ACHIEVING DEEP AND RAPID REDUCTIONS IN FOSSIL FUEL CO_2 EMISSIONS: WHY AND HOW

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My personal discovery of the global warming issue occurred as a new graduate student 1978. In 1980, I decided to change career paths and focus on the GW issue, as I was convinced – based on the science of the late 1970s – that GW would become *the* central environmental and political issue.

Since 1978,

- The climate science has become even *more compelling*
- We are starting to *clearly see* some of the predicted changes in climate
- We have come to realized that the impacts will be *much worse* than originally thought

The key parameter in the entire global warming issue is the *climate sensitivity*, which is the long-term, global average warming for a *fixed* doubling of atmospheric CO_2 concentration.

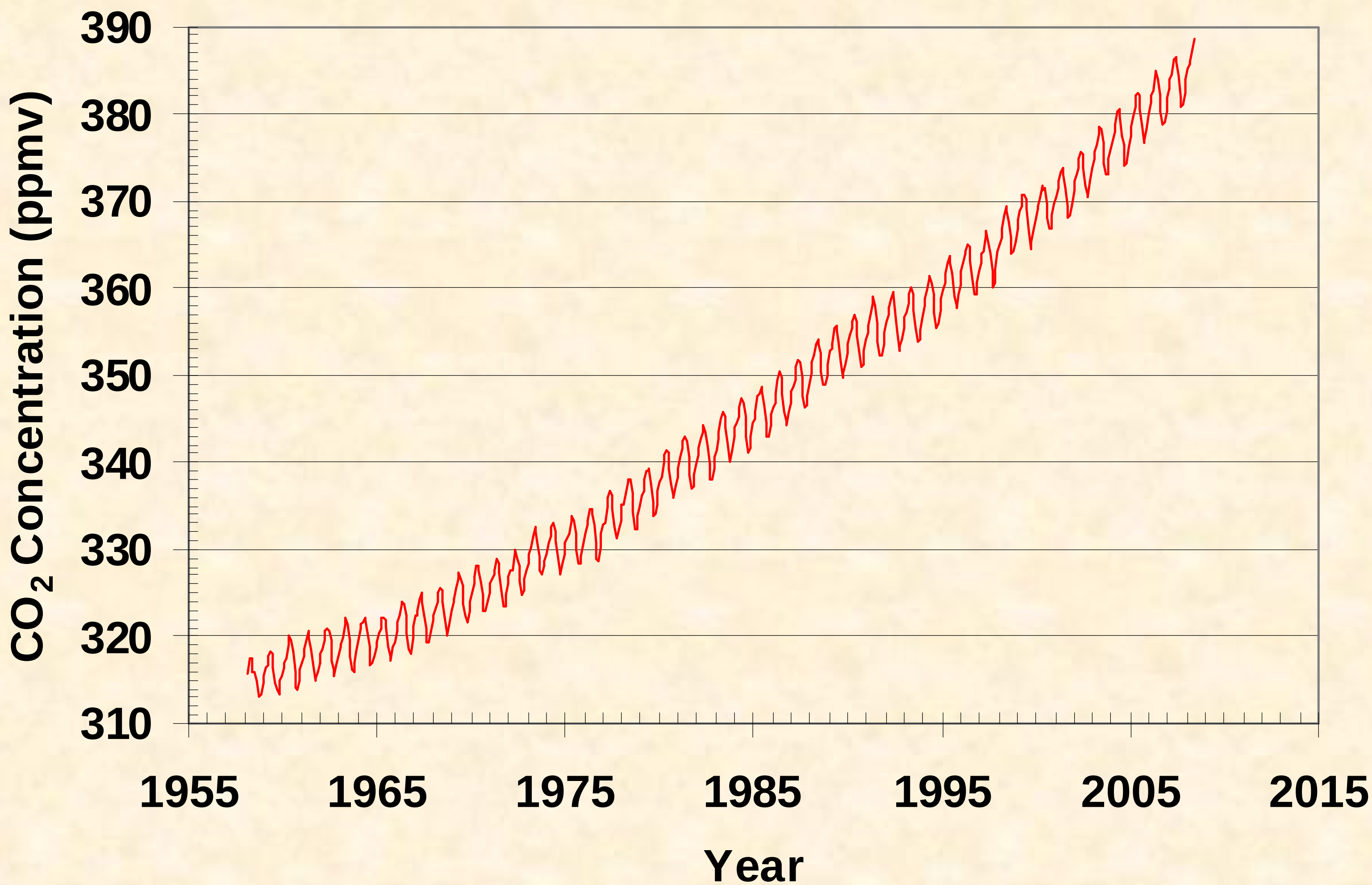
Since the late 1970s, the consensus scientific opinion has been that the climate sensitivity very likely falls between 1.5 C and 4.5 C.

Four independent lines of evidence:

- Simulations with 3D climate models, with validation from observations of some of the key climate feedback processes
- Analysis of global and regional temperature trends over the past 100 years (taking into account volcanic and solar variability, as well as the cooling effect of aerosols)
- Analysis of climates during past geological epochs (such as the last ice age, or the warm Cretaceous era)
- Analysis of past natural variations (over millions of years) in atmospheric CO_2 concentration (which are driven by variations in plate-tectonic activity but require a stabilizing negative feedback that depends on climate sensitivity) (too small an assumed climate sensitivity gives too large a CO_2 variation, and vice versa)

Observations

Monthly Atmospheric CO_2 Concentration at Mauna Loa Observatory, Hawaii, 1958-2008



Global Mean Temperature Variation, 1856-mid 2008

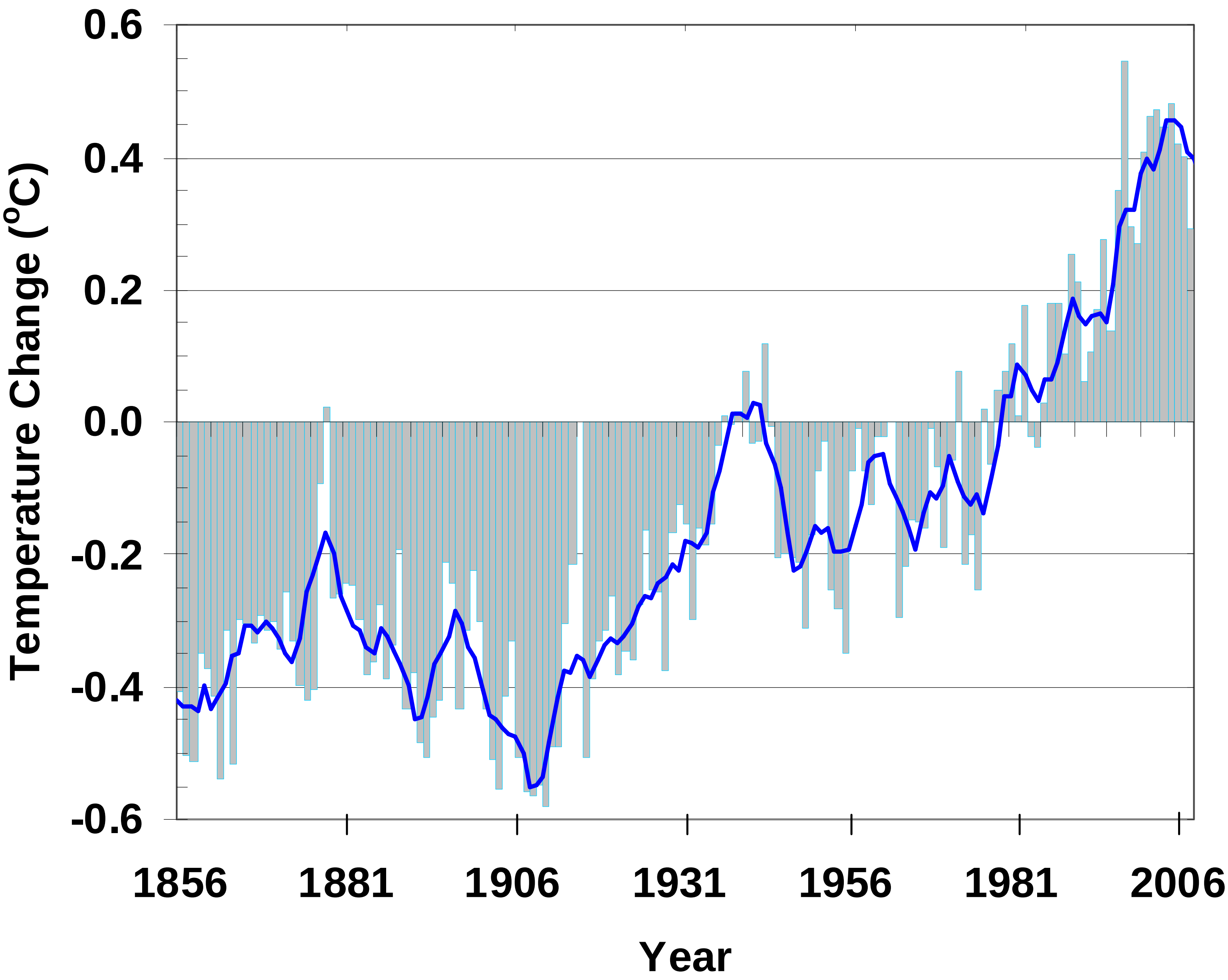
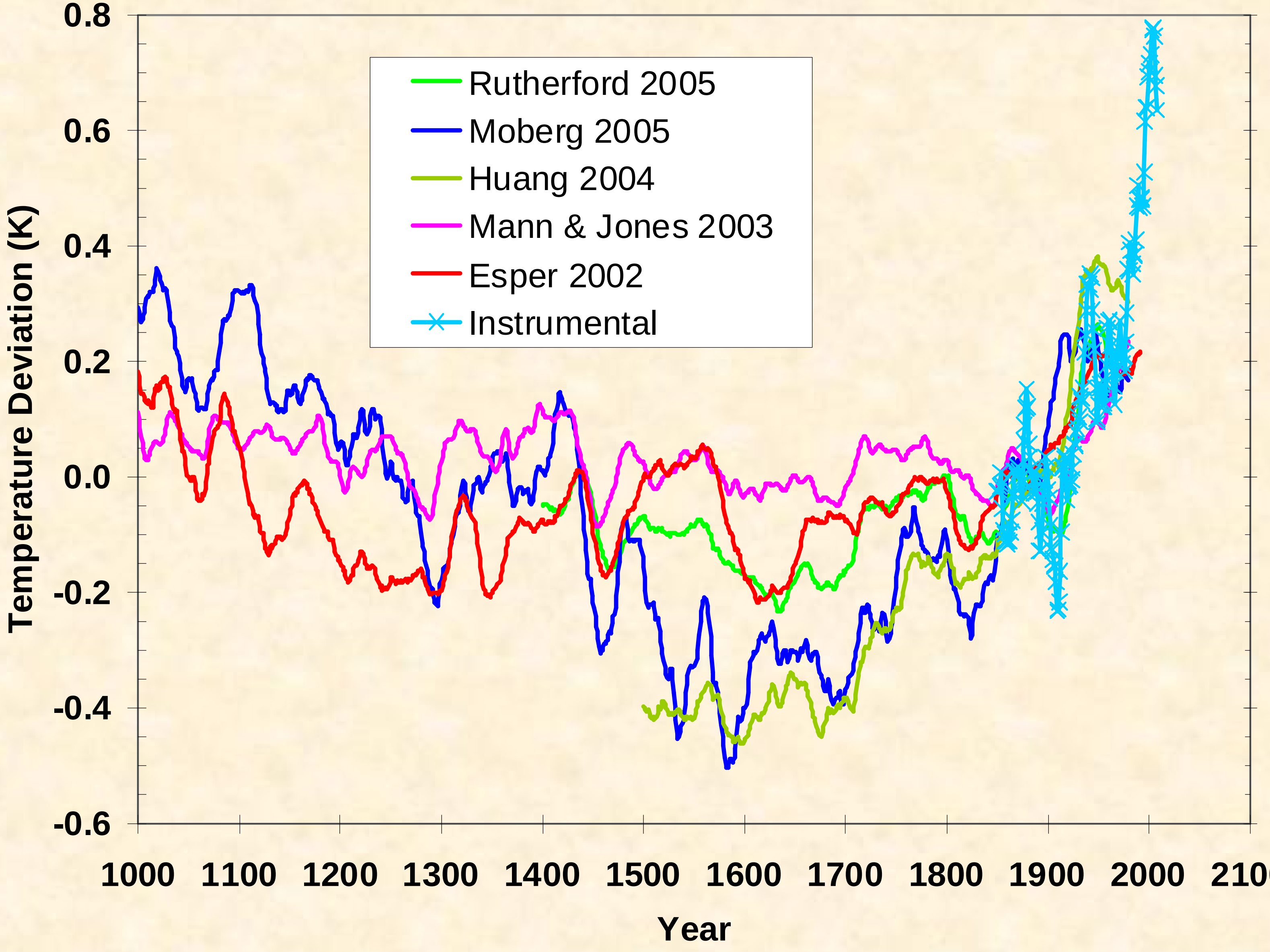
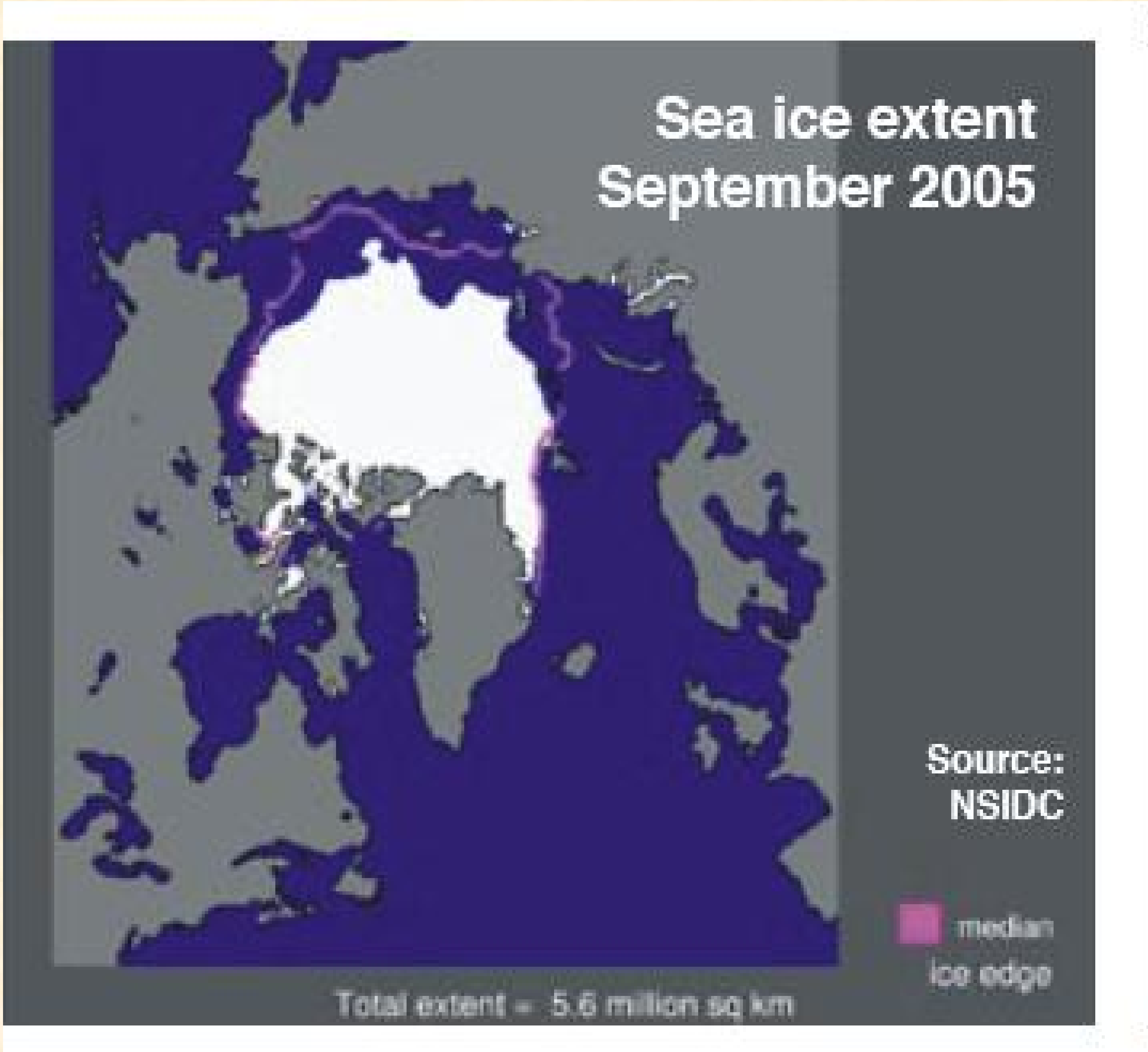
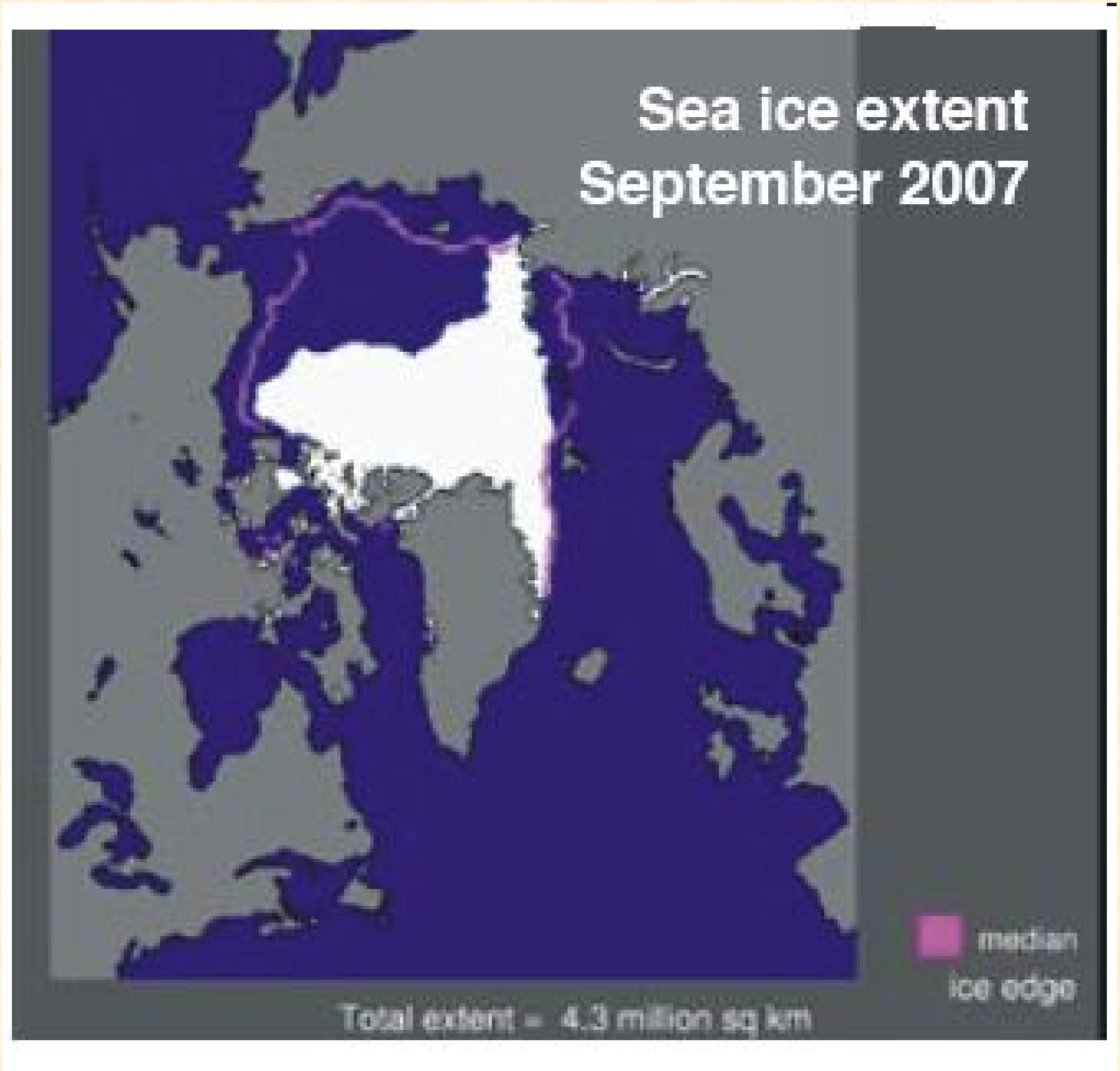
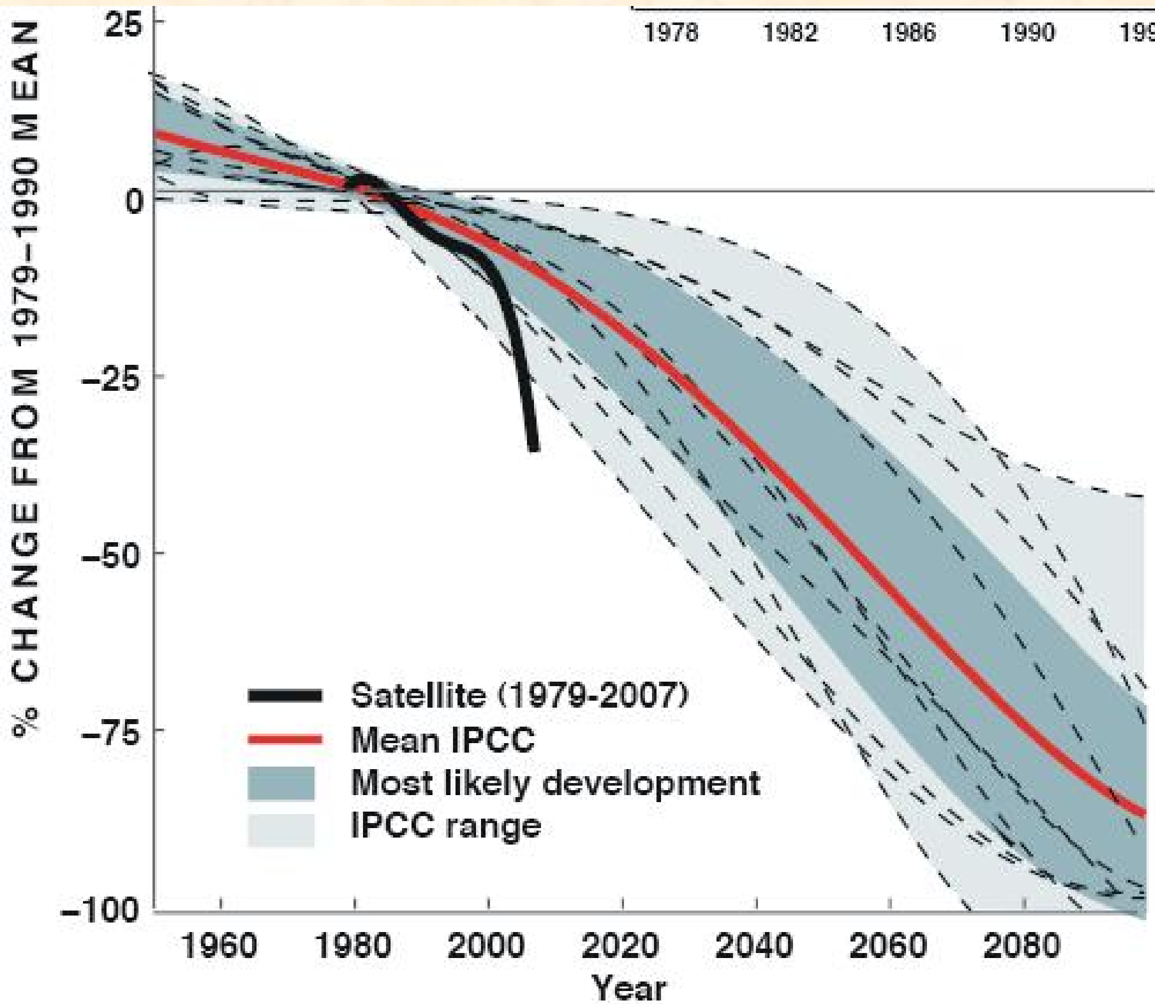


Figure 1.3 Variation in NH Surface Temperature



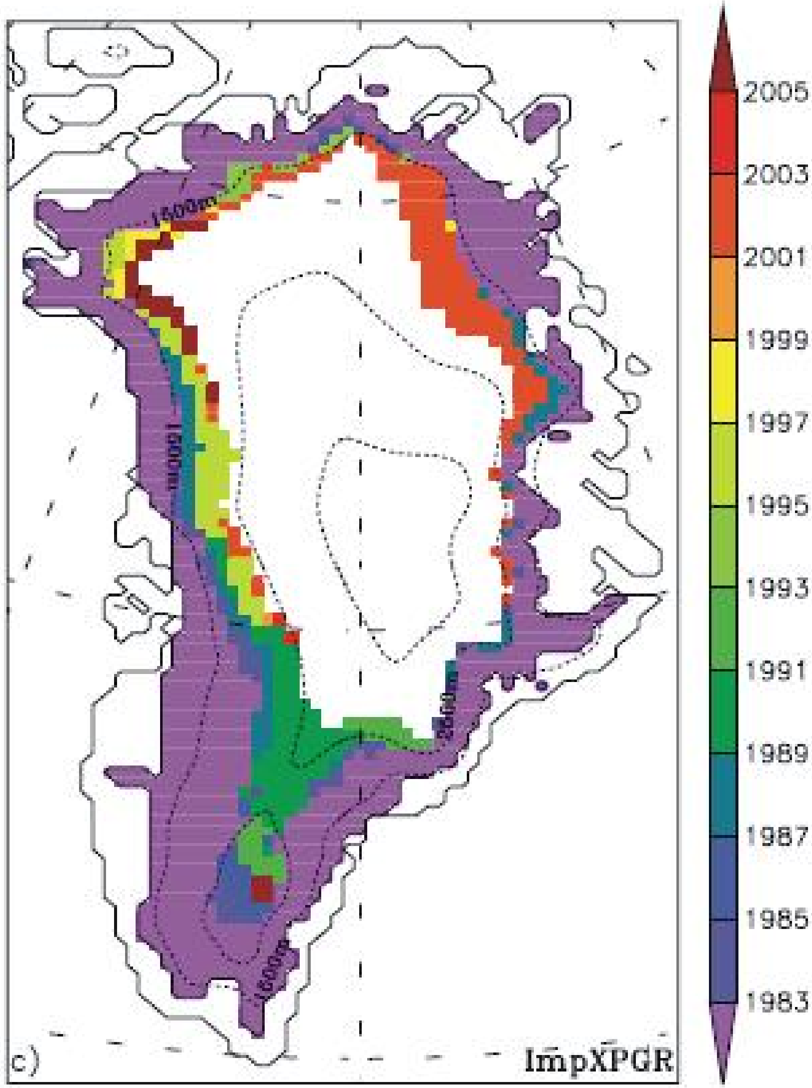

Sea ice extent
September 2005
Source:
NSIDC
median
ice edge
Total extent = 5.6 million sq km


Sea ice extent
September 2007
median
ice edge
Total extent = 4.3 million sq km



Arctic sea ice summer extent loss compared to IPCC projections

Arctic ice extent loss to September 2007 compared to IPCC modelled changes using the SRES A2 CO2 scenario (IPCC high CO2 scenario). September loss data from satellite observations. Data smoothed with a 4th order polynomial to smooth out the year-to-year variability. Chart courtesy Dr Asgeir Sorteberg, Bjeknes Centre for Climate Research and University Center at Svalbard, Norway.



Year of the first recorded melt day by ImpXPGR

Summer Melting of Greenland Ice Cap

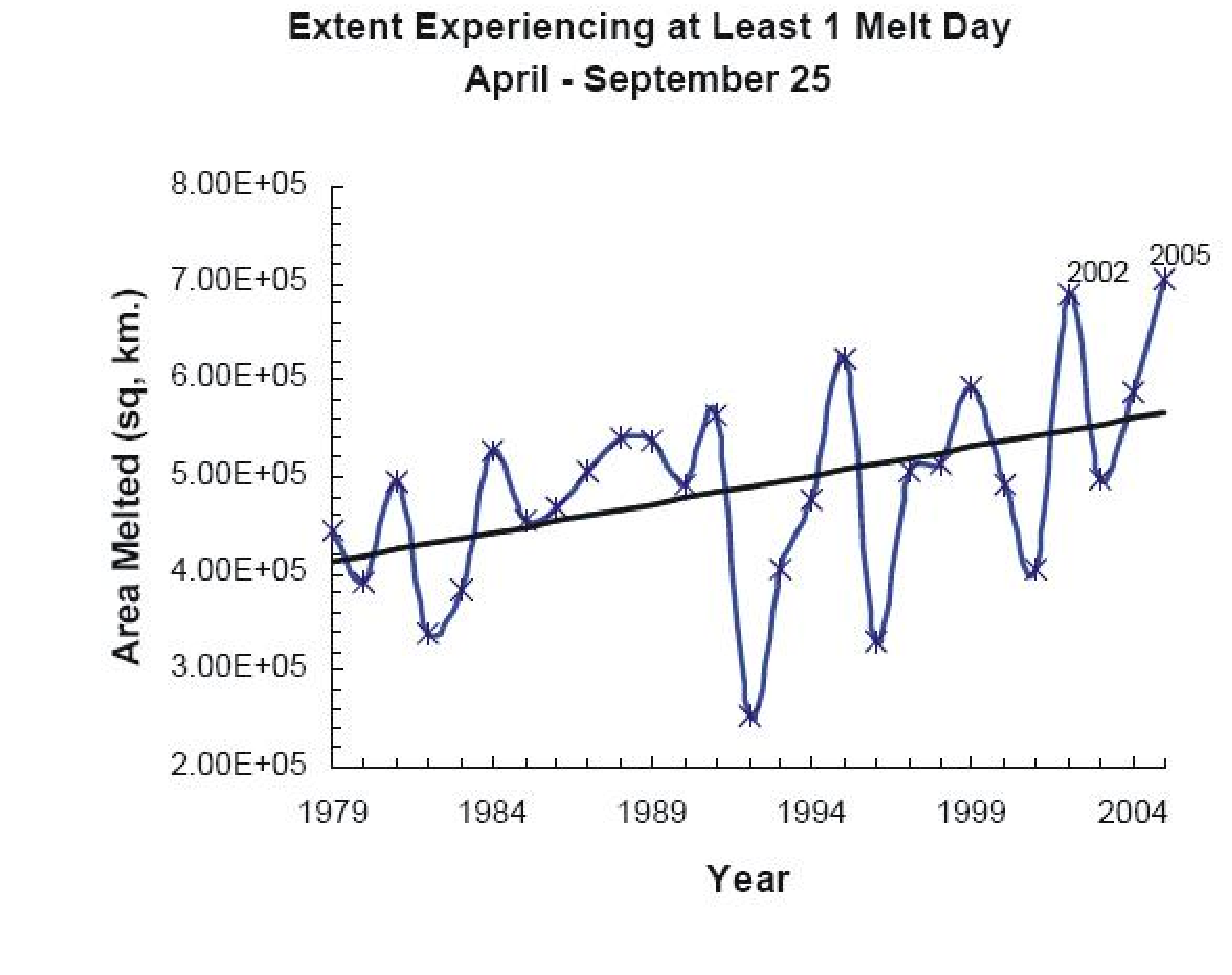
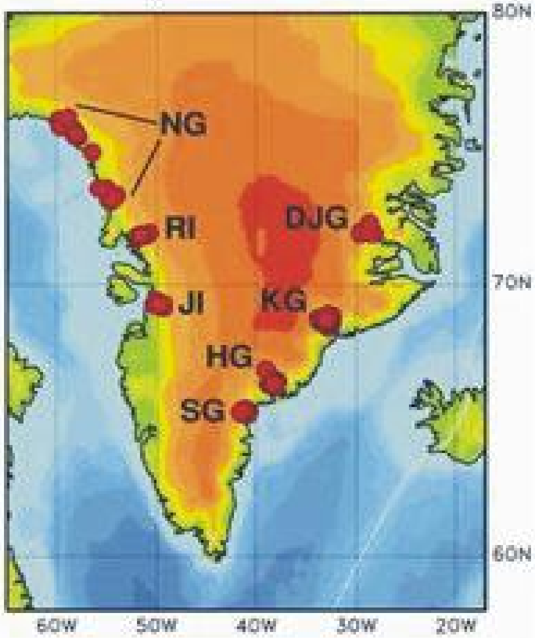


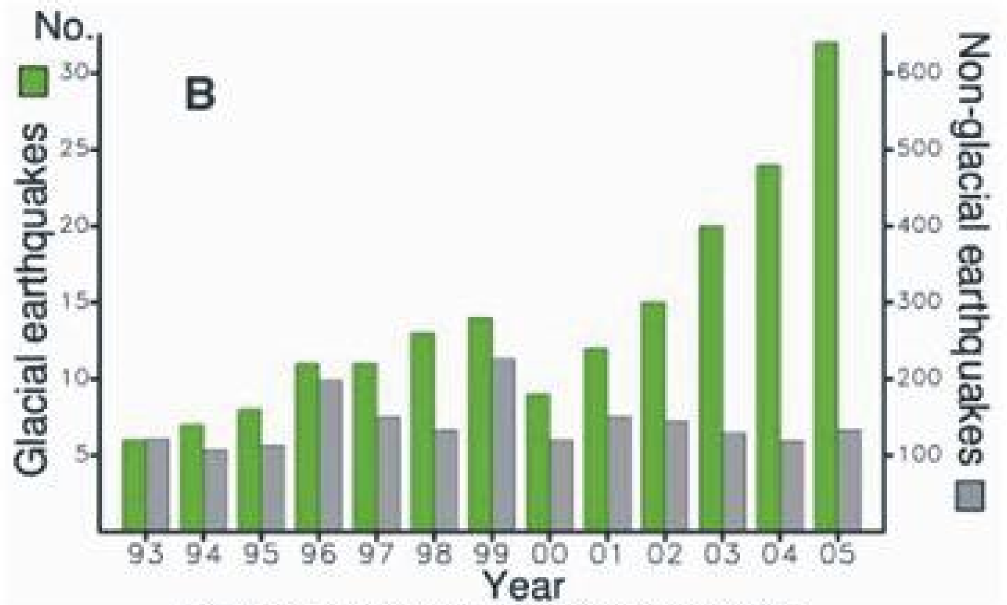
Exhibit 1-37

Glacial Earthquakes on Greenland

Earthquake Locations



Annual Number of Quakes*



* 2005 bars capture only first 10 months of 2005

Location and frequency of glacial earthquakes on Greenland. Seismic magnitudes are in range 4.6 to 5.1.

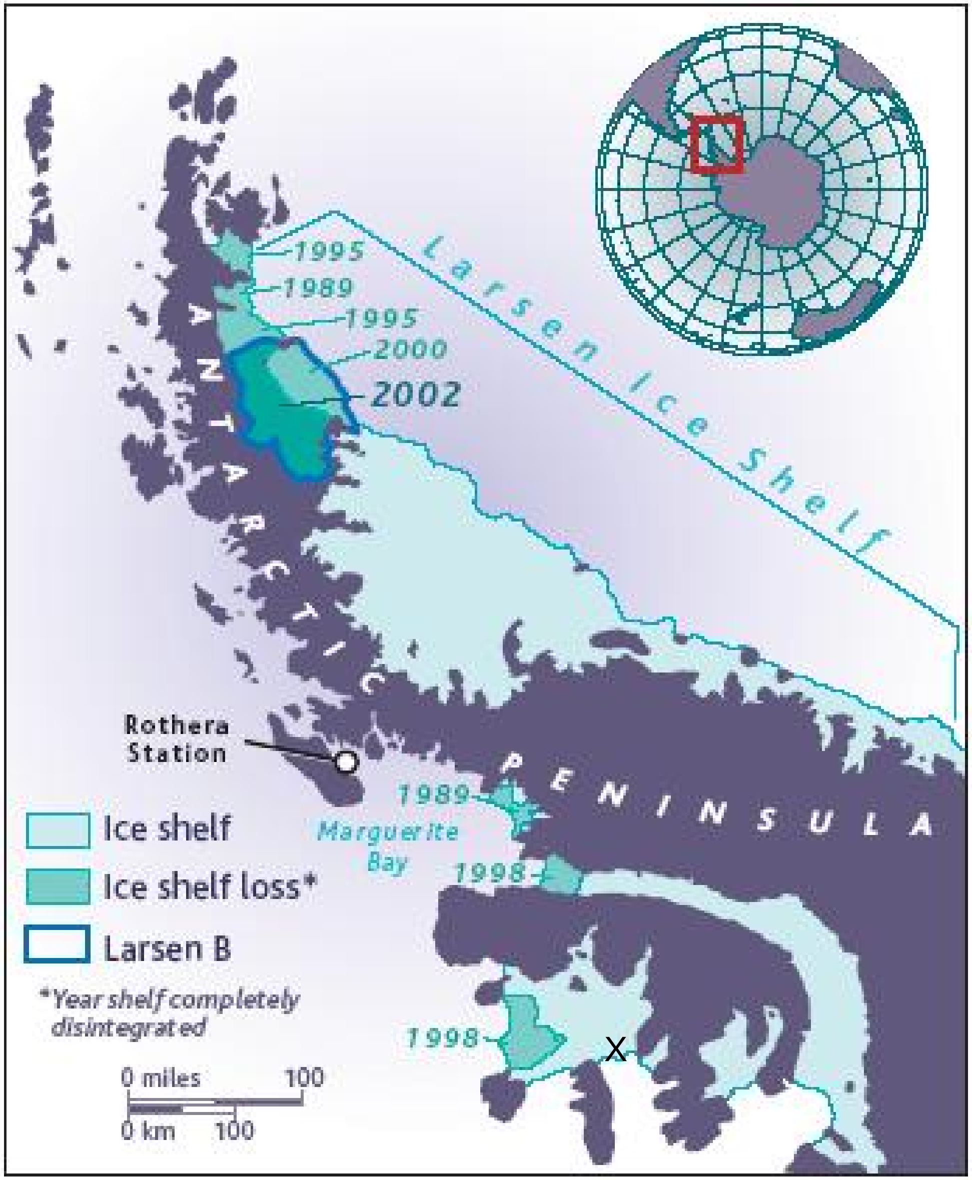
Source: Ekstrom, Nettles and Tsai, *Science*, **311**, 1756, 2006.

Exhibit 1-38

Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

Source: Prof. Konrad Steffen, Univ. of Colorado



Falling like dominoes. The Antarctic Peninsula has lost large chunks of its ice shelves to climate warming in recent years.

Successive loss of ice shelves

both sides of AA Peninsula

1. Focus on Larsen B Ice Shelf

Questions concerning cause + consequences of collapse (including acceleration of tributary glaciers and changing biological communities)

2. Paleo-perspective

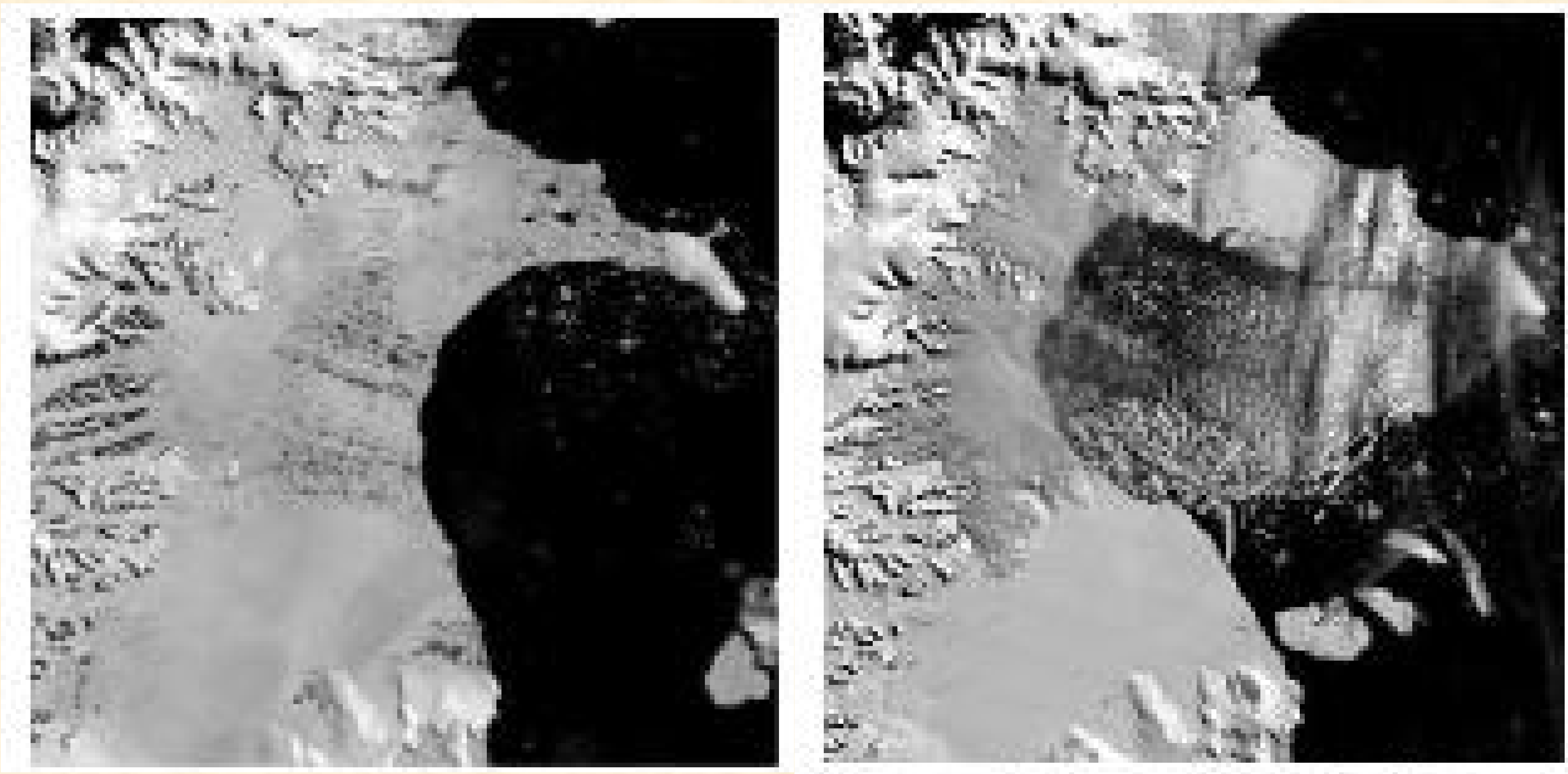
multi-proxy analytical work on sediment cores, swath bathymetry

3. Future work – International Polar Year project

Marine and Quaternary geology, glaciology, physical oceanography, biological oceanography

Kaiser, 2002, Science 297

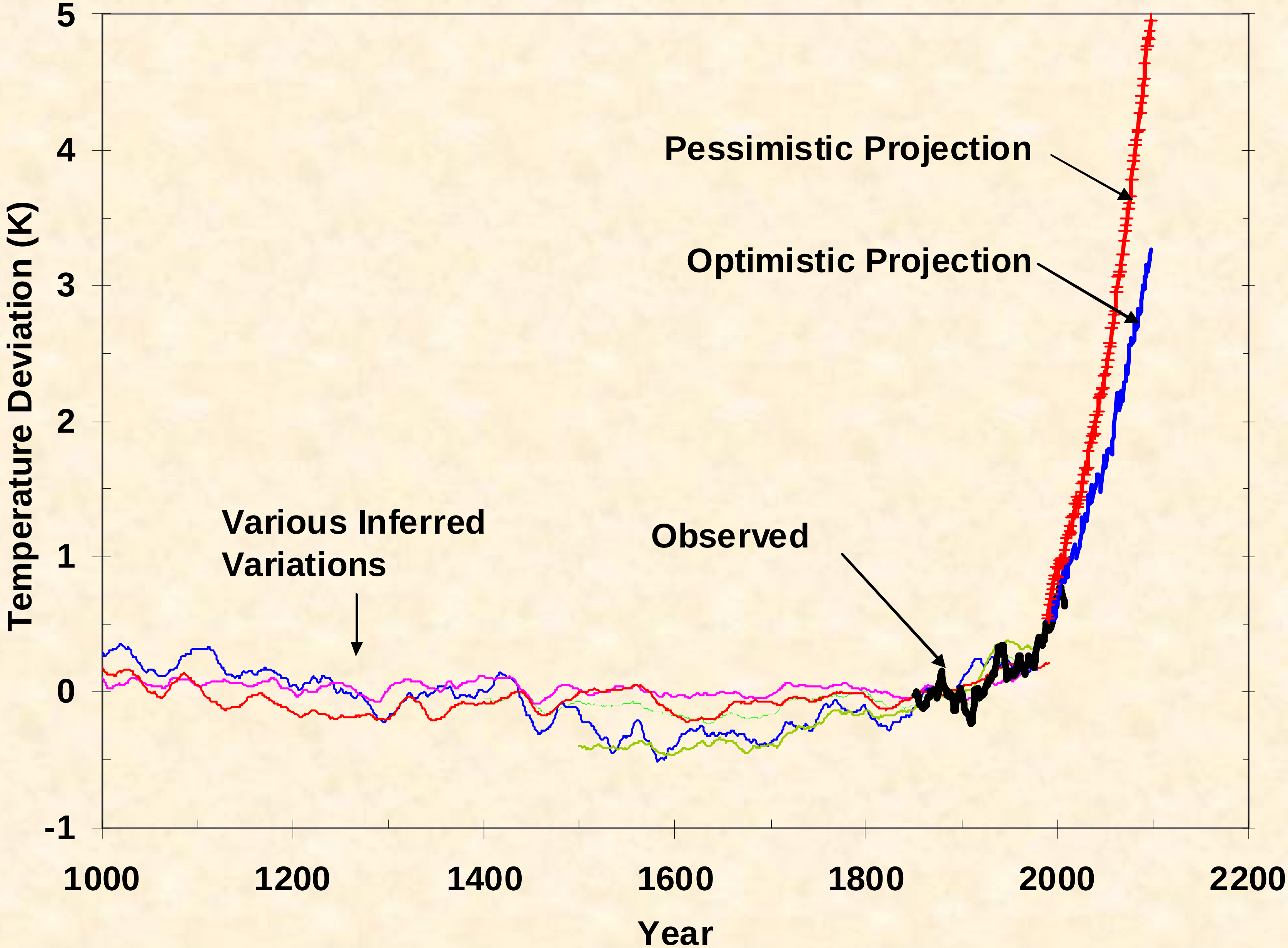
Exhibit 1-43: Loss of Larsen B Ice Shelf (15,000 km^2), between 31 Jan and 5 March 2002



Some benchmarks

- The longterm global mean warming for a CO_2 doubling, called the *climate sensitivity*, likely falls between 2°C and 4°C
- Pre-industrial CO_2 concentration was 280 ppmv; it is now 390 ppmv
- Because of the heat trapping effect of other GHGs, a CO_2 concentration of only 450 ppmv is the climatic equivalent of a CO_2 doubling (*if* there stringent reductions in emissions of non-CO_2 GHGs)

Business-as-Usual Projections of the Change in Global Mean Temperature

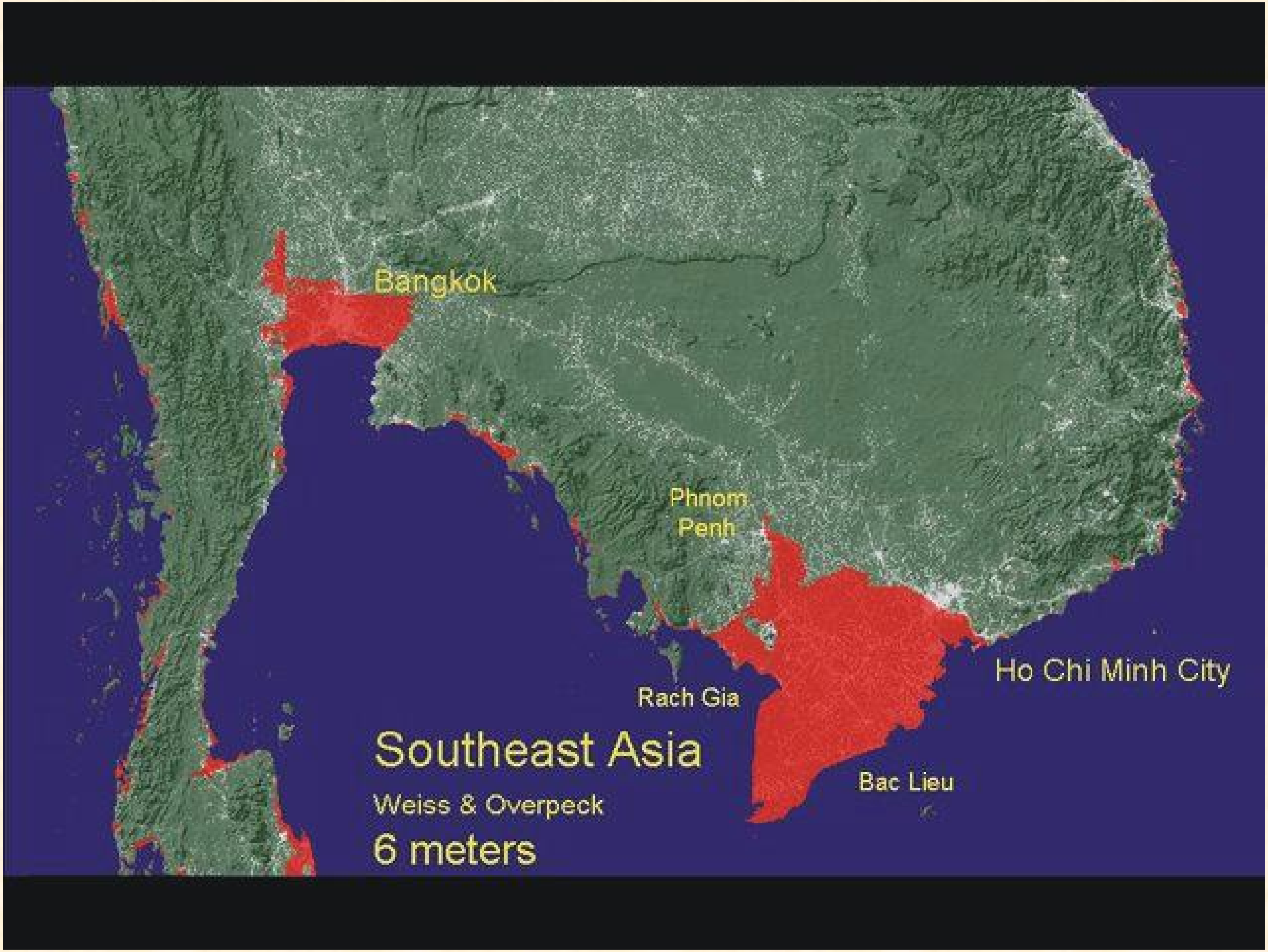


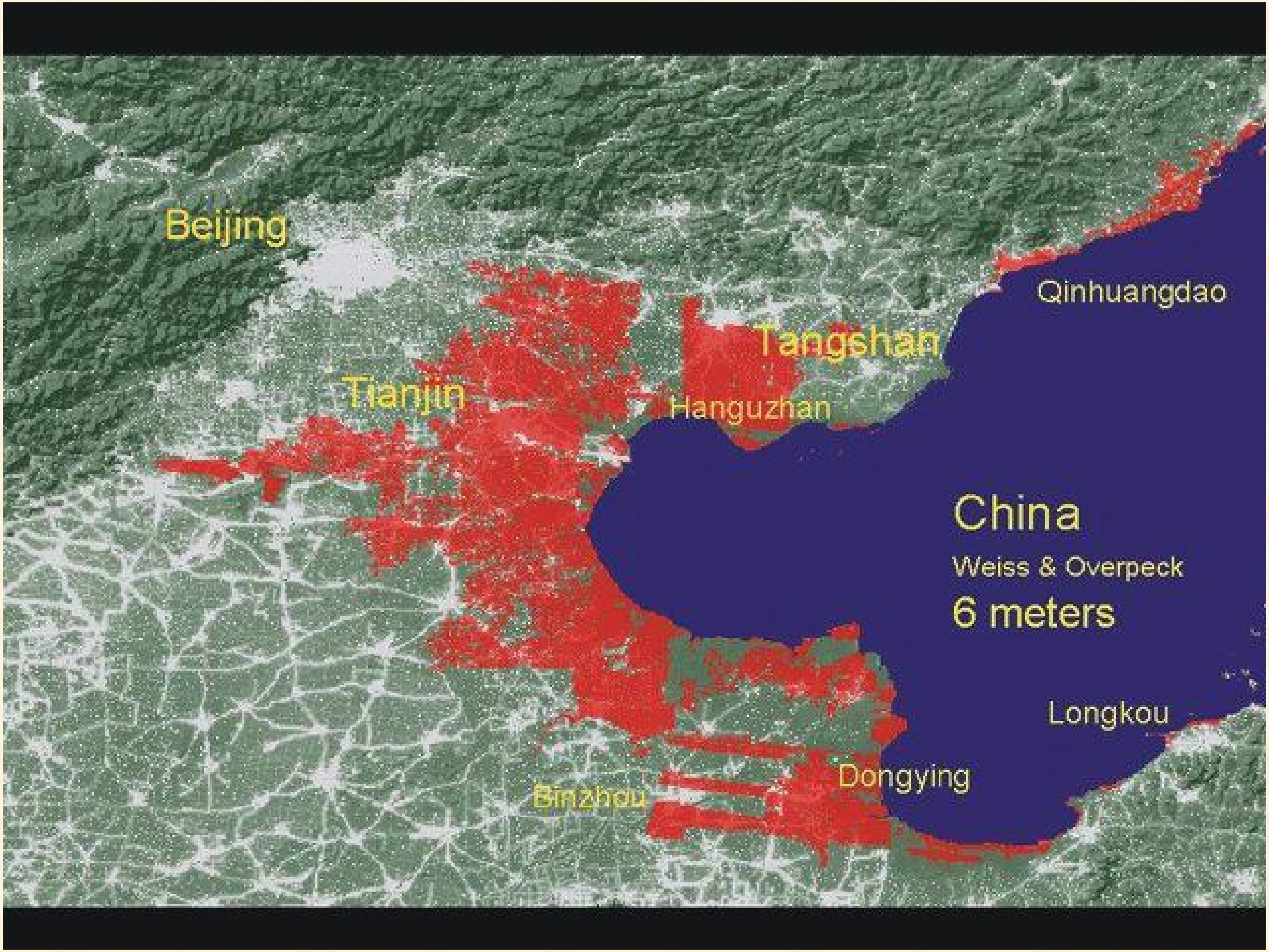
Major Impacts of Concern

- Sea level rise of 6-12 m over several centuries
- Increased occurrence of drought
- Increased water stress in vulnerable regions
- Species extinction (1/3 to ½ this century)
- Acidification of the oceans

Sea Level Rise

- The last time the world was only 1 C warmer than pre-industrial for a sustained period of time (the last interglacial), sea level was 5 m higher than today
- The last time the world was 2-3 C warmer (the Pliocene-Eocene boundary, 3 million years ago), sea level was 25 m higher than today
- The likely sea level rise during the next century (under business as usual GHG emissions) is 0.5-2.0 m


Bangkok
Phnom
Penh
Rach Gia
Ho Chi Minh City
Bac Lieu
Southeast Asia
Weiss & Overpeck
6 meters



Beijing
Qinhuangdao
Tangshan
Tianjin
Hanguzhan
China
Weiss & Overpeck
6 meters
Longkou
Dongying
Binzhou


Cancun
Puerto Morelos
Playa del Carmen
Puerto Aventuras
Tulum
Cozumel
Yucatan
Weiss & Overpeck
6 meters


West Palm Beach
Fort Meyers
Fort Lauderdale
Miami
Everglades
Key largo
Florida
Weiss & Overpeck
6 meters
Key West


Manhattan
Jersey
City
Queens
New York City
Weiss & Overpeck
6 meters

Mangroves – threatened by rapid sea level rise

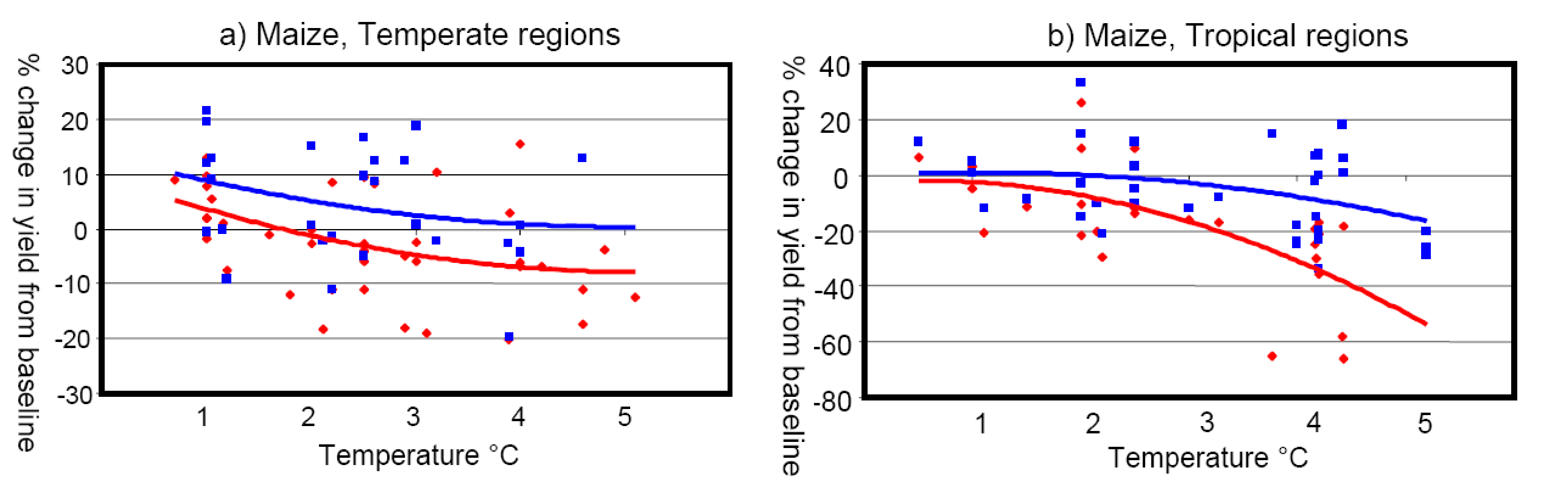
Emerging from the embrace of a mangrove tree–lined channel in northern Brazil, these pescadores, like coastal fishers worldwide, know that healthy mangroves mean good fishing and a secure livelihood.

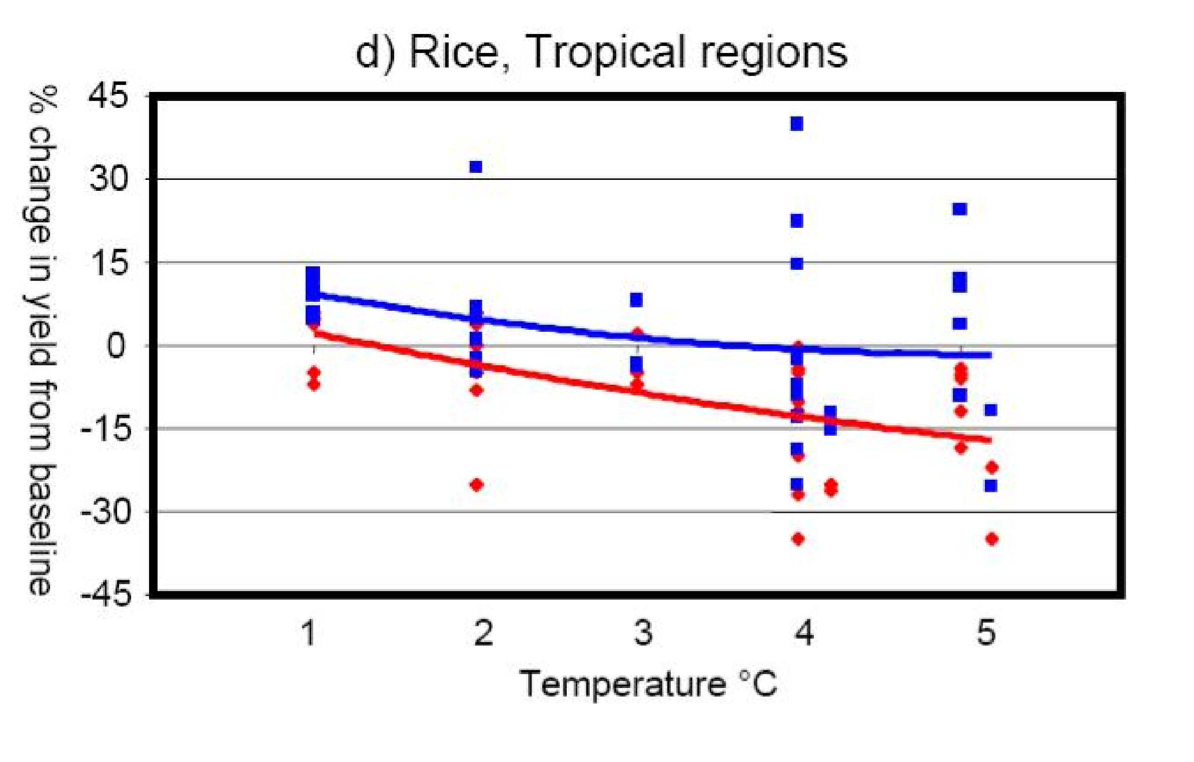
ECOLOGY

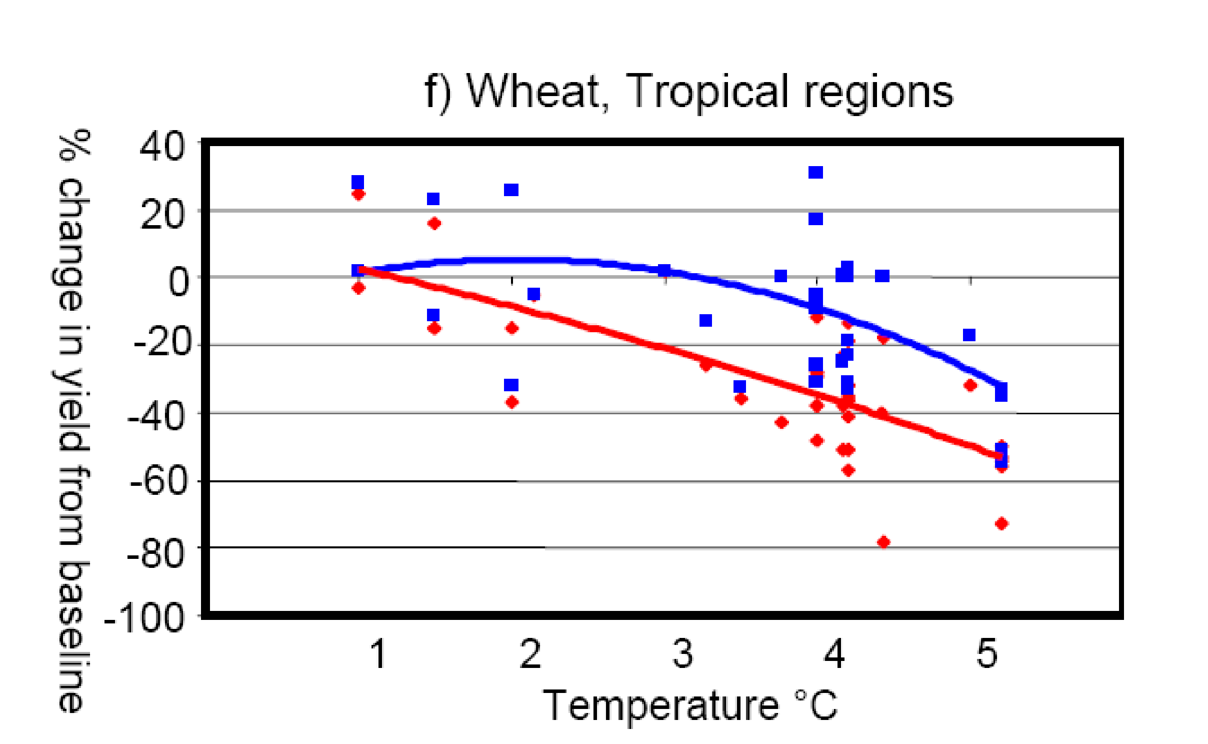
Climate Change and Crop Yields: Beyond Cassandra

An analysis of recent data from a wide variety of field experiments suggests that previous studies overestimated the positive effects of higher carbon dioxide concentrations on crop yields.

David Schimel

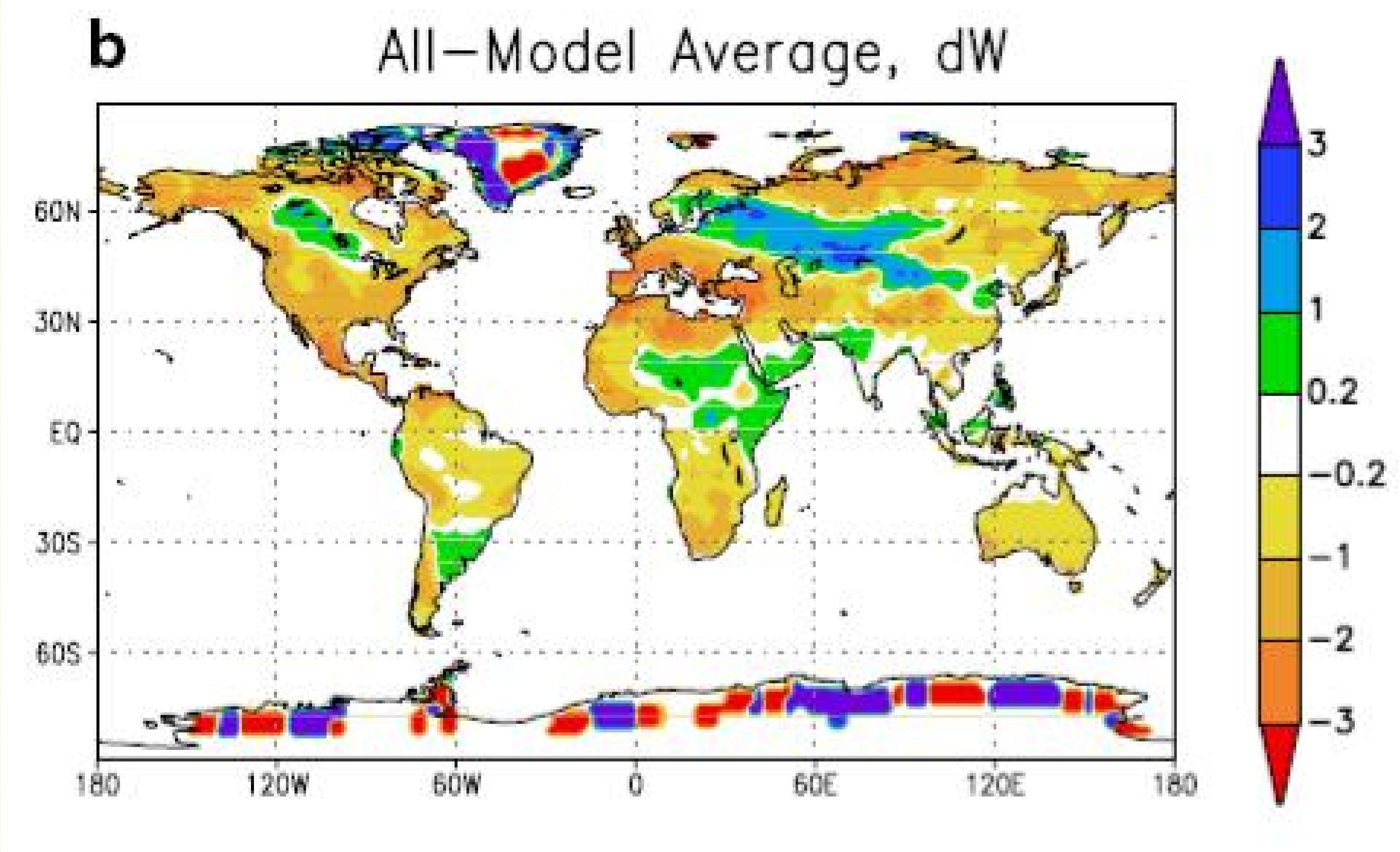



d) Rice, Tropical regions
% change in yield from baseline
45
30
15
0
-15
-30
-45
1
2
3
4
5
Temperature °C


f) Wheat, Tropical regions
% change in yield from baseline
40
20
0
-20
-40
-60
-80
-100
1
2
3
4
5
Temperature °C

Guiling Wang

Agricultural drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment



June–July–August season

Climate Dynamics (2005) 25: 739–753
DOI 10.1007/s00382-005-0057-9

REVIEWS

Potential impacts of a warming climate on water availability in snow-dominated regions

T. P. Barnett[1], J. C. Adam[2] & D. P. Lettenmaier[2]

All currently available climate models predict a near-surface warming trend under the influence of rising levels of greenhouse gases in the atmosphere. In addition to the direct effects on climate—for example, on the frequency of heatwaves—this increase in surface temperatures has important consequences for the hydrological cycle, particularly in regions where water supply is currently dominated by melting snow or ice. In a warmer world, less winter precipitation falls as snow and the melting of winter snow occurs earlier in spring. Even without any changes in precipitation intensity, both of these effects lead to a shift in peak river runoff to winter and early spring, away from summer and autumn when demand is highest. Where storage capacities are not sufficient, much of the winter runoff will immediately be lost to the oceans. With more than one-sixth of the Earth's population relying on glaciers and seasonal snow packs for their water supply, the consequences of these hydrological changes for future water availability—predicted with high confidence and already diagnosed in some regions—are likely to be severe.

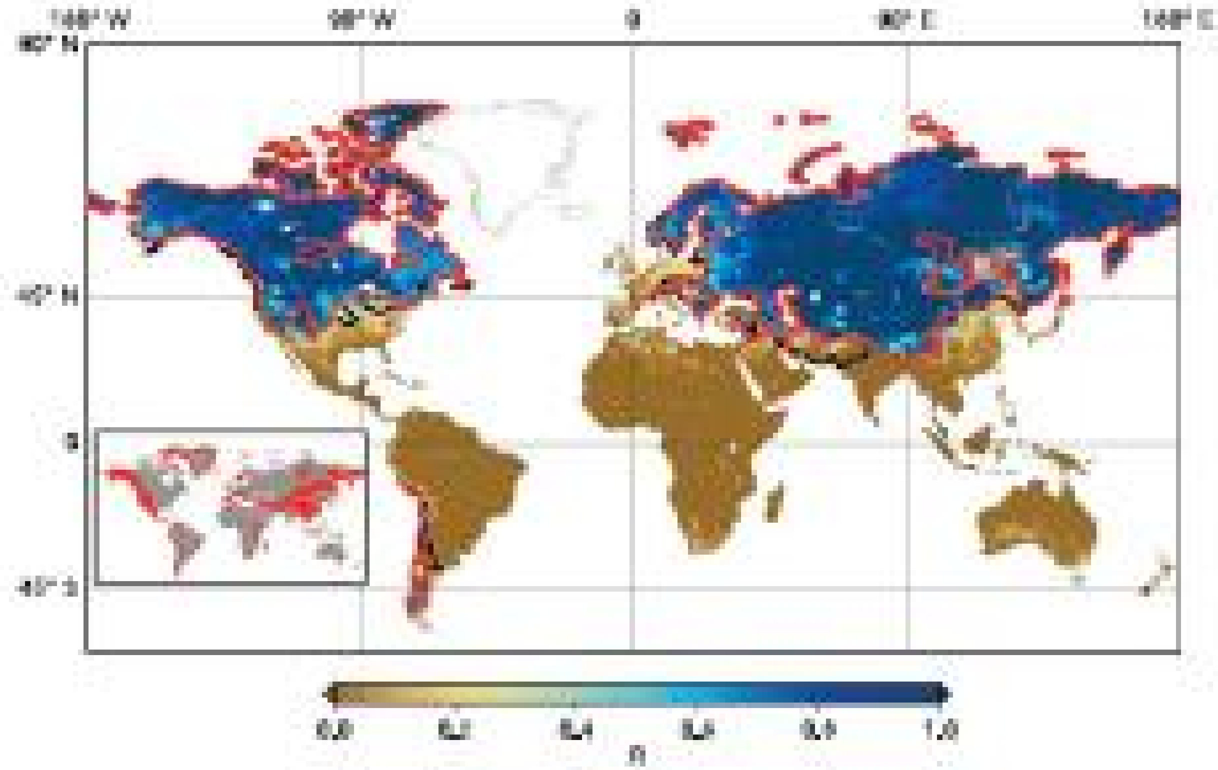


Figure 1 | Accumulated annual snowfall divided by annual runoff over the global land regions. The value of this dimensionless ratio lies between 0 and 1 and is given by the colour scale, R. The red lines indicate the regions where streamflow is snowmelt-dominated, and where there is not adequate reservoir storage capacity to buffer shifts in the seasonal hydrograph. The black lines indicate additional areas where water availability is predominantly influenced by snowmelt generated upstream (but runoff generated within these areas is not snowmelt-dominated). The inset shows regions of the globe that have complex topography using the criterion of ref. 17.

Glaciers in the Himalaya occupy 17% of the mountain area.
They are retreating faster than anywhere else in the world.
They could be largely gone by 2035 (80% loss compared to present).
The Indus, Ganges, and Bahmaputra rivers could all become seasonally dry, affecting 50 million people in India and more in Pakistan.

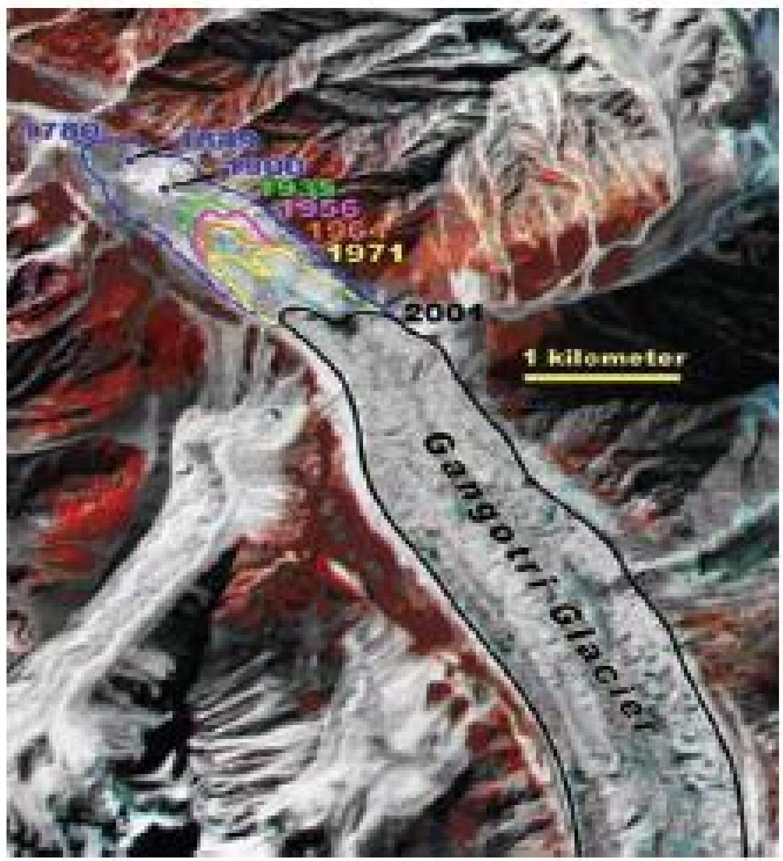


Figure 10.6. *Composite satellite image showing how the Gangotri Glacier terminus has retracted since 1780 (courtesy of NASA EROS Data Center, 9 September 2001).*

Extinction risk from climate change

Chris D. Thomas[1], Alison Cameron[1], Rhys E. Green[2], Michel Bakkenes[3], Linda J. Beaumont[4], Yvonne C. Collingham[5], Barend F. N. Erasmus[6], Marinez Ferreira de Siqueira[7], Alan Grainger[8], Lee Hannah[9], Lesley Hughes[4], Brian Huntley[5], Albert S. van Jaarsveld[10], Guy F. Midgley[11], Lera Miles[8*], Miguel A. Ortega-Huerta[12], A. Townsend Peterson[13], Oliver L. Phillips[8] & Stephen E. Williams[14]

Climate change over the past ~30 years has produced numerous shifts in the distributions and abundances of species[1,2] and has been implicated in one species-level extinction[3]. Using projections of species' distributions for future climate scenarios, we assess extinction risks for sample regions that cover some 20% of the Earth's terrestrial surface. Exploring three approaches in which the estimated probability of extinction shows a power-law relationship with geographical range size, we predict, on the basis of mid-range climate-warming scenarios for 2050, that 15–37% of species in our sample of regions and taxa will be 'committed to extinction'. When the average of the three methods

Climate and amphibian declines

J. Alan Pounds

Various reasons have been proposed for the falling numbers of amphibians in many parts of the world. Changing climate is likely to be a key factor — but with complicated links to the immediate causes of these population declines.

EXTINCTIONS

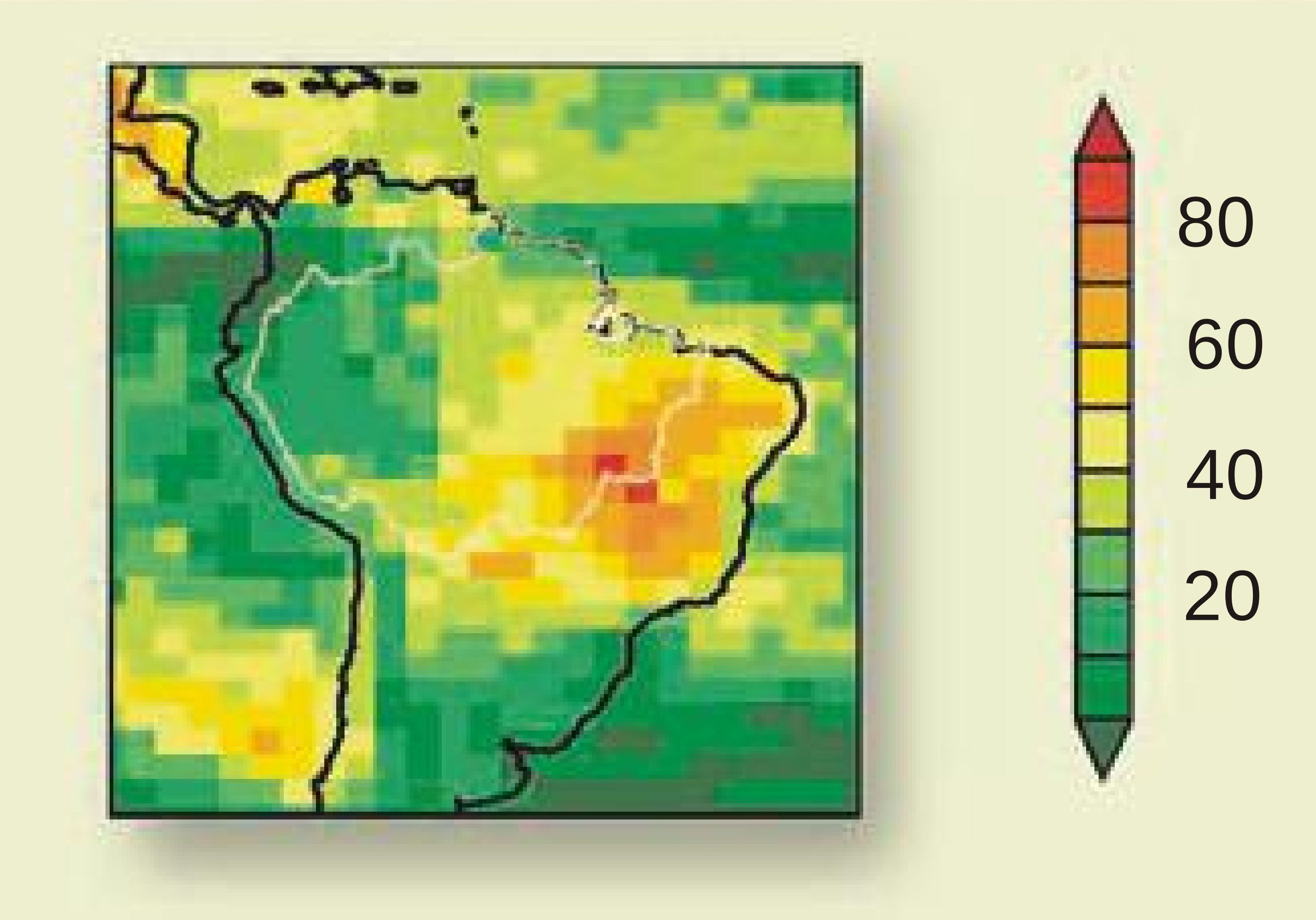
A message from the frogs

Andrew R. Blaustein and Andy Dobson

The harlequin frogs of tropical America are at the sharp end of climate change. About two-thirds of their species have died out, and altered patterns of infection because of changes in temperature seem to be the cause.

Figure 1 | Amphibian alarm call. The Panamanian golden frog is one of roughly 110 species of harlequin frog (*Atelopus*), many of which are dying out. Although this species still survives, its numbers have fallen significantly.

Probability of > 20% decrease in dry season (SH) rainfall by 2080-2100



SICK SEAS

The rising level of carbon dioxide in the atmosphere is making the world's oceans more acidic. **Jacqueline Ruttimann** reports on the potentially catastrophic effect this could have on marine creatures.

It's not hard to imagine a tonne of water: it is a week's worth of not-very-deep baths. Getting to grips with a billion tonnes of water is more of a challenge. That would be a similar bath for every man, woman and child on the planet; a week's worth of flow for the Nile. To really expand your mind, go further still, to a billion billion tonnes — enough water to give every human a day's worth of the Nile instead of a shallow bath. There are dwarf planets that weigh less than a billion billion tonnes. Yet Earth's oceans weigh more.

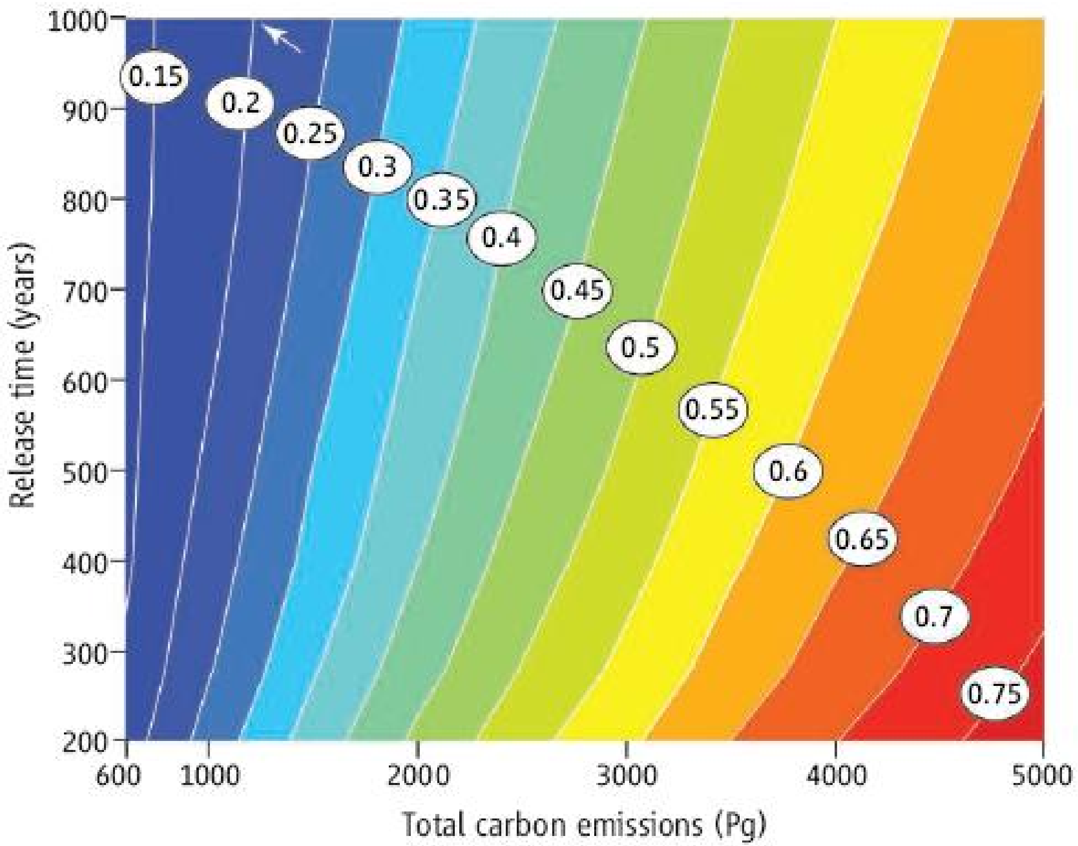
If it is hard to imagine something so vast, it is perhaps even harder to imagine changing it. But humanity is changing the oceans. From the tropics to the Arctic, the seas are sucking up human-driven emissions of carbon dioxide — about half of the excess belched into the atmosphere over the past two centuries from fossil-fuel burning and cement manufacturing plants[1]. When carbon dioxide dissolves in water, carbonic acid is produced: as a result the oceans are becoming more acidic. "It's basic chemistry," says Joanie Kleypas, a marine ecologist at the National Center for Atmospheric Research in Boulder, Colorado. "It's hard to say unprecedented. Before the industrial revolution, the rise in the level of carbon dioxide in the atmosphere was relatively slow — giving oceans time to circulate the waters being made more acidic in the shallows with acid-neutralizing carbonate sediments in the depths.

In the past few decades, carbon dioxide has been building up far more quickly, and the ocean is becoming acidified at a rate that outpaces the action of sedimentary antacids. The rate of change is perhaps 100 times anything seen in the past hundreds of millennia, as suggested by isotope studies of ancient sediments. In the century to come, sea creatures will find themselves in conditions that their ancestors never had to face. These organisms have never been forced to adapt to lower pH, says Ulf Riebesell, a marine biogeochemist at the Leibniz Institute for Marine Sciences in Germany. "They've never seen this before in their evolution."

Acid attack

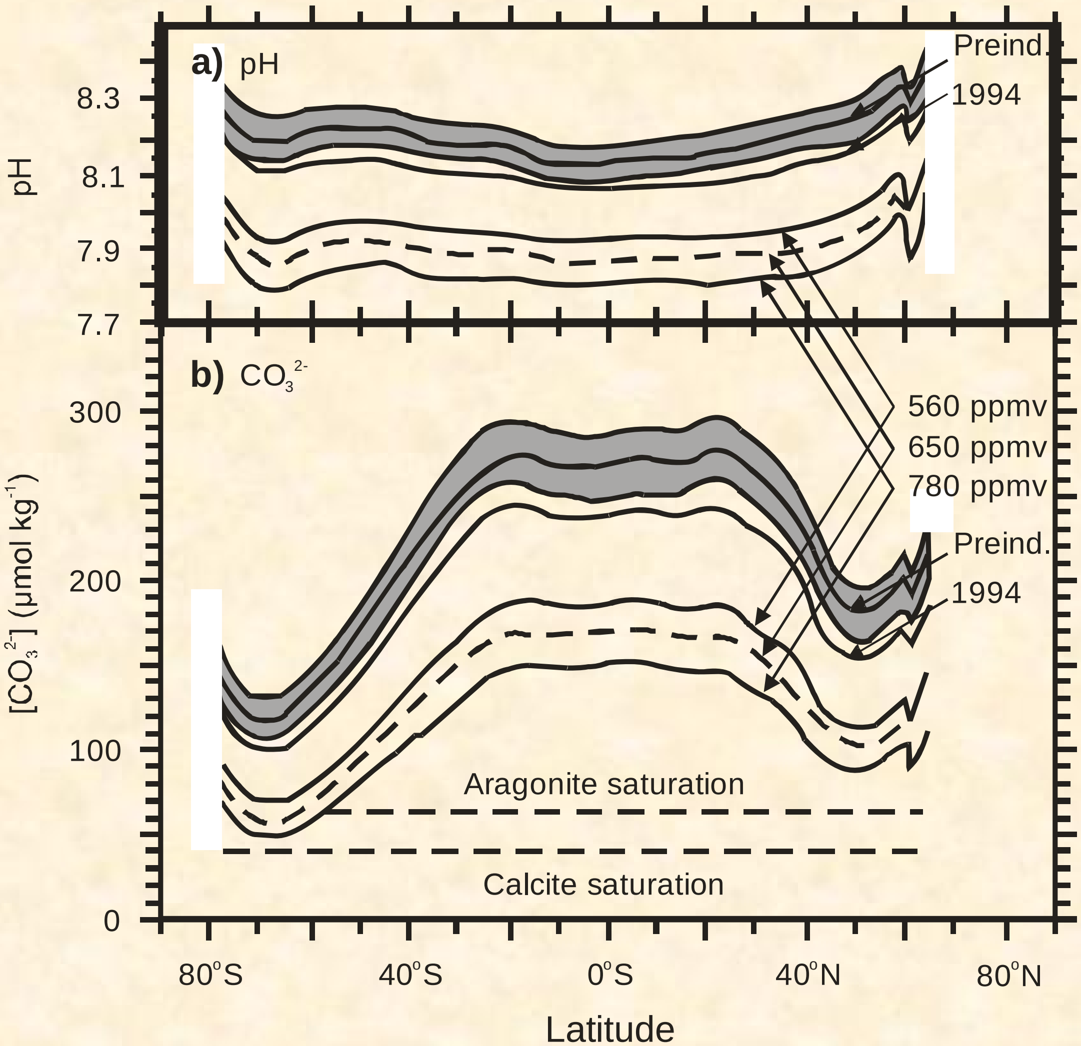
The acidified waters eat away at the carbonate skeletons that protect many marine organisms. By some estimates, calcification rates will

Decrease in pH of ocean surface waters

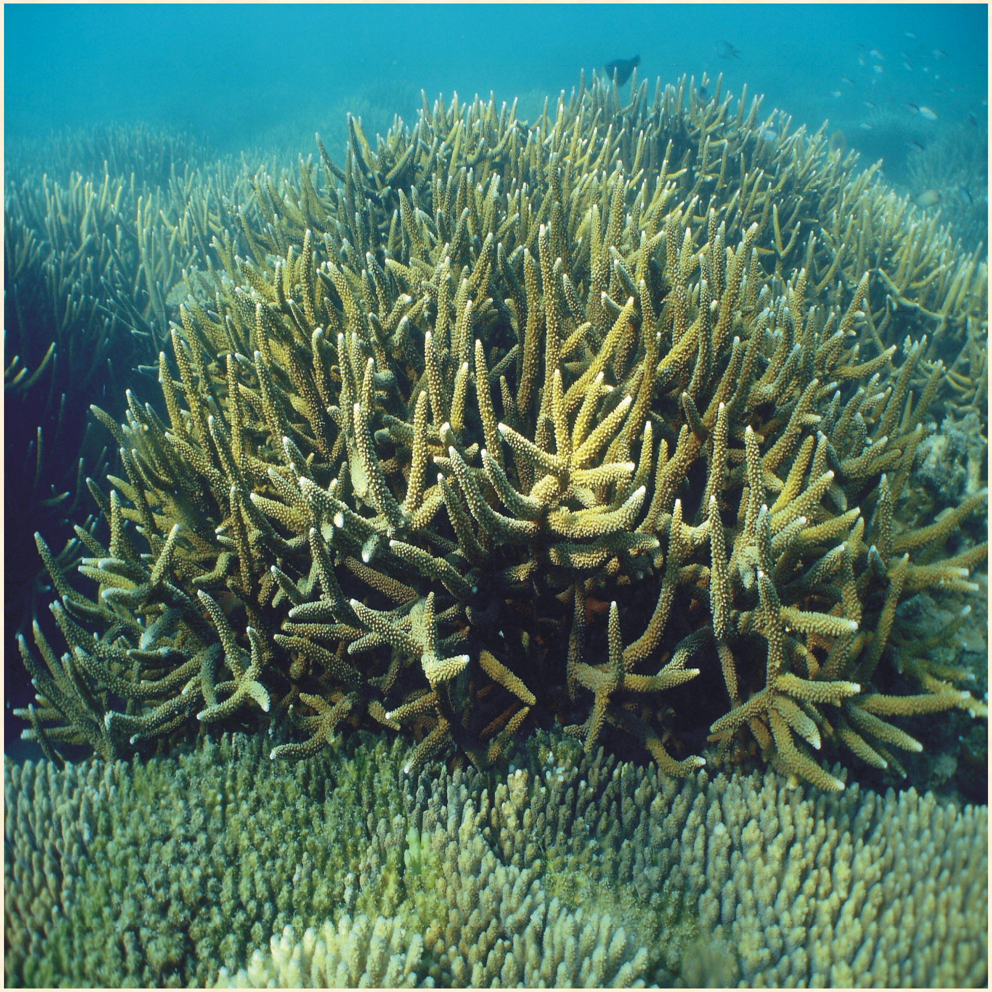


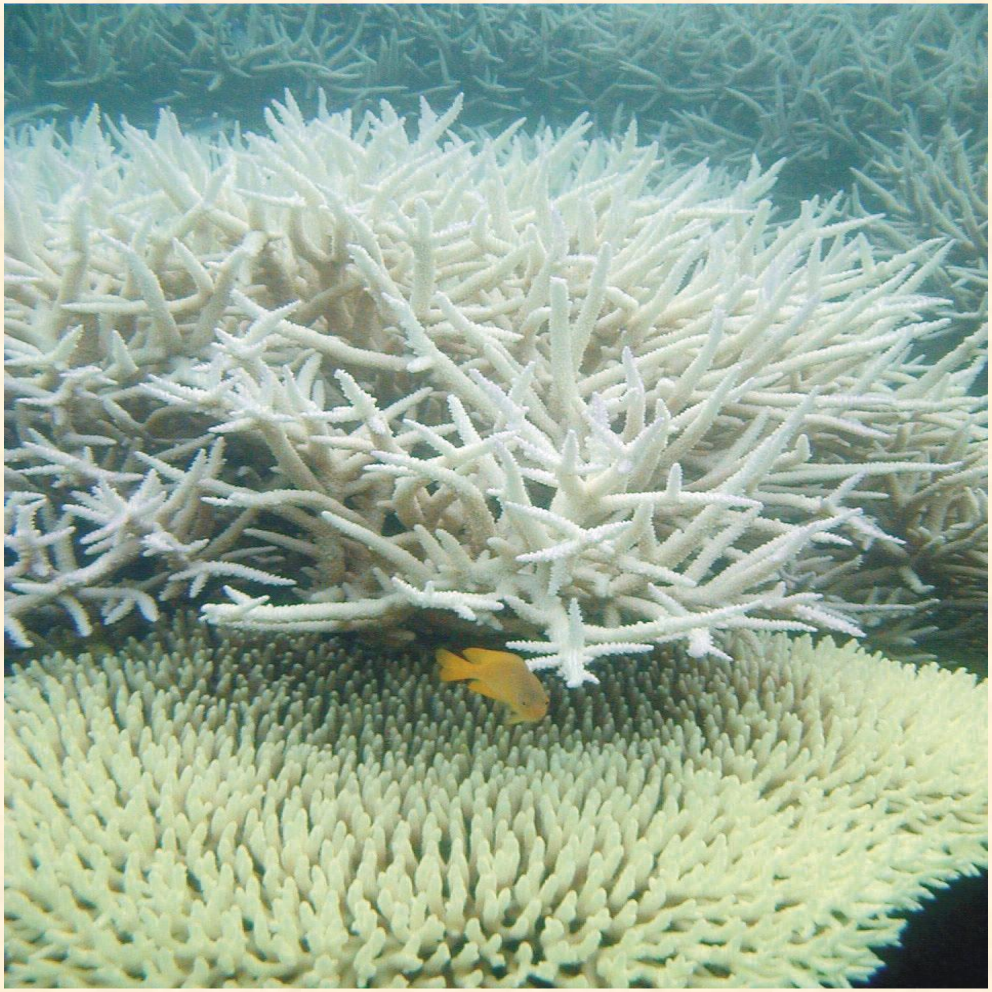
Surface ocean pH decline. The white contour lines illustrate the expected maximum pH decrease of average surface ocean waters in the future (in pH units) as a function of total anthropogenic CO_2 emissions (in petagrams of carbon, 1 Pg = 10^{15} g) and release time (in years, see supporting online material). For example, if humans release a total of 1200 Pg C over 1000 years, surface ocean pH will drop by about 0.2 units (arrow).

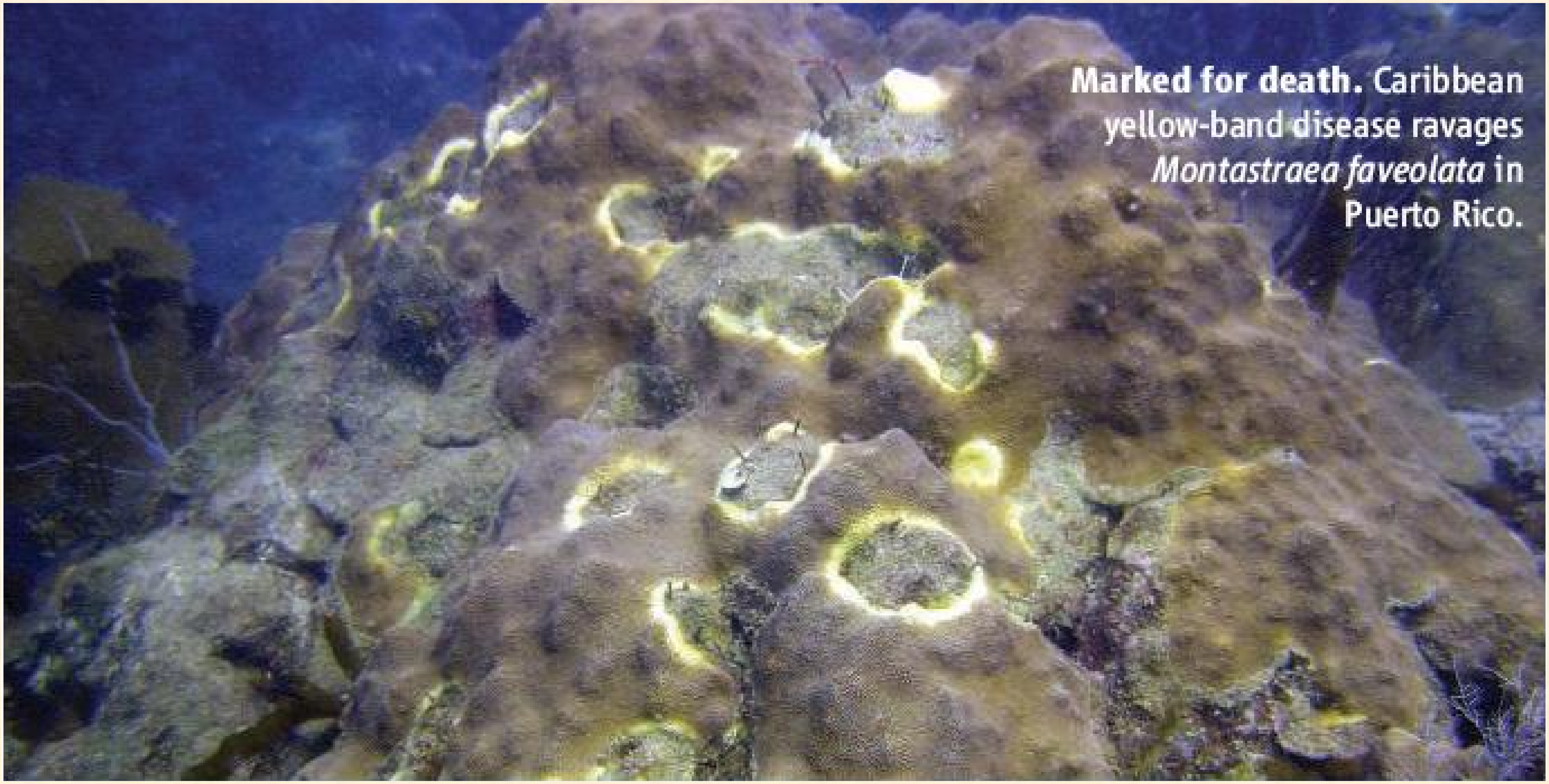
Decrease in pH and carbonate supersaturation of surface ocean waters



Staghorn Acropora Coral Before and After Bleaching

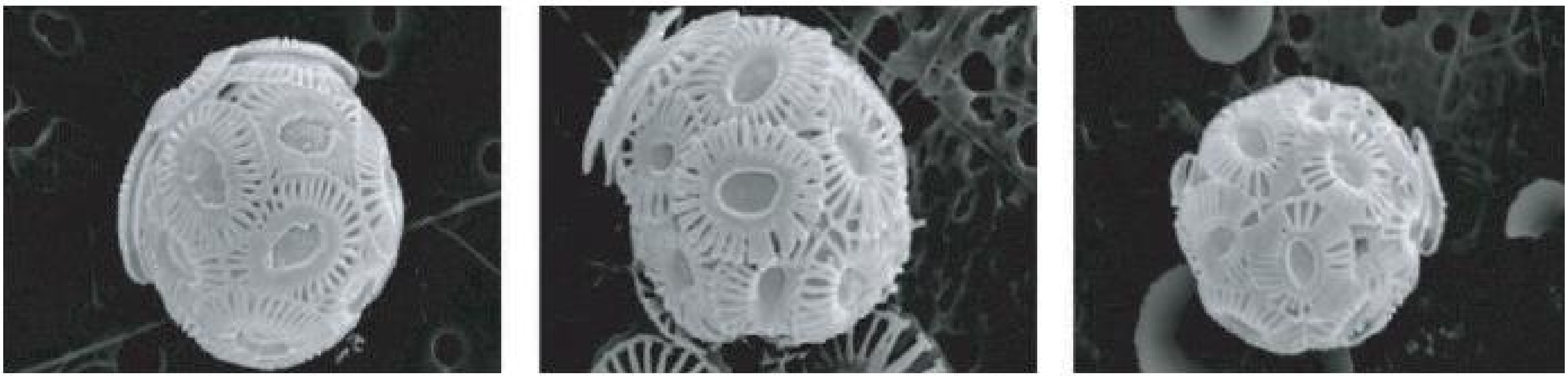






(Science 318:1716)

Dissolution effects on coccoliths

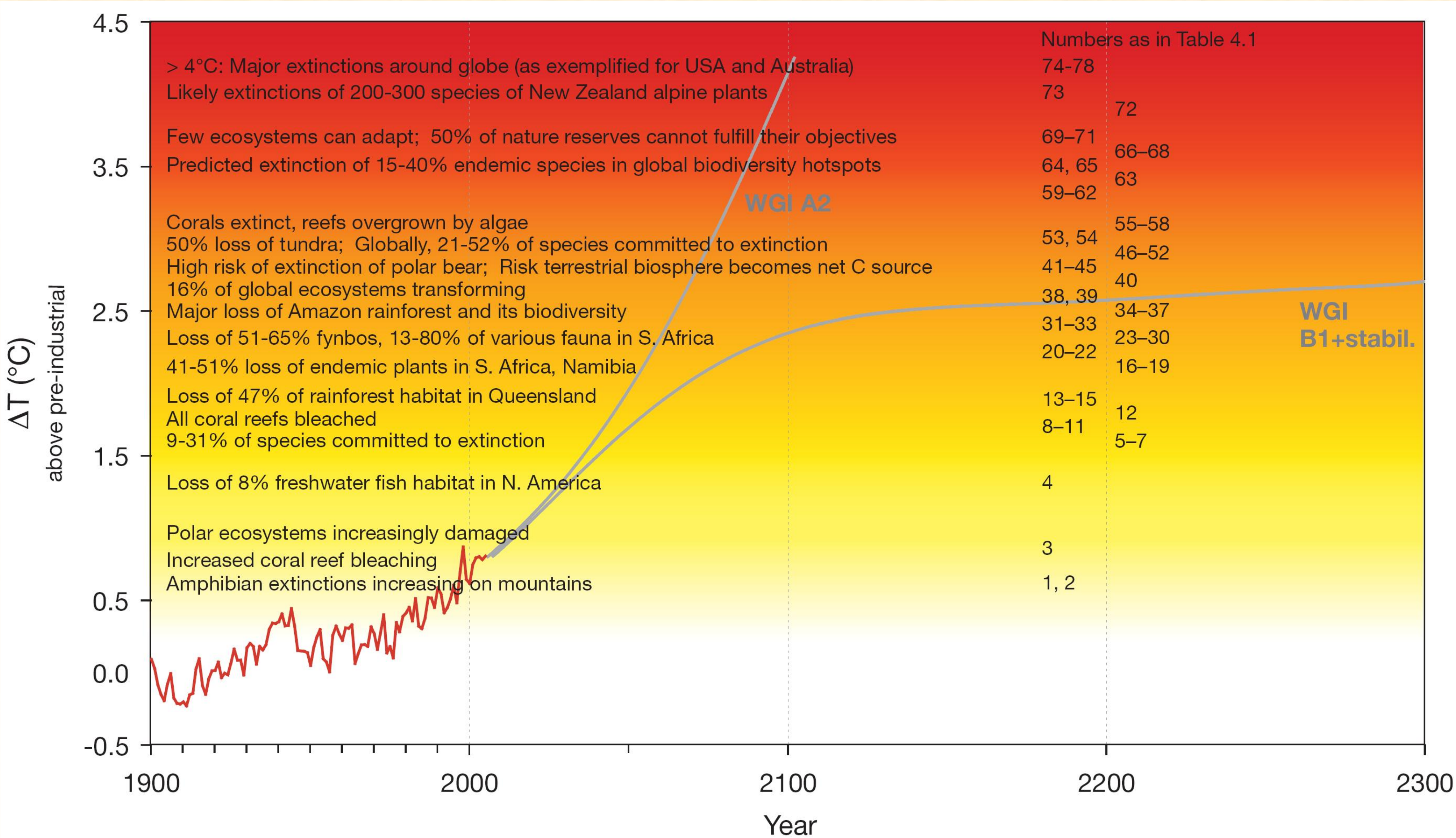


Lost protection: making sea water more acidic (centre and right) dissolves the outer casings of coccolithophores, tiny plankton that form the basis of food webs.

Table 10.6. *The 2004 status of coral reefs in selected regions of Asia (Wilkinson, 2004).*

Region	Coral reef area (km²)	Destroyed reefs (%)	Reefs recovered since 1998 (%)	Reefs at critical stage (%)	Reefs at threatened stage (%)	Reefs at low or no threat level (%)
Red Sea	17,640	4	2	2	10	84
The Gulfs	3,800	65	2	15	15	5
South Asia	19,210	45	13	10	25	20
S-E Asia	91,700	38	8	28	29	5
E & N Asia	5,400	14	3	23	12	51
Total	137,750	34.4	7.6	21.6	25.0	19.0
Asia	(48.4%)					

Note: Destroyed reefs: 90% of the corals lost and unlikely to recover soon; Reefs at a critical stage: 50% to 90% of corals lost or likely to be destroyed in 10 to 20 years; Reefs at threatened stage: 20 to 50% of corals lost or likely to be destroyed in 20 to 40 years.



Numbers as in Table 4.1
> 4°C: Major extinctions around globe (as exemplified for USA and Australia) 74-78
Likely extinctions of 200-300 species of New Zealand alpine plants 73
72
Few ecosystems can adapt; 50% of nature reserves cannot fulfill their objectives 69–71
66–68
Predicted extinction of 15-40% endemic species in global biodiversity hotspots 64, 65
63
59–62
WGI A2
Corals extinct, reefs overgrown by algae
55–58
50% loss of tundra; Globally, 21-52% of species committed to extinction 53, 54
46–52
High risk of extinction of polar bear; Risk terrestrial biosphere becomes net C source 41–45
40
16% of global ecosystems transforming 38, 39
Major loss of Amazon rainforest and its biodiversity 34–37
31–33
Loss of 51-65% fynbos, 13-80% of various fauna in S. Africa 23–30
20–22
41-51% loss of endemic plants in S. Africa, Namibia 16–19
Loss of 47% of rainforest habitat in Queensland 13–15
All coral reefs bleached 12
8–11
9-31% of species committed to extinction 5–7
Loss of 8% freshwater fish habitat in N. America 4
Polar ecosystems increasingly damaged
Increased coral reef bleaching 3
Amphibian extinctions increasing on mountains 1, 2
WGI
B1+stabil.
ΔT (°C)
above pre-industrial
4.5
3.5
2.5
1.5
0.5
0.0
-0.5
1900
2000
2100
2200
2300
Year

Methane release from melting yedoma soils in Siberia

Fire and ice: decomposition under thaw lakes is releasing large amounts of methane, which bubbles to the surface and adds to carbon emissions.

Analogies to the sinking of the Titanic

- Clear warnings of icebergs were ignored
- The captain was more interested in charging ahead at full speed
- By the time the ice bergs were sighted, it was too late to avoid a collision (due to the momentum of the ship)
- With a coordinated response, many people who died could have been saved
- For quite some time after hitting the iceberg, there was no noticeable sinking of the ship – the dire emergency was not immediately evident

- Clear warnings of risks were ignored
- The captains of industry were more interested in charging ahead (economic growth above all else)
- By the time effects are clearly discernable (i.e., now), it is too late to prevent significant losses (due to the momentum of the energy and climate systems)
- With a timely and coordinated response, much can still be saved
- The fact that we are in an emergency situation, which requires an emergency response, is still not evident to most people

Current approaches:

- Revival of nuclear energy
- Biofuels
- C sequestration
- Assume continued exponential growth in GDP/person
- No efforts to limit population growth

Figure 8.28 Distribution of "identified" uranium resources with respect to the ore grade

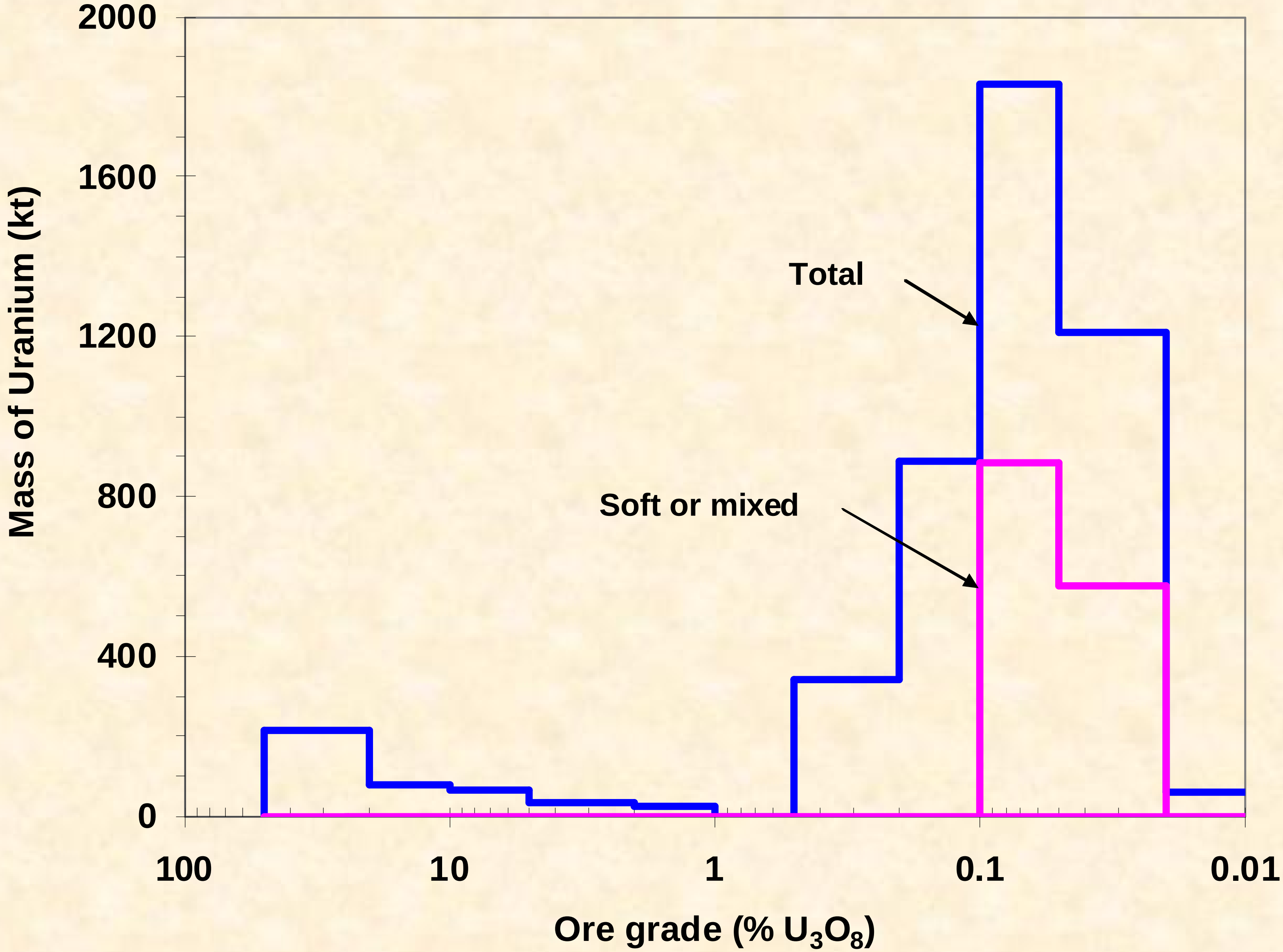


Figure 8.29 Cost of uranium vs the grade of ore supplying the uranium

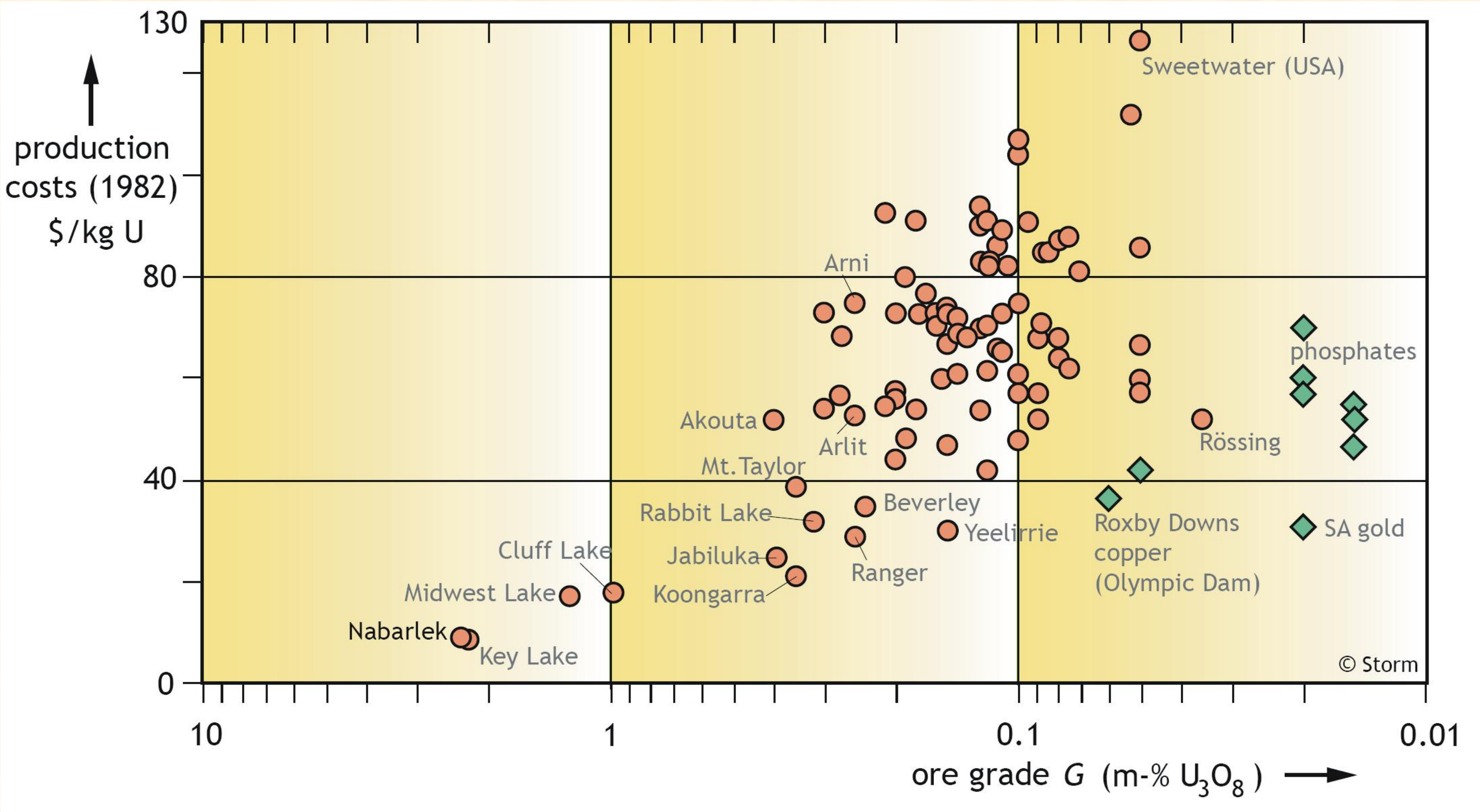


Figure 8.22a EROEI based on secondary energy for the nuclear powerplant featured in Fig. 8.21

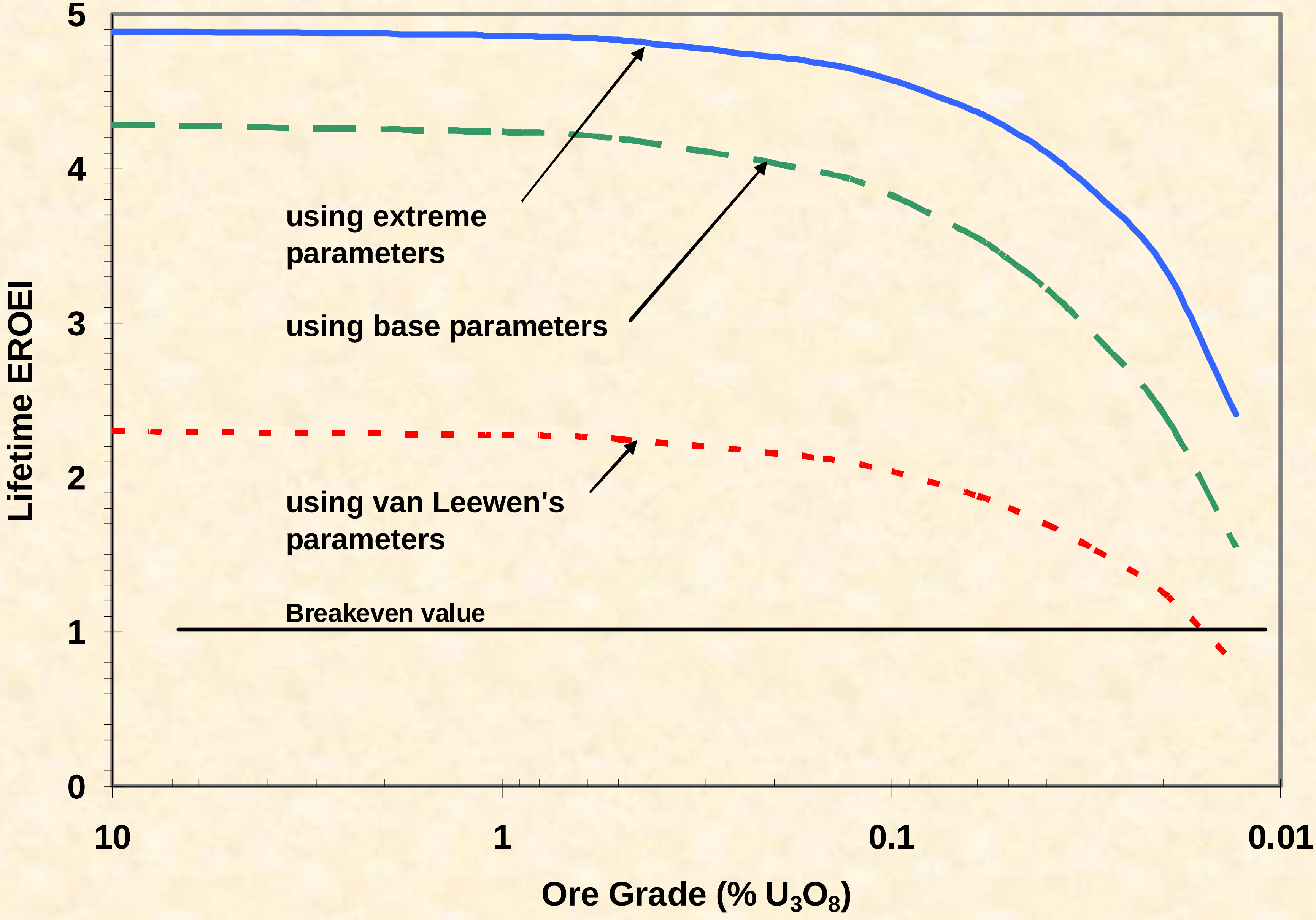


Figure 8.16 Capital cost of nuclear power plants

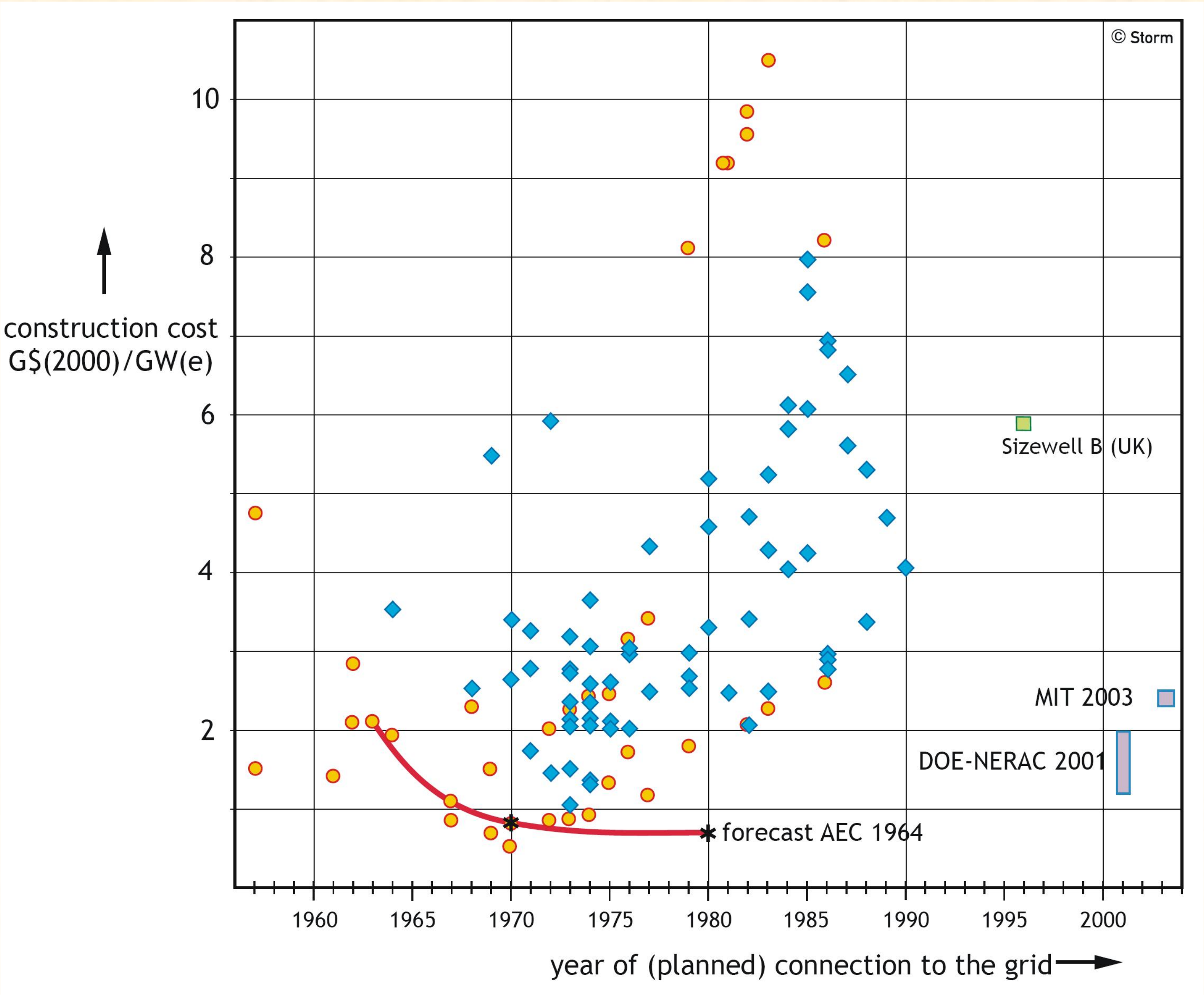
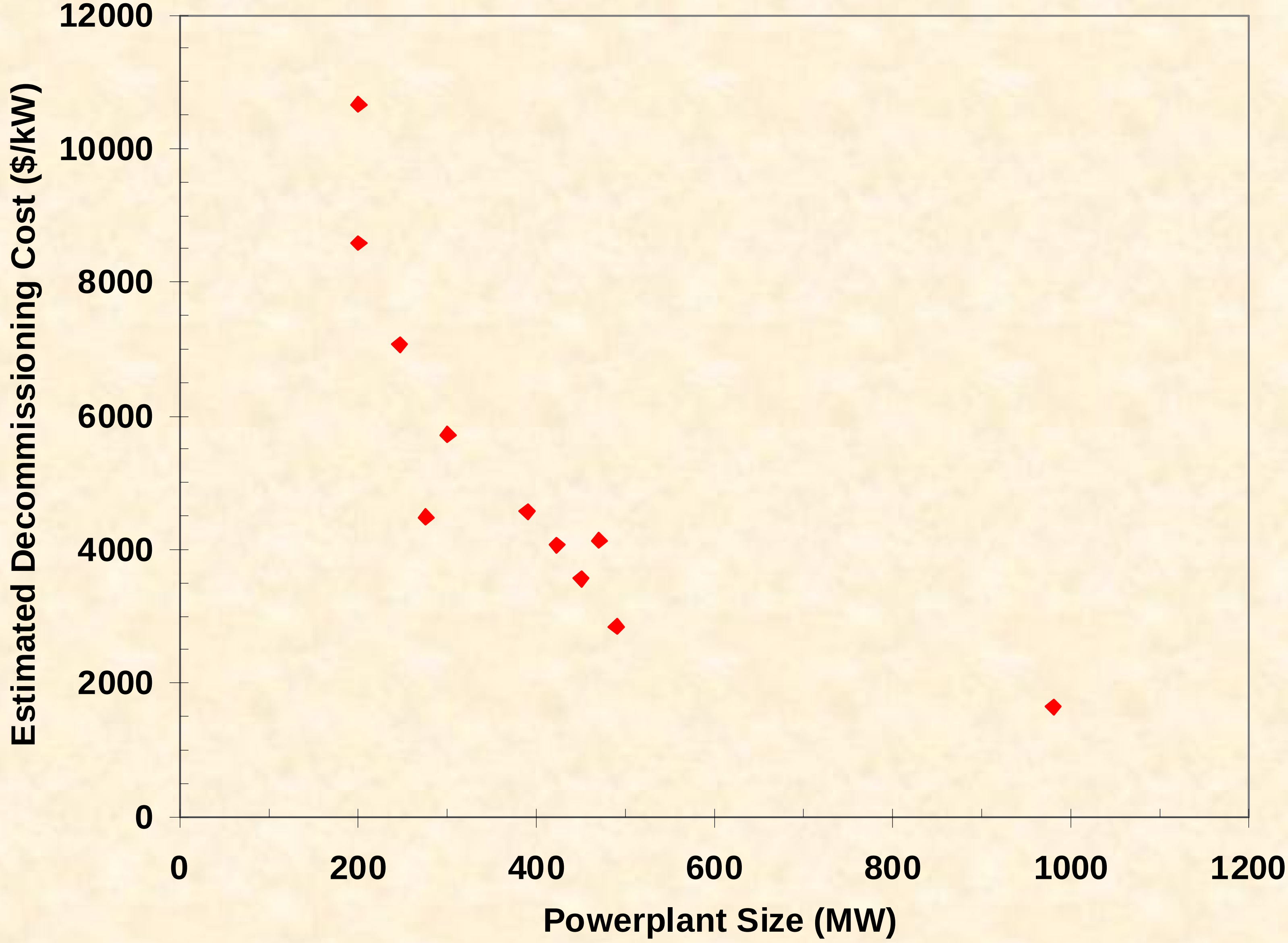


Figure 8.17: Estimated cost of decommissioning graphite-moderated nuclear power plants in the UK



What Environmental Groups Should be Advocating:

- At least a DOUBLING of the fuel economy standards for automobiles+light trucks (to 50 mpg average)
- A massive strengthening of the energy performance requirements of buildings (or adoption of stringent energy performance requirements in states where there are none) – eventually 3-4 times better than present requirements
- A national program of building retrofits (if there is any money left!)
- Investments in urban rapid transit systems
- Development of a North American HVDC power grid to permit the integration of wind, solar thermal-electricity, hydro-electric, and geothermal power so as to get coal off the grid in 30 years
- Low-meat or even vegetarian diets (swamps the effect of all other things together over which individuals have direct control)

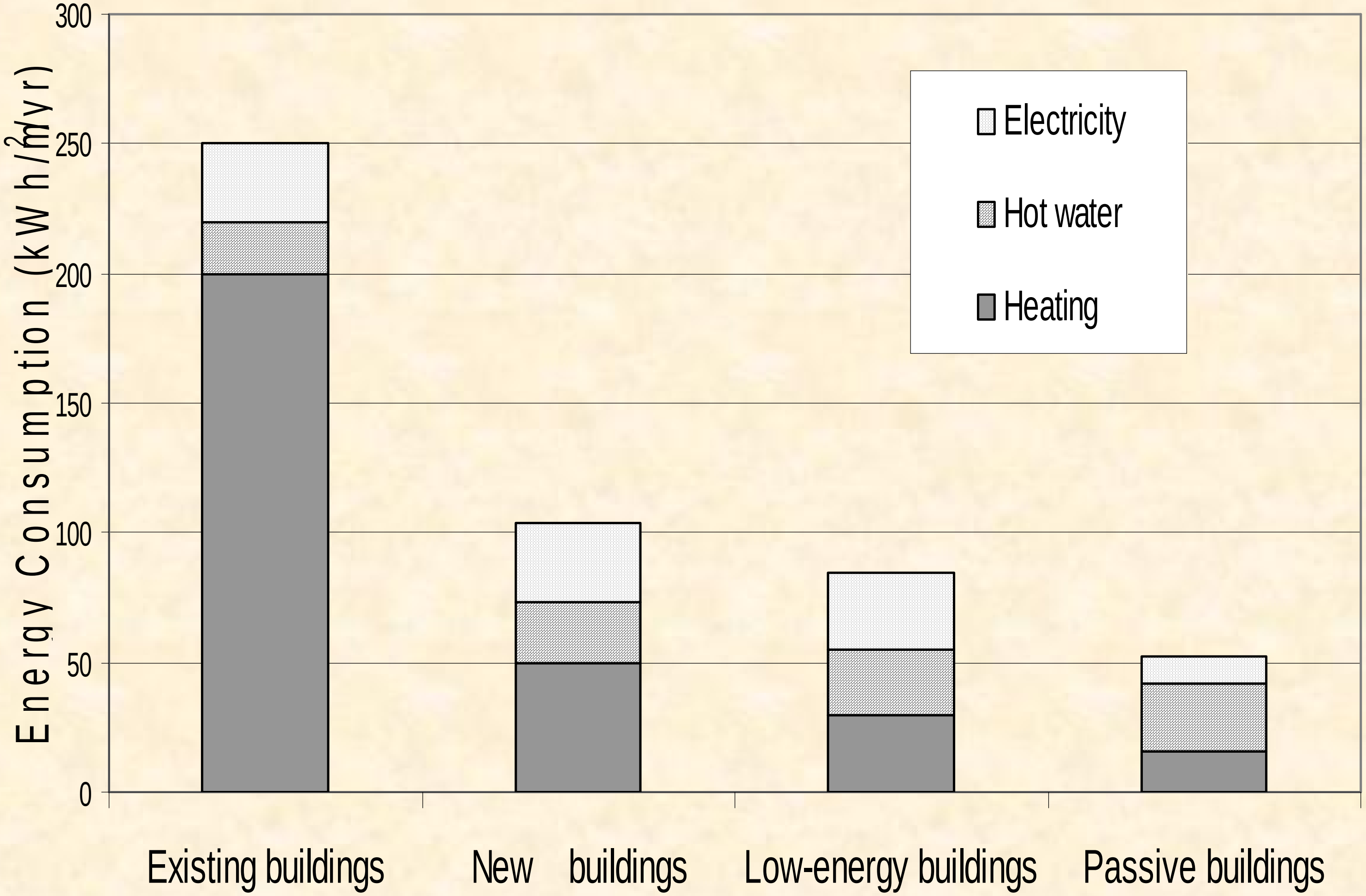
Energy Use in Buildings

- Accounts for about 1/3 of CO_2 emissions in OECD countries
- More than any other sector, epitomizes the difference between *device* efficiency and *system* efficiency
- Savings of 75% or more in new buildings is possible through an *integrated design process*

Elements of the Integrated Design Process:

- Focus on building shape and form and a high performance envelope to reduce heating and cooling loads
- Design to utilize passive heating, cooling, and ventilation, along with daylighting
- Choose the most efficient mechanical systems to meet remaining loads
- Possibly augment these savings with active forms of solar energy

Energy Intensity of Residential Buildings in Germany



Solar Chimneys, Building Research Establishment offices, Garston, UK

Commercial Building Example

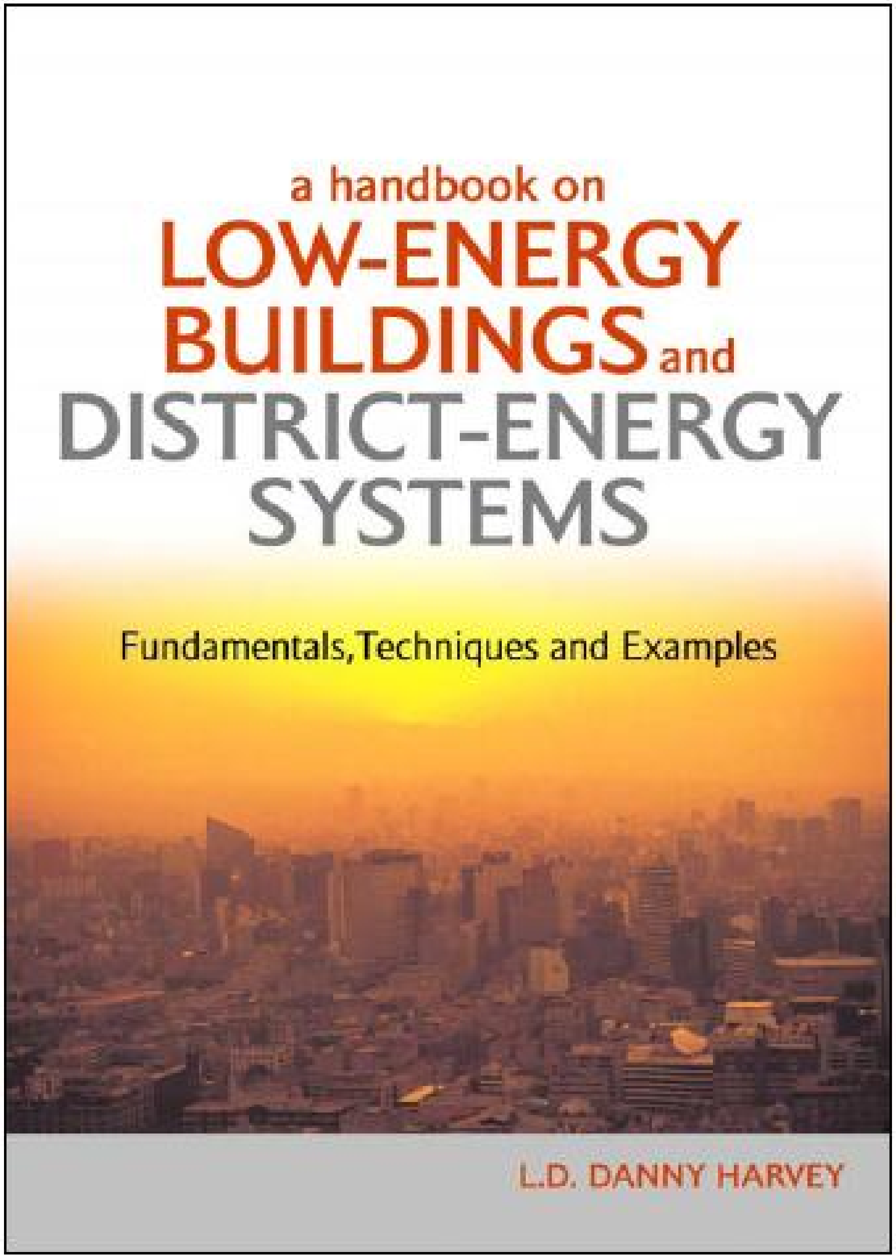
- The energy required to move air (for ventilation purposes) varies with the flow rate to the third power
- Thus, if the required flow can be cut in half, the energy required to move the air will flow by a *factor of 8* (actually, a factor of 6-7), whereas the potential to reduce energy use with better fans and motors is only 10% or so
- It is easy to design buildings to reduce required air flows by a factor of two, while also improving indoor air quality and reducing noise.

Savings and Costs

- With *nothing fancy* and without requiring detailed computer simulations, the integrated design approach will frequently give a 50% savings in annual energy use compared to current practice
- Use of *computer simulation models* run by simulation experts to fully optimize the design of the building and mechanical systems and use of more advanced designs can push the savings to 60-70%
- Savings can be pushed to 75-80% with *enlightened occupant behaviour*
- Buildings achieving such high energy savings sometimes cost no more than conventional buildings, due to the downsizing of mechanical equipment, and are superior in other respects

What is required to achieve this?

Nothing less than the complete retraining of the building design and construction professions



701 pages,
160 tables,
330 figures,
1600 references

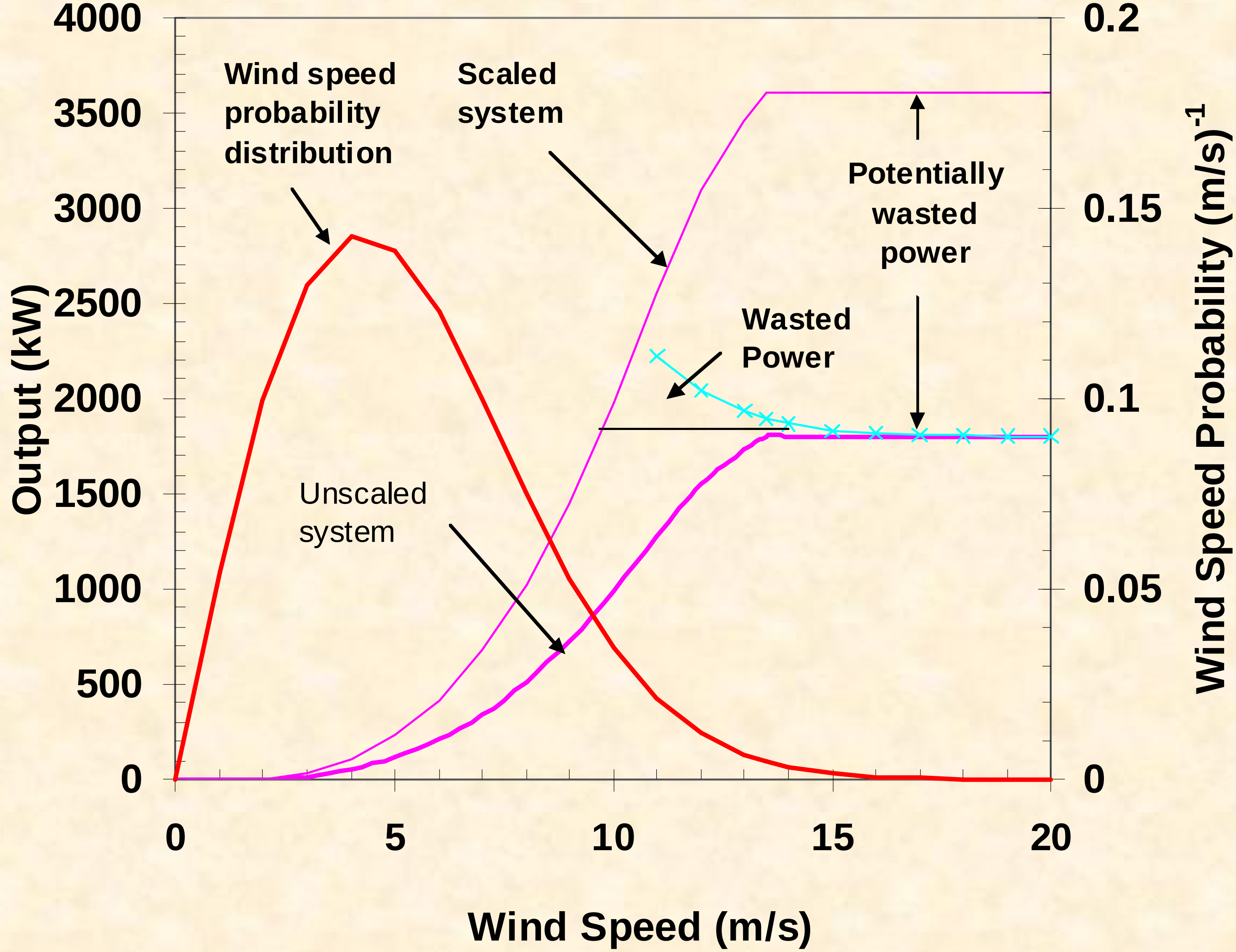
Large-Scale Renewable Energy Options:

- Dispersed wind farms
- Concentrating solar thermal electricity generation
- Hydro-electric power where available
- Geothermal electricity generation where viable
- Efficient combined heat and power generation using biomass

There are many techniques for getting reliable, baseload or close-to baseload power from wind energy:

- Deliberate oversizing (relative to the transmission link) of distant wind farms located in windy sites
- Compressed air energy storage
- Integration with electric heat pumps for heating and cooling in district energy systems

Concept of deliberate Oversizing of Wind Farms



Cost of wind-generated electricity:

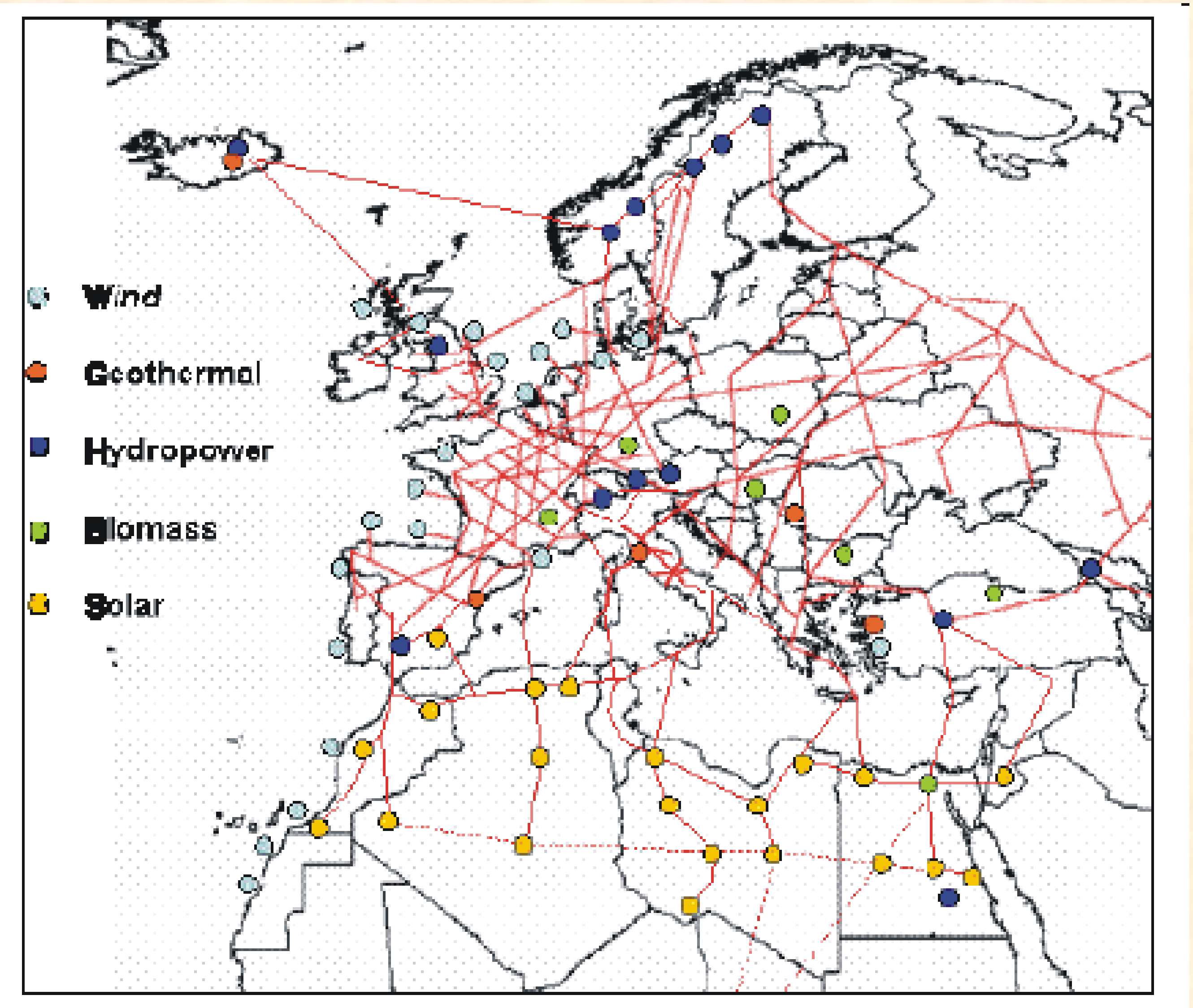
- Wind farm component:

$$C_{WF}=(CRF+OM)*CC_{WF}/(8760*CF_{WF})$$

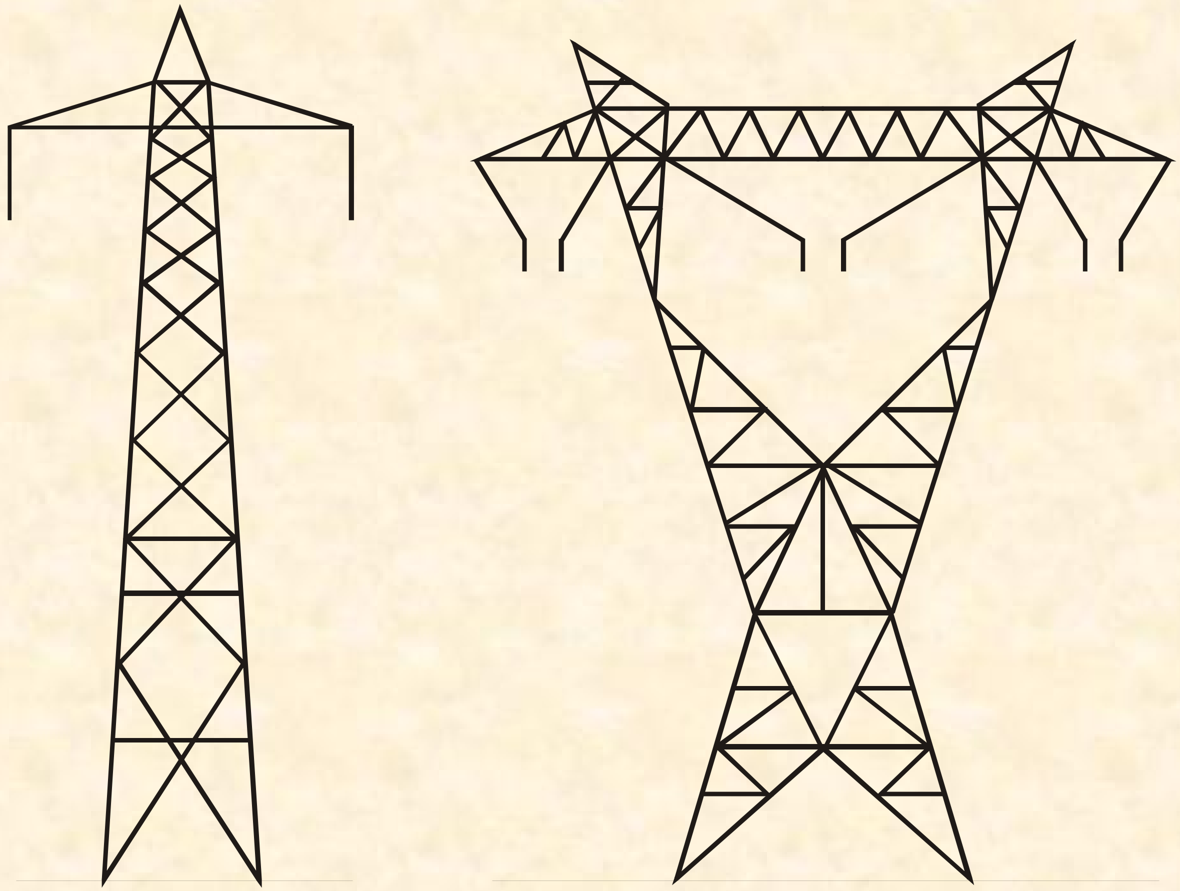
- Transmission link component:

$$CTr=(CRF+OM)*(CC_{Tr}/(8760*CF_{Tr})$$

European Plan to Largely Eliminate Fossil Fuel Electricity by 2050:



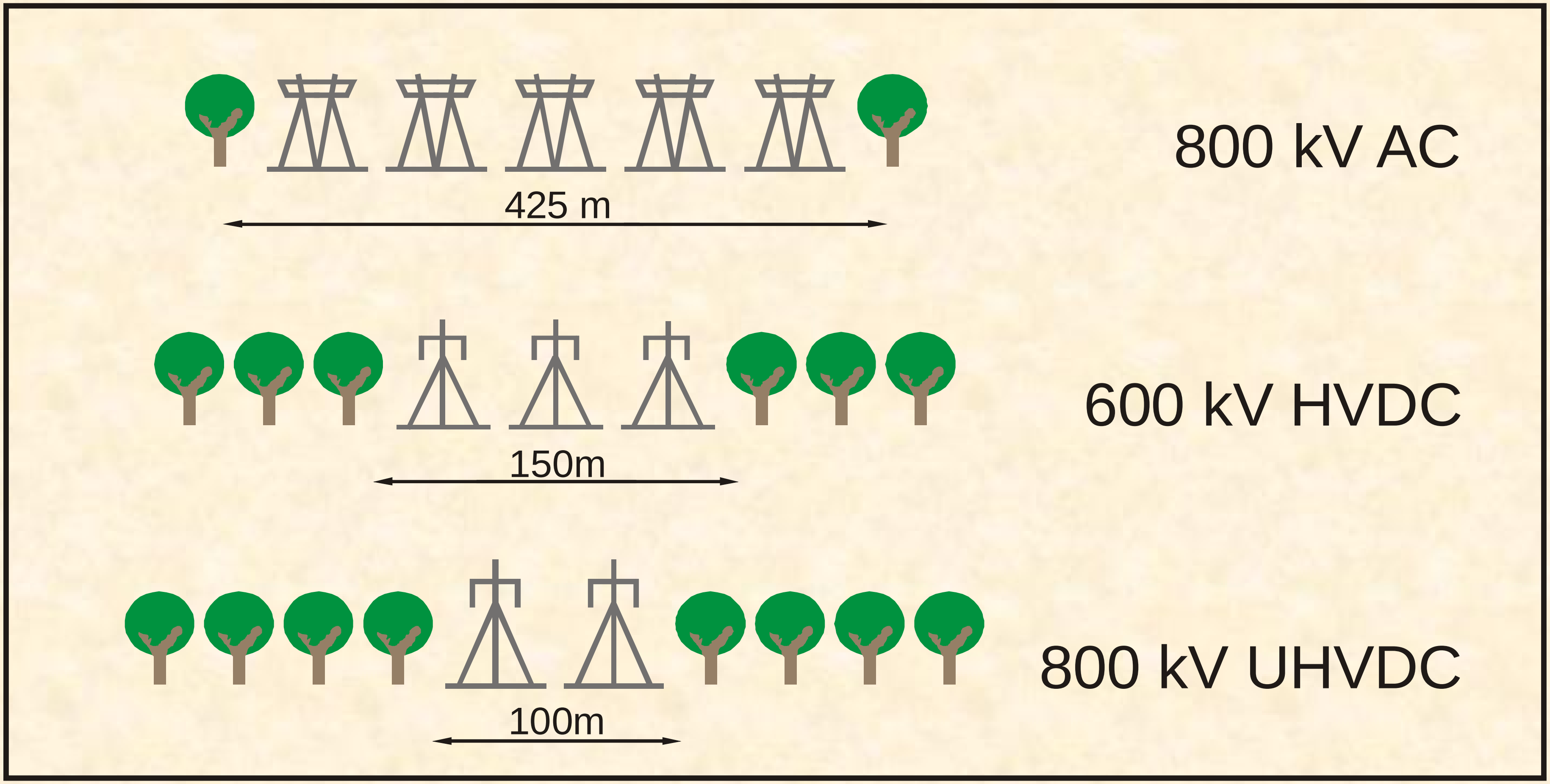
Comparison of pylons for DC and AC transmission



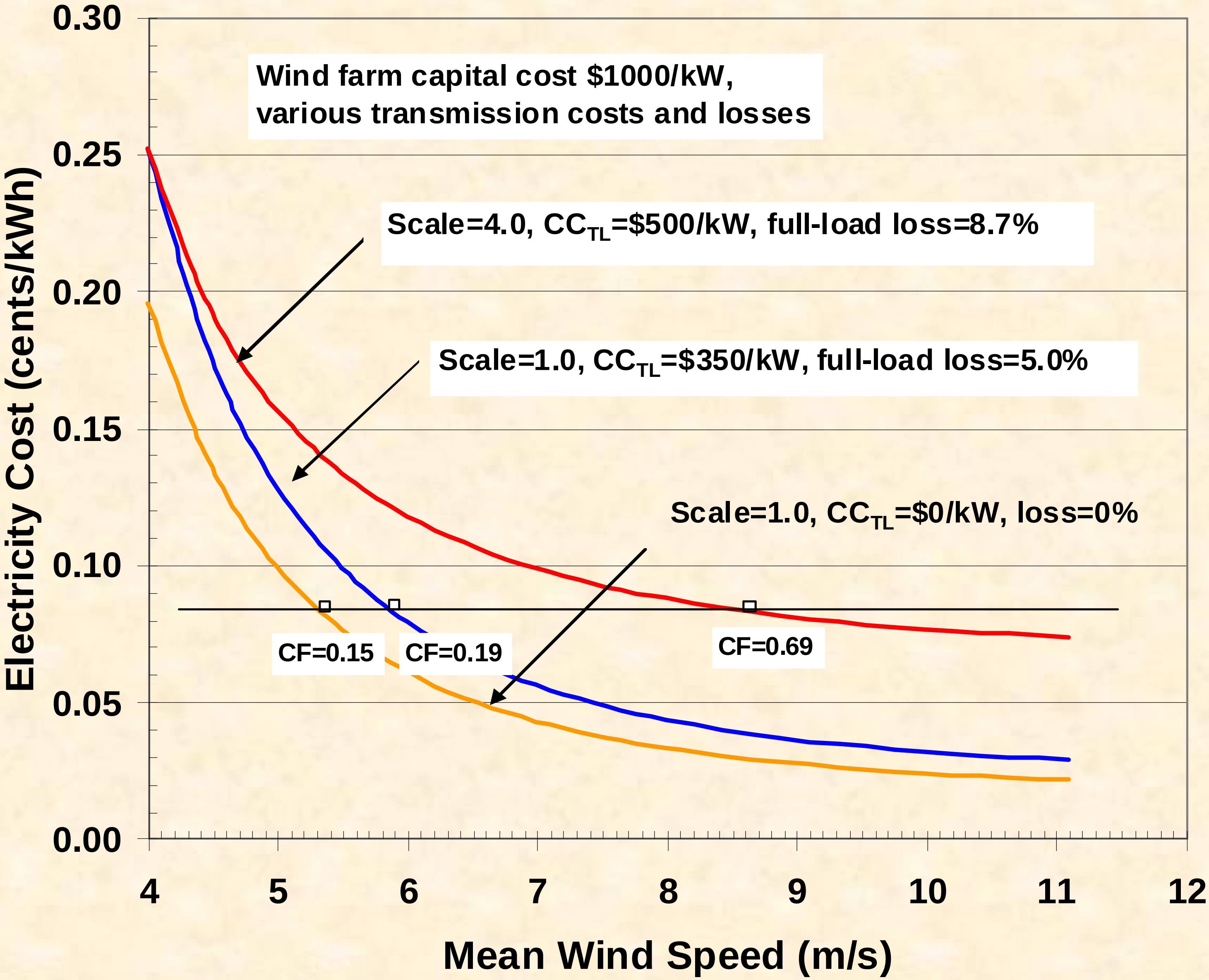
± 500 kV DC
route width: 50 m

800 kV AC
85 m

Comparison of 10-GW transmission corridors



Tradeoff: Local windfarms with low wind speed, vs distant oversized windfarms where wind speed is higher



Relevant Facts:

- The electricity-generation potential from *feasible* building-integrated PV is 60% of current total US electricity demand
- Covering all parking lots in the US with 15% PV modules would produce an amount of electricity equal to current total US electricity demand
- Wind farms covering the states of North and South Dakota alone could generate an amount of electricity equal to current total US electricity demand
- Concentrating solar thermal powerplants in the US southwest could alone generate an amount of electricity equal to current total US electricity demand (and at lower cost than PV)
- 40 million cars are produced per year, with an average engine power of 100 kW. Thus, the power of the passenger vehicles produced every year is equal to the total world electrical power capacity of 4000 GW.

Over the next 30 years, eliminate all fossil-fuel based electricity in North America by building an HVDC grid that links together

- Wind farms in the American and Canadian prairies, southern James Bay, and Labrador
- Concentrating solar thermal in the American southwest
- Existing and new hydropower in BC, American NW, Manitoba, Quebec, and Labrador
- Geothermal power in parts of the American west, where it makes sense

Renovate the existing building stock over the next 40 years to

- Dramatically reduce energy demands
- Incorporate building integrated PV to meet peak summer electricity loads and to overcome local transmission bottlenecks

Concluding Comments:

- The human race right now is in big trouble with regard to global warming
- The situation warrants being treated as a planetary emergency, requiring strong and coordinated action
- It is technically possible and affordable to make a rapid transition away from fossil fuels, largely using existing technology
- Technology alone is not the answer –restrains on human consumption (i.e., restraints on economic growth) and population will also be needed sooner or later

All of the above is extensively discussed in my two forthcoming books (Spring 2010):

Energy and the New Reality: Facing up to Climatic Change

Book 1: Energy Efficiency and the Demand for Energy Services

Book2: C-Free Energy and Integrated Scenarios