DPG – AKE, Berlin, 8 March 2005

The Climate Problem: Diagnosis, Prognosis, and Therapy

John Schellnhuber

P I K

Tyndall Centre for Climate Change Research

PART I: THE DIAGNOSIS

One view of climate change

"I believe that climate change is the most important long-term issue we face as a global community. It is an issue that will require sustained action over the coming decades. A sound understanding of the science must be the basis for this action."

Tony Blair, UK Prime Minister

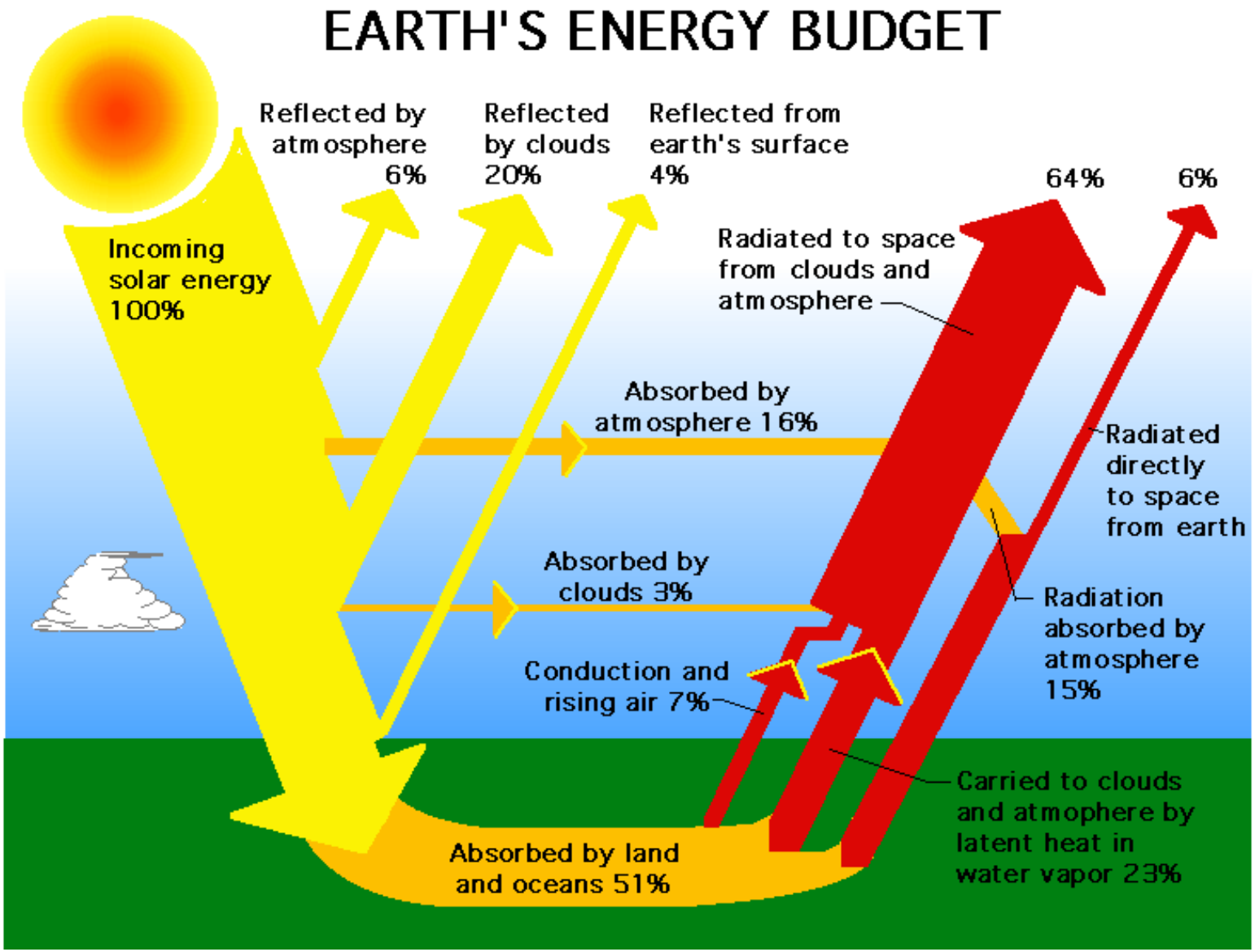
3 Nov 2004

….and another

“Much of the debate over global warming is predicated on fear, rather than science. I called the threat of catastrophic global warming the greatest hoax ever perpetrated on the American people”

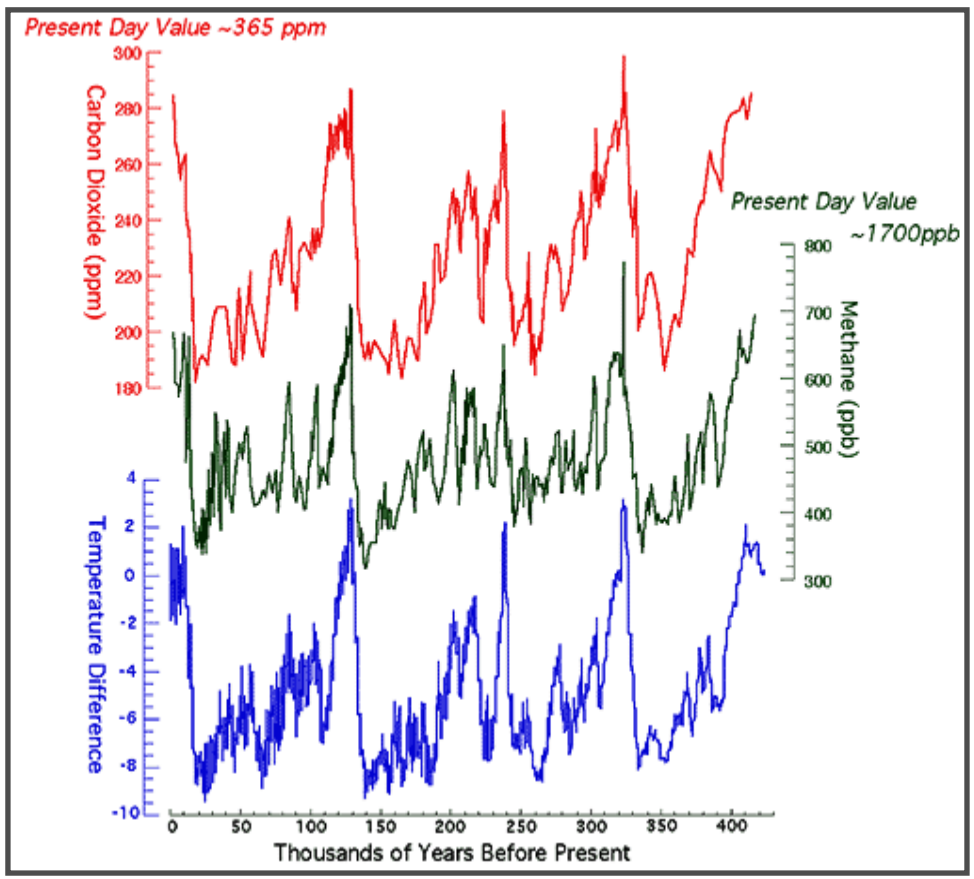
James M. Inhofe, US Senator &
Chairman of Environment and Public Works Committee
4 Jan 2005

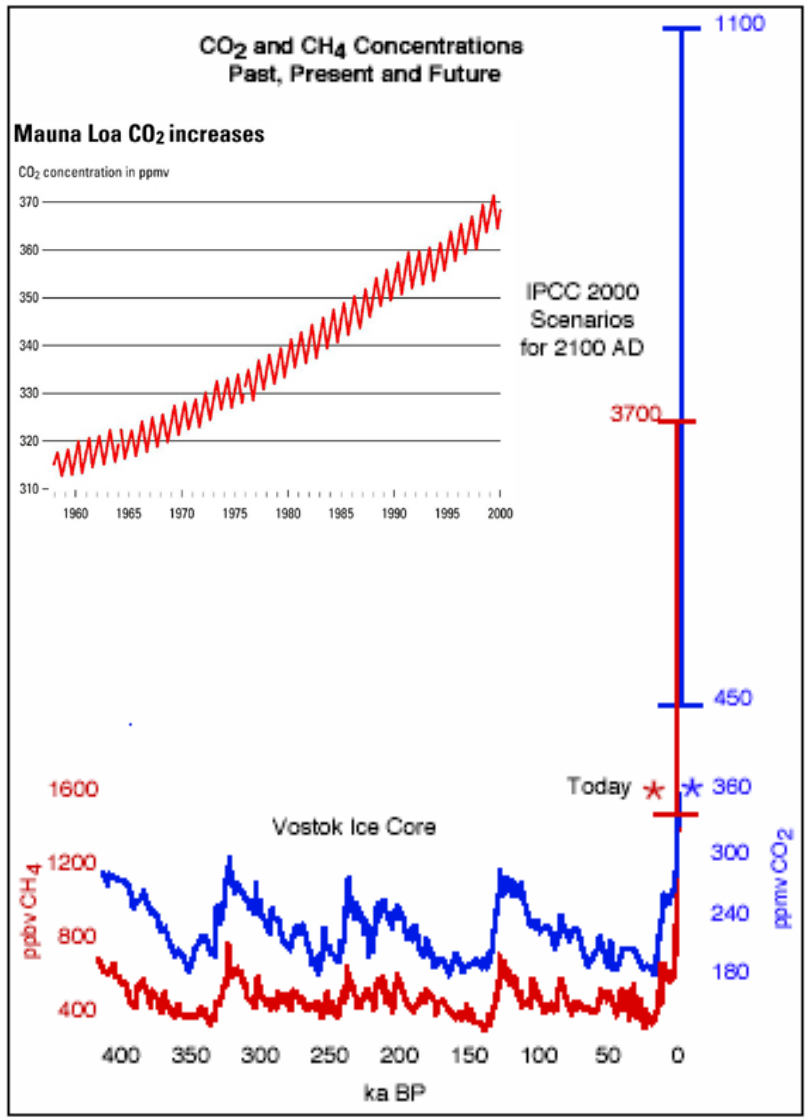
The Greenhouse Effect



Human Impact on Atmosphere

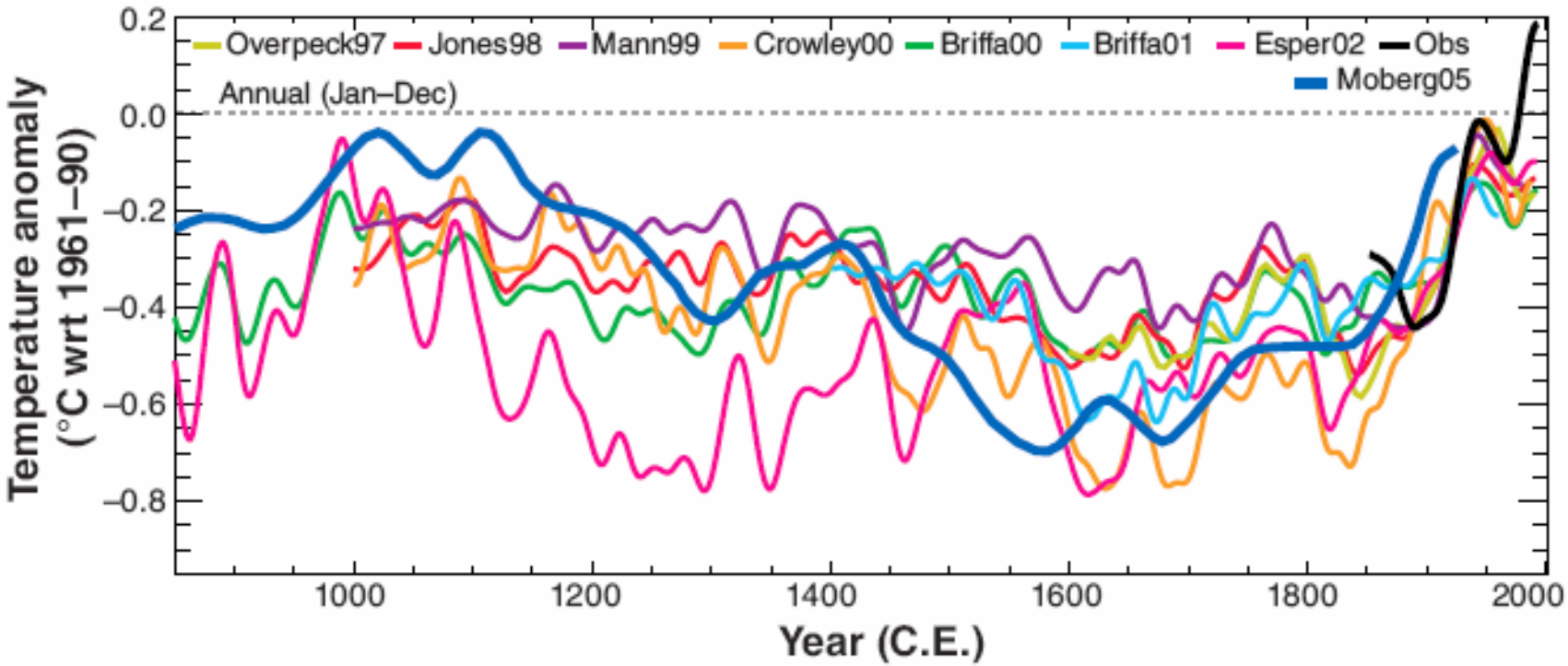
Vostok Ice Core – the record of the last 420,000 years





Images from WDCP/IPCC

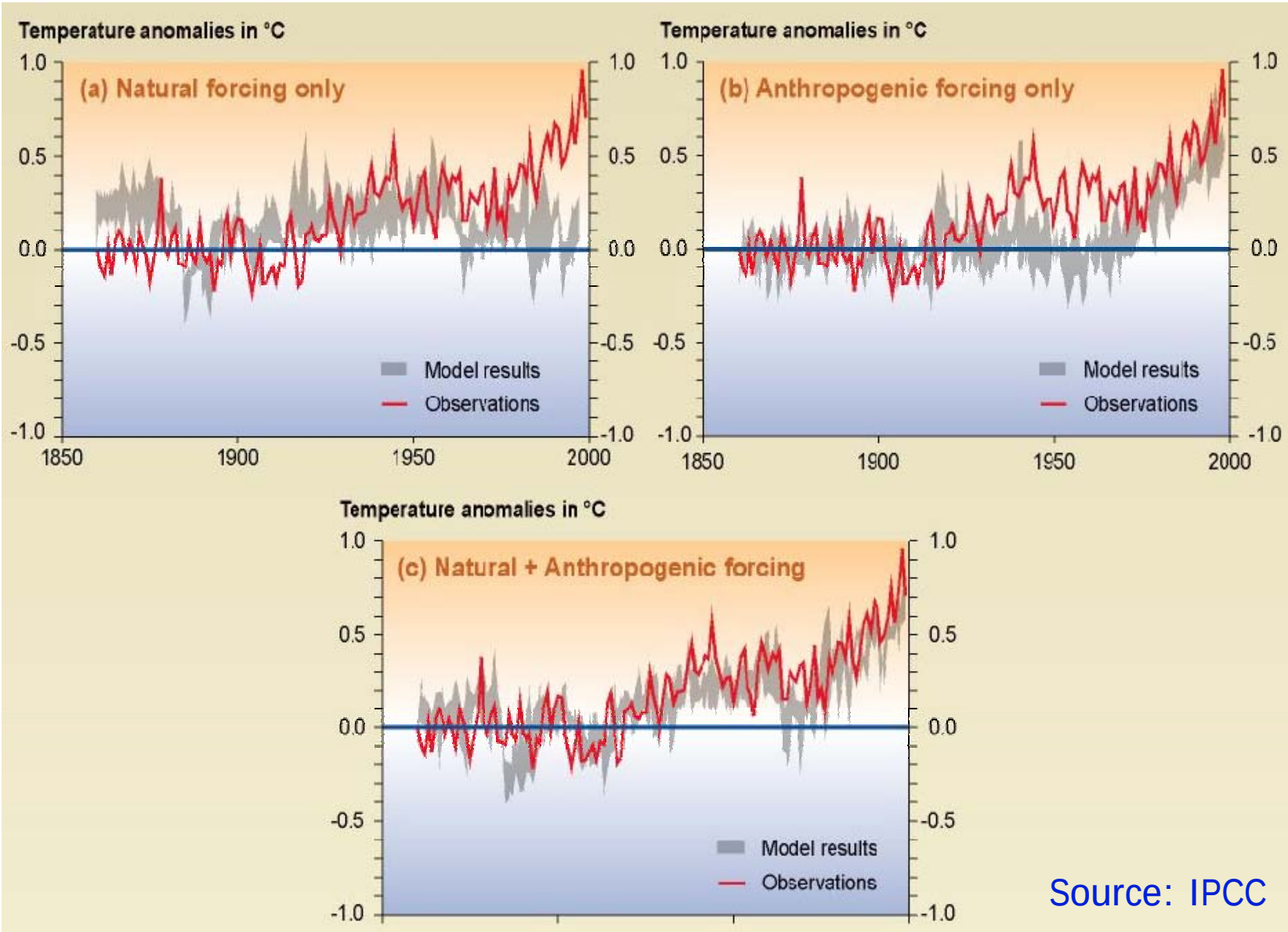
Temperature Since 850 AD



Still no equal. Temperature records recovered from tree rings and other proxies broadly agree that no time in the past millennium has been as warm as recent decades (black).

***Science*, 10 February 2005**

Modelled and Observed Temperature Rise Since 1860



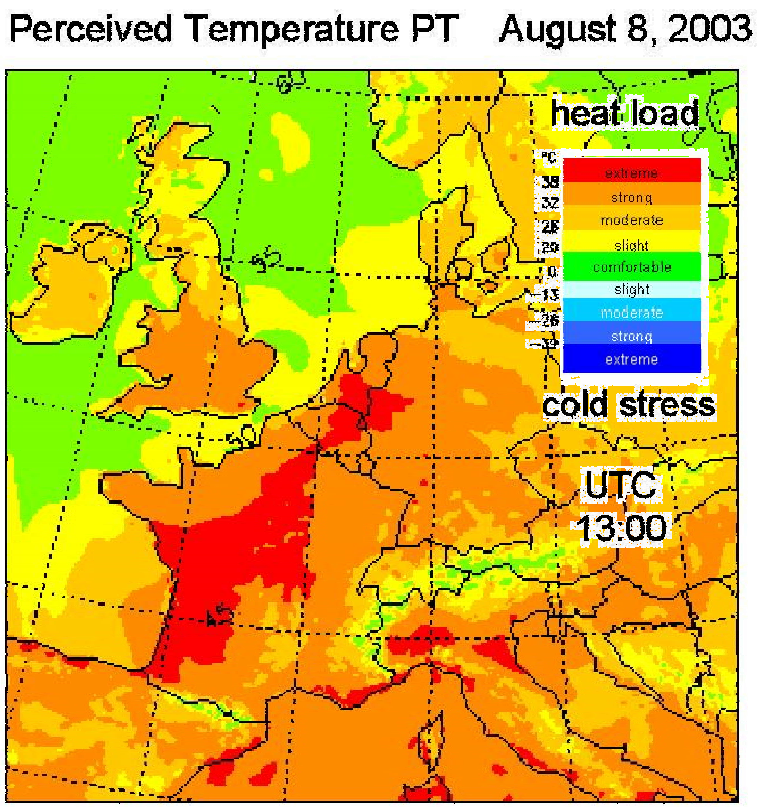
Source: IPCC

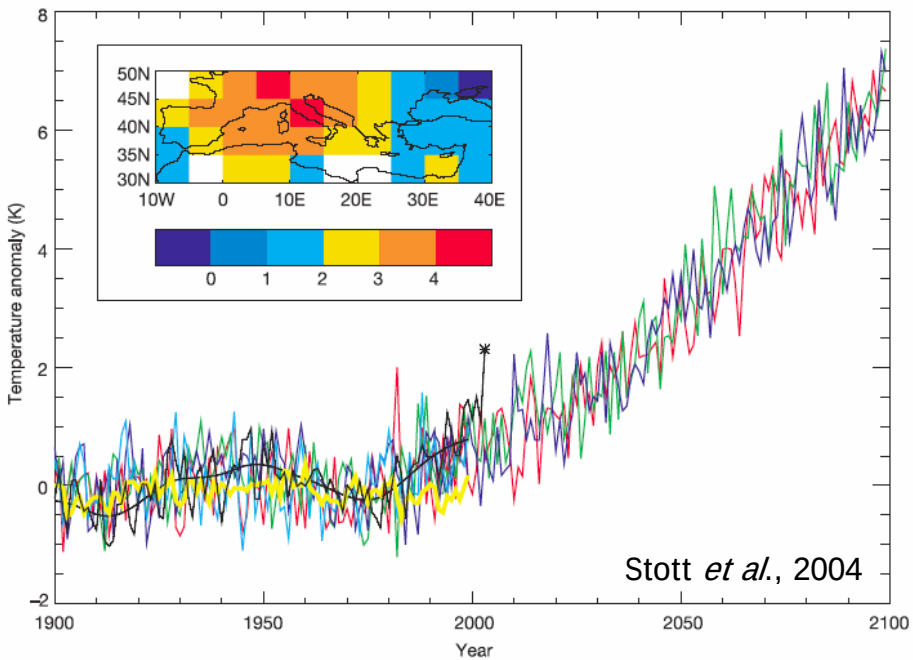
Extreme Events

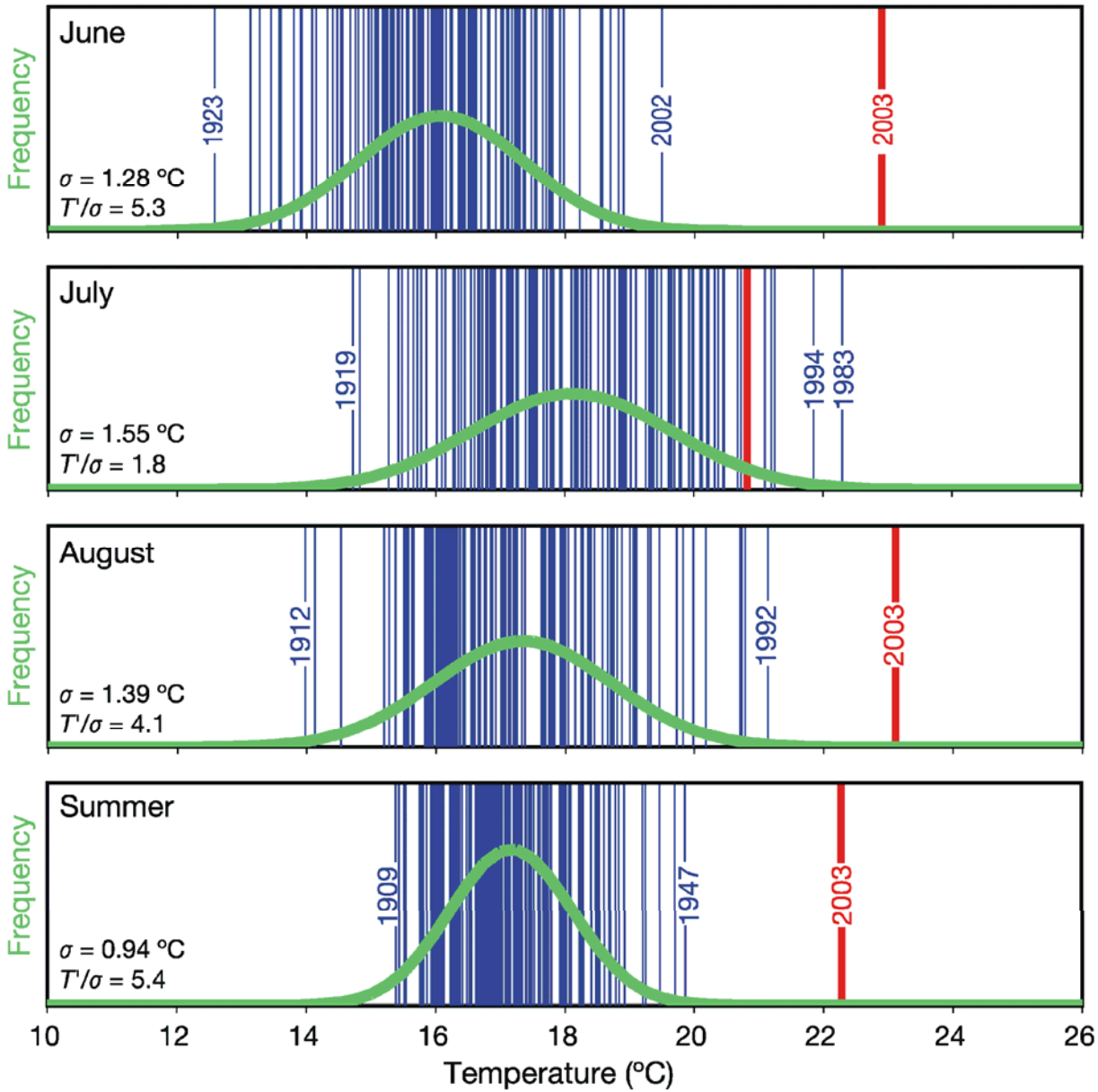
2003 European Heatwave

"Very likely (confidence level > 90%) that human influence has at least doubled the risk of a heatwave exceeding this threshold magnitude"

Stott *et al.*, Nature, 2004







Distribution of
Swiss Monthly and
Seasonal Temperatures
1864-2003

Source: Schär et al. 2004

Arctic Warming

Arctic warming twice as fast as rest of world according to Arctic Climate Impact Assessment

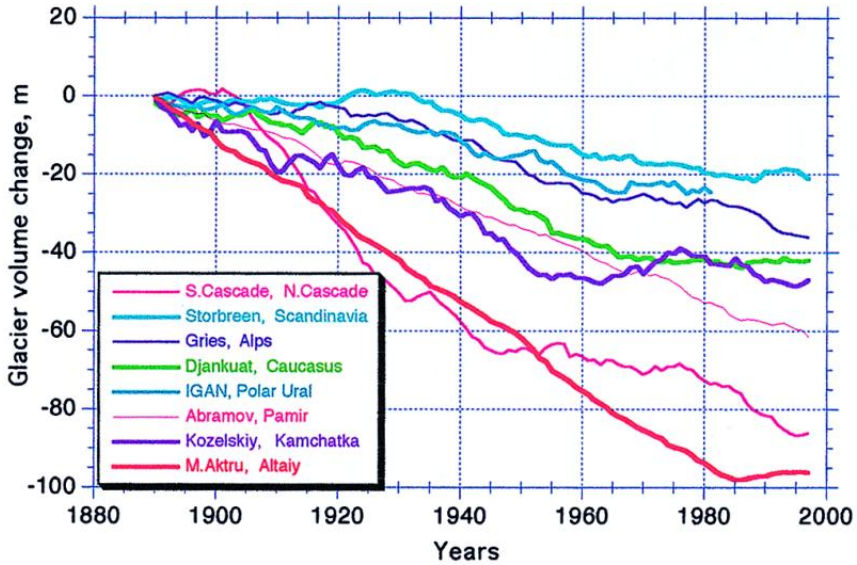
Sea Ice

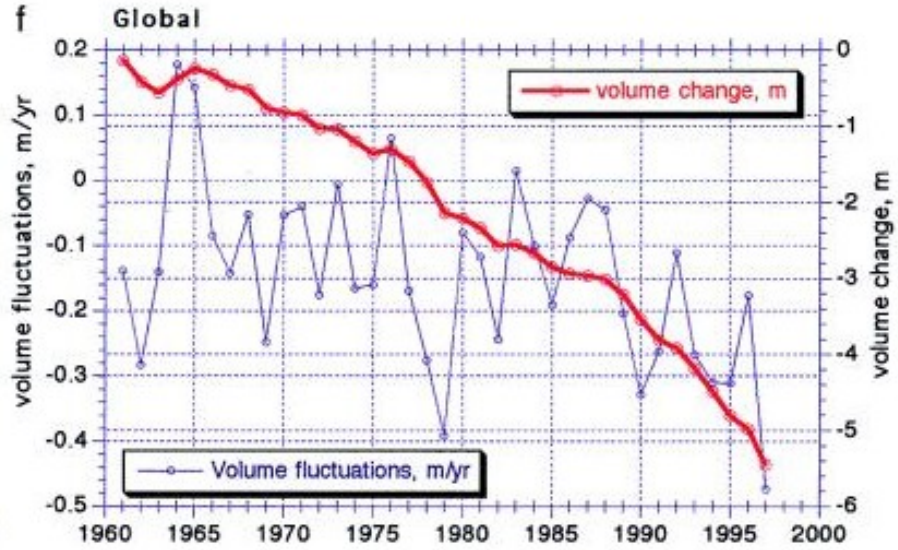
- 7.4% decrease in past 25 yrs
- Minimum in Sep 2002
- Almost ice-free by 2100

Alaska

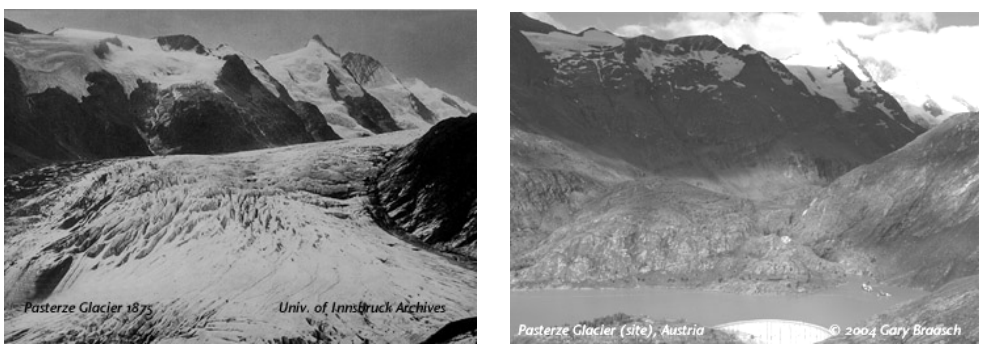
- Winter warming of 2-3°C in past 30 years
- 2003 - greatest recorded summer sea-ice melt
- Sea-ice retreat exposes coasts to erosion
- Melting permafrost threatens built infrastructure

Glacial Retreat

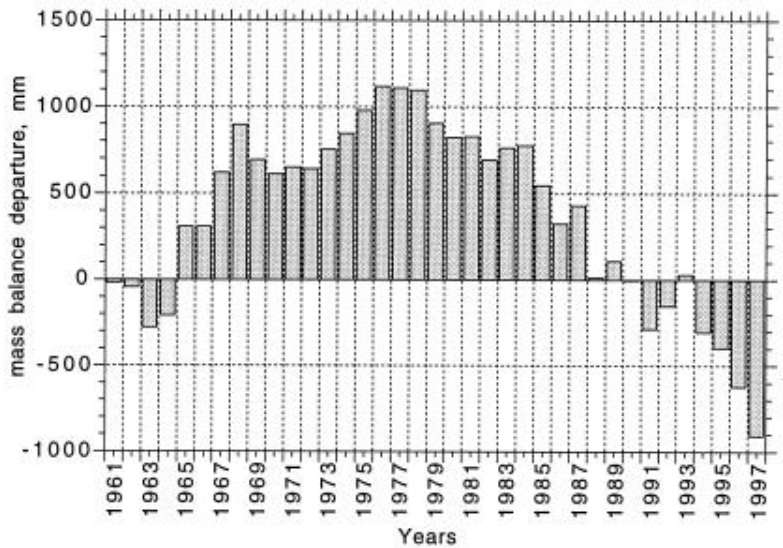




Graphics from Dyurgerov & Meier, PNAS, 2000



Pasterze Glacier, Austria, 1875 (left), 2004 (right)

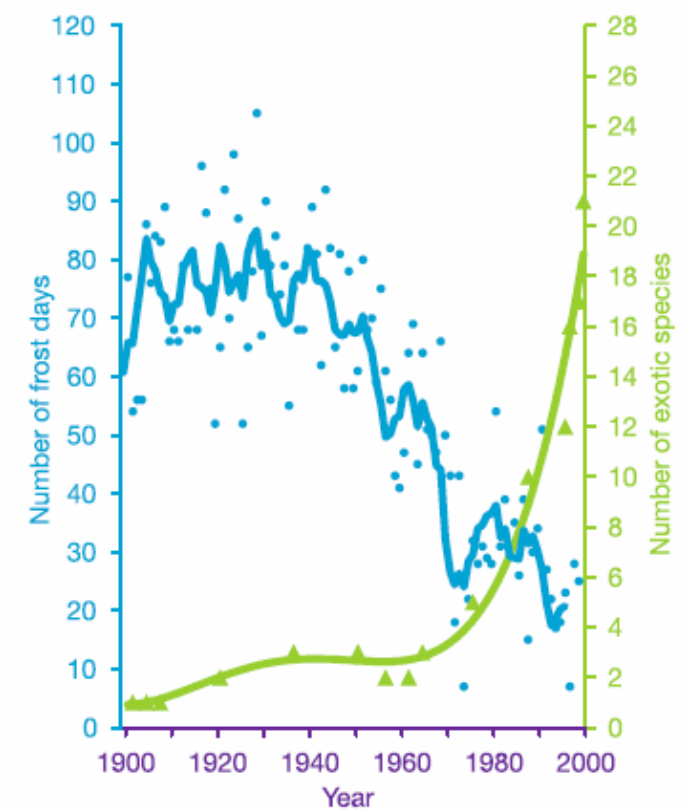


Cumulative departures of globally averaged annual glacier mass balances relative to 1961–1990 baseline

Phenology

"Although we are only at an early stage of the projected trends of global warming, ecological responses to recent climate change are already clearly visible." Walther *et al.*, Nature, 2002.

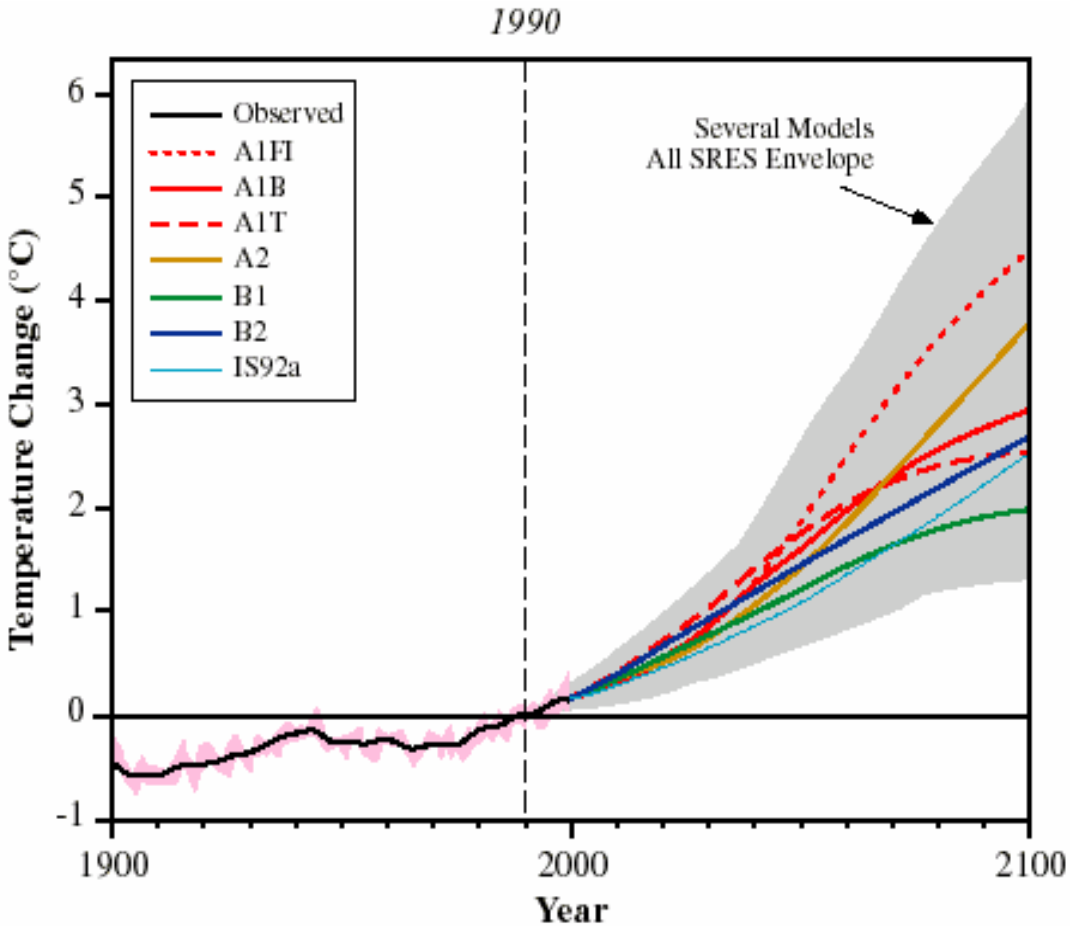
- Northward shift 22 out of 35 species of non-migratory European butterfly
  (Parmesan *et al.*, Nature 1999)
- Spring events in Europe advanced by 6 days, autumn delayed by ~5 days
  (Menzel & Fabian, Nature, 1999)
- Recent biological trends match climate change predictions
  (Parmesan & Yohe, Nature, 2003)

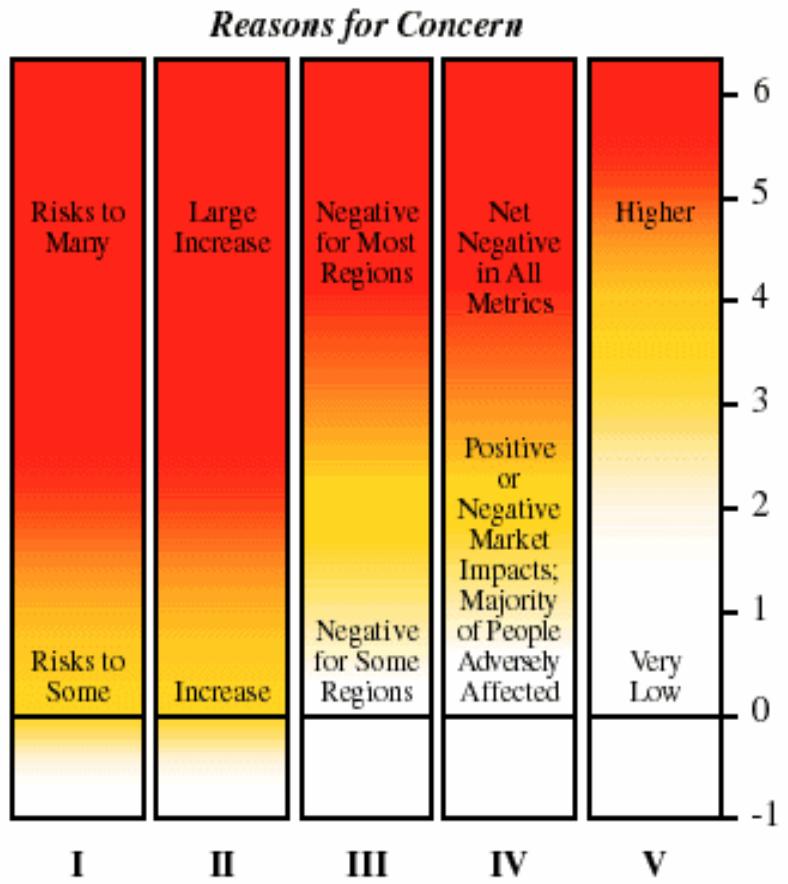


Vegetation shift, S. Switzerland

(from Walther *et al.*, 2002)

PART II: THE PROGNOSIS



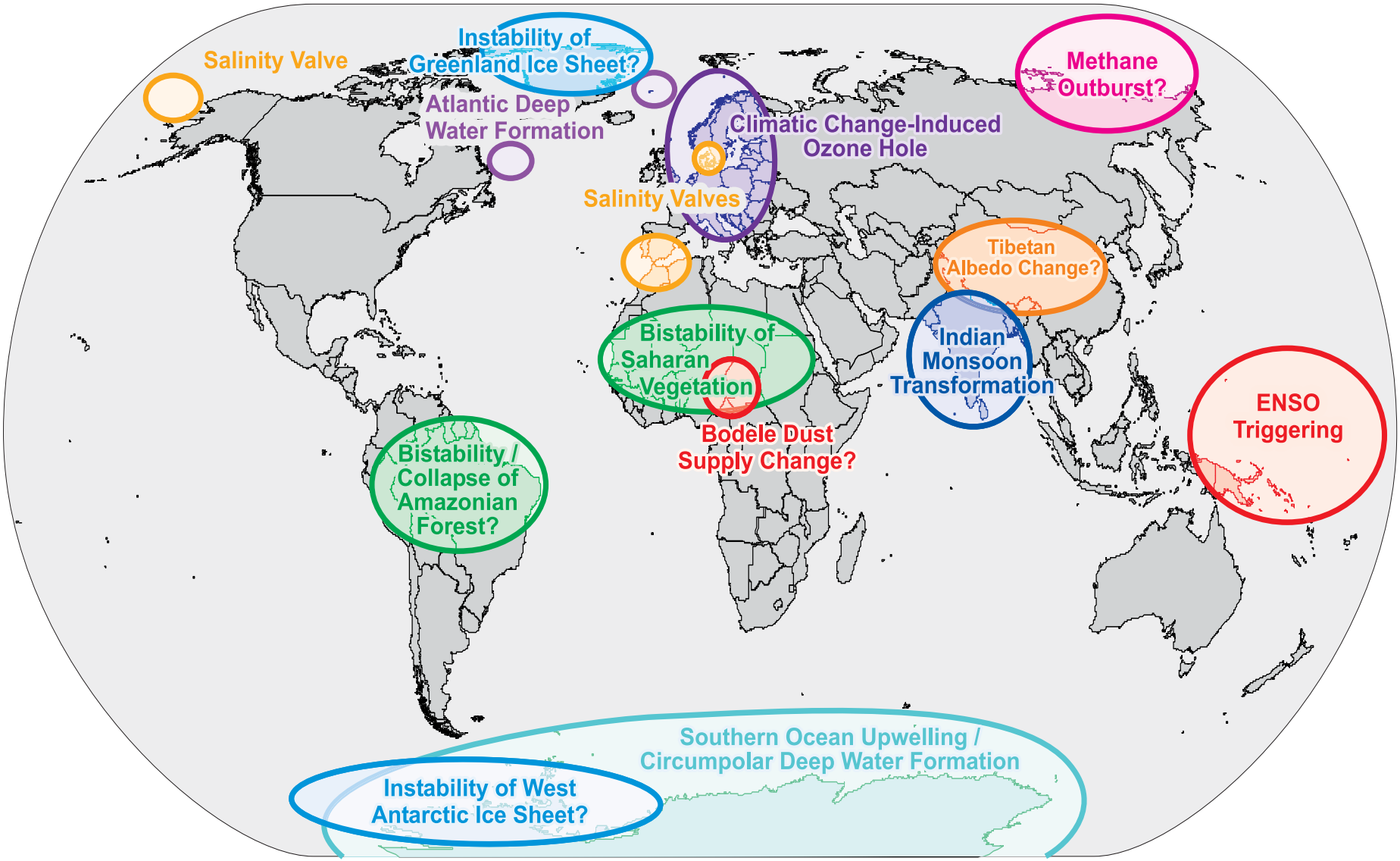


I	Risks to Unique and Threatened Systems
II	Risks from Extreme Climate Events
III	Distribution of Impacts
IV	Aggregate Impacts
V	Risks from Future Large-Scale Discontinuities

PIK

Tyndall Centre for Climate Change Research

The Planet's Achilles Heels



AVOIDING DANGEROUS CLIMATE CHANGE

1-3 February 2005 Met Office, Exeter, UK

International Symposium on Stabilisation of Greenhouse Gases

Met Office, Exeter
United Kingdom

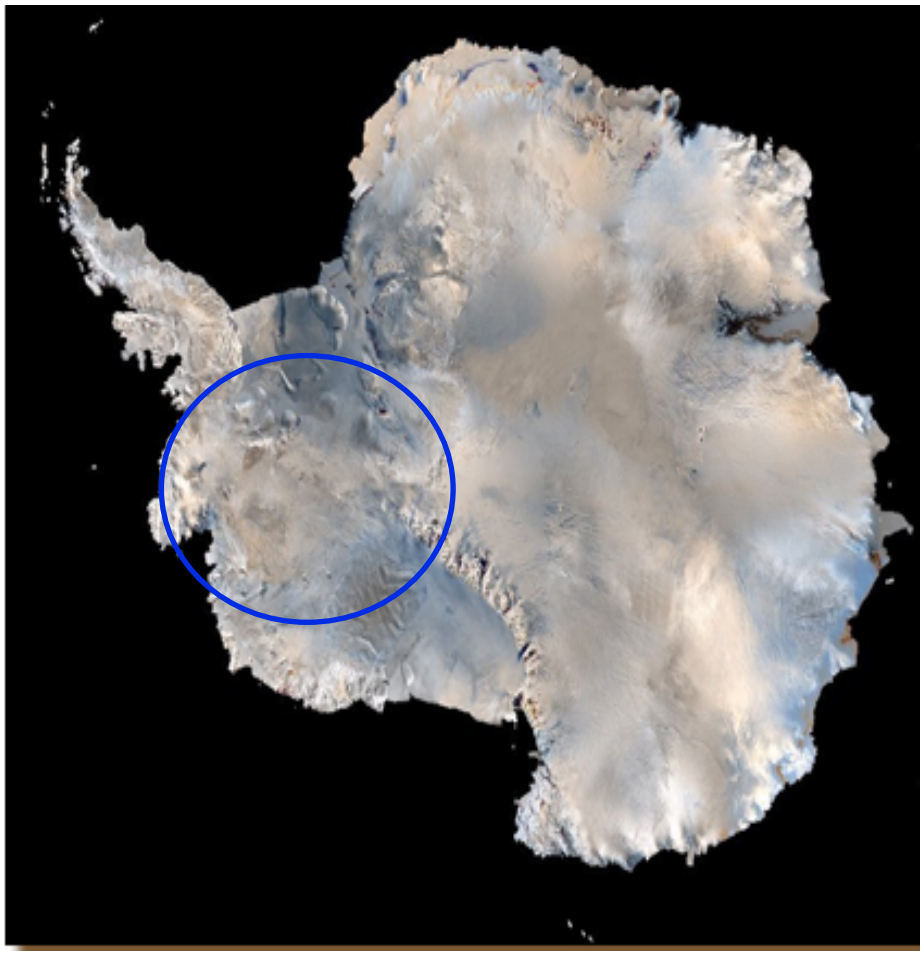
1 – 3 February 2005

Abstracts of Symposium Papers

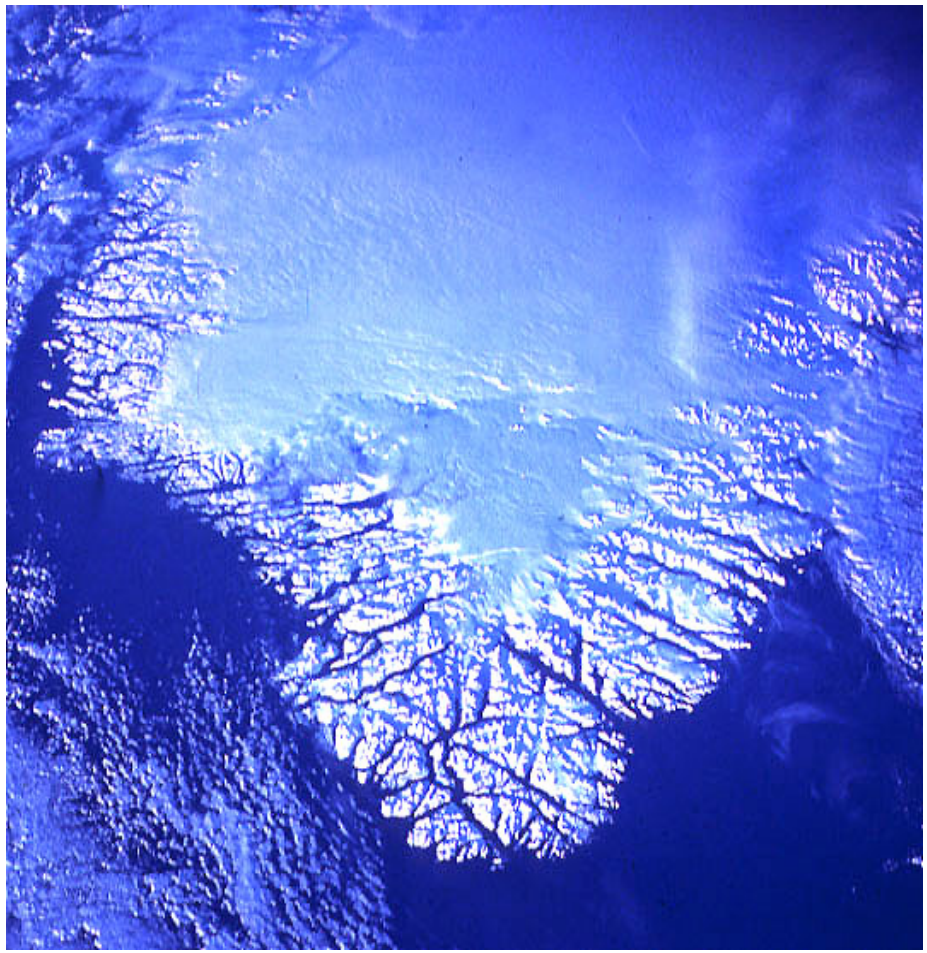
Scientific Steeering Committe

Dennis Tirpak (chair), OECD, France
John Ashton, E3G, UK
Zhou Dadi, Beijing Energy Efficiency Centre, China
Luiz Gylvan Meira Filho, University of São Paulo, Brazil
Bert Metz, RIVM, Netherlands
Martin Parry, Hadley Centre, Met Office, UK
John Schellnhuber, Tyndall Centre for Climatic Research, UK
K S Yap, Malaysian Meteorological Service, Malaysia
Robert Watson, World Bank, USA
Tom Wigley, National Centre for Atmospheric Research, Colorado

This event is sponsored by the UK Department of Environment, Food and Rural Affairs (DEFRA)



West Antarctic Ice Sheet

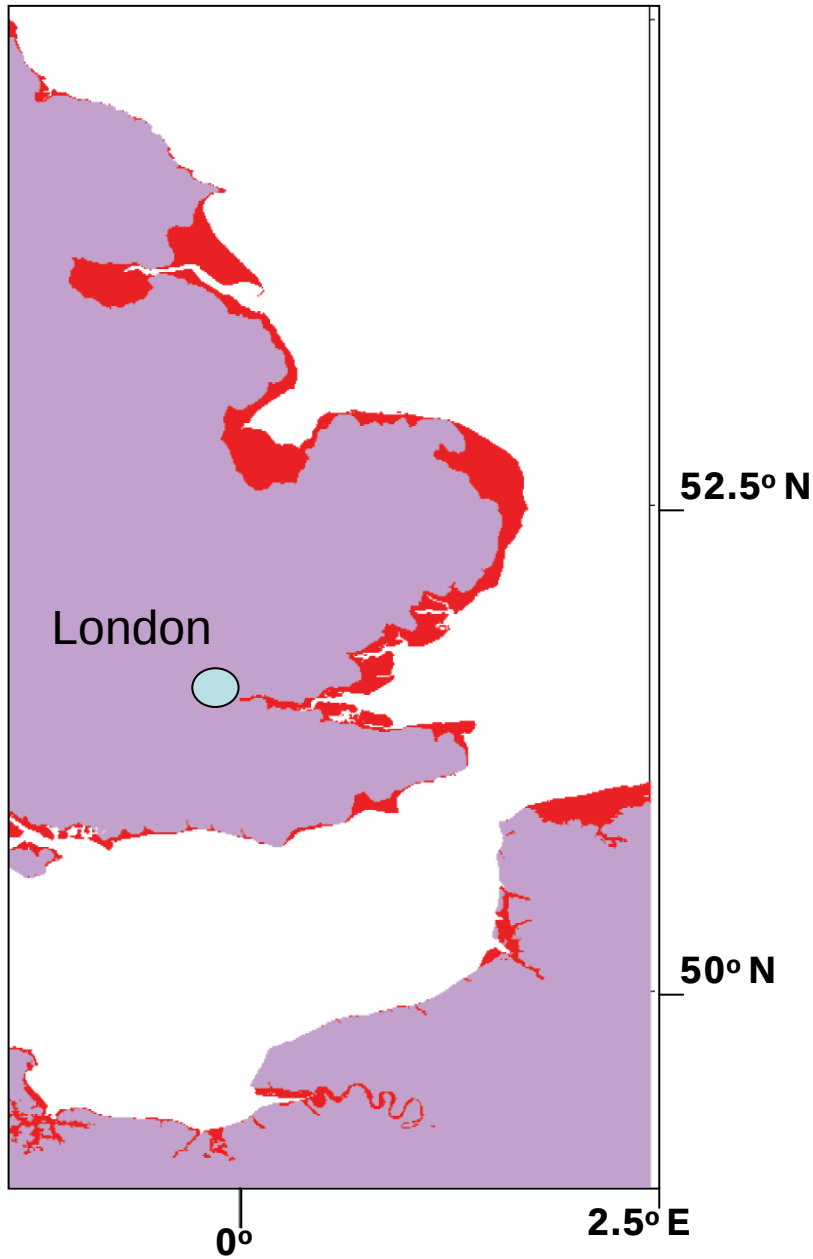


Greenland Ice Sheet

PIK

Tyndall Centre
for Climate Change Research

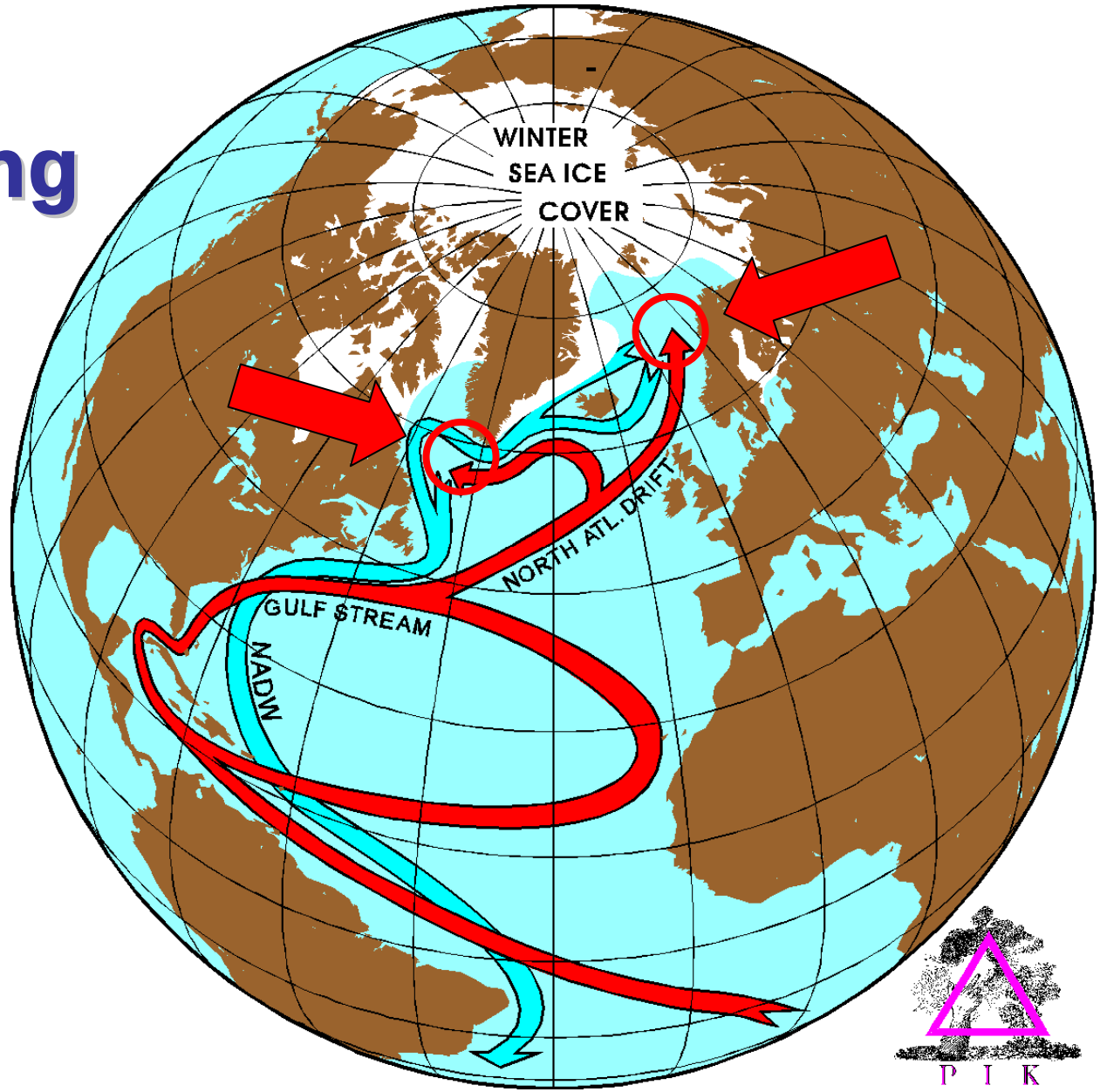
The coastline of south-eastern UK, assuming **6m of sea level rise** in the wake of **Greenland Ice Sheet melting**



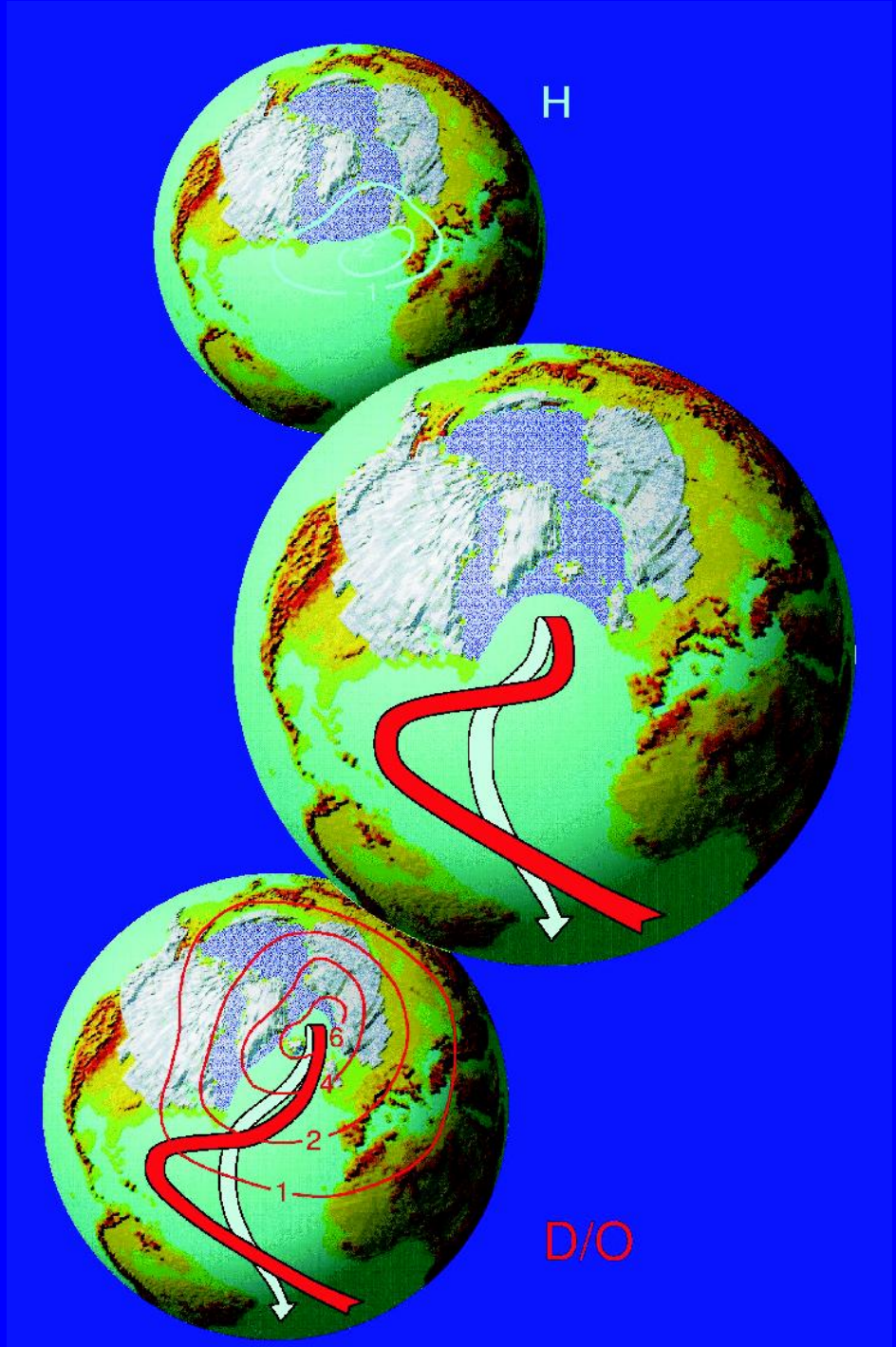
PIK

Tyndall Centre for Climate Change Research

Europe's Free Heating System



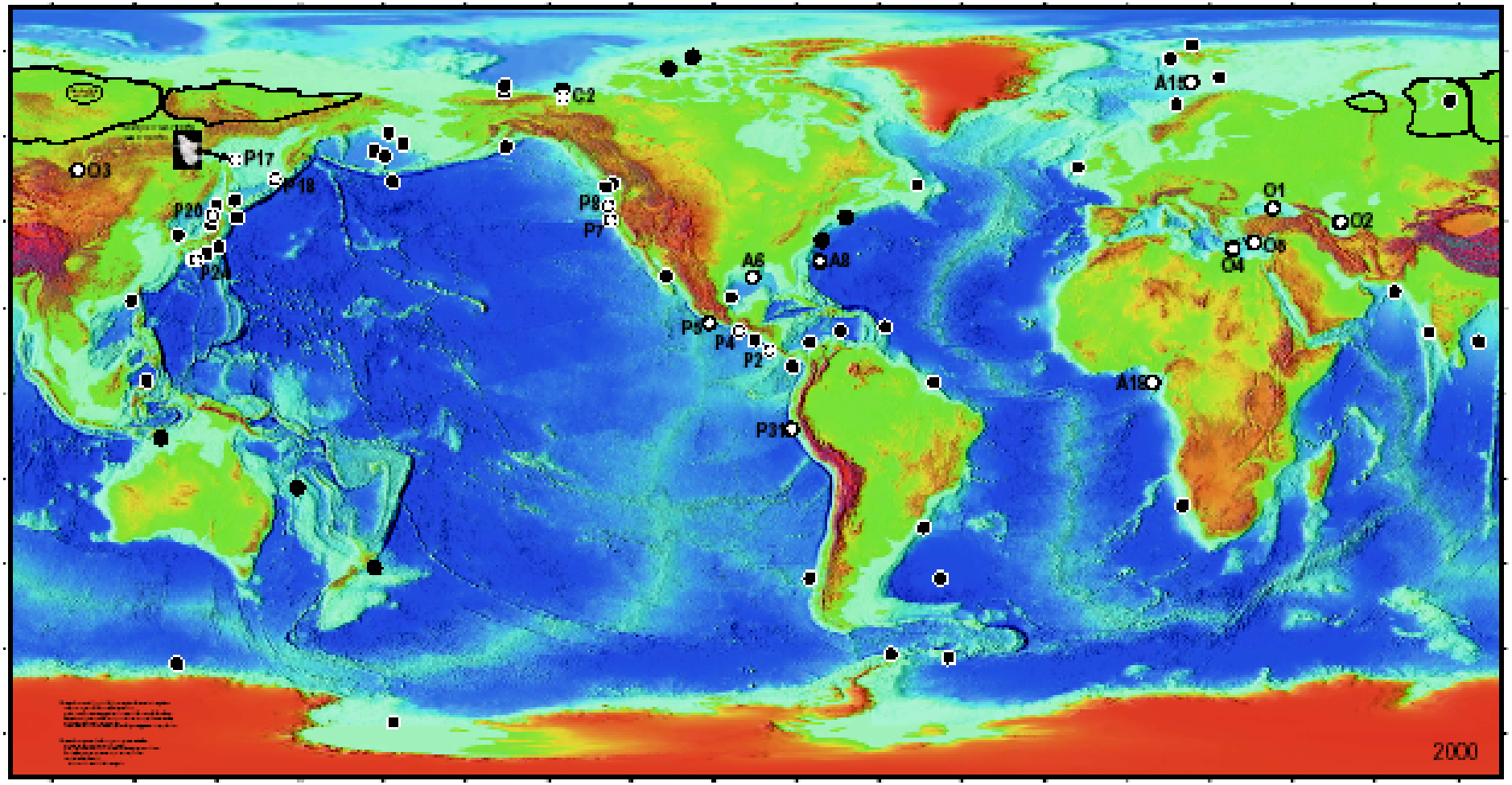
PIK



Modes of the North Atlantic Thermohaline Circulation

"Gulf-Stream"

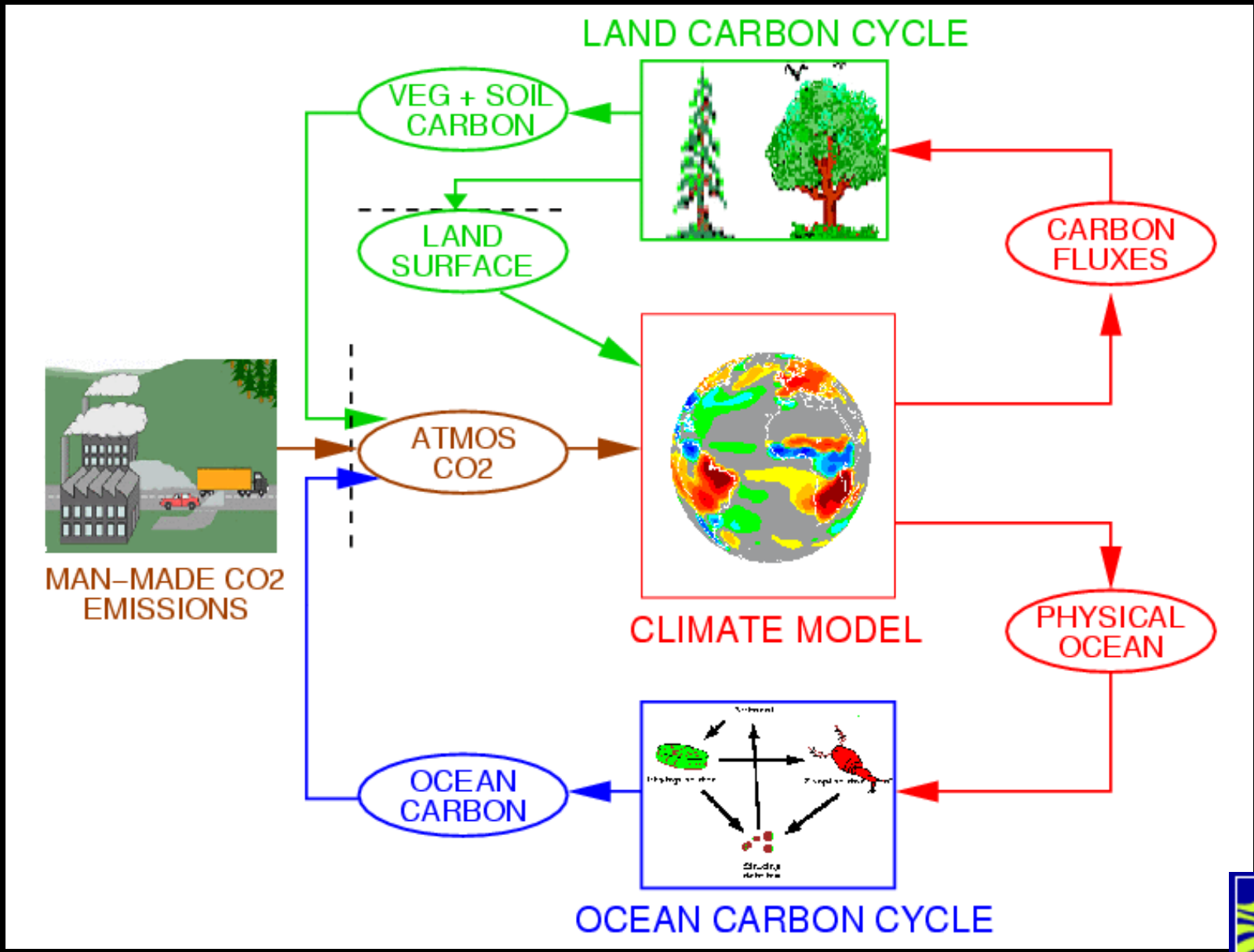
A Global Inventory of Natural Gas Hydrate Occurrence



Keith A. Kvenvolden and Thomas D. Lorenson

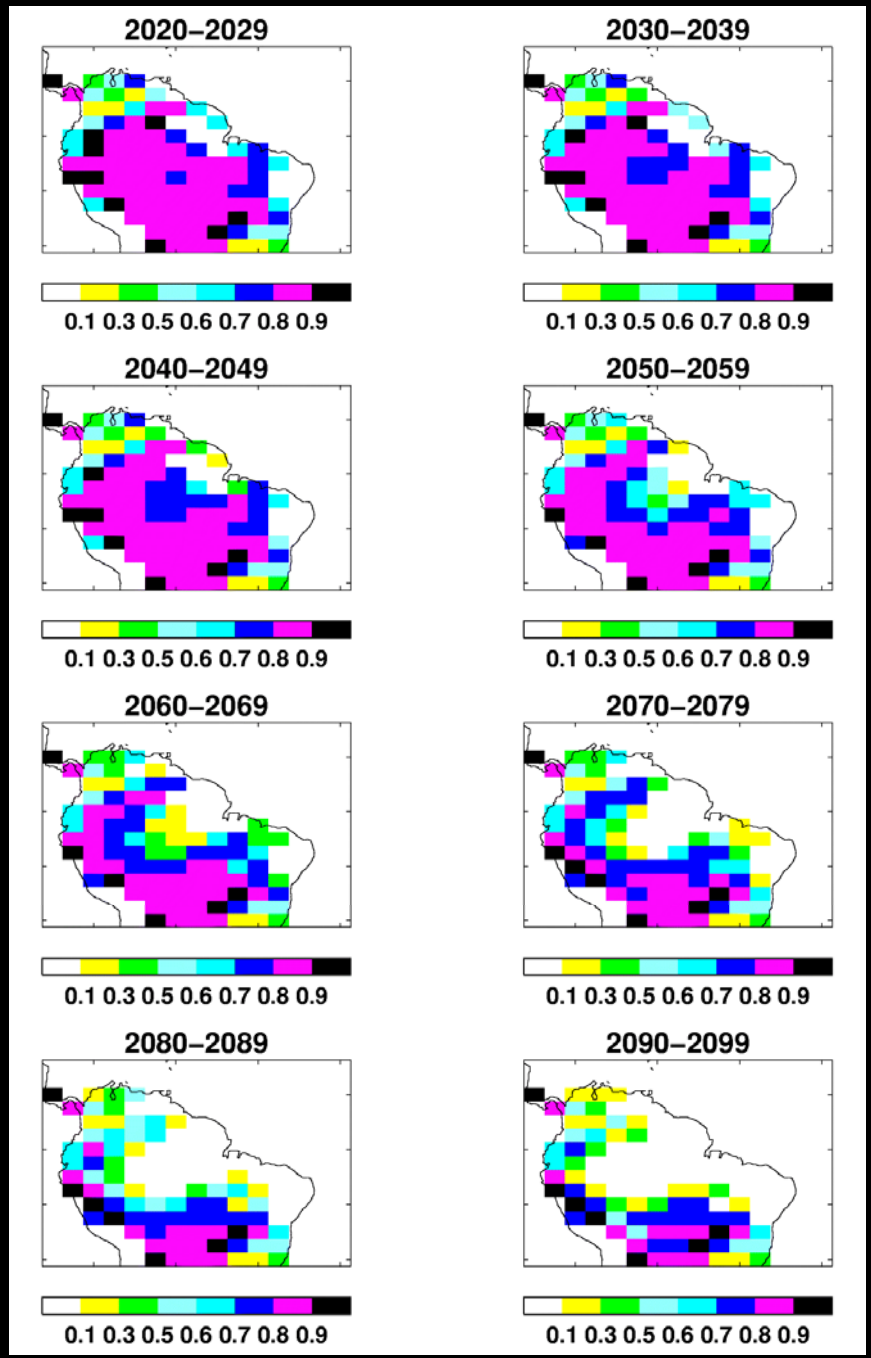
USGS, 2001. More information: http://walrus.wr.usgs.gov/globalhydrate/

Hadley Centre Coupled Climate-Carbon Cycle Model



Met Office

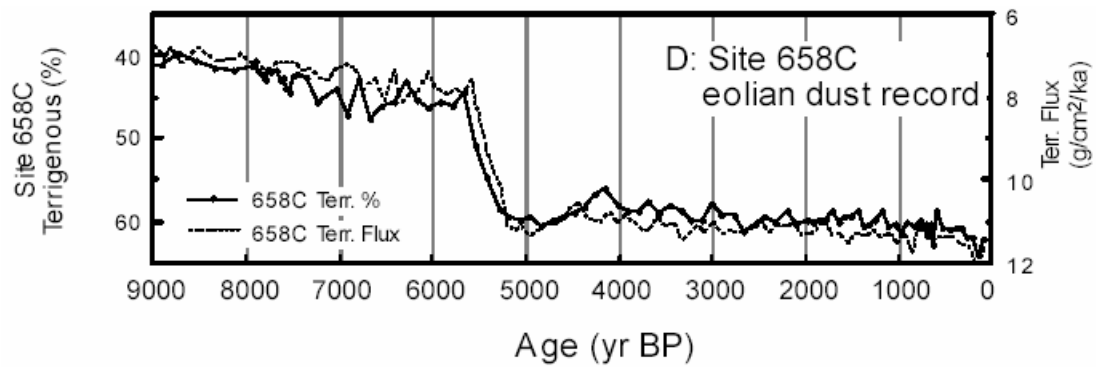
Broadleaf tree cover (gridbox fraction) in coupled climate-carbon cycle simulation



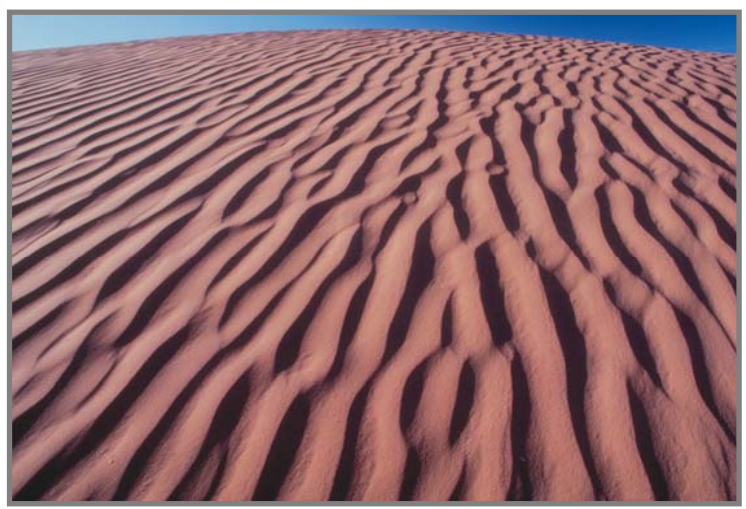
Met Office

Will Greenhouse Green the Sahara?

(N. Petit-Maire, 1990)

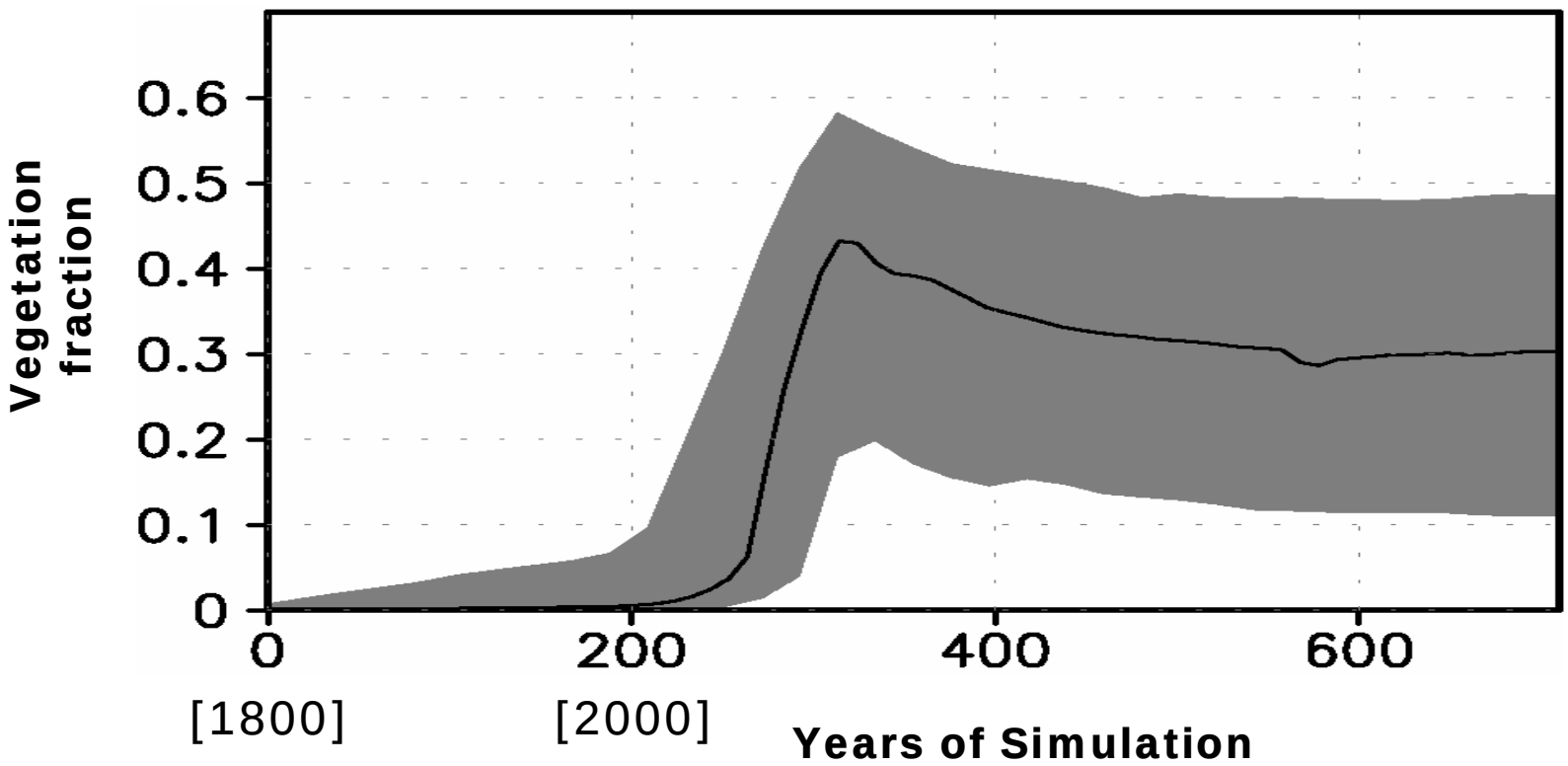


deMenocal et al., 2000

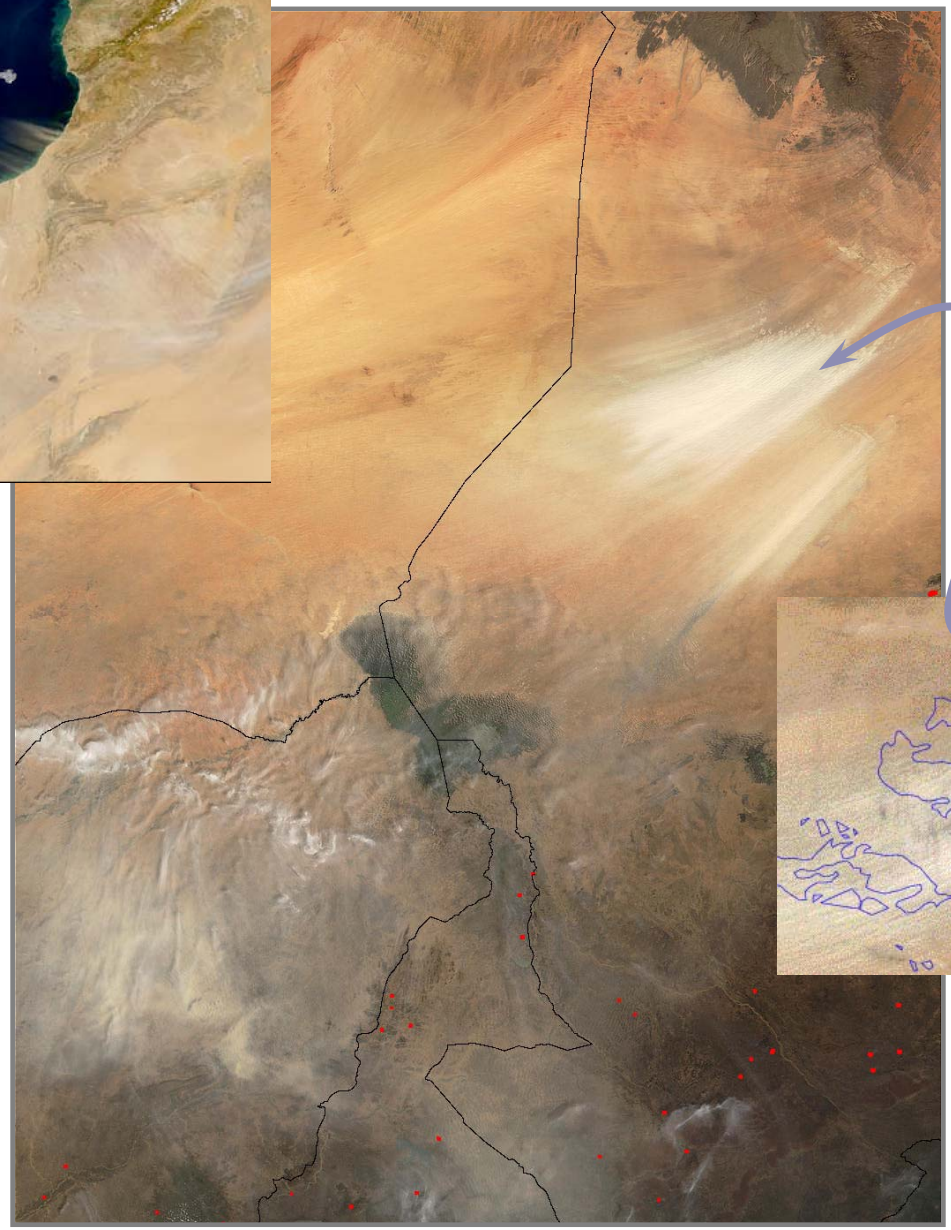


Changes in Potential Vegetation Cover in the Sahara

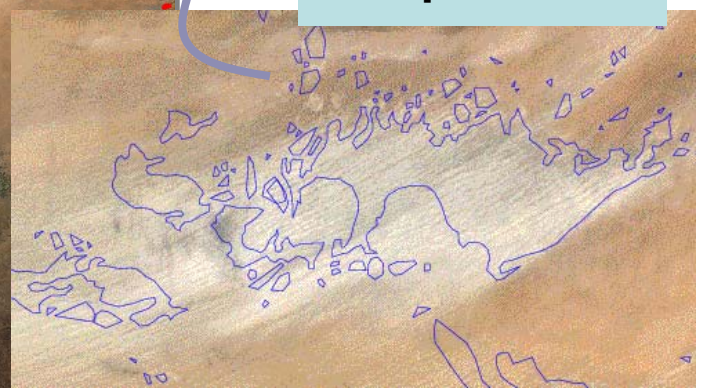
Transient CO_2 scenario (1%, 1000 ppm)



Claussen et al., 2003



The location of dry lakes in the Bodele Depression



PIK

Tyndall Centre for Climate Change Research

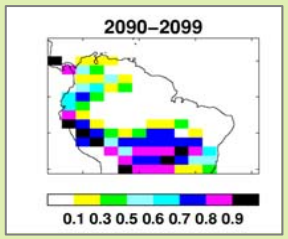
Dust Storm - Bodele Depression, Chad

Thanks to Joseph M. Prospero
RSMAS, Univ. of Miami

(+)

Reduced Dust Export

Amazon Forest Die-Back



Regional Climate Change

(+)

Regional Climate Change

(+)

Re-Greening of Sahara

(-)

(+)

Additional Carbon Release

Anthropogenic Global Warming

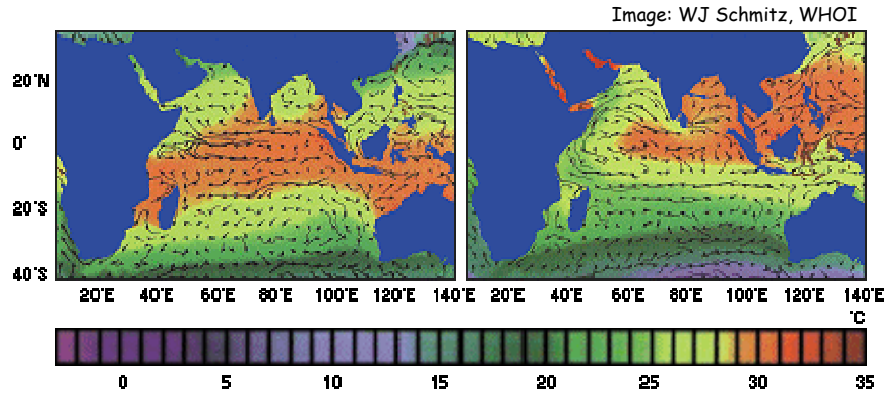
Land Surface Disturbance

(+)

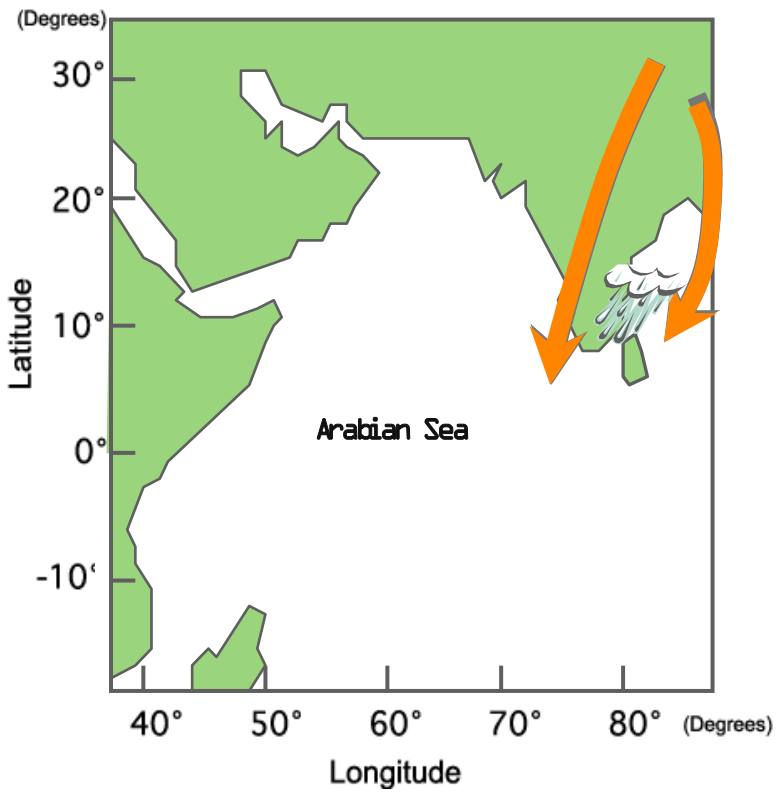
Additional GHG Emissions

Lifestyle & Recreation Change

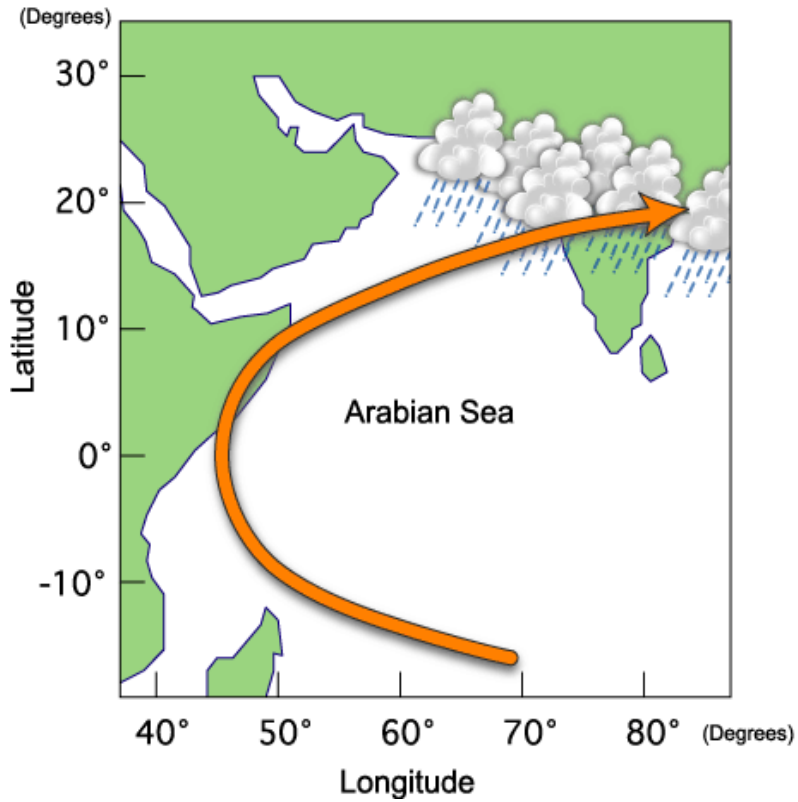
Global Change Synergism



Northeasterly Winter Monsoon



Southwesterly Summer Monsoon



Reduced-form model of the Indian monsoon

- Energy balance:

$$\int_0^{H_a} c_p \rho \frac{\partial \theta}{\partial t} dz + h_s c_s \frac{\partial T_a}{\partial t} = L(C - E) + F_S \left(1 - A_{sys}\right) - F_{LW} + A_T$$

- Water vapour balance:

$$\int_0^{H_a} \rho \frac{\partial q}{\partial t} dz = E - C + A_q$$

- Soil moisture balance:

$$\frac{\partial w_1}{\partial t} = \frac{P - E - R}{f_1} - \frac{w_1 - w_2}{\tau}, \qquad \frac{\partial w_2}{\partial t} = \frac{f_1}{f_2} \frac{w_1 - w_2}{\tau}$$

Reduced-form model of the Indian monsoon

- Condensation, for instance, is described as:

$$C = P = \frac{N}{\tau_p}\int_0^{H_t} \rho q dz$$

- Advection of heat is given by:

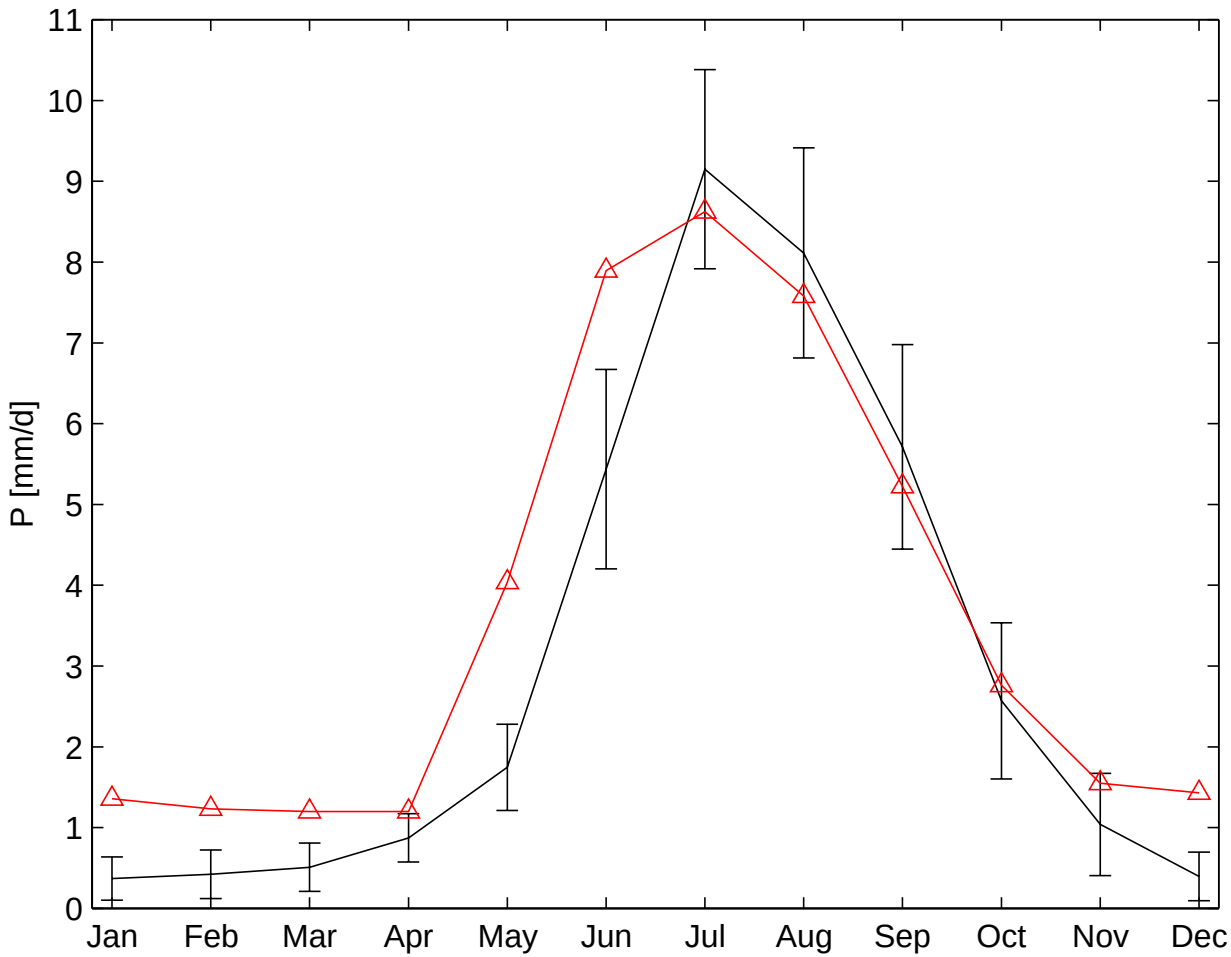
$$A_T = \frac{c_p L}{S}\sum_i \left[u_{m,i}^0 \int_0^{h_m} \rho\theta(T_i)dz + u_{m,i}^1 \int_{h_m}^{H_t} \rho\theta(T_a)dz \right]$$

- where

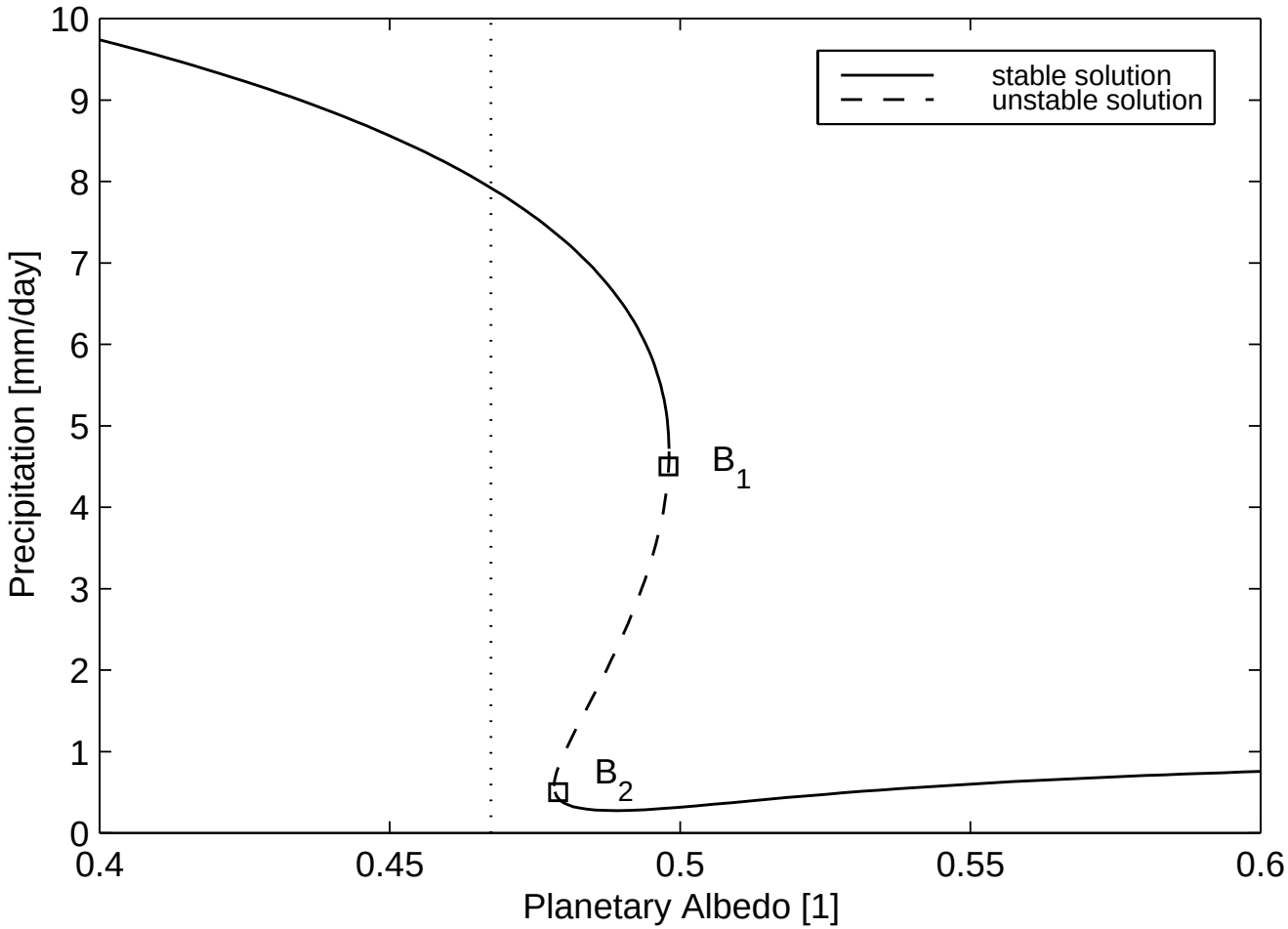
$$u_{m,i}^0 = \frac{\sin(\alpha_o)}{\rho_0 f}\nabla p_i = \frac{\sin(\alpha_0) g p_0 H_t}{\rho_0 f 2RT_0^2 \Delta L}(T_a - T_i)$$

$$u_{m,i}^0 \int_0^{h_m} \rho dz = u_{m,i}^1 \int_{h_m}^{H_t} \rho dz$$

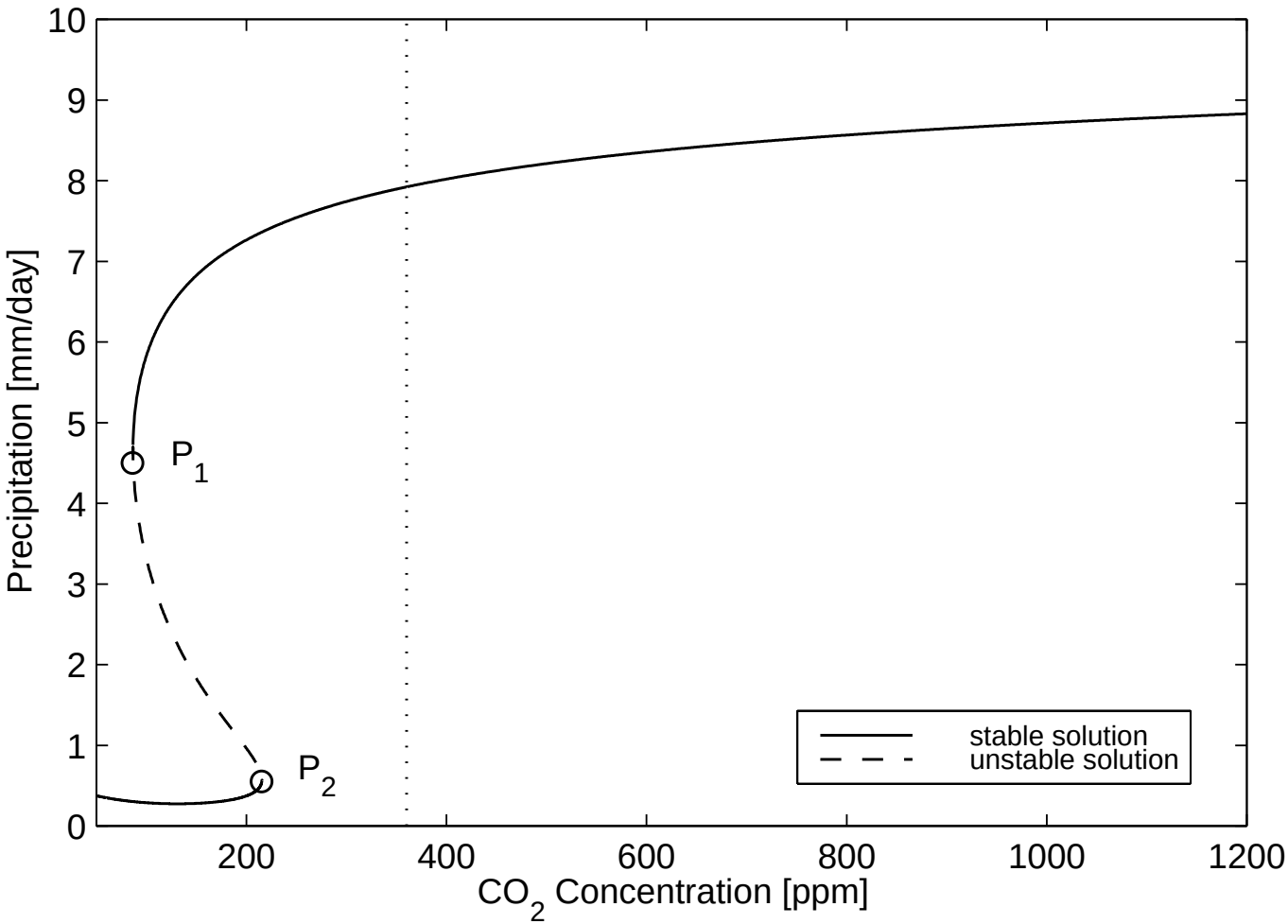
Seasonal distribution of monsoon rainfall



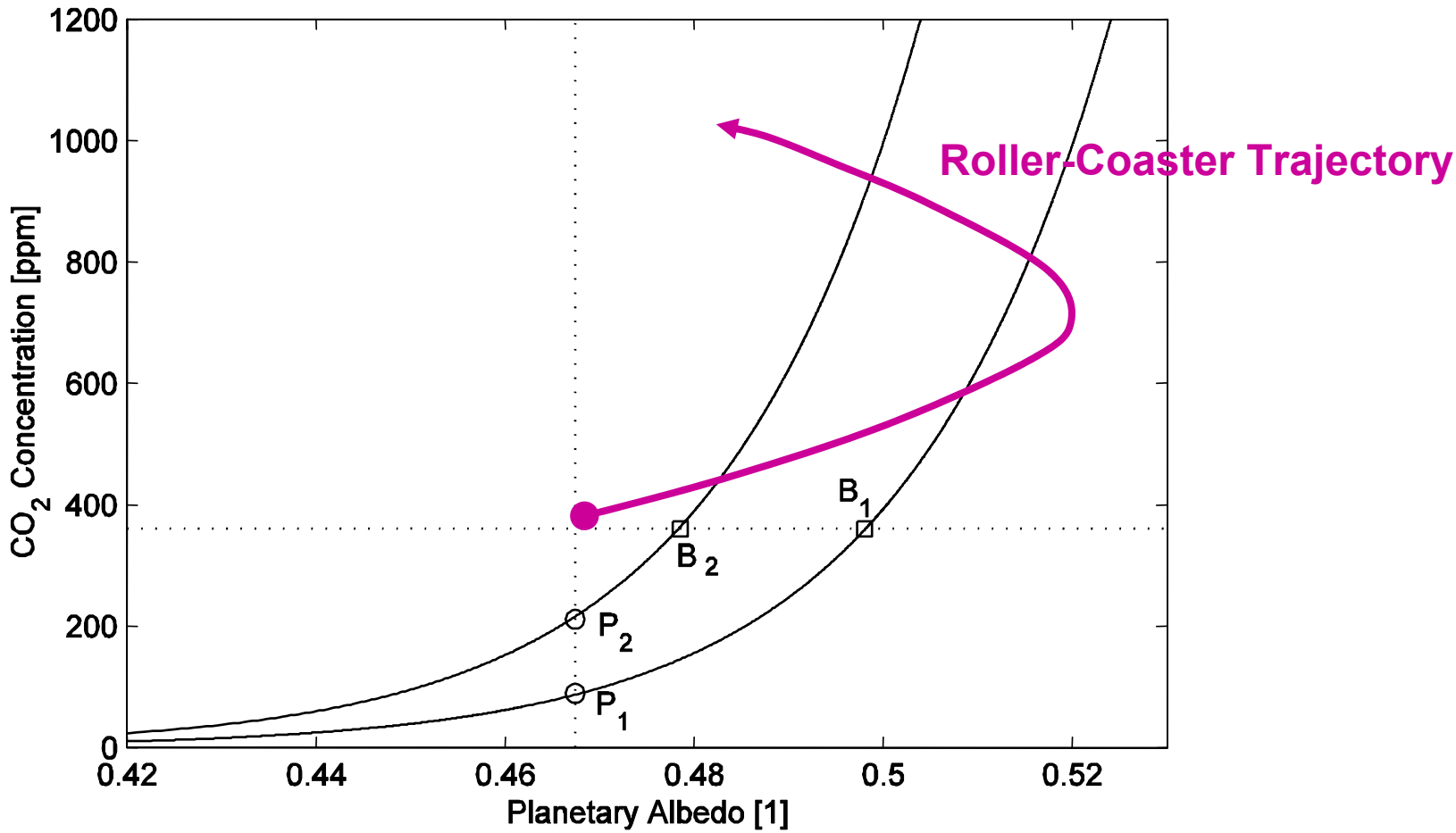
Planetary albedo influences monsoon



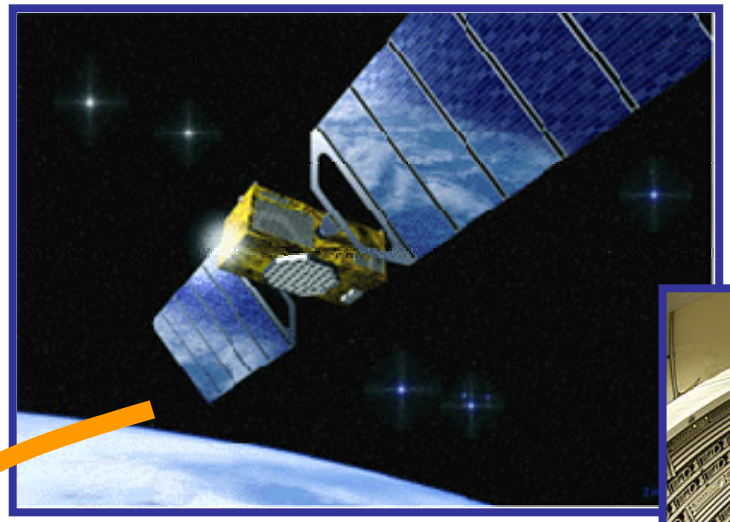
CO_2 concentration influences monsoon



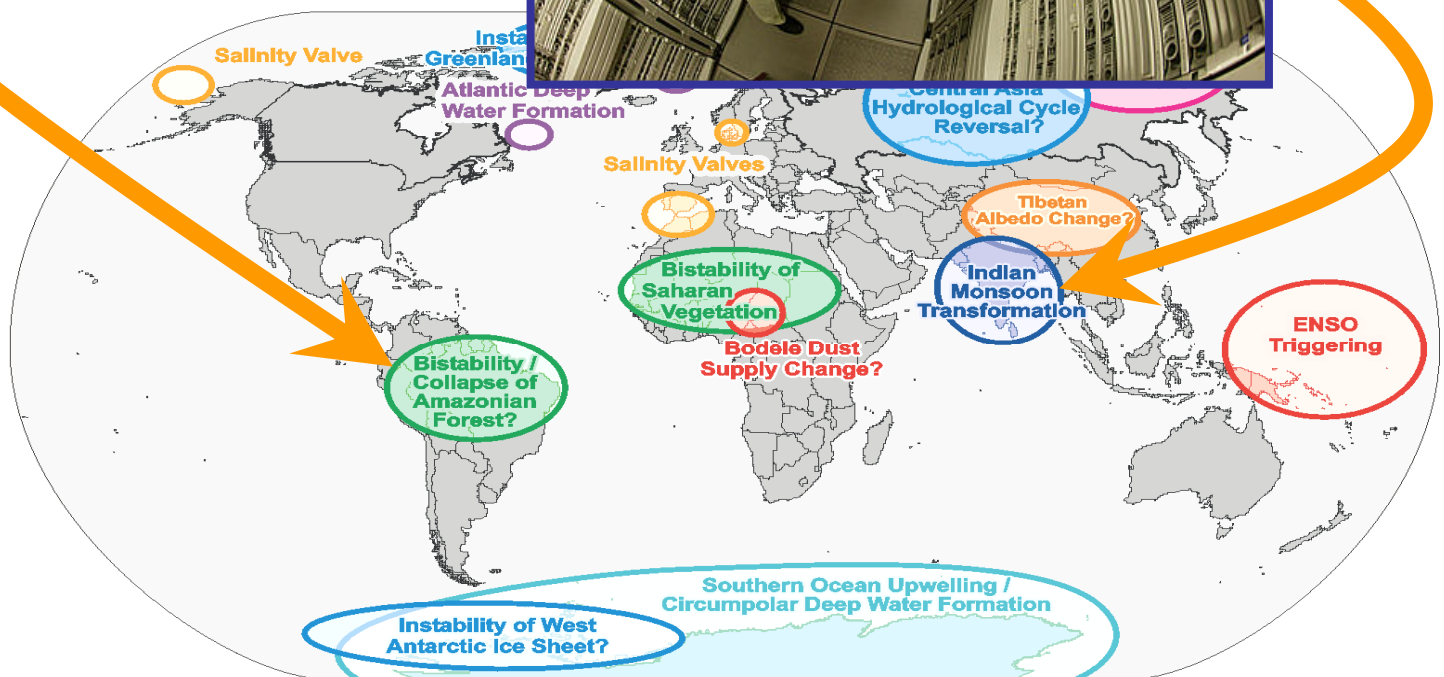
Worst Case Scenario for Monsoon Development



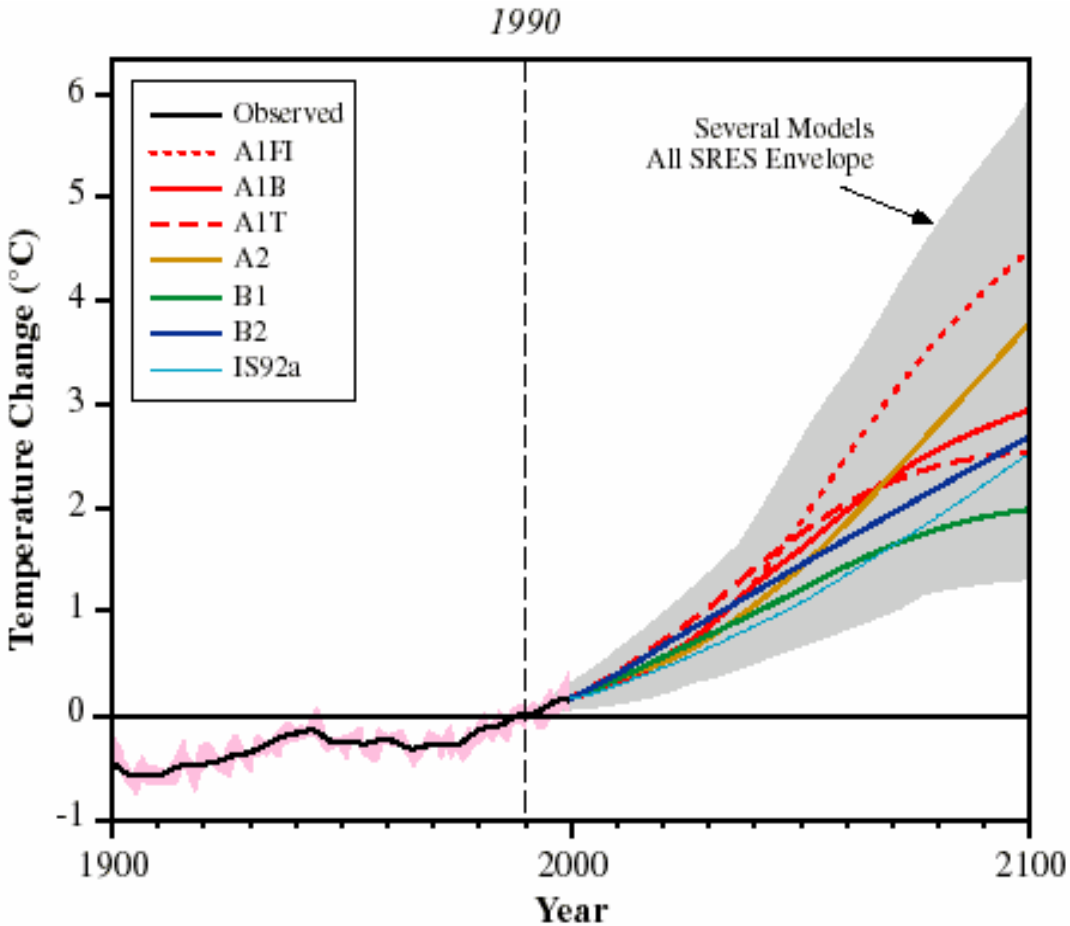
Switch Watch

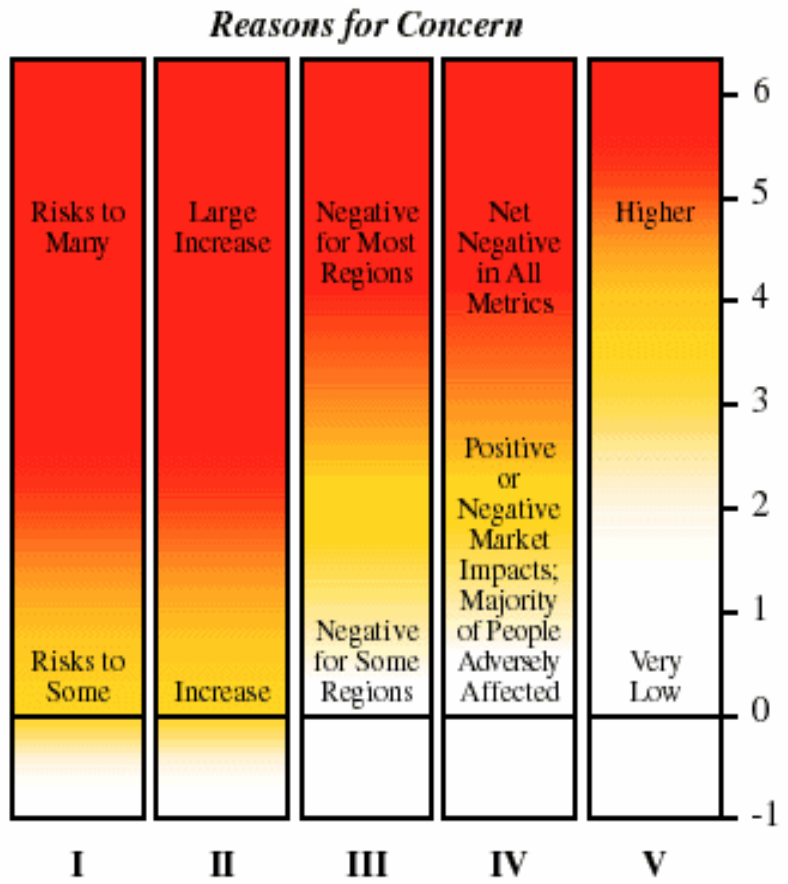


- Earth Observation
- Earth System Modelling



Satellite image from www.laas.fr/DISCO/ DISCO-Diag.html
Supercomputer photo courtesy of Pacific Northwest National Laboratory





I	Risks to Unique and Threatened Systems
II	Risks from Extreme Climate Events
III	Distribution of Impacts
IV	Aggregate Impacts
V	Risks from Future Large-Scale Discontinuities

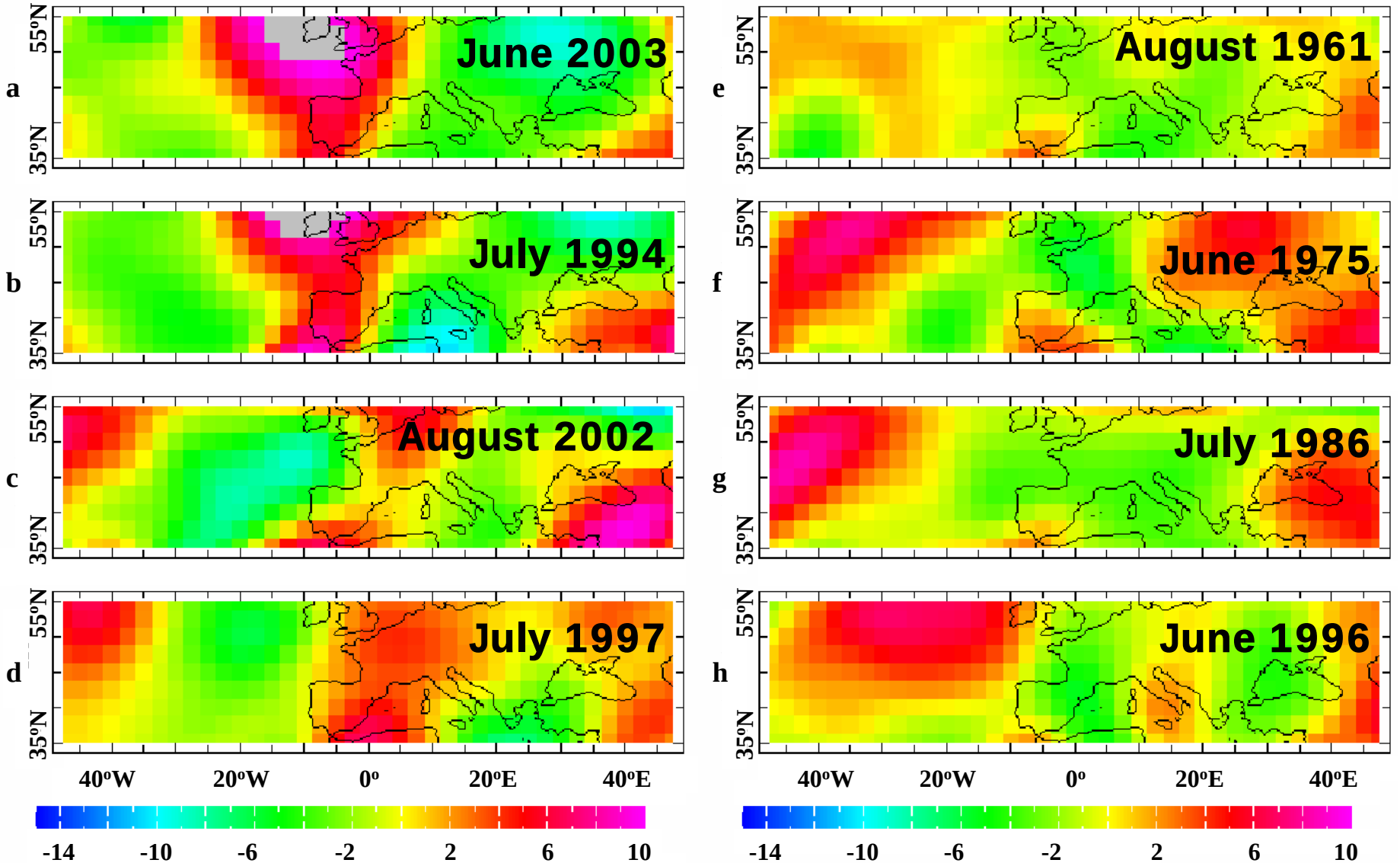
PIK

Tyndall Centre for Climate Change Research

Recent Extreme Weather Events in Europe

2002 Floods

2003 Heatwave



Meridional wind [m/s] at 500 mb

Fig.1

Petukhov, Rahmstorf, Schellnhuber & Oesterle (2004): submitted to *Nature*

Atmospheric wave resonance as a possible mechanism for the recent extreme weather events in Europe

V. Petoukhov*, S. Rahmstorf*, H.-J. Schellnhuber*† & H. Österle*

**Potsdam Institute for Climate Impact Research, Box 601203, 14412 Potsdam, Germany*

†*Tyndall Centre for Climate Change Research, UEA, Norwich, NR4 7TJ, UK*

In recent years Europe suffered several extreme weather events: the Odra flooding of 1997, the Elbe flooding of 2002 and the heat wave of 2003. The latter was associated with monthly mean temperatures deviating by over five standard deviations from long-term averages; this extremely unlikely event requires an explanation. Here we propose a possible mechanism for the extreme events: we show that these weather situations were associated with resonant stationary wave patterns in the atmosphere. We further argue that the likelihood for the occurrence of such resonance is increasing due to observed long-term trends in the large-scale atmospheric circulation, possibly as a result of greenhouse gas forcing.

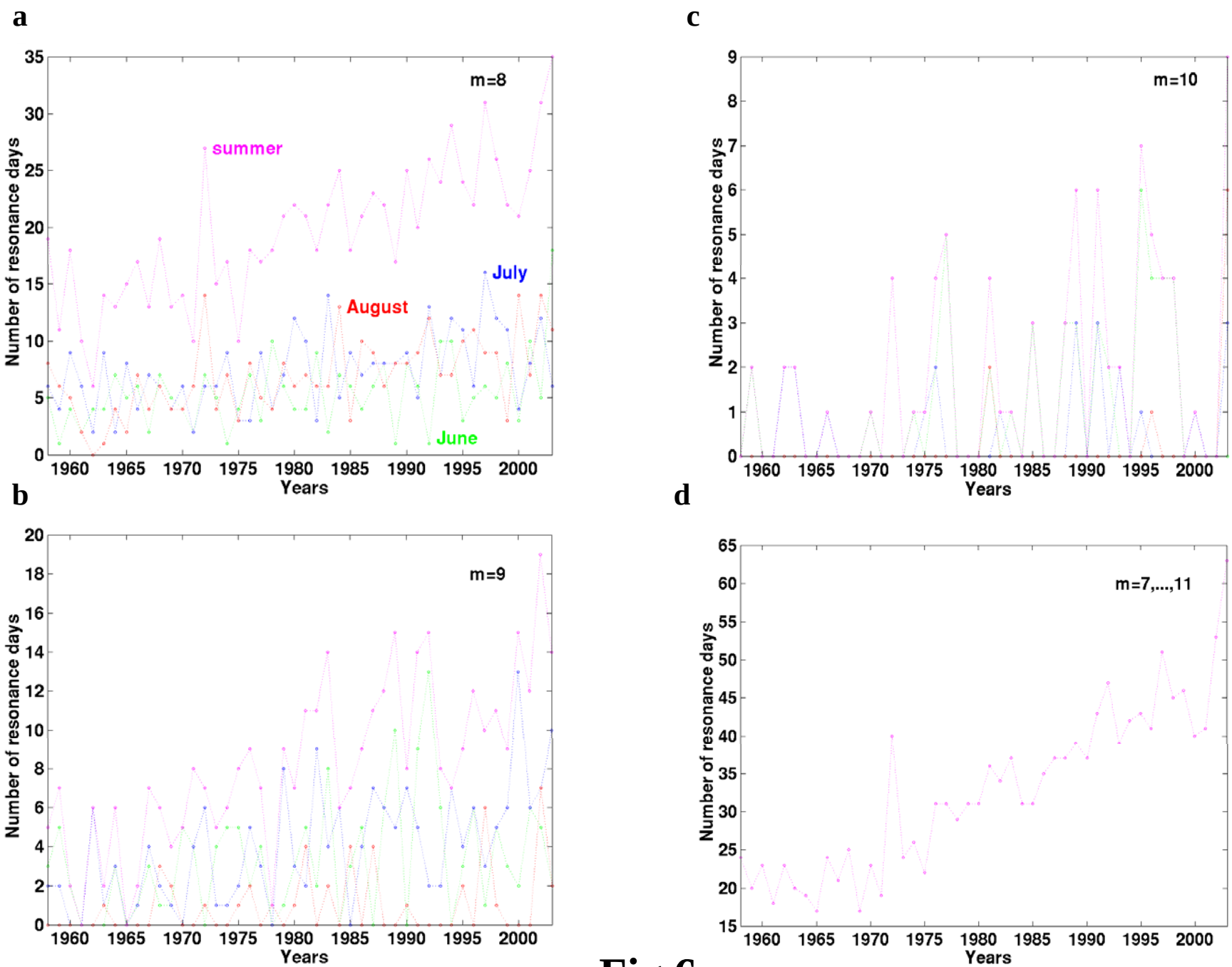

a
m=8
summer
July
August
June
Number of resonance days
Years
b
m=9
Number of resonance days
Years
c
m=10
Number of resonance days
Years
d
m=7,...,11
Number of resonance days
Years

Fig.6

PART III: THE THERAPY

Lomborg Cost Benefit Approach

Forget climate change, that's the least of our worries, say Nobel winners

Economists brought together by controversial scientist say money would be better spent on Aids, water and free trade

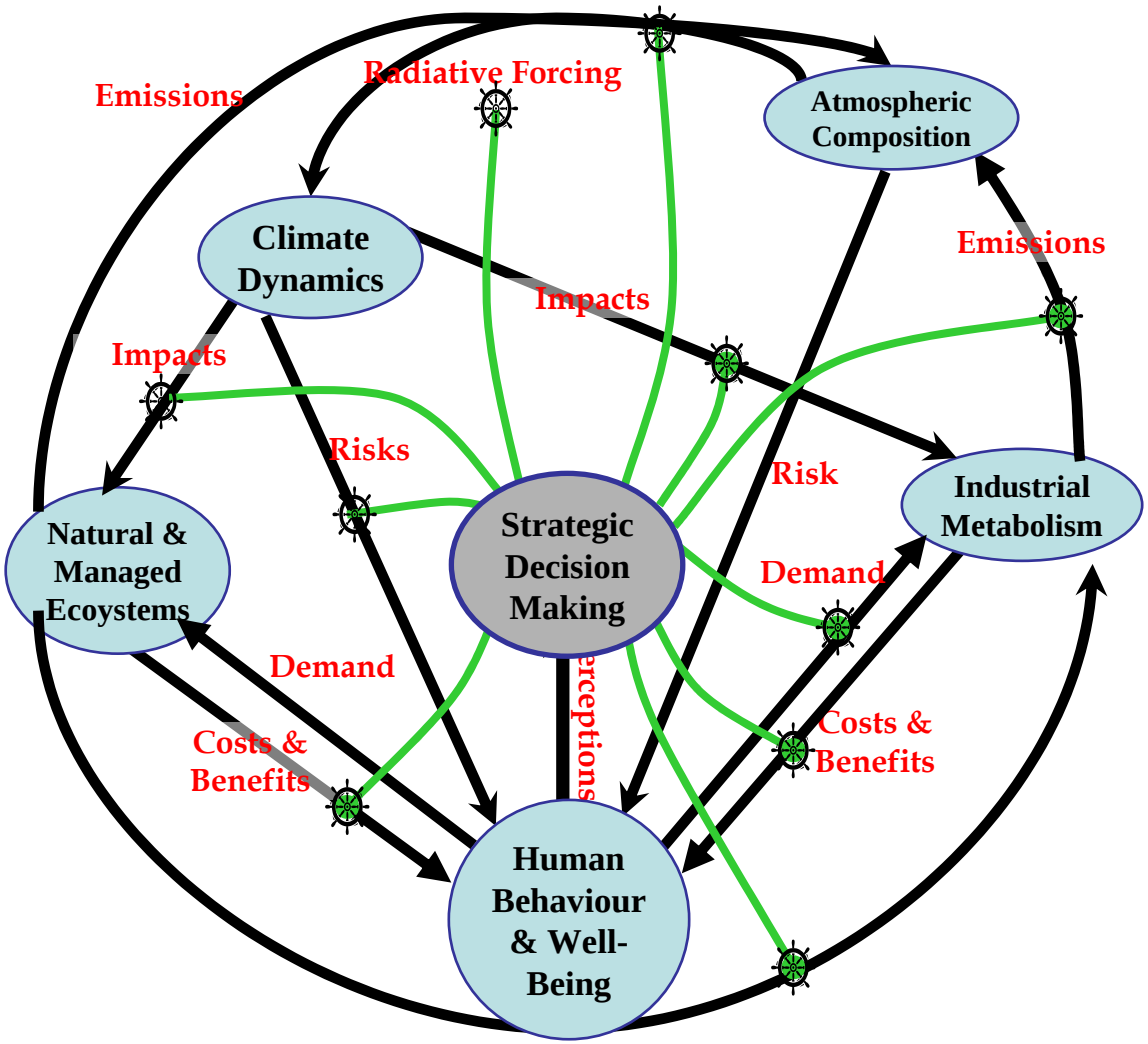
John Vidal, environment editor
Thursday October 21, 2004
The Guardian
www.guardian.co.uk

For every complex problem there is a simple solution

…which is wrong!

(*unknown physicist)*

Whole-Systems Approach



For every complex problem there is a complex solution

…which is useless!

Paul Valéry

Conclusion: Intermediate Complexity (IC) Approach

Strategic options appraisal based on three IC cornerstones:

1. "King's Equation" (**Integration**)
2. Kaya Identity (**Mitigation**)
3. "Schellnhuber Identity" (**Adaptation**)

POLICY FORUM

ENVIRONMENT

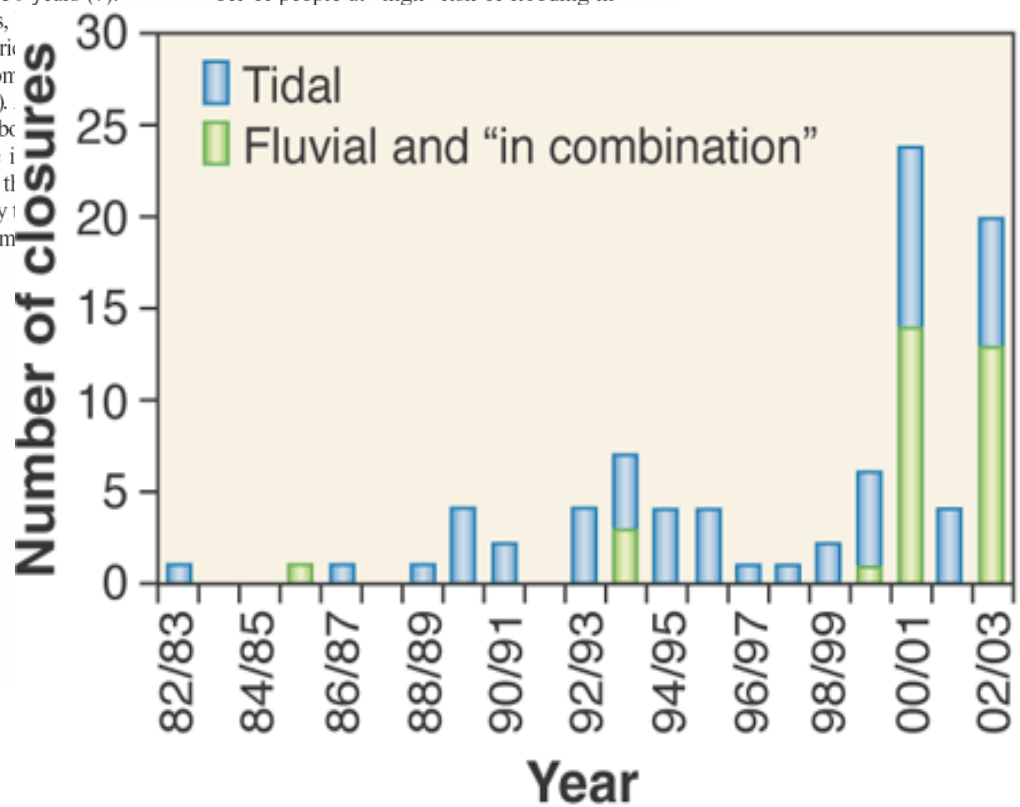
Climate Change Science: Adapt, Mitigate, or Ignore?

David A. King

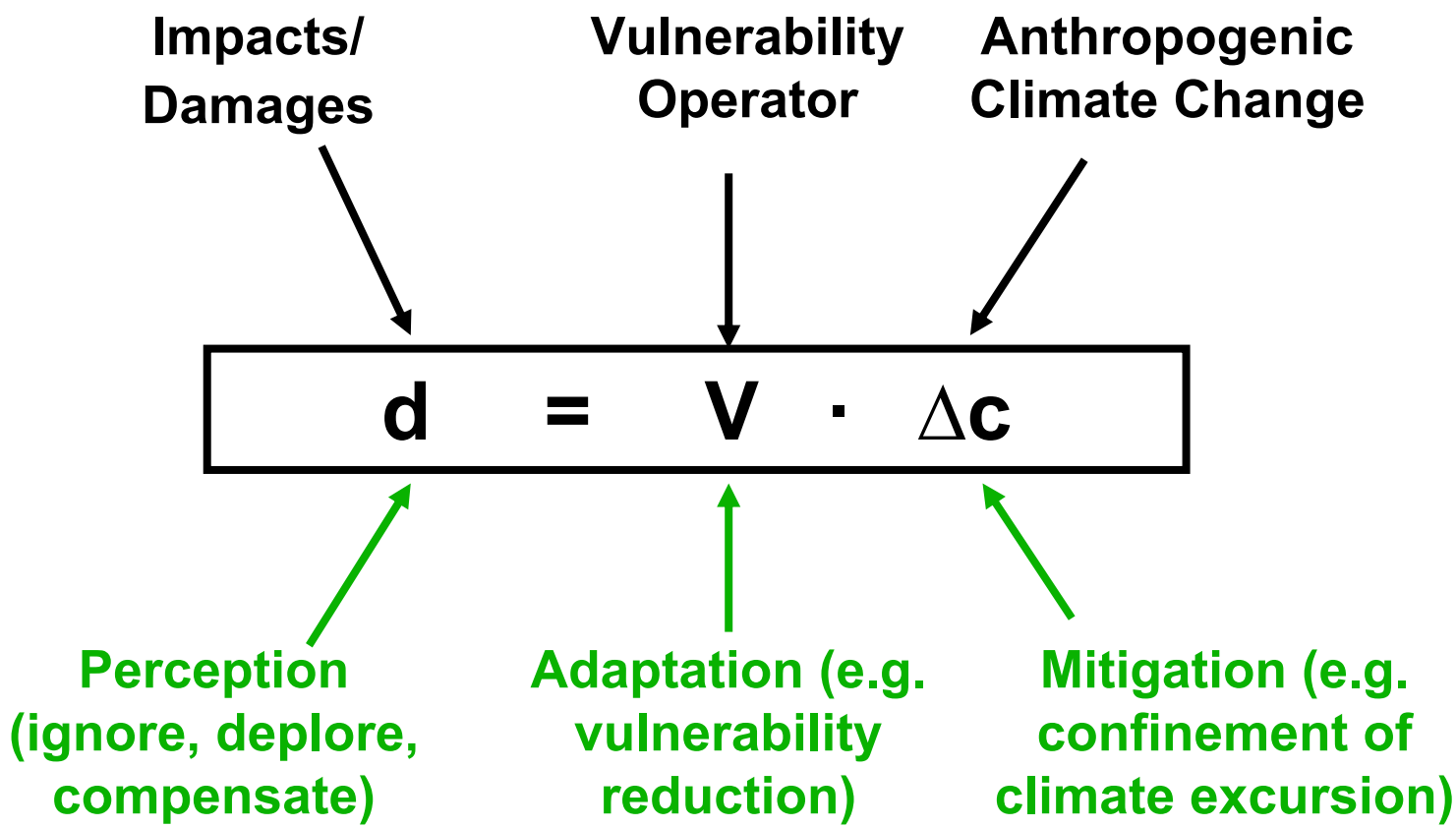
Climate change is real, and the causal link to increased greenhouse emissions is now well established. Globally, the ten hottest years on record have occurred since 1991, and in the past century, temperatures have risen by about 0.6°C (*1*). In that same period, global sea level has risen by about 20 cm—partly from melting of land ice and partly from thermal expansion of the oceans. Ice caps are disappearing from many mountain peaks (*2*, *3*), and summer and autumn Arctic sea ice has thinned by up to 40% in recent decades, although there is some evidence for stabilization (*4*, *5*). In Britain, usage of the Thames Barrier, which protects London from flooding down the Thames Estuary, has increased from less than once a year in the 1980s to an average of more than six times a year (see the figure, right) (*6*, *7*). This is a clear measure of increased frequency of high storm surges around North Sea coasts, combined with high flood levels in the River Thames. Last year, Europe experienced an unprecedented heat wave, France alone bearing around 15,000 excess or premature fatalities as a consequence. Although this was clearly an extreme event, house gas and aerosol concentrations could explain the general upward trend in temperature over the past 150 years (7).

In less than 200 years, increased the atmospheri greenhouse gases by son preindustrial levels (*1*, *8*). today's atmospheric carb higher than at any time i 420,000 years. Owing to t mate system, it is already further warming from However, if we could stabilize the atmosphere's carbon dioxide concentration at some realistically achievable and relatively low level, there is still a good chance of mitigating the worst effects of climate change. For instance, current models suggest that stabilizing carbon dioxide levels at around 550 ppm by 2100 could reduce flooding frequency by some 80 to much further inland, so that Britain's coastal defenses will be subjected both to higher water levels and to more energetic wave attack. If we assume continuation of existing shoreline management strategies, these combined effects have the potential to increase risk of floods in 2080 by up to 30 times present levels. In the highest emission scenario, by 2080, flood levels that are now expected only once in 100 years could be recurring every 3 years. Also in the worst-case scenario, the number of people at "high" risk of flooding in

Number of closures per annum of the Thames barrier to protect London from flooding. [Source: DEFRA, U.K.]



“King’s Equation”



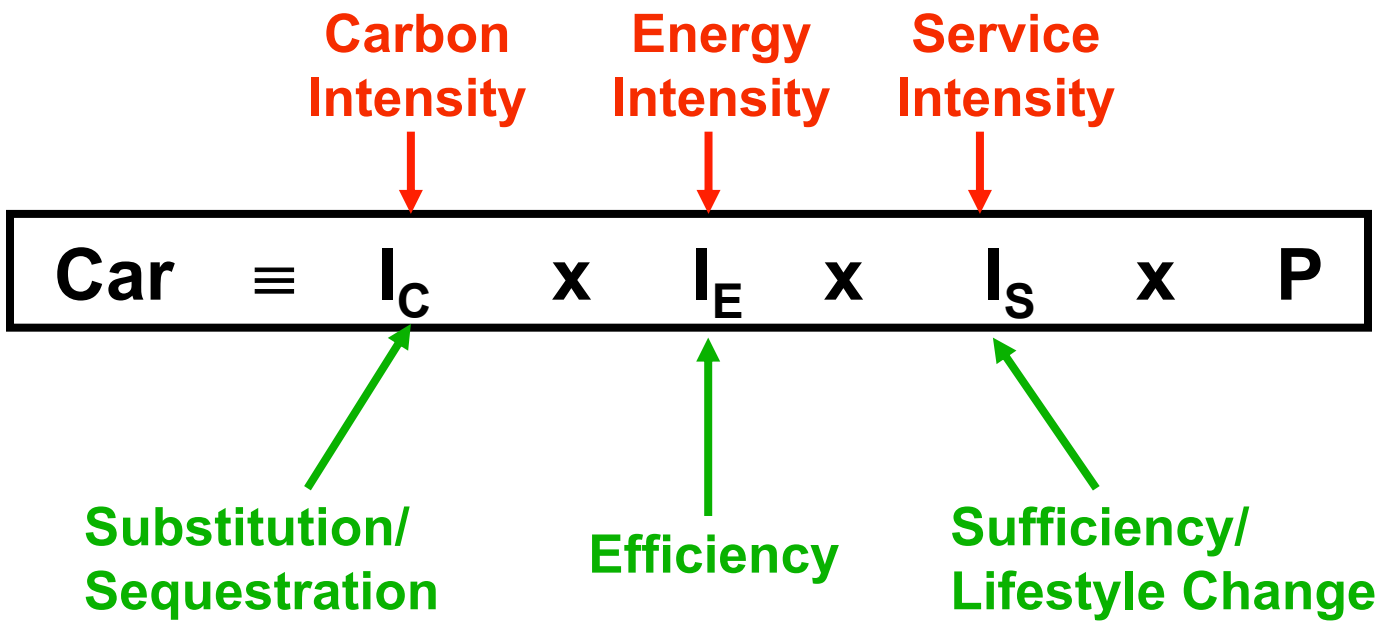
Strategic Options

Kaya Identity

$$\text{Carbon} \equiv \frac{\text{Carbon}}{\text{Energy}} \times \frac{\text{Energy}}{\text{Service}} \times \frac{\text{Service}}{\text{Population}} \times \text{Population}$$

(emitted in total)

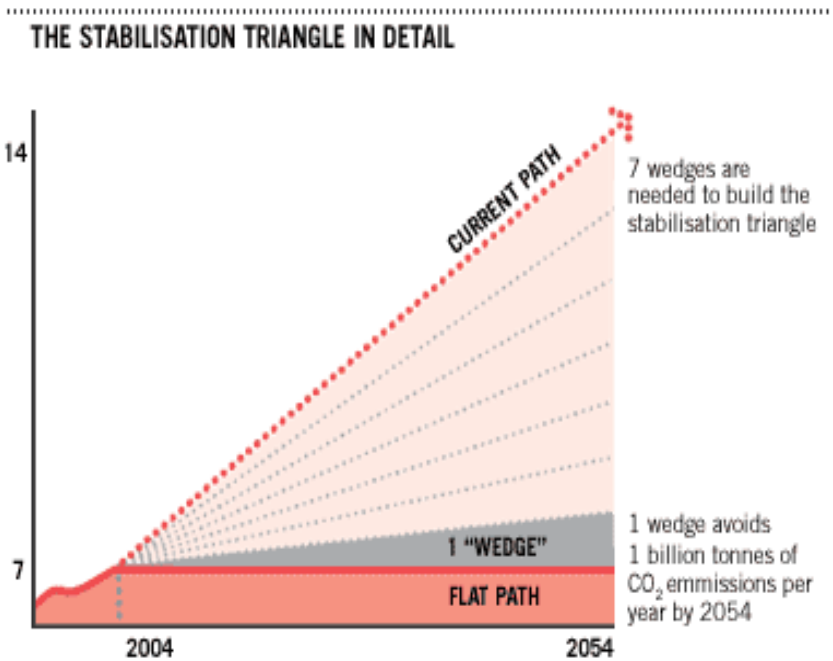
or



Strategic Options

“Wedgeology”

Potential wedges: strategies available to reduce CO_2 emission rate in 2054 by 1GtC/yr or to reduce C emissions from 2004 to 2054 by 25 Gt.

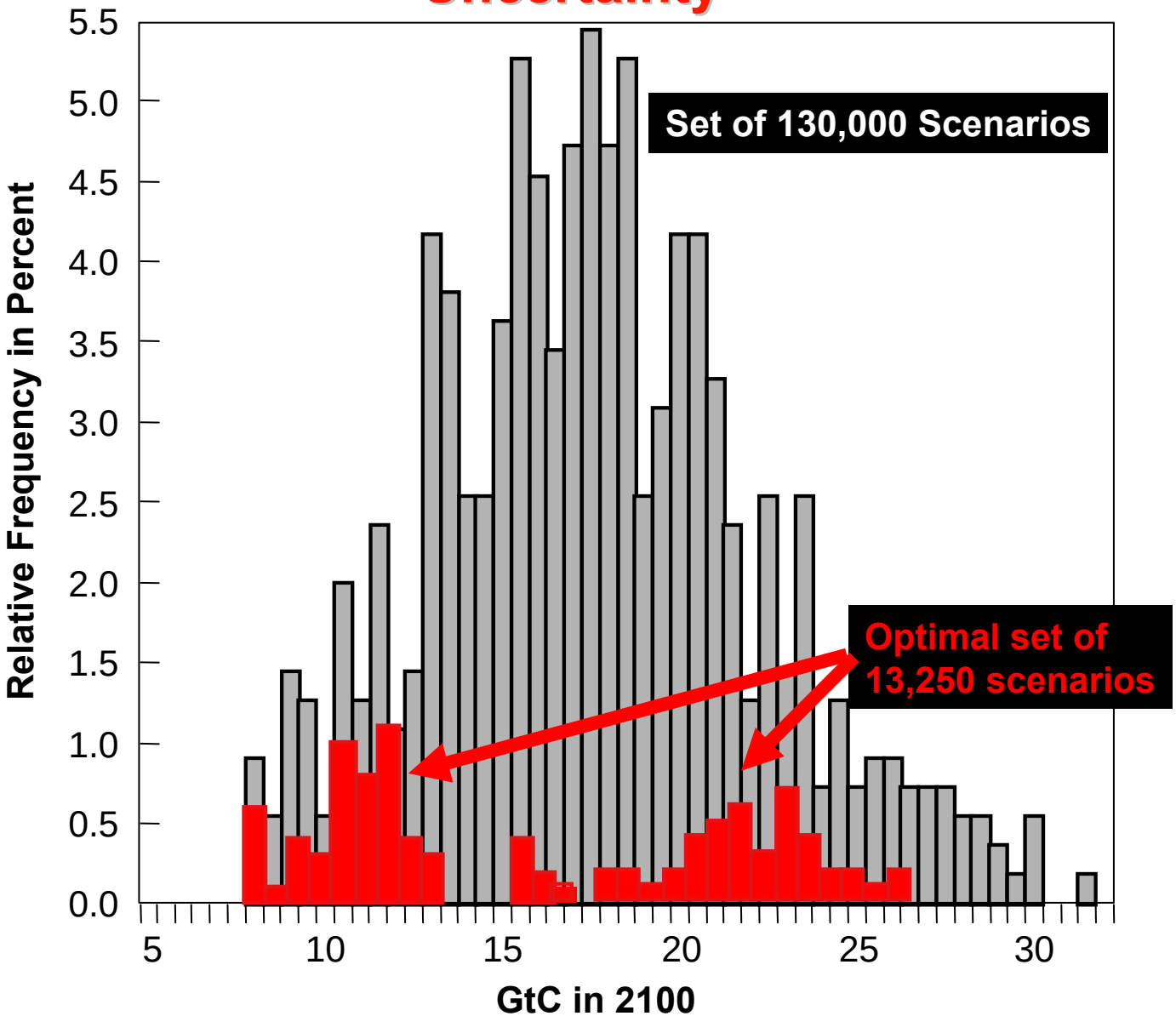


Pacala and Socolow, Science 305, 2004.

1. **Efficient vehicles**
2. **Reduced vehicle use**
3. **Efficient buildings**
4. **Efficient baseload coal plants**
5. **Gas baseload power for coal baseload power**
6. **Capture CO2 at baseload power plant**
7. **Capture CO2 at H2 plant**
8. **Capture CO2 at coal to synfuels plant**
9. **Nuclear power for coal power**
10. **Wind power for coal power**
11. **PV power for coal power**
12. **Wind H2 in fuel cell car for gasoline in hybrid car**
13. **Biomass fuel for fossil fuel**
14. **Reduced deforestation, plus reforestation, afforestation and new plantations**
15. **Conservation tillage**

***6-8: Geological storage**

CO_2 Emissions from Scenarios with Technological Uncertainty

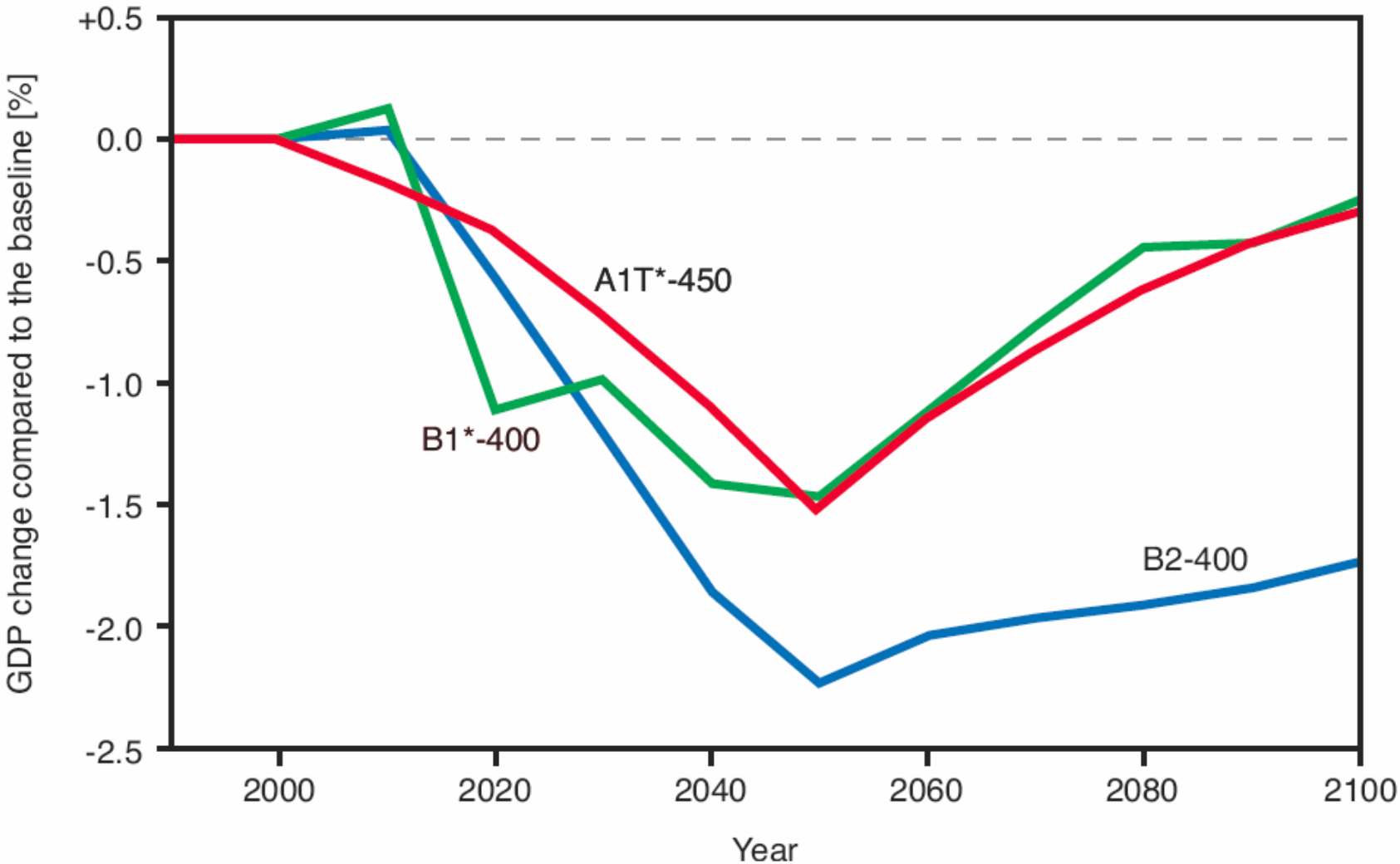


Gritsevkyi & Nakicenovic

IIASA 2000

Relative losses of global GDP

as a consequence of Climate Change mitigation measures

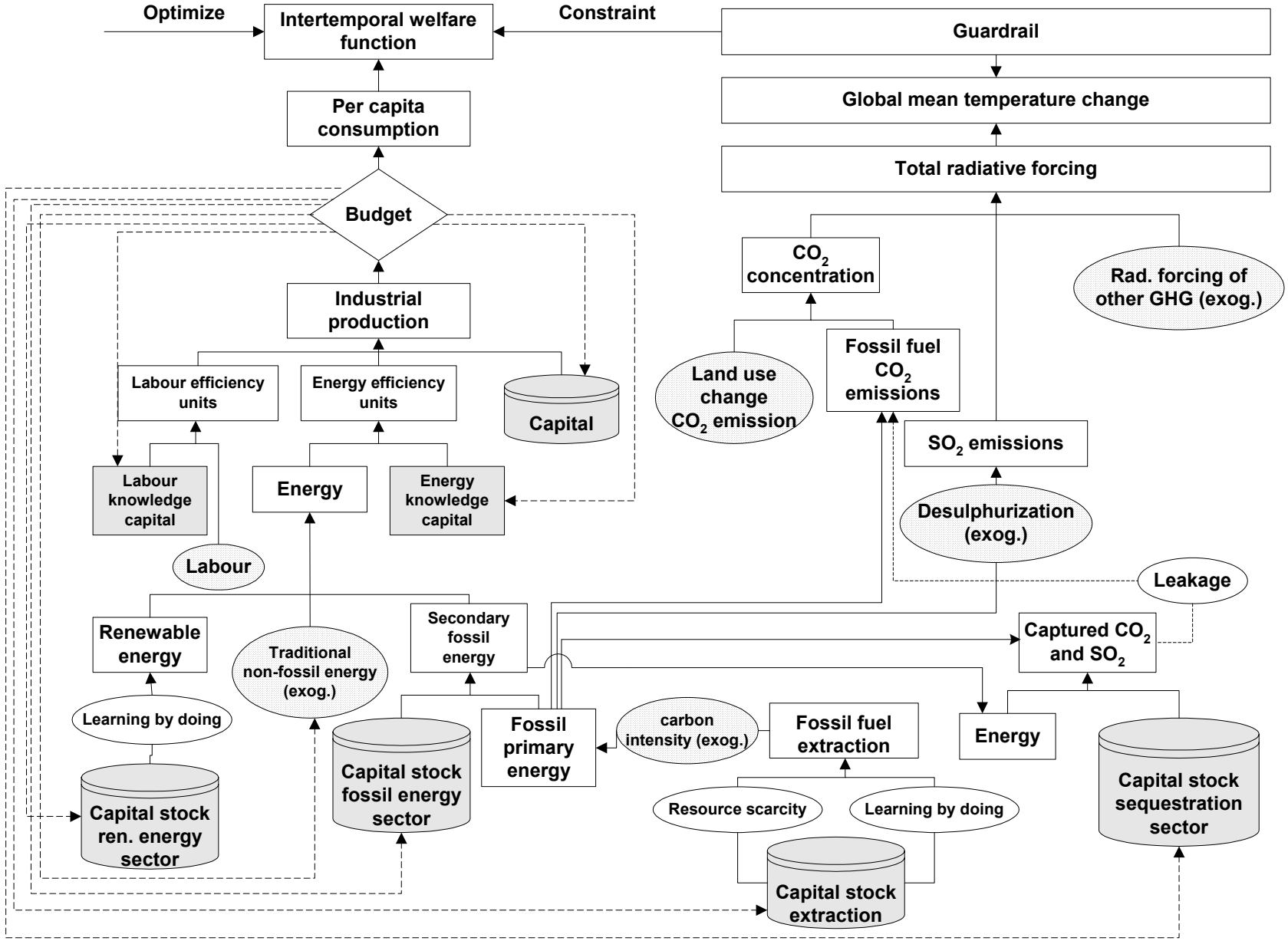


The Model MIND

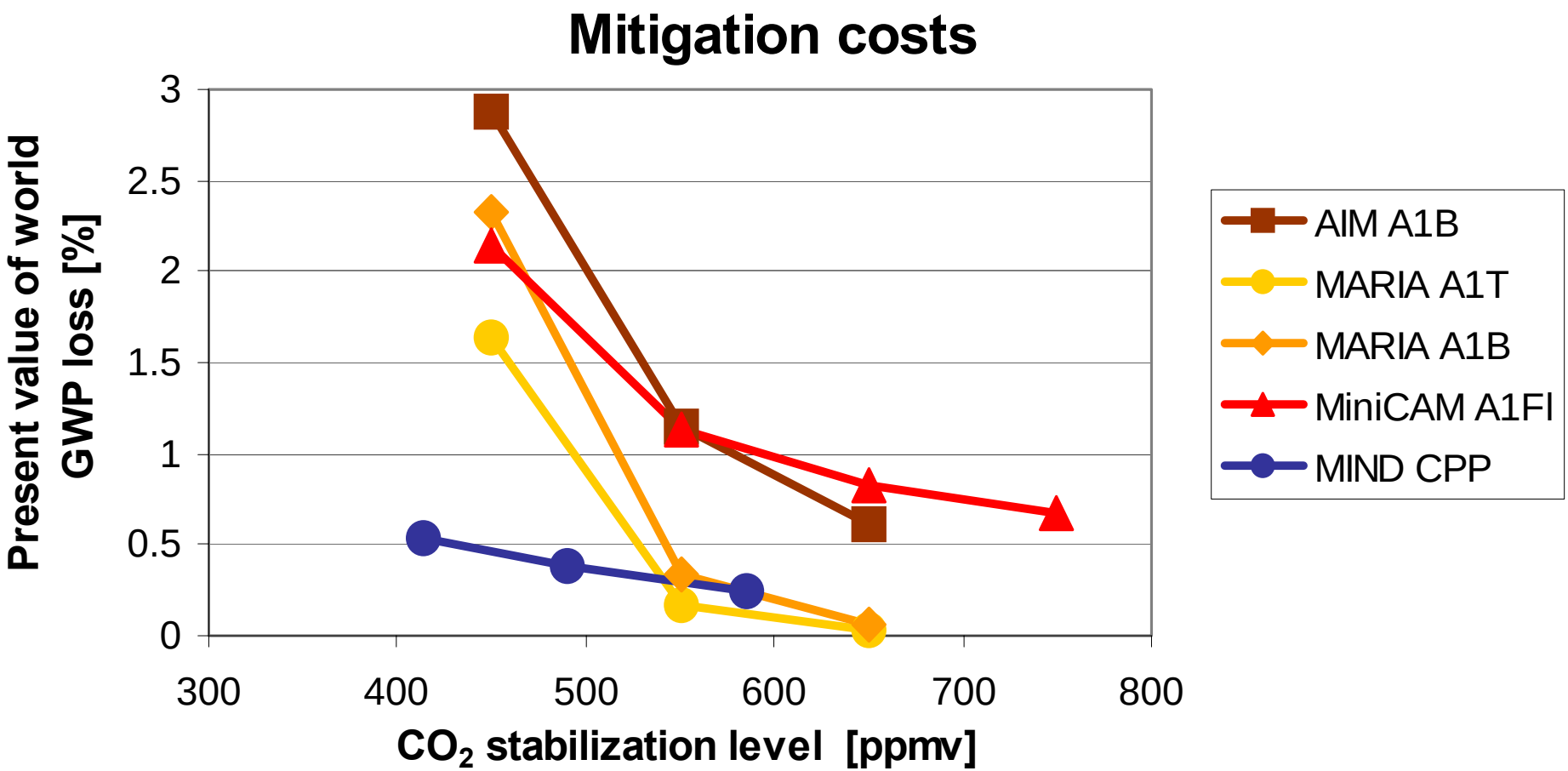
Technological change is driven by investment decisions

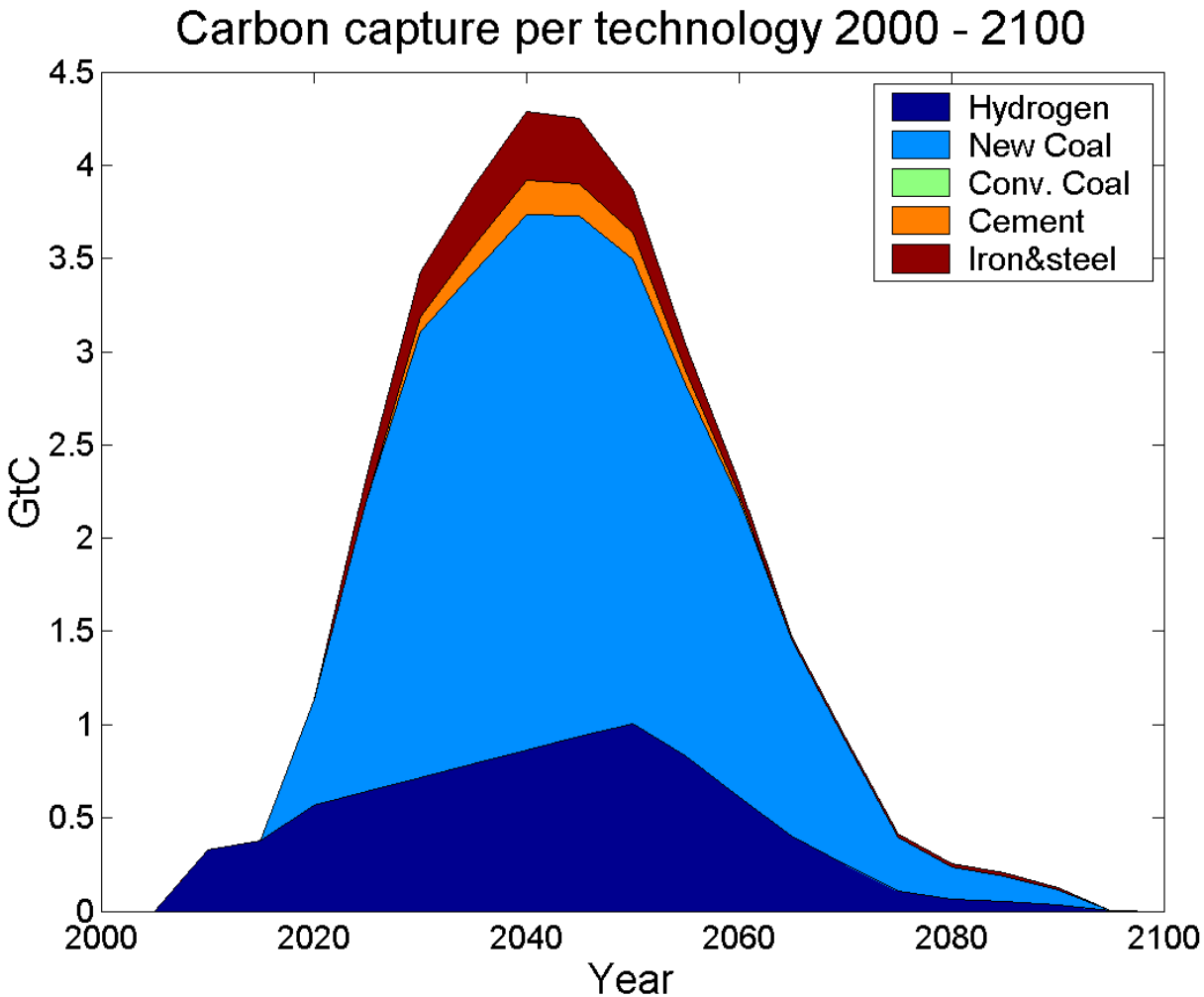
- Learning-by-doing in the energy sectors

- Assessment of Mitigation Options
  - Energy efficiency
  - Renewable energy sources
  - Carbon Capturing and Sequestration

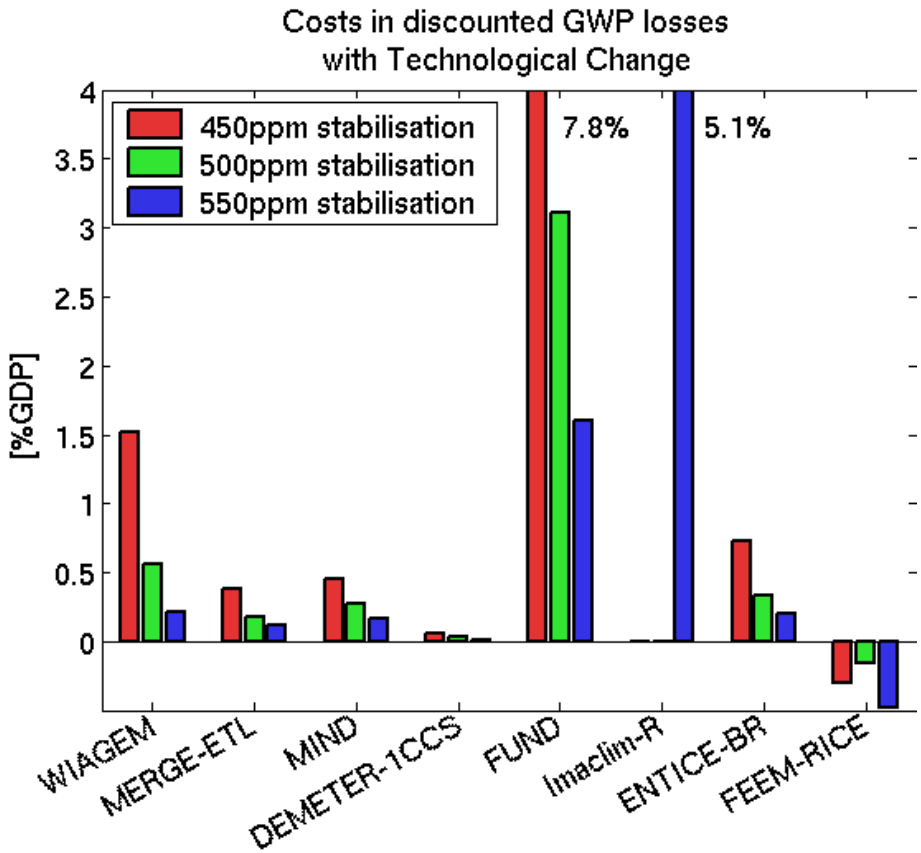

Optimize
Intertemporal welfare function
Constraint
Guardrail
Global mean temperature change
Total radiative forcing
Per capita consumption
Budget
CO_2 concentration
Rad. forcing of other GHG (exog.)
Industrial production
Land use change CO_2 emission
Fossil fuel CO_2 emissions
Labour efficiency units
Energy efficiency units
Capital
SO_2 emissions
Labour knowledge capital
Energy
Energy knowledge capital
Desulphurization (exog.)
Labour
Leakage
Renewable energy
Traditional non-fossil energy (exog.)
Secondary fossil energy
Captured CO_2 and SO_2
Learning by doing
Capital stock fossil energy sector
Fossil primary energy
carbon intensity (exog.)
Fossil fuel extraction
Energy
Capital stock sequestration sector
Capital stock ren. energy sector
Resource scarcity
Learning by doing
Capital stock extraction

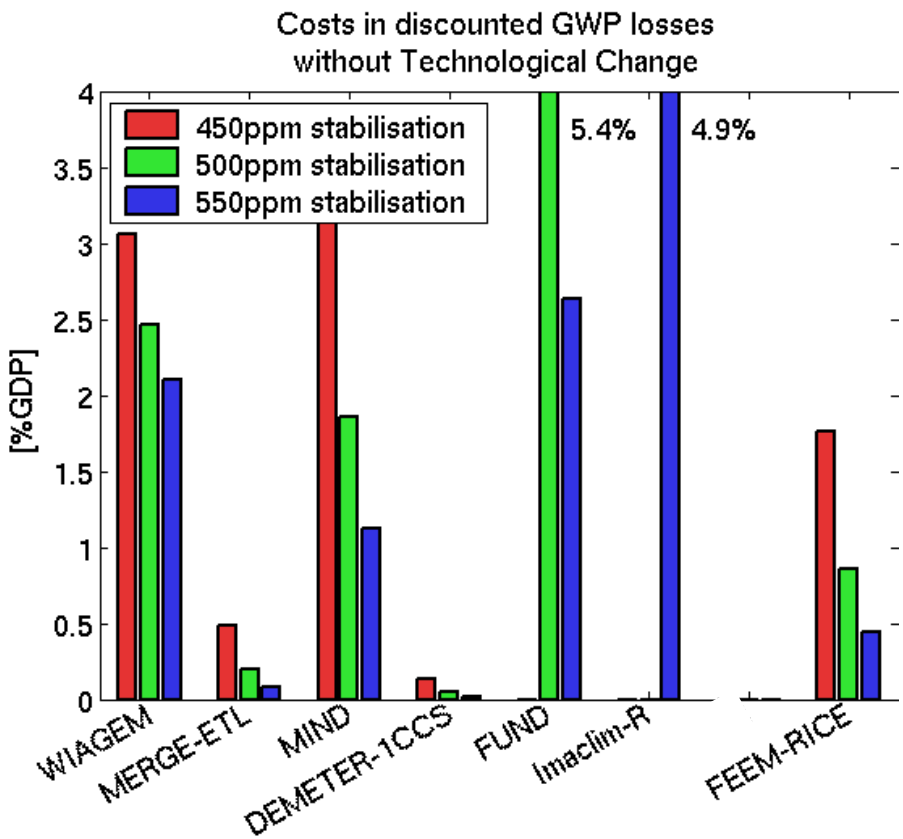
Costs of Reducing Climate Change




Carbon capture per technology 2000 - 2100
Hydrogen
New Coal
Conv. Coal
Cement
Iron&steel
GtC
Year
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
2000
2020
2040
2060
2080
2100

Macro-economic Costs



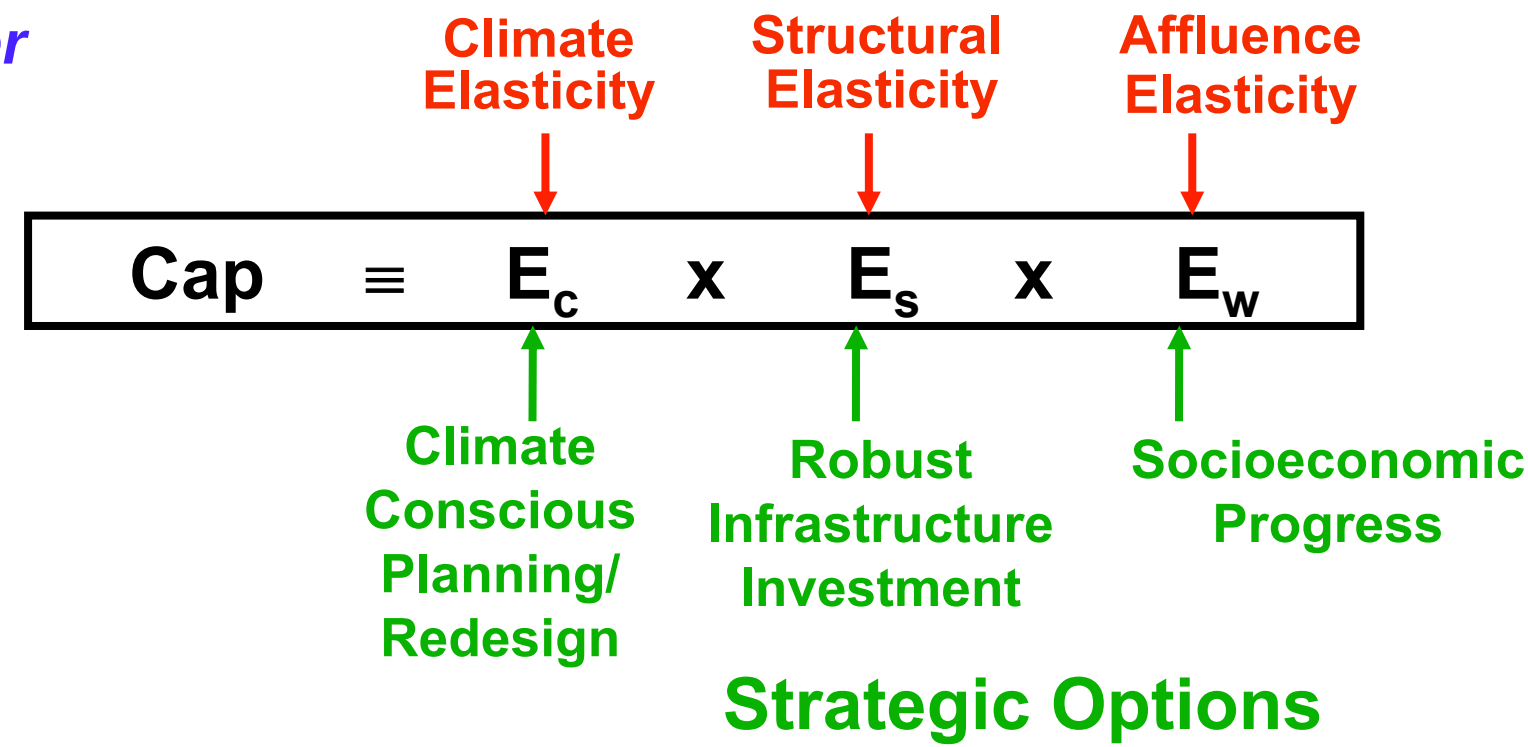


"SchellnhuberIdentity"

Climate Change Coping Capacity (C^4) ≡

$$\equiv \frac{C^4}{\text{Overall Capacity}} \times \frac{\text{Overall Capacity}}{\text{Generalized Wealth}} \times \frac{\text{Generalized Wealth}}{\text{Population}} \times \text{Population}$$

or



Intermediate-Complexity Solution of Climate Problem

King's Equation: $d = V \cdot \Delta c$

Kaya Identity: $Car = I_C \cdot I_E \cdot I_S \cdot P$

Schellnhuber Identity: $Cap = E_C \cdot E_S \cdot E_W \cdot P$

Assumptions:

1. $\Delta c \sim Car \quad ; \quad V \sim 1/Cap$

2. $Car' = \frac{1}{2} I_C \frac{1}{2} I_E \frac{1}{2} I_S \cdot P = \frac{1}{8} Car$

$Cap' = 2E_C \cdot 2E_S \cdot 2E_W \cdot P = 8\ Cap$

$\Rightarrow \quad V' \cdot \Delta c' = \frac{1}{8} V \cdot \frac{1}{8} \Delta c = \frac{1}{64} V \cdot \Delta c$

$$d' = \frac{1}{64} d$$

Problem Solved by Portfolio Strategy!

UNICS:

A Unified Certificate System for Climate Change Management

Based Upon the Principles of

- **Precaution**
- **Equity**
- **Responsibility**
- **Efficiency**
- **Flexibility**

UNICS:
Main Ingredients of Simplest Version

- **Emission Permits for GHG:**

  "Permissions"

  - **Confinement of Climate Change**

- **Adaptation Vouchers for Climate-Change Damage:**

  "Admissions"

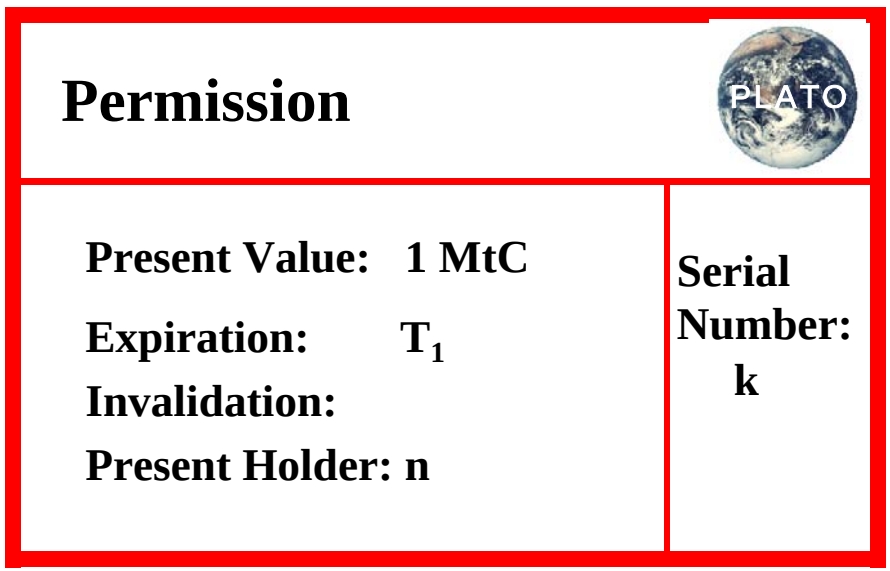
  - **Compensation for Residual Climate Change**

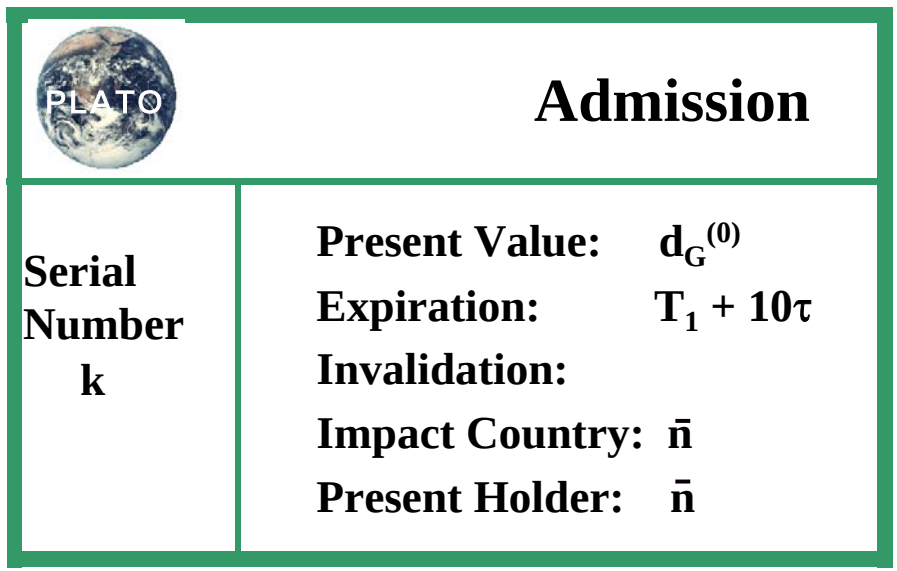
- **Planetary Authority for Overseeing the Allocation, Expiration, (Re-)Valuation and Transaction of Permissions & Admissions:**

  "PLATO"

  - **Enforcement of Justice, Adequacy and Efficiency in Climate Change Management**

UNICS: Twin Currency





Crucial Implication

Holder of permission with
serial number k
owes the holder of mirror admission
with same serial number
a compensation worth $d^{(0)}(G)$

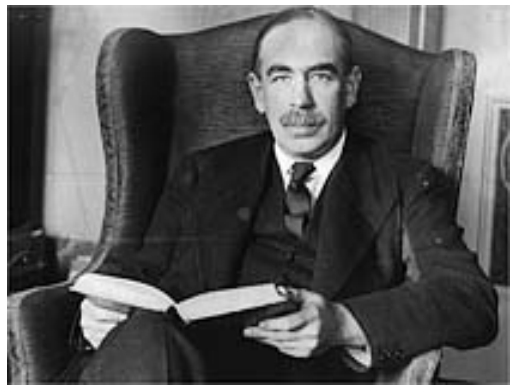
We threw good housekeeping to the winds.

But we saved ourselves

…. and helped save the world

John Maynard Keynes

(Of Britain in the Second World War)



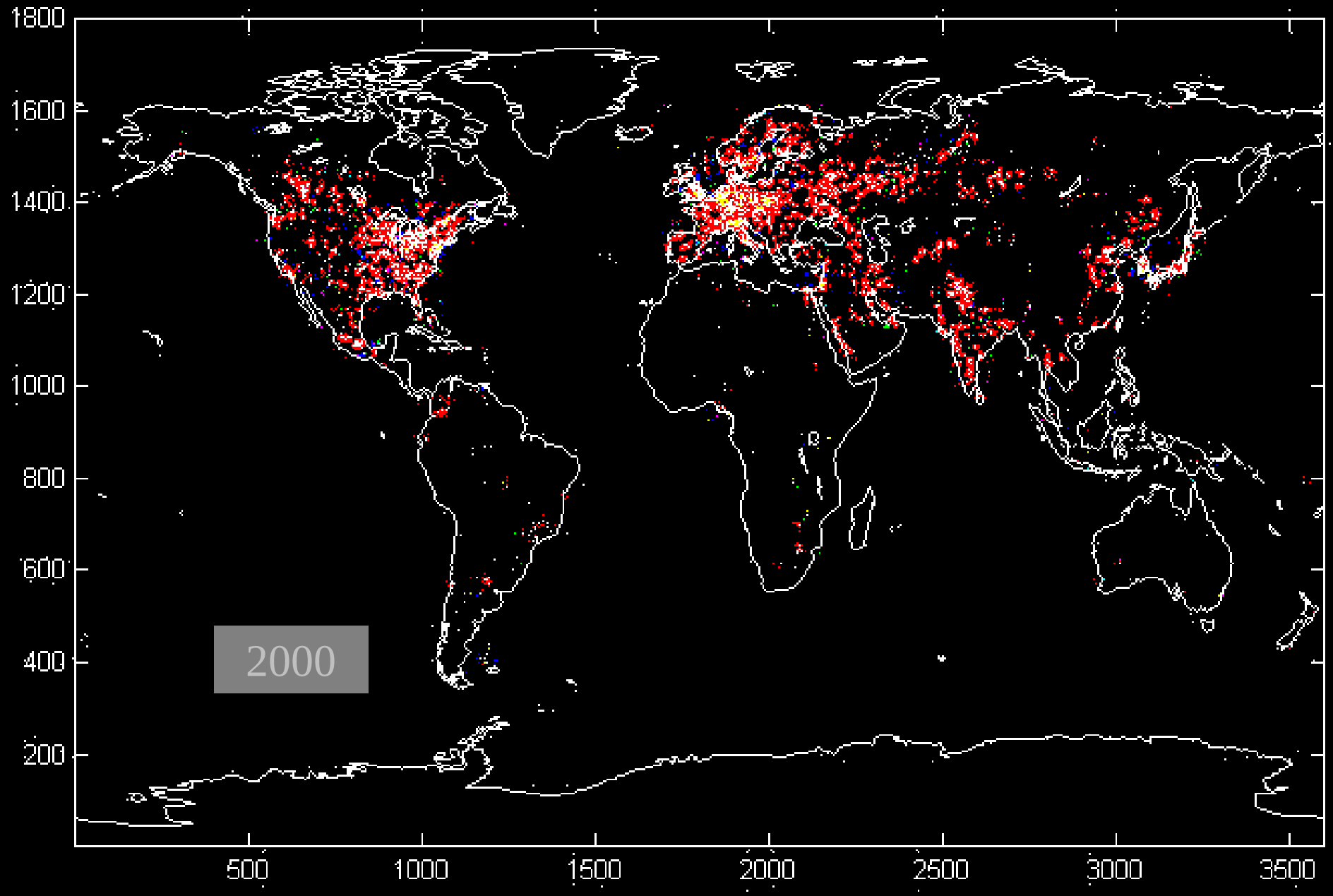
We abolished unsustainable housekeeping.

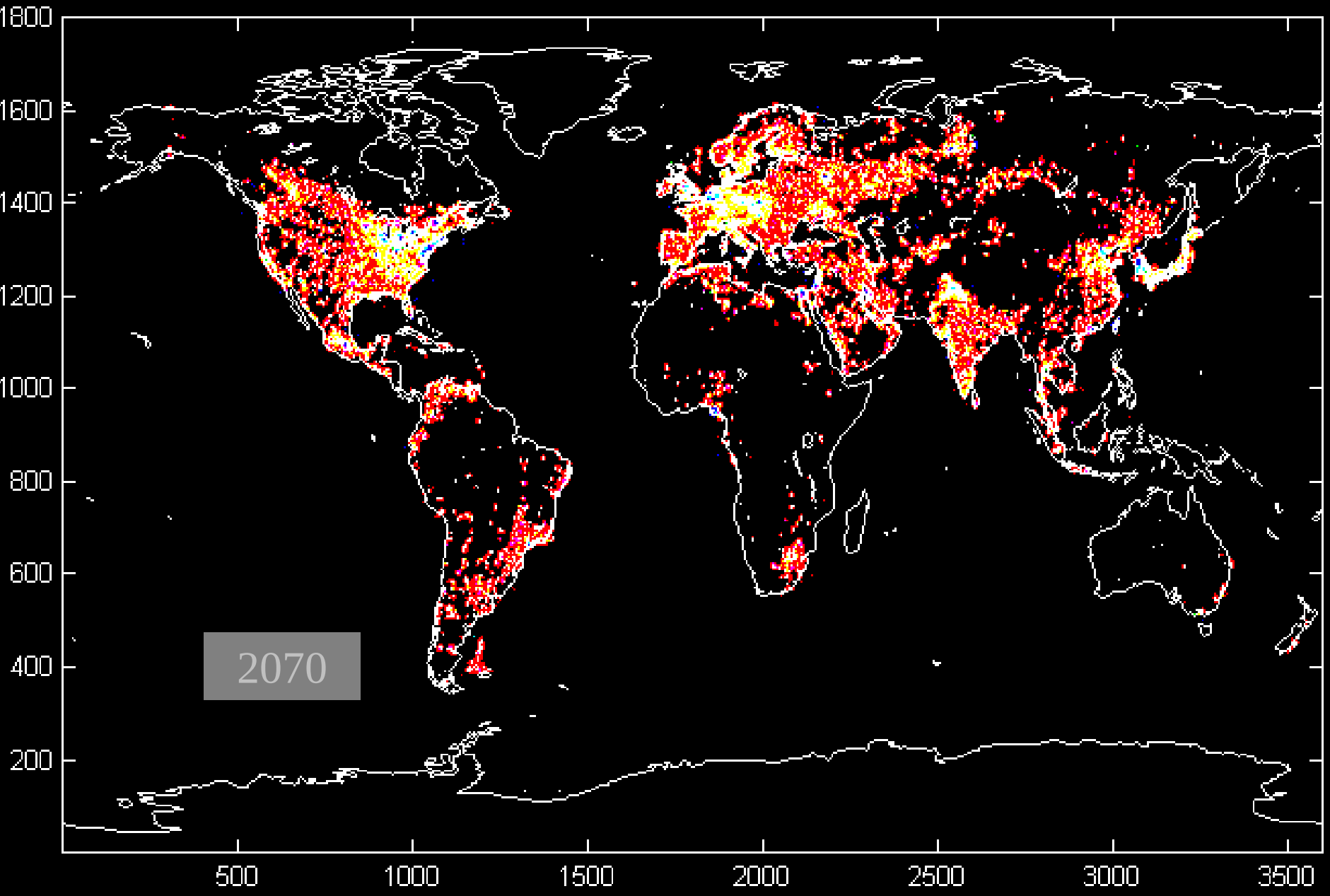
So we ensured our long-term prosperity

…. and helped save the climate

David King, Crispin Tickell & Klaus Töpfer

(Of Europe in the 21st century)


1800
1600
1400
1200
1000
800
600
400
200
500
1000
1500
2000
2500
3000
3500
2000


1800
1600
1400
1200
1000
800
600
400
200
500
1000
1500
2000
2500
3000
3500
2070