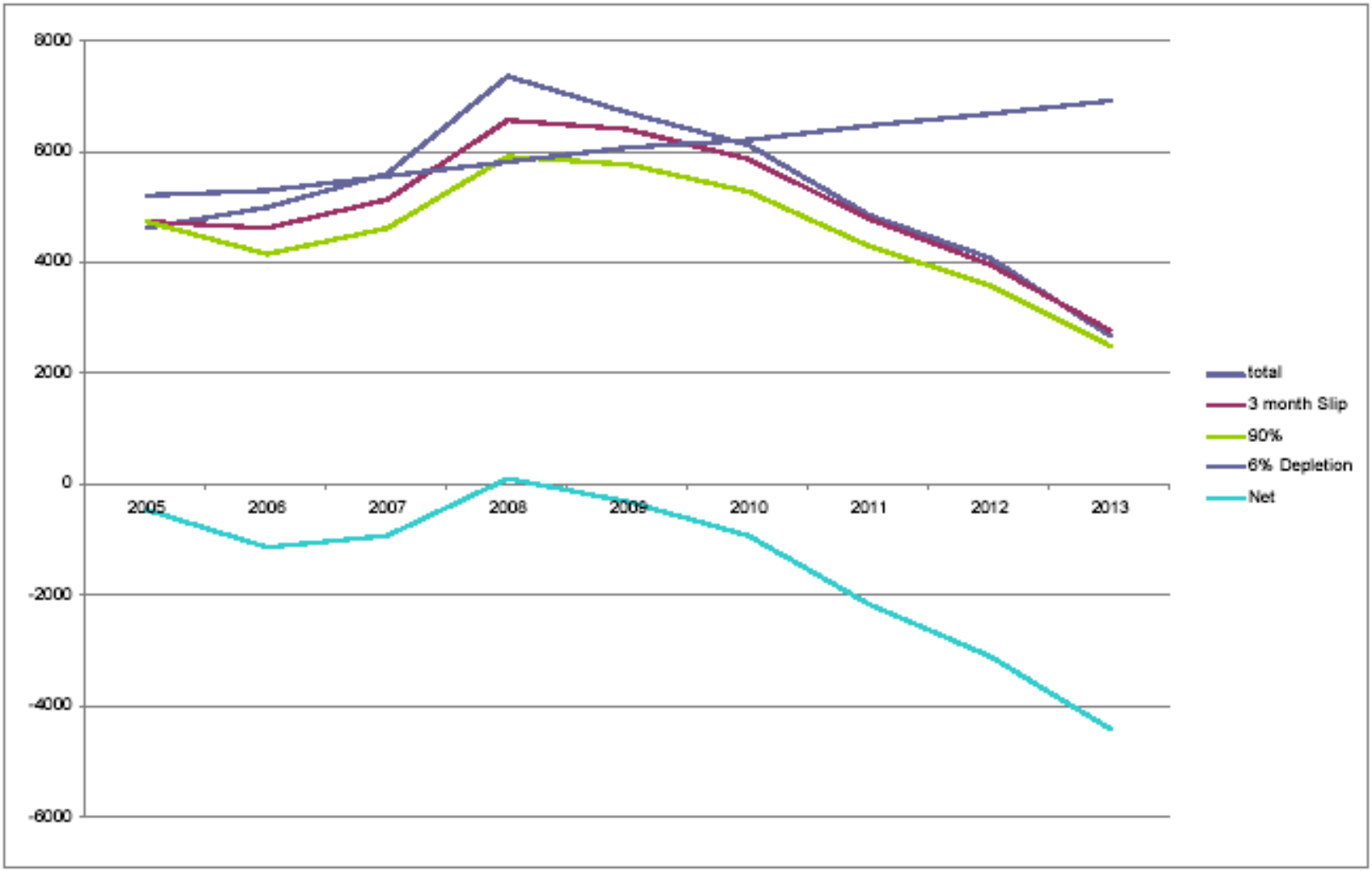
Massive deployment of carbon capture and storage (CCS) is therefore essential to avoid catastrophic climate change

Global oil discovery peaked in the early 1960s



Source: Harry Longwell, "The Future of the Oil and Gas Industry: Past Approaches, New Challenges," World Energy 5 3 (2002): 100-4, and Colin Campbell, personal correspondence.

Figure 6. Effect of 6% Decline Rates on Global Gross Oil Supply Growth, 2005 – 2013E



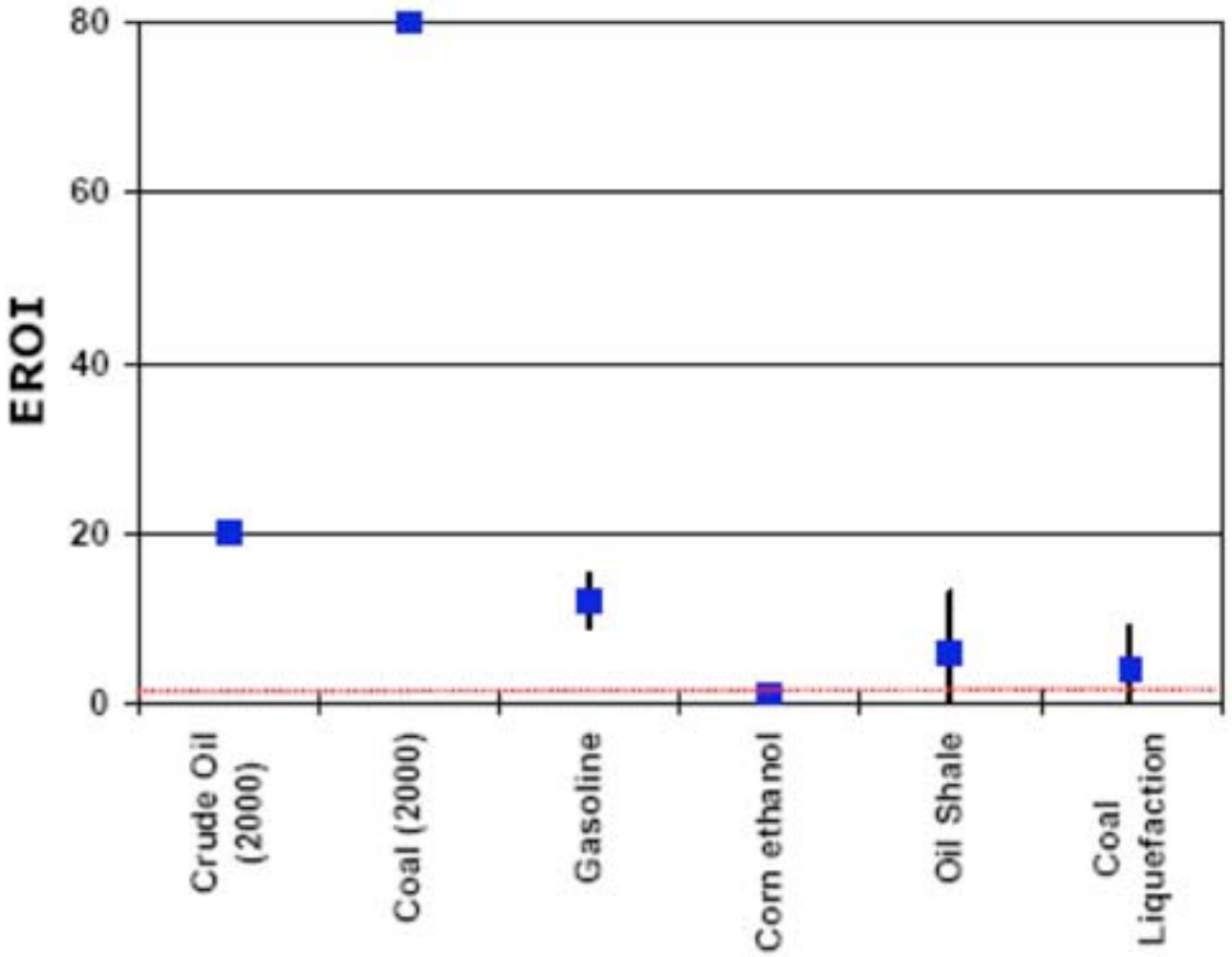
Source: Petroleum Review, Presentation to Citi, 31,01,08

Producing energy costs energy

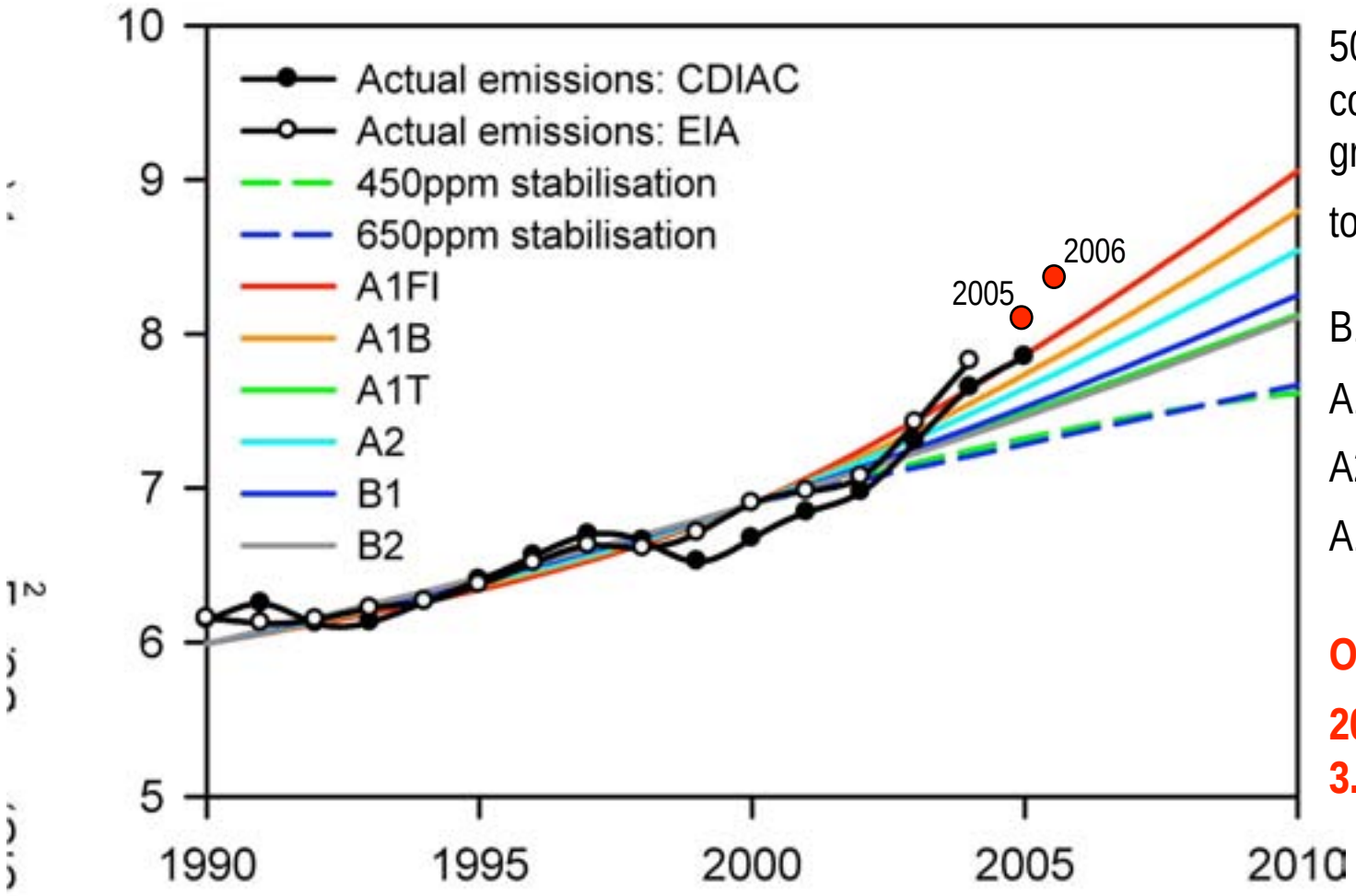
This principle is best understood through the concept of

Energy Return on Investment (EROI)

EROI for Fuel Systems



Trajectory of Global Fossil Fuel Emissions



50-year constant growth rates to 2050

B1 1.1%,

A1B 1.7%,

A2 1.8%

A1FI 2.4%

Observed 2000-2006 3.3%

Raupach et al. 2007, PNAS

CO2 concentrations, Jubany Station, Antarctica

Year	ppm	Δ	
1994	356.75		
1995	358.18	1.43	1.64
1996	360.33	2.15	
1997	361.81	1.48	
1998	363.95	2.14	
1999	365.65	1.70	
2000	366.69	1.04	
2001	368.22	1.53	
2002	370.47	2.25	2.14
2003	372.19	1.72	
2004	374.87	2.68	
2005	376.73	1.86	
2006	378.74	2.01	
2007	381.05	2.31	

Causes of Accelerating Atmospheric CO2 Growth

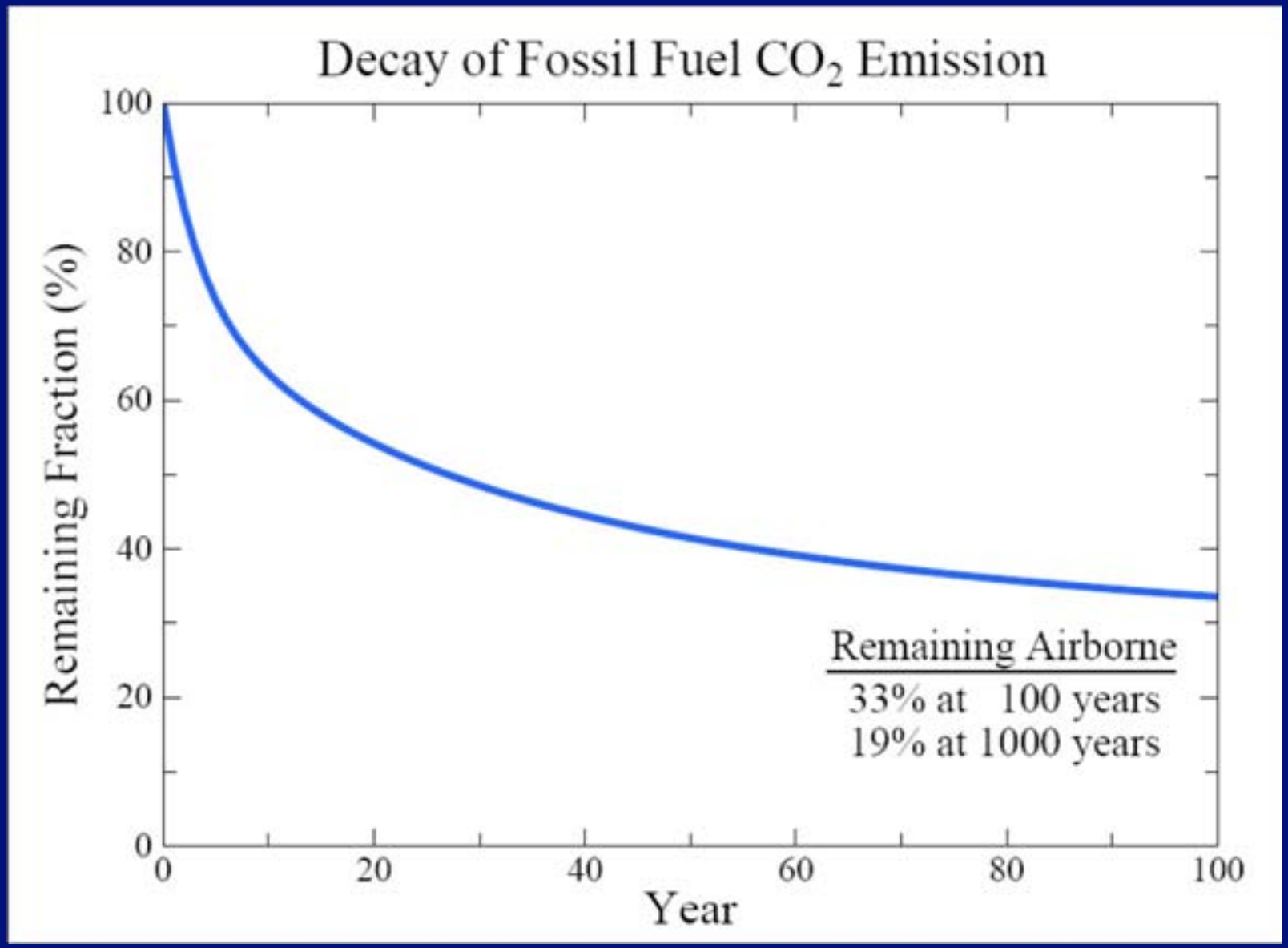
- 65% of acceleration due to increasing global economic activity
- 17% of acceleration due to increasing carbon intensity of global economy

[Emissions growth rate rose from 1.3% to 3.3% per year from 1990s to 2000-2006]

- 18% of acceleration due to increased airborne fraction
- "An increasing AF is consistent with results of climate-carbon cycle models, but the magnitude of the observed signal appears larger than that estimated by models. All of these changes characterize a carbon cycle that is generating stronger-than-expected and sooner -than-expected climate forcing."
- Canadell, et al., *Proceedings of the National Academy of Sciences*, Oct. 2007

" [We show] that to hold climate constant at a given global temperature requires near zero future carbon emissions. . . . As a consequence, any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales."

Matthews, H. D., and K. Caldeira (2008), "Stabilizing climate requires near-zero emissions," *Geophys. Res. Lett.*

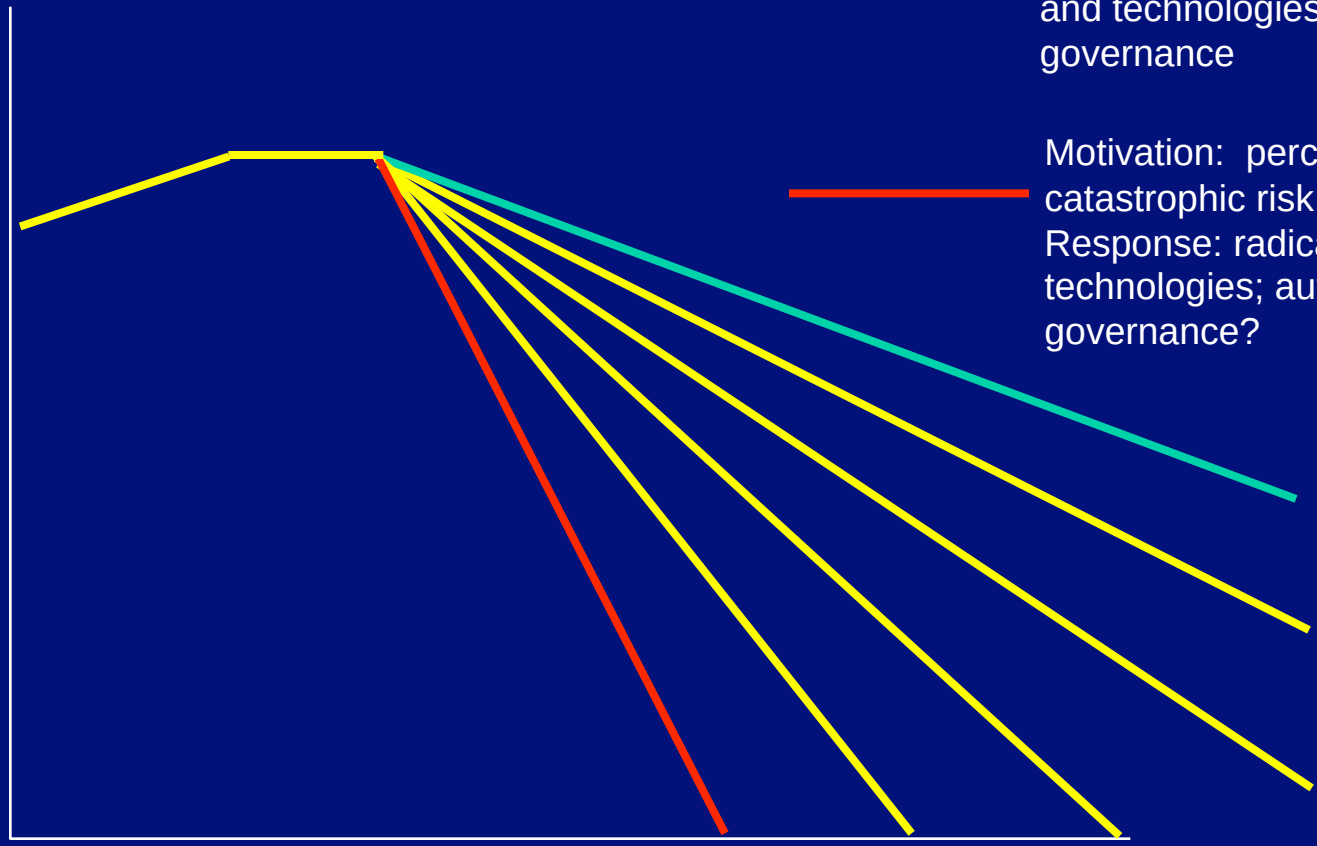


Hansen, *Atmos. Chem. Phys.* 7 (2007): 2287-2312.

Plan Zs: Ramp-down rates

Motivation: perception of manageable risk;
Response: Conventional institutions and technologies; democratic governance

Motivation: perception of catastrophic risk;
Response: radical institutions and technologies; authoritarian governance?



<350

Remember this number
for the rest of your life.

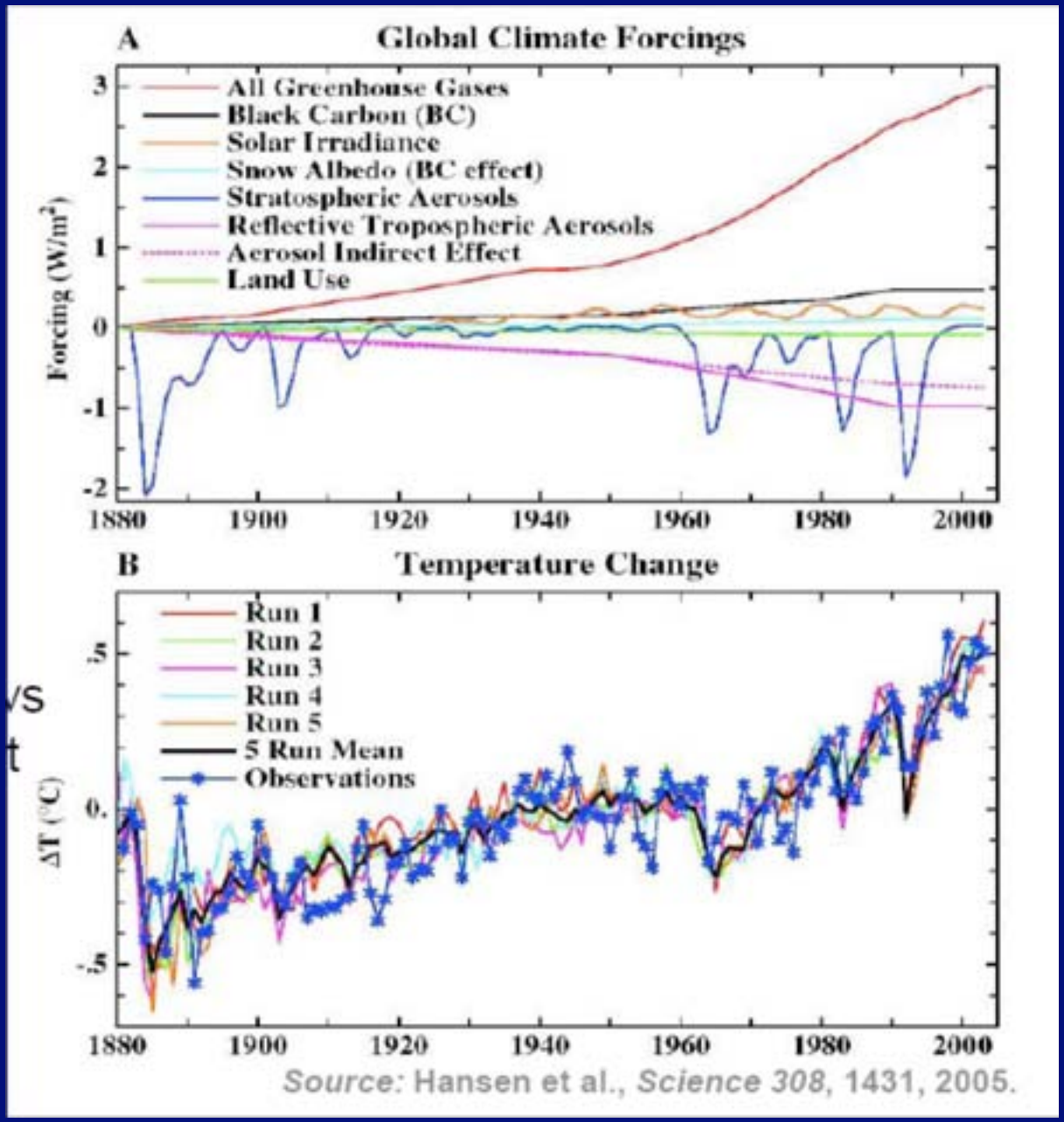
Crisis and Creativity

Mitigation strategies, from conventional to radical

(predicated on a significant carbon price)

- Efficiency and conservation
- Renewables (GSHPs)
- Coal with CCS and nuclear
- Unconventional technologies (UCG, enhanced geothermal, stratospheric windmills)
- Atmospheric carbon capture
- Geoengineering
- Shifting away from conventionally defined “growth”

How about you spend LESS time studying how MY generation destroyed the environment and MORE time figuring out a magical solution?
BIZARRO.COM Dist. by King Features
1-11-07


A
Global Climate Forcings
All Greenhouse Gases
Black Carbon (BC)
Solar Irradiance
Snow Albedo (BC effect)
Stratospheric Aerosols
Reflective Tropospheric Aerosols
Aerosol Indirect Effect
Land Use
Forcing (W/m²)
3
2
1
0
-1
-2
1880
1900
1920
1940
1960
1980
2000
B
Temperature Change
Run 1
Run 2
Run 3
Run 4
Run 5
5 Run Mean
Observations
ΔT (°C)
.5
0.
-.5
1880
1900
1920
1940
1960
1980
2000
Source: Hansen et al., Science 308, 1431, 2005.