

Global Climate Disruption

What Do We Know? What Should We Do?

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Main messages

- “Global warming” is a misnomer because it implies something gradual, uniform, & benign, none of which is true; “global climatic disruption” is a more accurate description.
- The disruption & its impacts are growing more rapidly than was expected; widespread harm is already occurring.
- In this situation society has only 3 options: mitigation, adaptation, & suffering. We’re already doing some of each & will do more of all three; mix still up for grabs.
- Minimizing suffering will require early & large deflections from the “business as usual” emissions path.
- There’s no panacea; many things must be done. Most important is putting a price on carbon dioxide emissions.
- The United States must switch from laggard to leader – and sooner rather than later – if the world is to act in time.

What climate is & what climate change means

Climate is the pattern of weather, meaning averages, extremes, timing, spatial distribution of...

- hot & cold
- cloudy & clear
- humid & dry
- drizzles & downpours
- snowfall, snowpack, & snowmelt
- zephyrs, blizzards, tornadoes, & typhoons

Climate change means altered patterns.

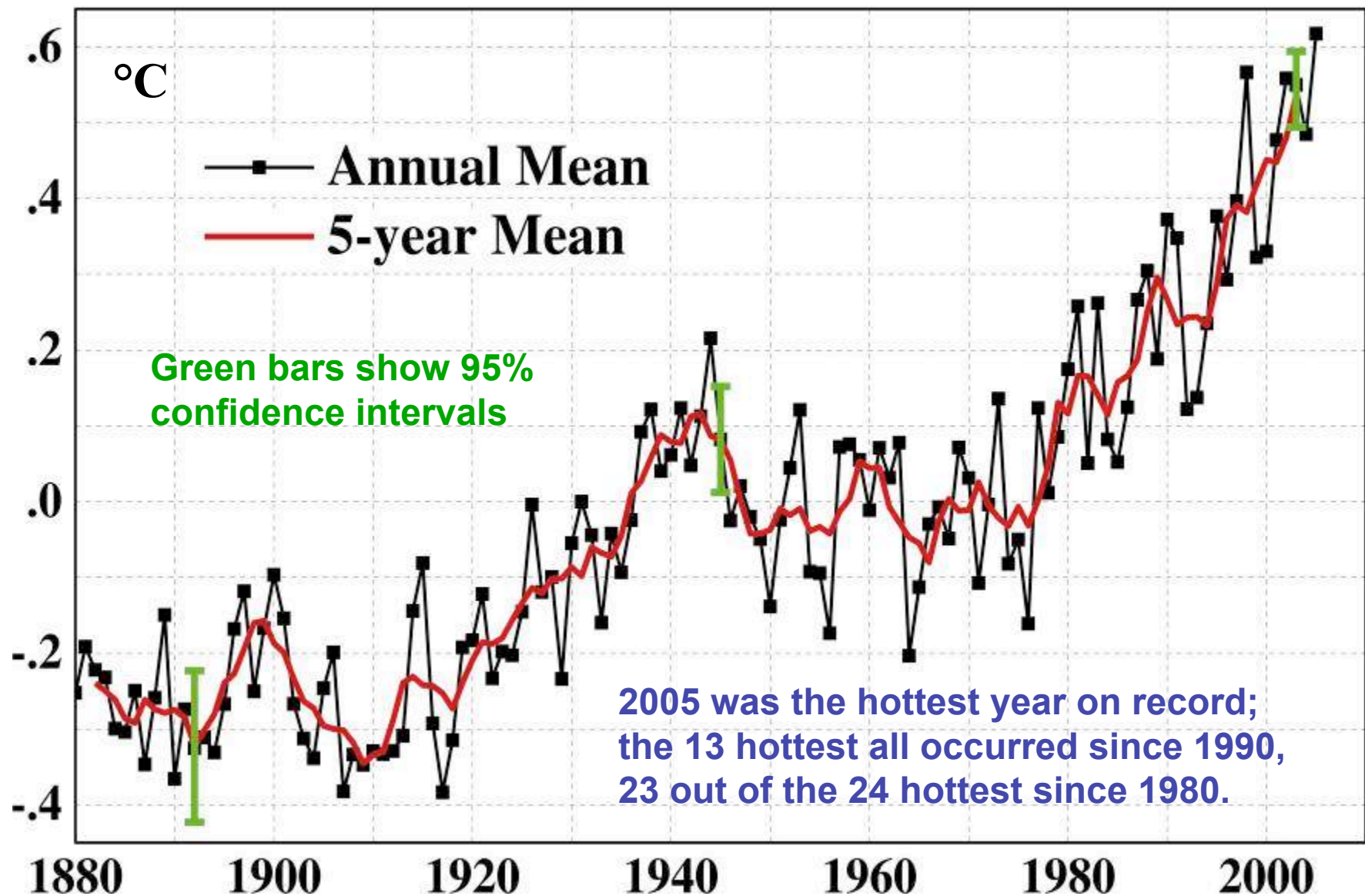
Global average temperature is just an index of the state of the global climate as expressed in these patterns. Small changes in the index → big changes in the patterns.

What climate change puts at risk

Climate governs (so climate change affects)

- availability of water
- productivity of farms, forests, & fisheries
- prevalence of oppressive heat & humidity
- formation & dispersion of air pollutants
- geography of disease
- damages from storms, floods, droughts, wildfires
- property losses from sea-level rise
- expenditures on engineered environments
- distribution & abundance of species

The Earth is getting hotter.



J. Hansen et al., *PNAS* 103: 14288-293 (26 Sept 2006)

We know why:

Human vs natural influences 1750-2005 (watts/m²)

Human emissions leading to increases in...

atmospheric carbon dioxide	+ 1.7
methane, nitrous oxide, CFCs	+ 1.0
net ozone (troposphere↑, stratosphere↓)	+ 0.3
absorptive particles (soot)	+ 0.3
reflective particles (sulfates, etc.)	- 0.7
indirect (cloud forming) effect of particles	- 0.7

Human land-use change increasing reflectivity - 0.2

Natural changes in sunlight reaching Earth + 0.1

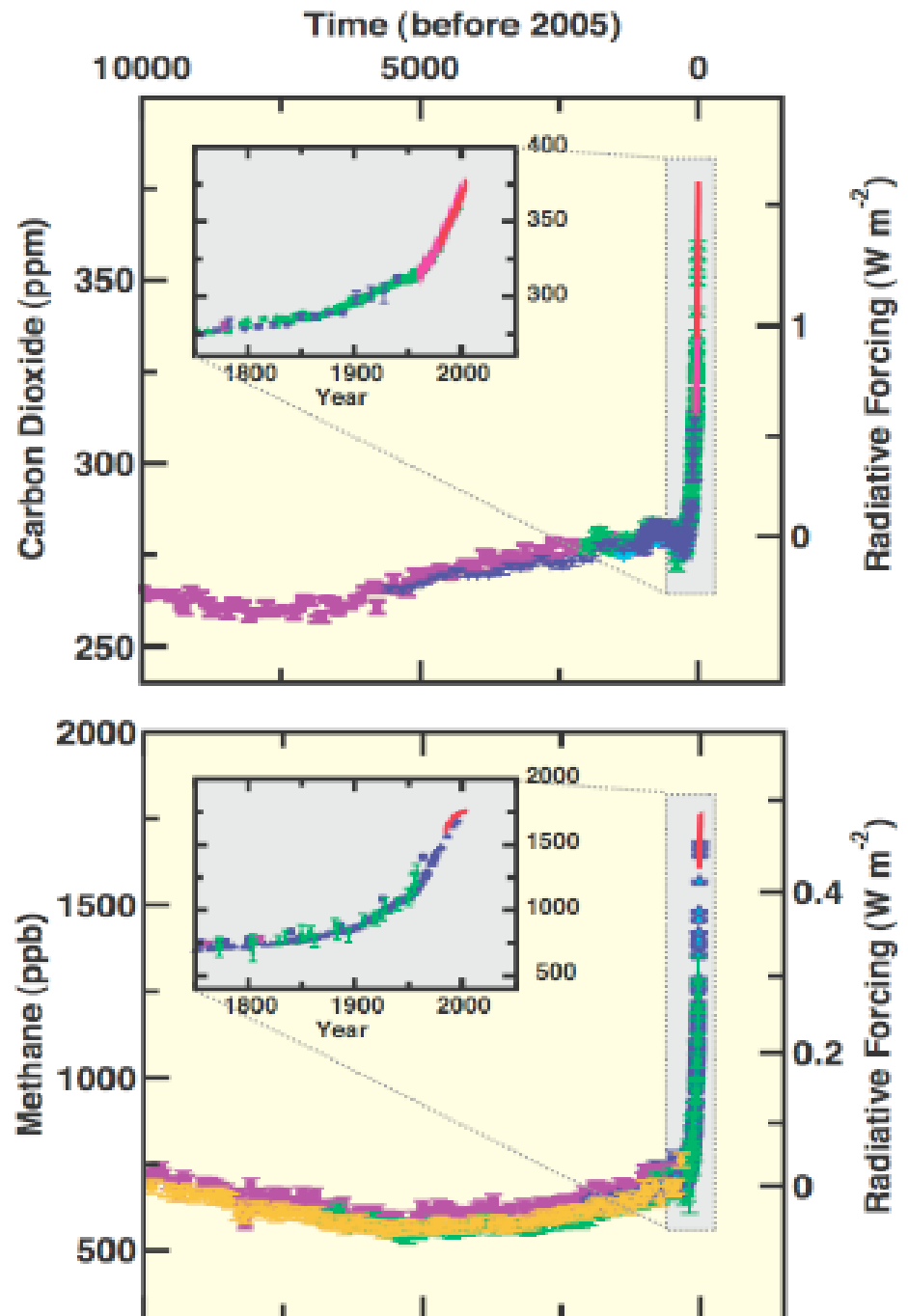
The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

The key greenhouse-gas increases were caused by human activities.

Compared to natural changes over the past 10,000 years, the spike in concentrations of CO₂ & CH₄ in the past 250 years is extraordinary.

We know humans are responsible for the CO₂ spike because fossil CO₂ lacks carbon-14, and the drop in atmospheric C-14 from the fossil-CO₂ additions is measurable.

IPCC AR4, WG1 SPM, 2007

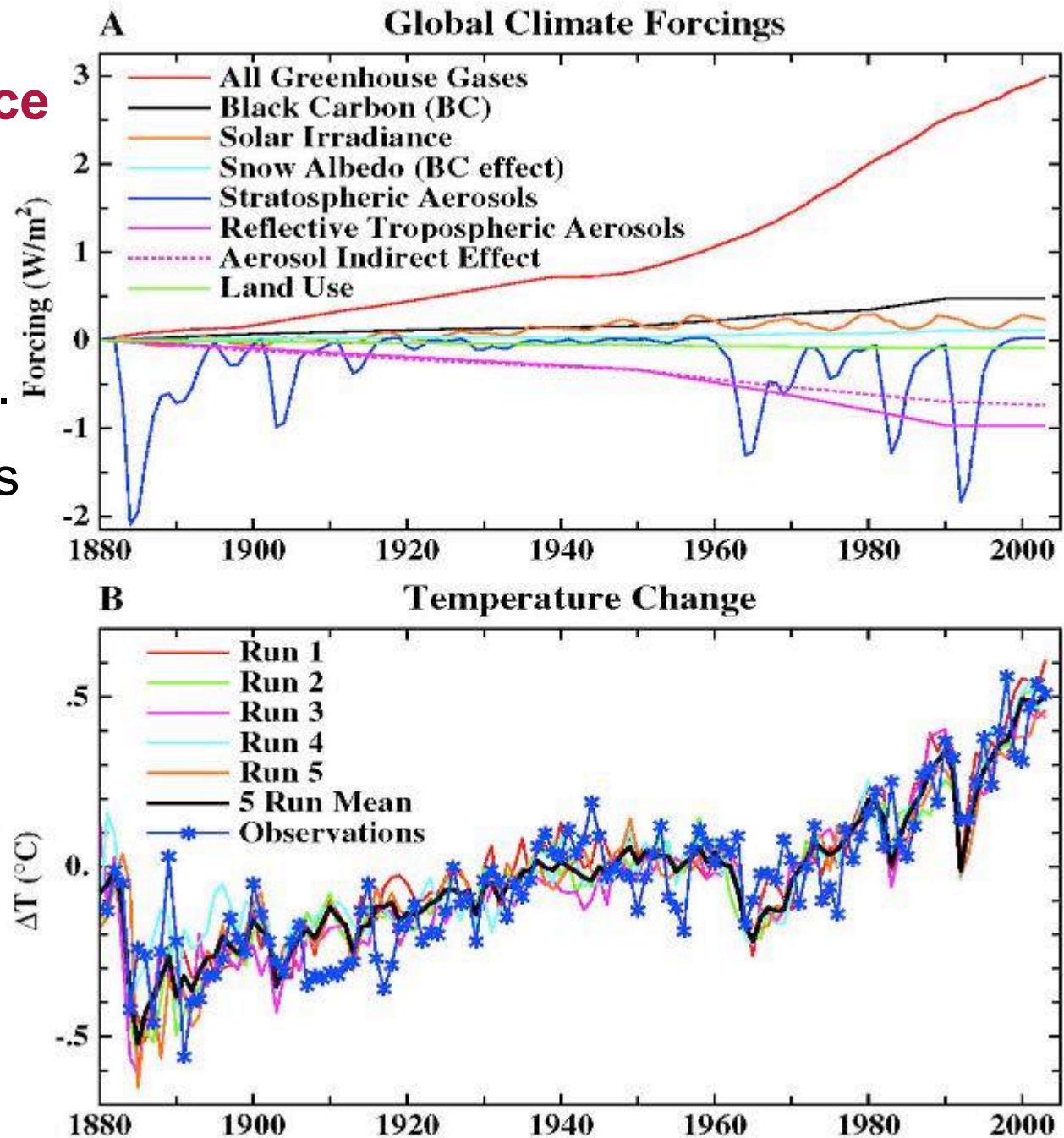


The smoking gun for human influence

Top panel shows best estimates of human & natural forcings 1880-2005.

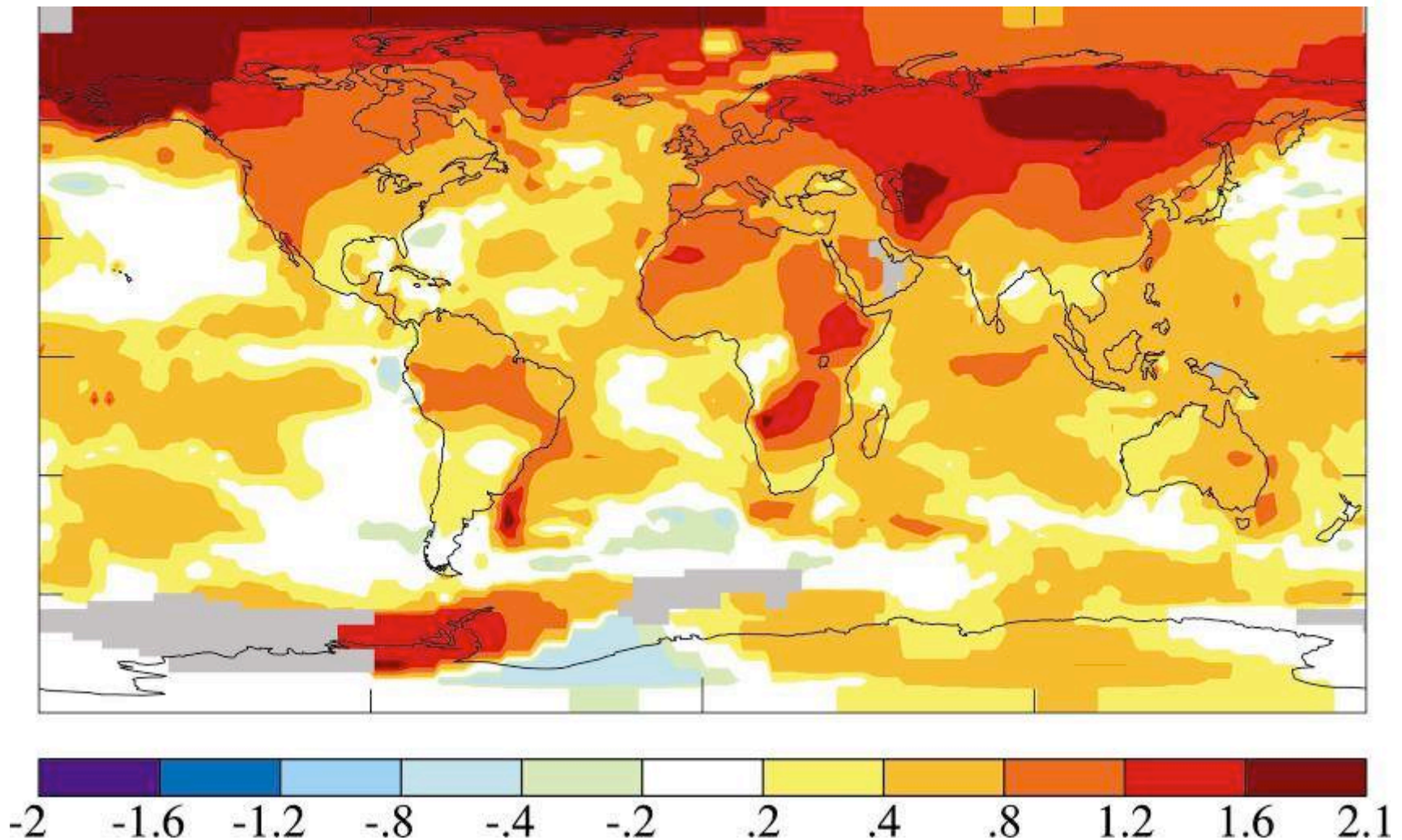
Bottom panel shows that state-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.

Source: Hansen et al.,
Science 308, 1431, 2005.



The current heating is not uniform geographically

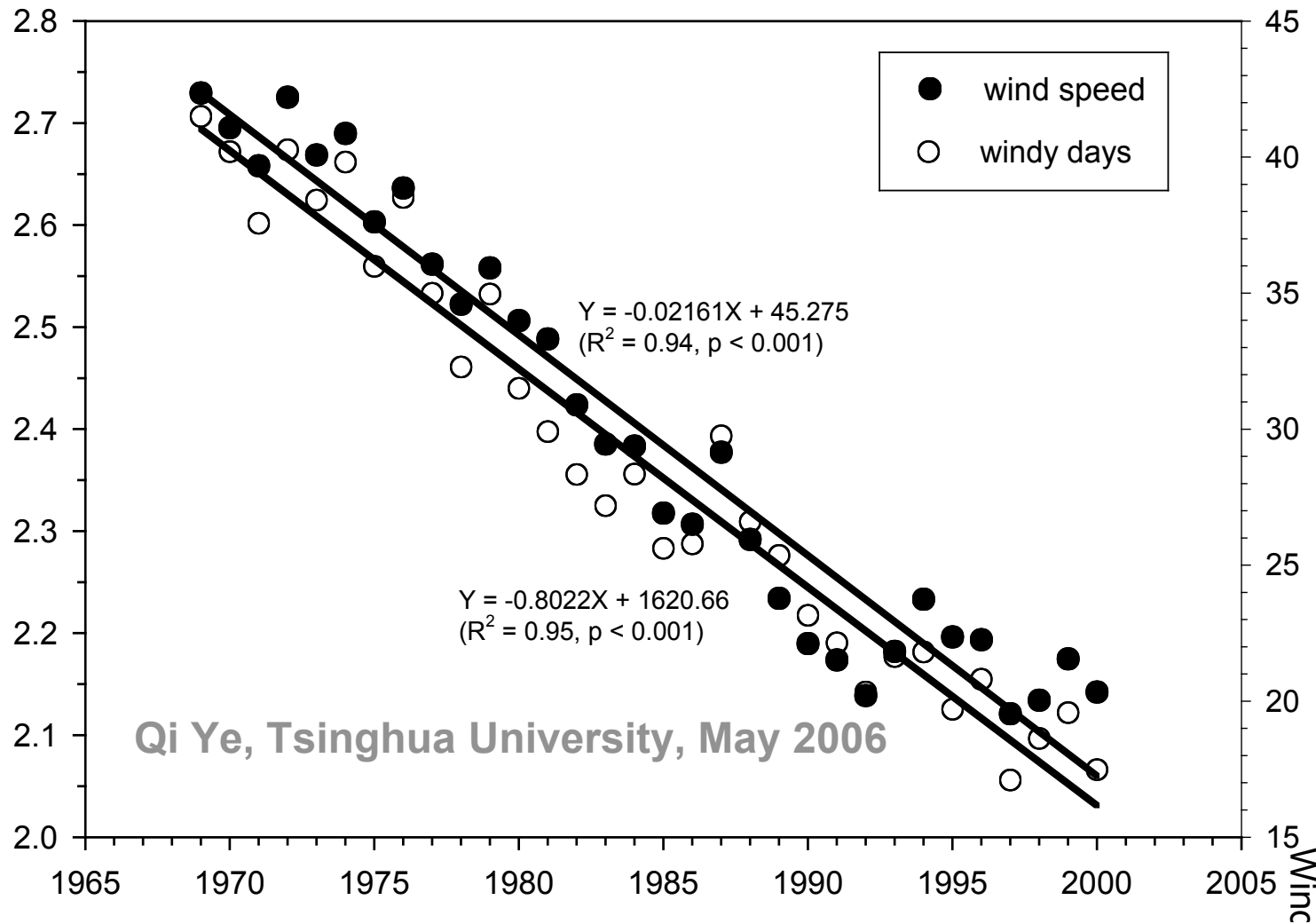
Average T for 2001-2005 compared to 1951-80, degrees C



J. Hansen et al., *PNAS* 103: 14288-293 (2006)

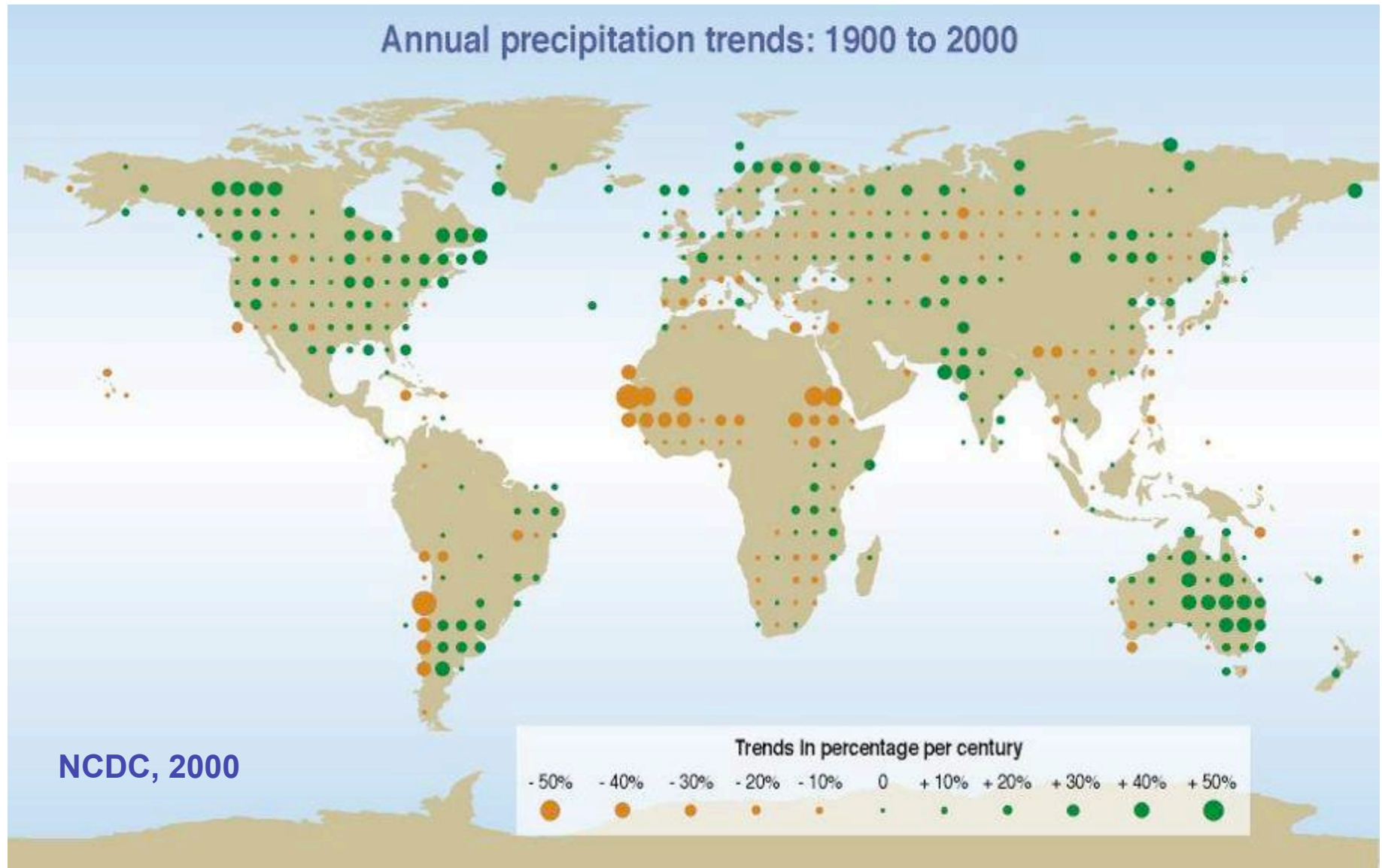
Circulation patterns are changing

Weakening of the East Asia Monsoon is an example



Chinese studies conclude that this phenomenon is indeed a result of greenhouse-gas-driven global climatic change.

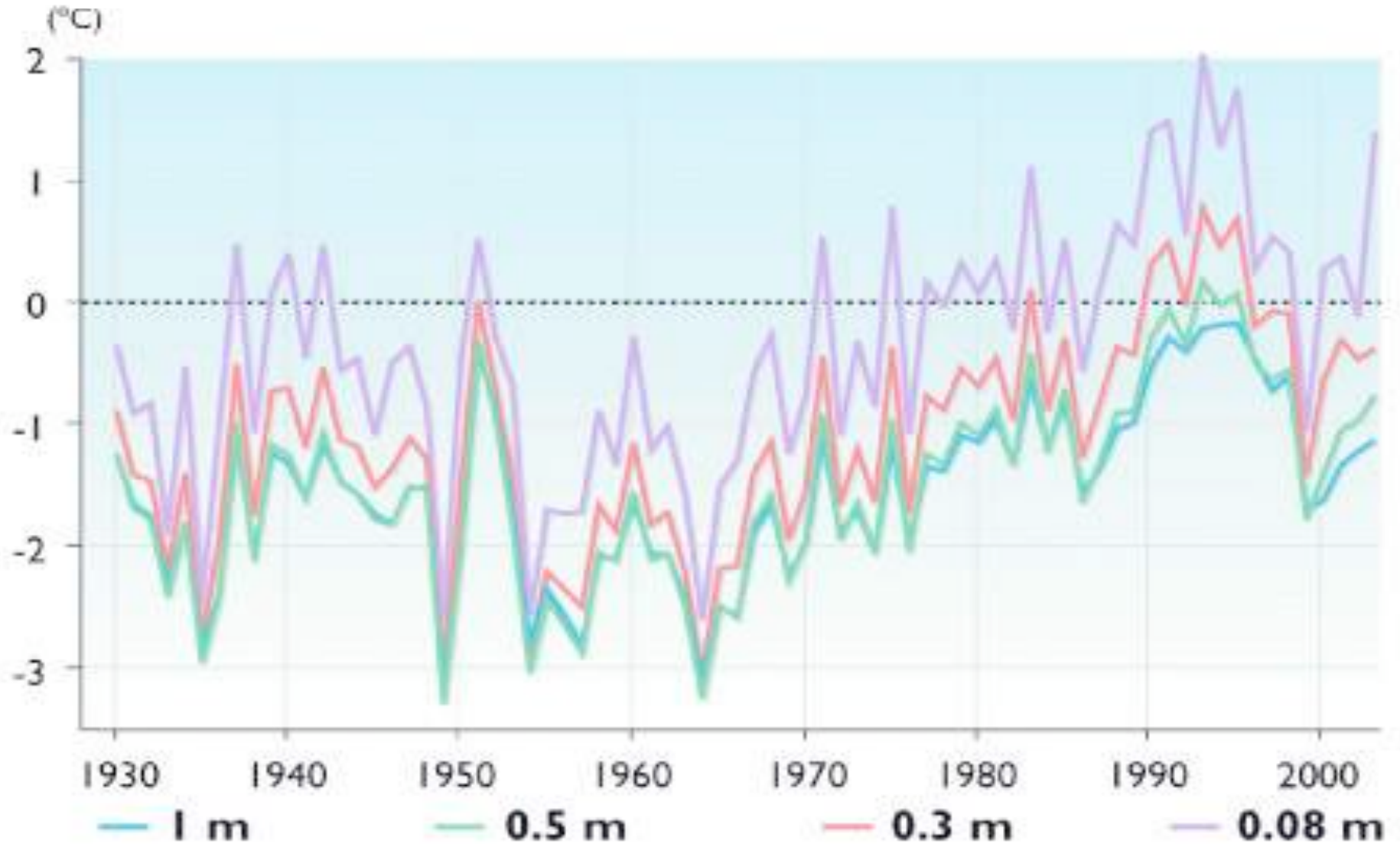
Evaporation & precipitation are increasing



Effect is not uniform; most places getting wetter, some getting drier.

Permafrost is thawing

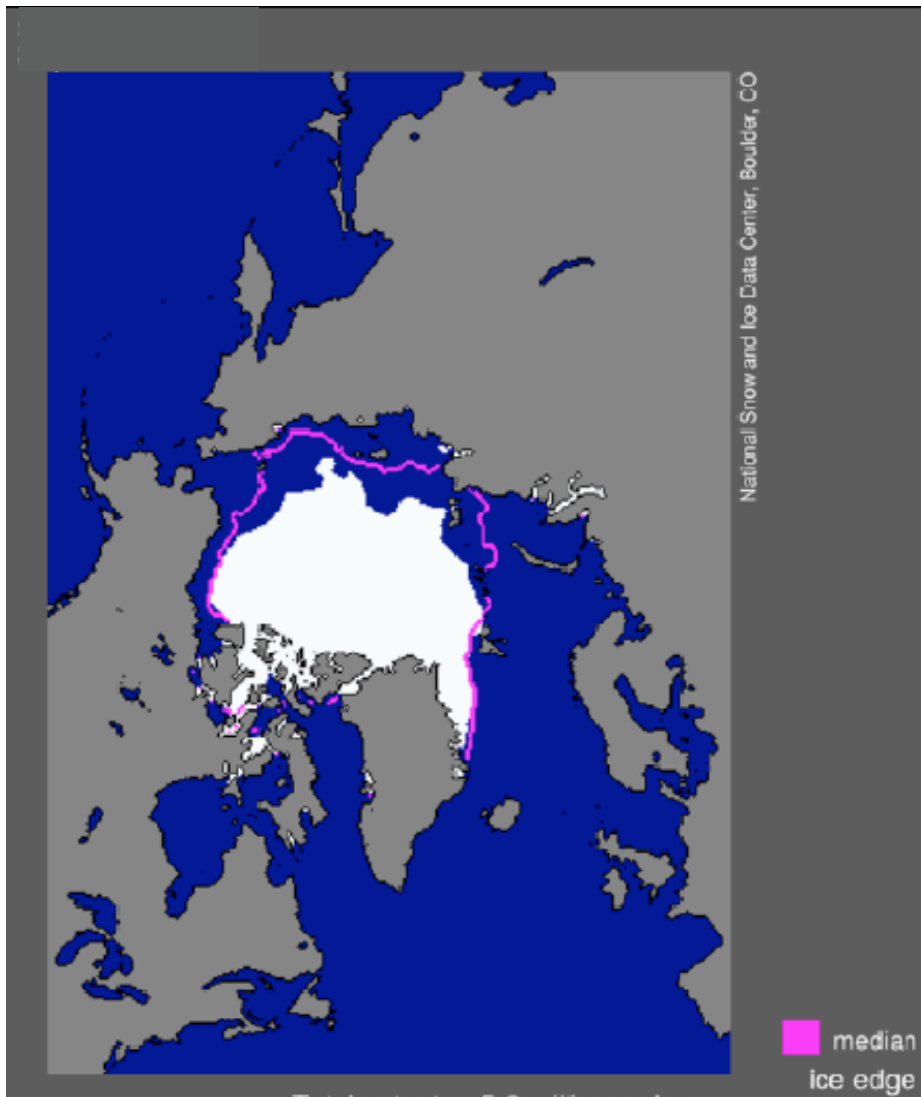
Average ground temperature near Fairbanks, Alaska, degrees C



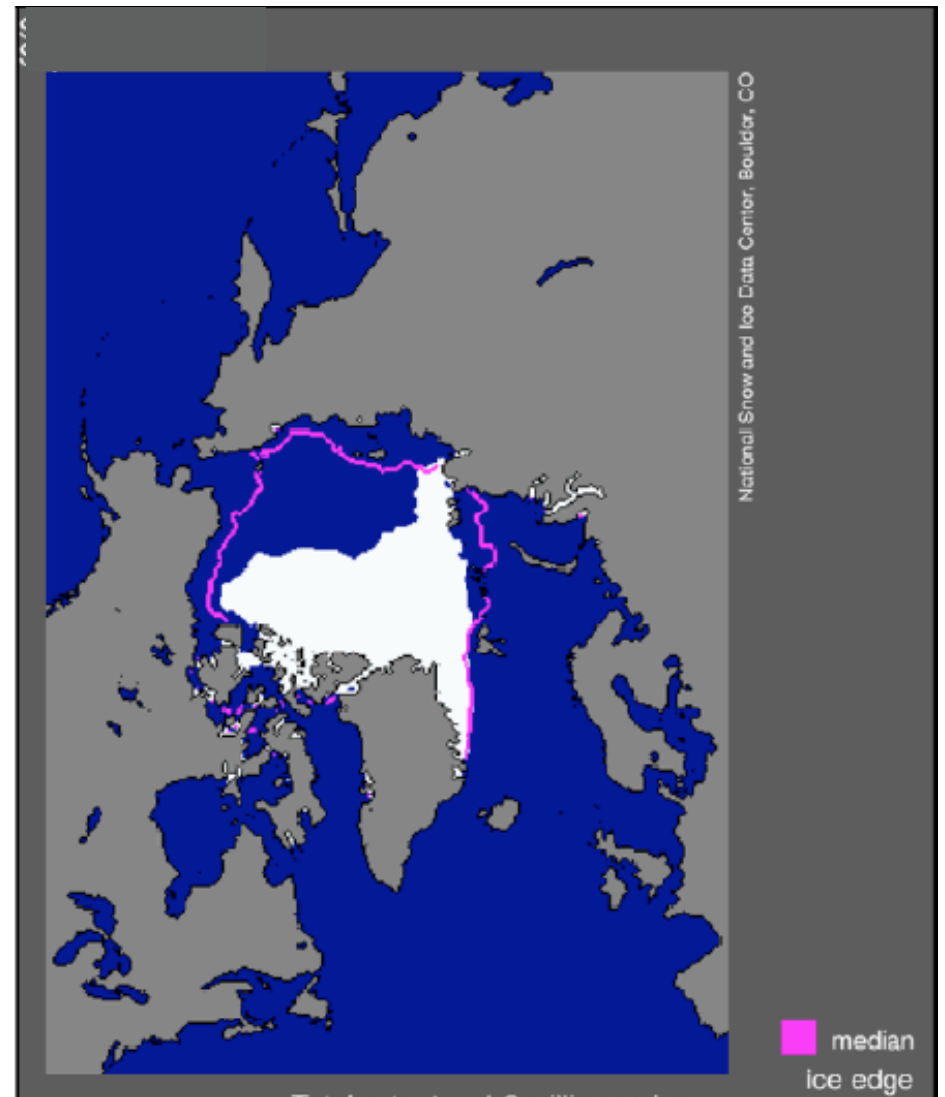
Permafrost thaws when $T \geq 0^\circ\text{C}$

ACIA 2004

Arctic summer sea ice is disappearing



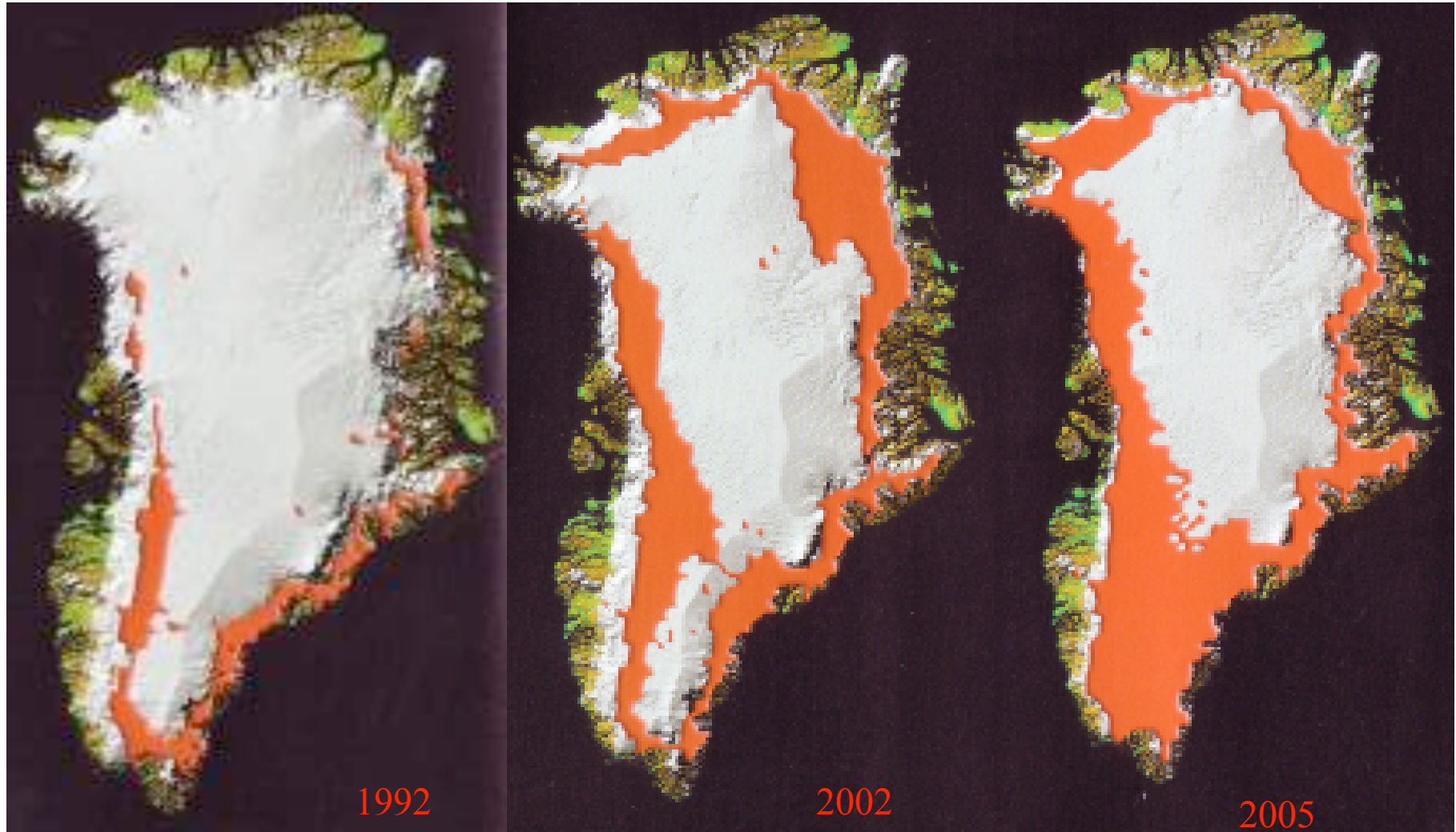
September 2005



September 2007

US National Snow & Ice Data Center, 2007

Surface melting on Greenland is expanding



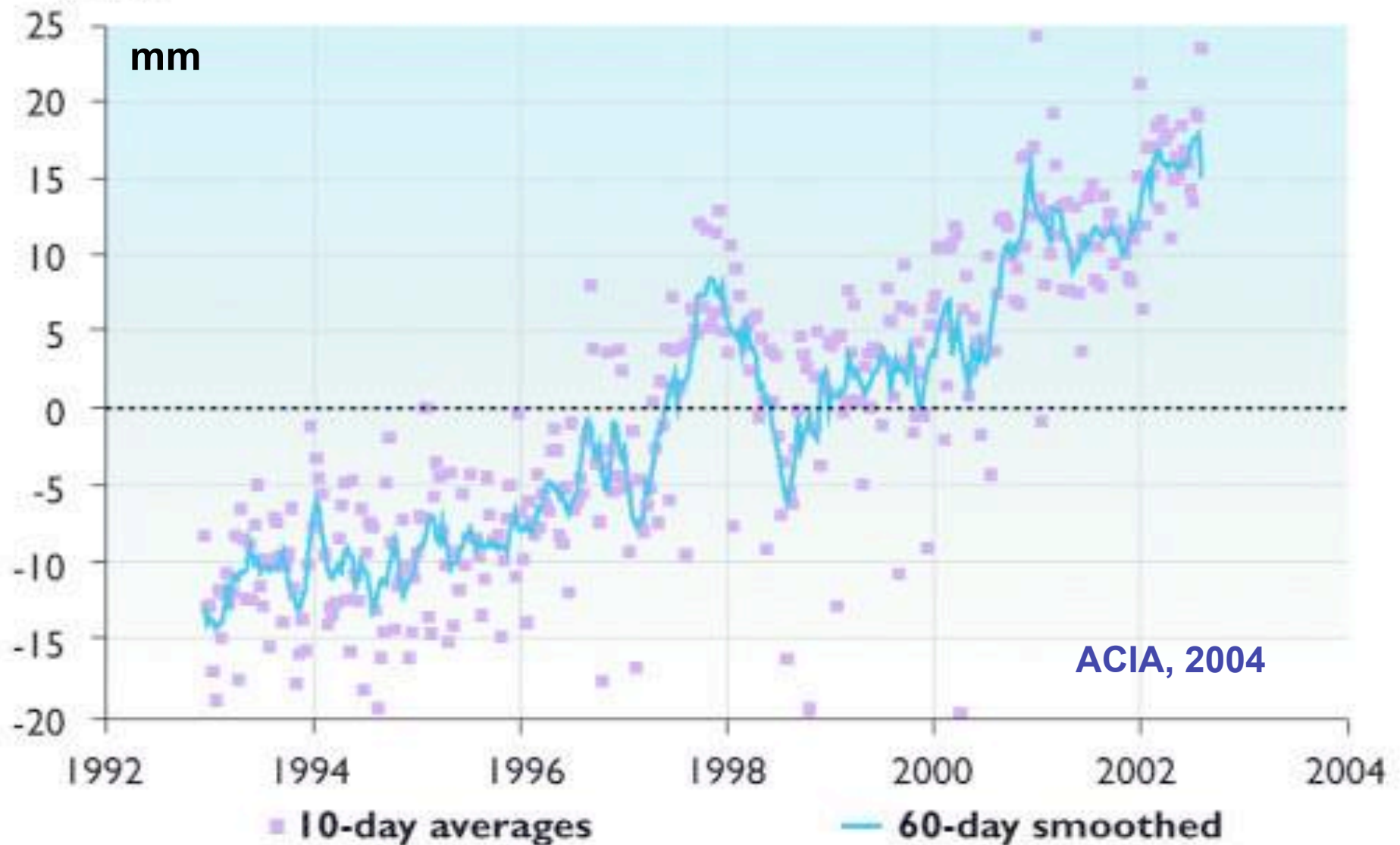
In 1992 scientists measured this amount of melting in Greenland as indicated by red areas on the map

Ten years later, in 2002, the melting was much worse

And in 2005, it accelerated dramatically yet again

Source: ACIA, 2004 and CIRES, 2005

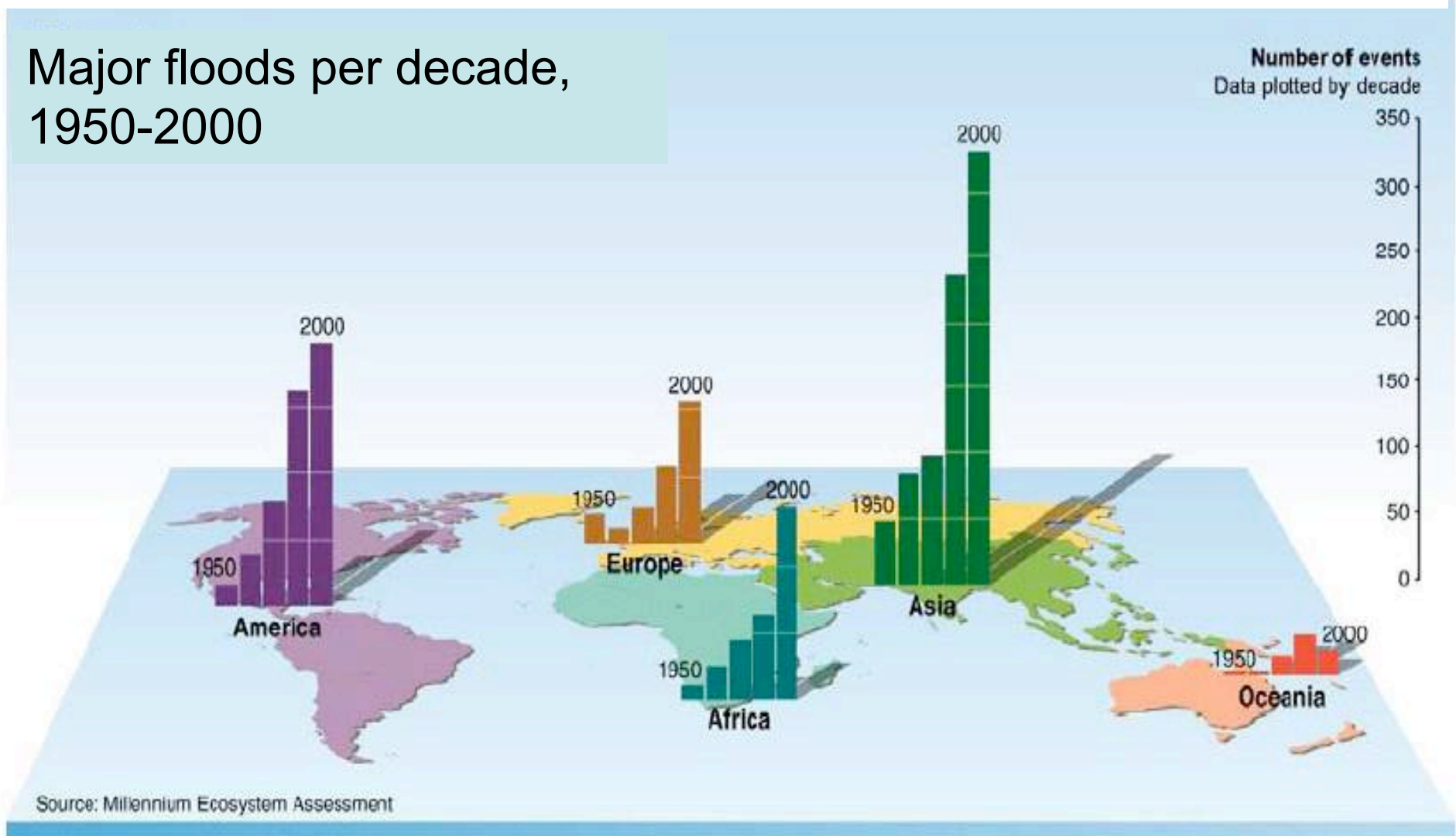
Sea-level is rising



1993-2003 \approx 30 mm = 3.0 mm/yr; compare 1910-1990 = 1.5 ± 0.5 mm/yr.

These changes are already causing harm

Major floods per decade,
1950-2000



There's a consistent 50-year upward trend in every region except Oceania.

Harm is already occurring (continued)

Wildfires in the Western USA have increased 4-fold in the last 30 years.

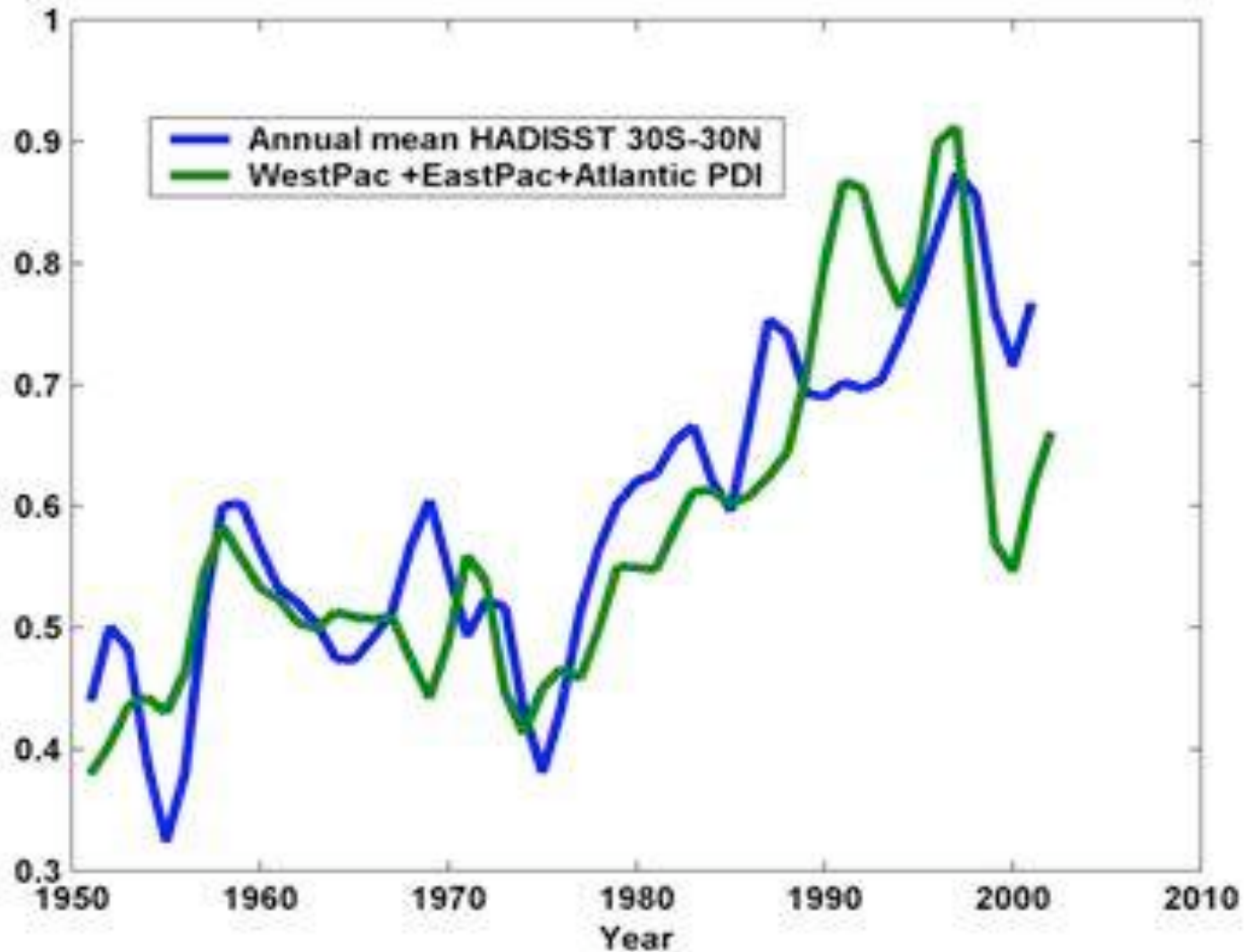
Western US area burned



Source: Westerling et al. 2006

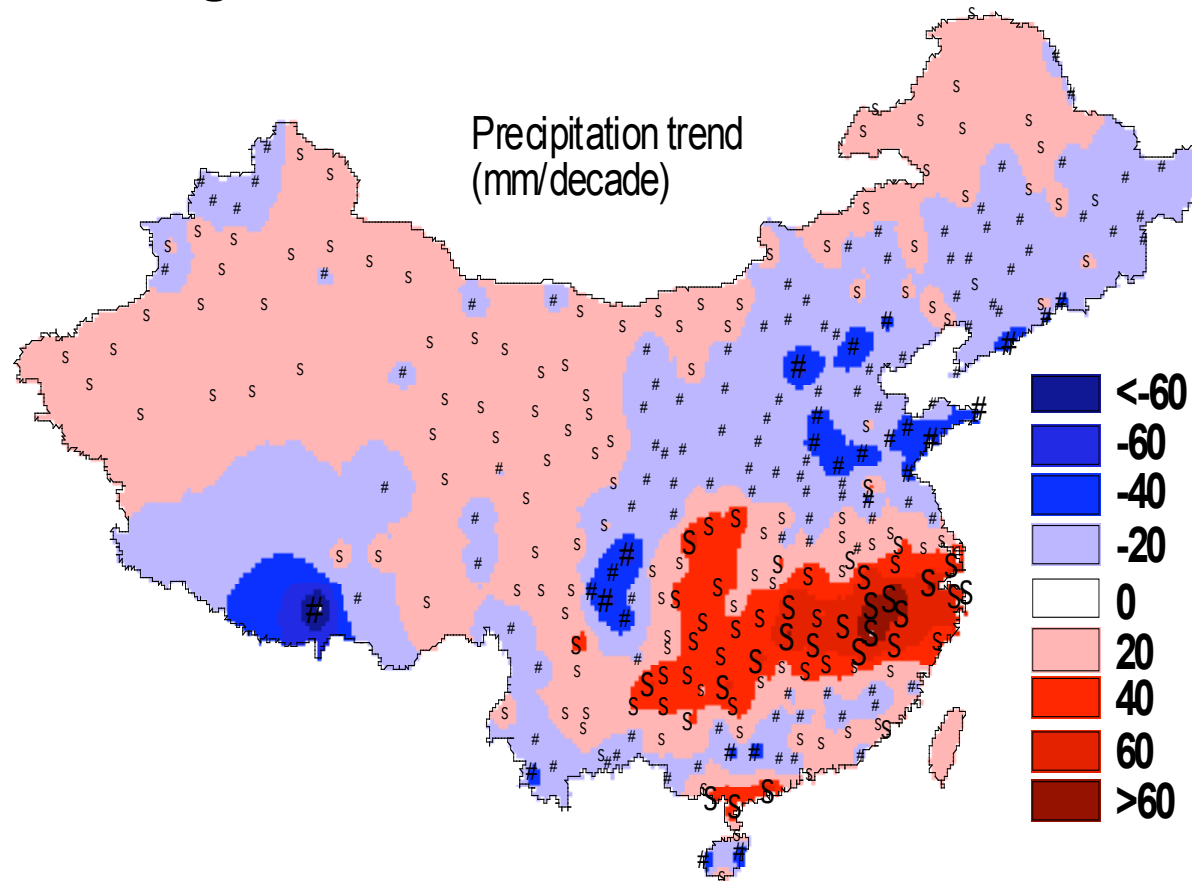
Harm is already occurring (continued)

Total power released by tropical cyclones (green) has increased along with sea surface temperatures (blue).



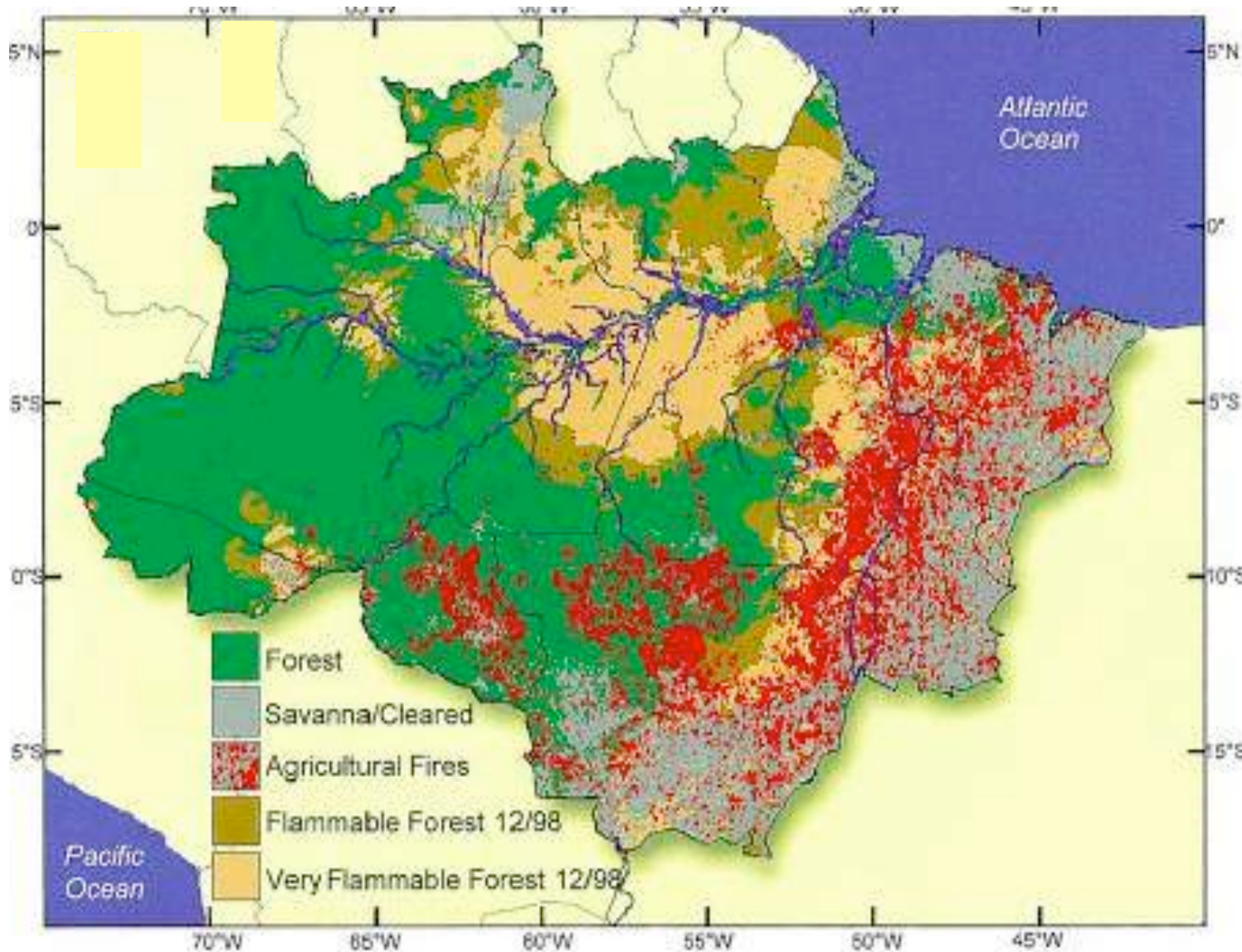
Harm is already occurring (continued)

Weakening East-Asia monsoon has meant less moisture flow South to North, producing increased flooding in South, drought in North



Qi Ye, Tsinghua University, May 2006

Harm is already occurring (continued) **The Amazon is drying & burning**



Drying results from combined effects of altered regional atmospheric circulation linked to global climate change and local influence of deforestation itself.

Harm is already occurring (concluded)

WHO estimates climate change already causing $\geq 150,000$ premature deaths/yr in 2000

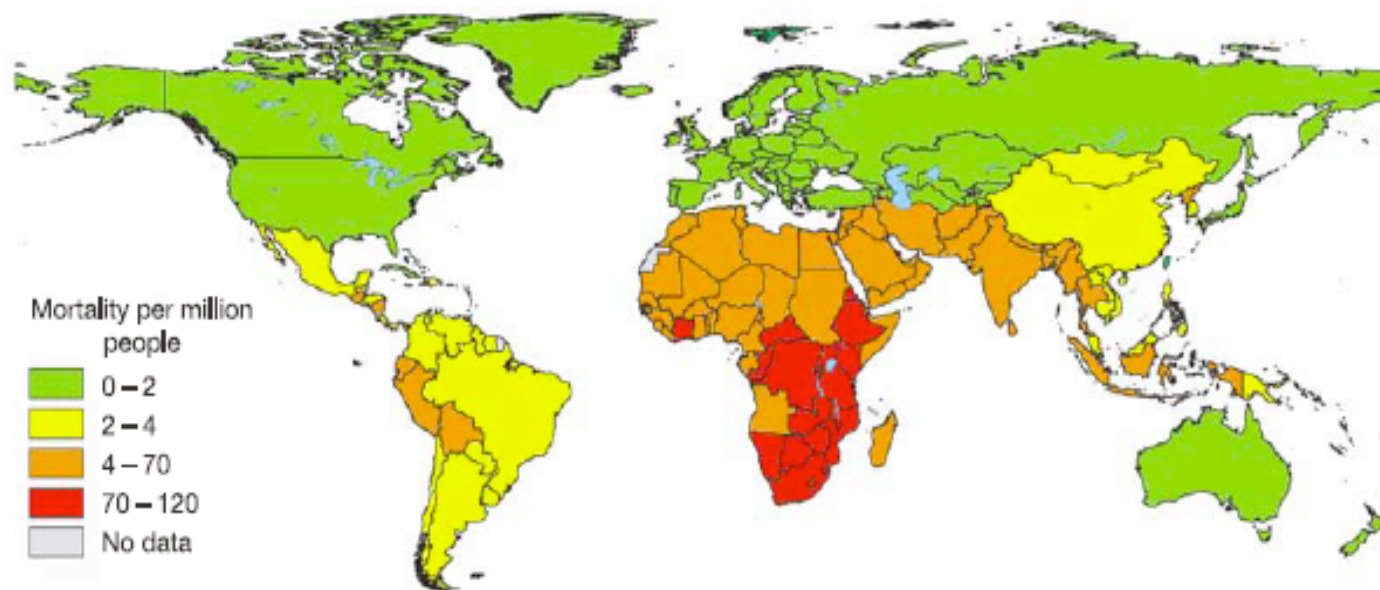
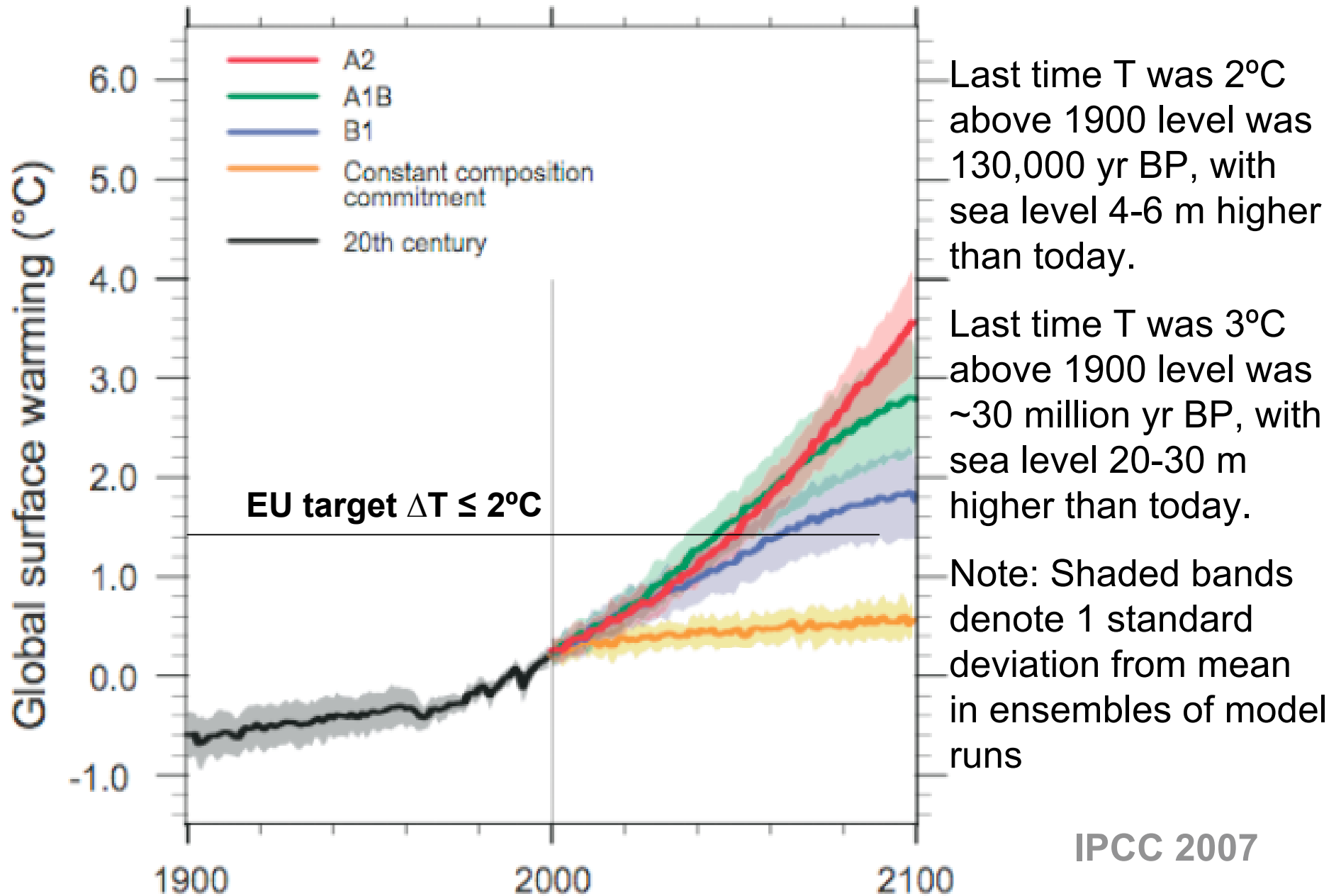


Figure 2 | WHO estimated mortality (per million people) attributable to climate change by the year 2000. The IPCC 'business as usual' greenhouse gas emissions scenario, 'IS92a' and the HadCM2 GCM of the UK Hadley Centre were used to estimate climate changes relative to 'baseline' 1961-1990 levels of greenhouse gases and associated climate conditions. Existing quantitative studies of climate-health relationships were used to estimate relative changes in a range of climate-sensitive health outcomes including: cardiovascular diseases, diarrhoea, malaria, inland and coastal

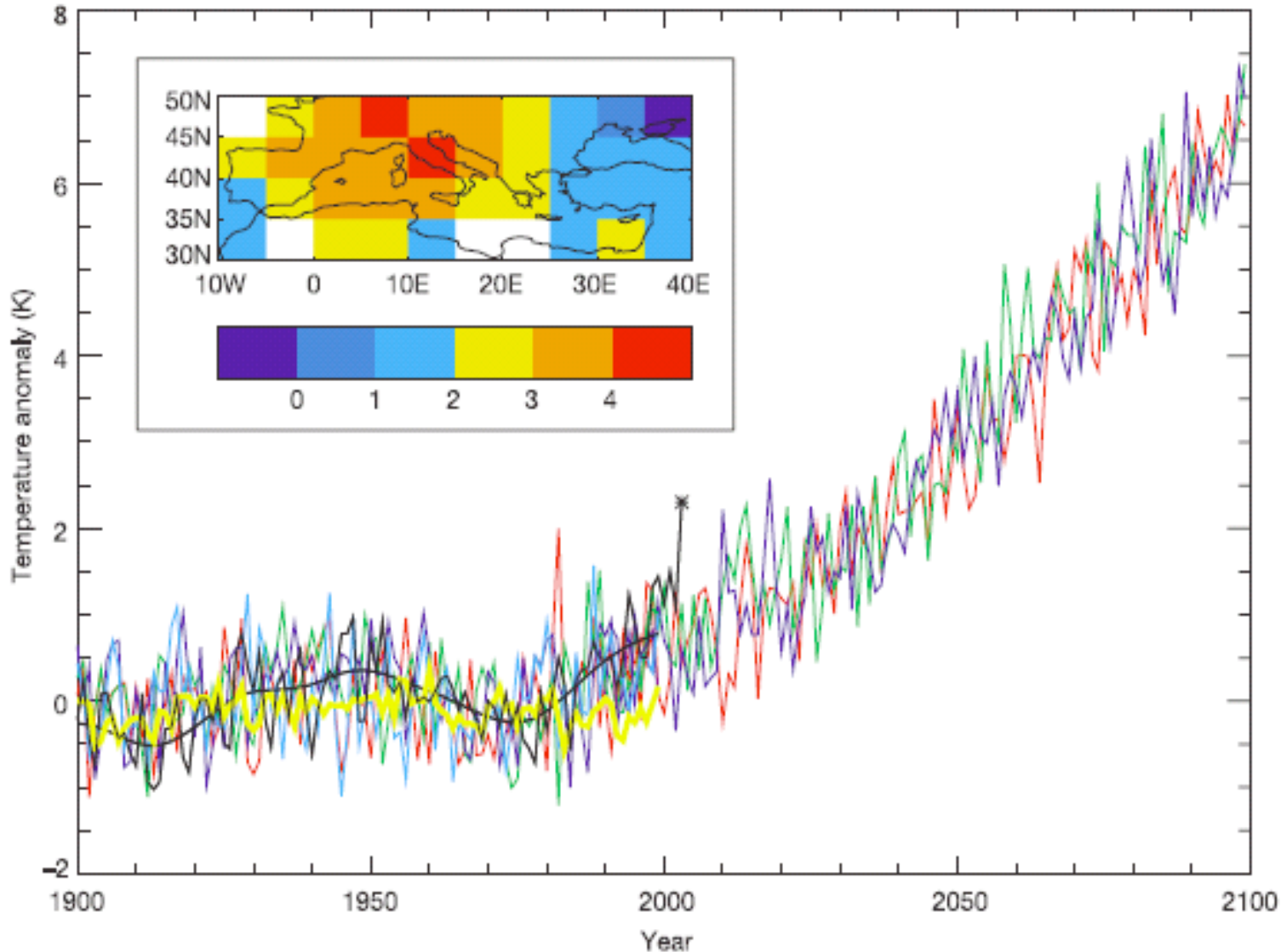
flooding, and malnutrition, for the years 2000 to 2030. This is only a partial list of potential health outcomes, and there are significant uncertainties in all of the underlying models. These estimates should therefore be considered as a conservative, approximate, estimate of the health burden of climate change. Even so, the total mortality due to anthropogenic climate change by 2000 is estimated to be at least 150,000 people per year. Details on the methodology are contained in ref. 57.

Bigger disruption is coming: IPCC 2007 scenarios



Where we're headed: Heat waves

Extreme heat waves in Europe, already 2X more frequent because of global warming, will be “normal” in mid-range scenario by 2050



Black lines are observed temps, smoothed & unsmoothed; red, blue, & green lines are Hadley Centre simulations w natural & anthropogenic forcing; yellow is natural only.

Asterisk and inset show 2003 heat wave that killed 35,000.

Stott et al., *Nature* 432: 610-613 (2004)

Where we're headed: Agriculture in the tropics

Crop yields in tropics start dropping at local $\Delta T \geq 1-1.5^\circ\text{C}$

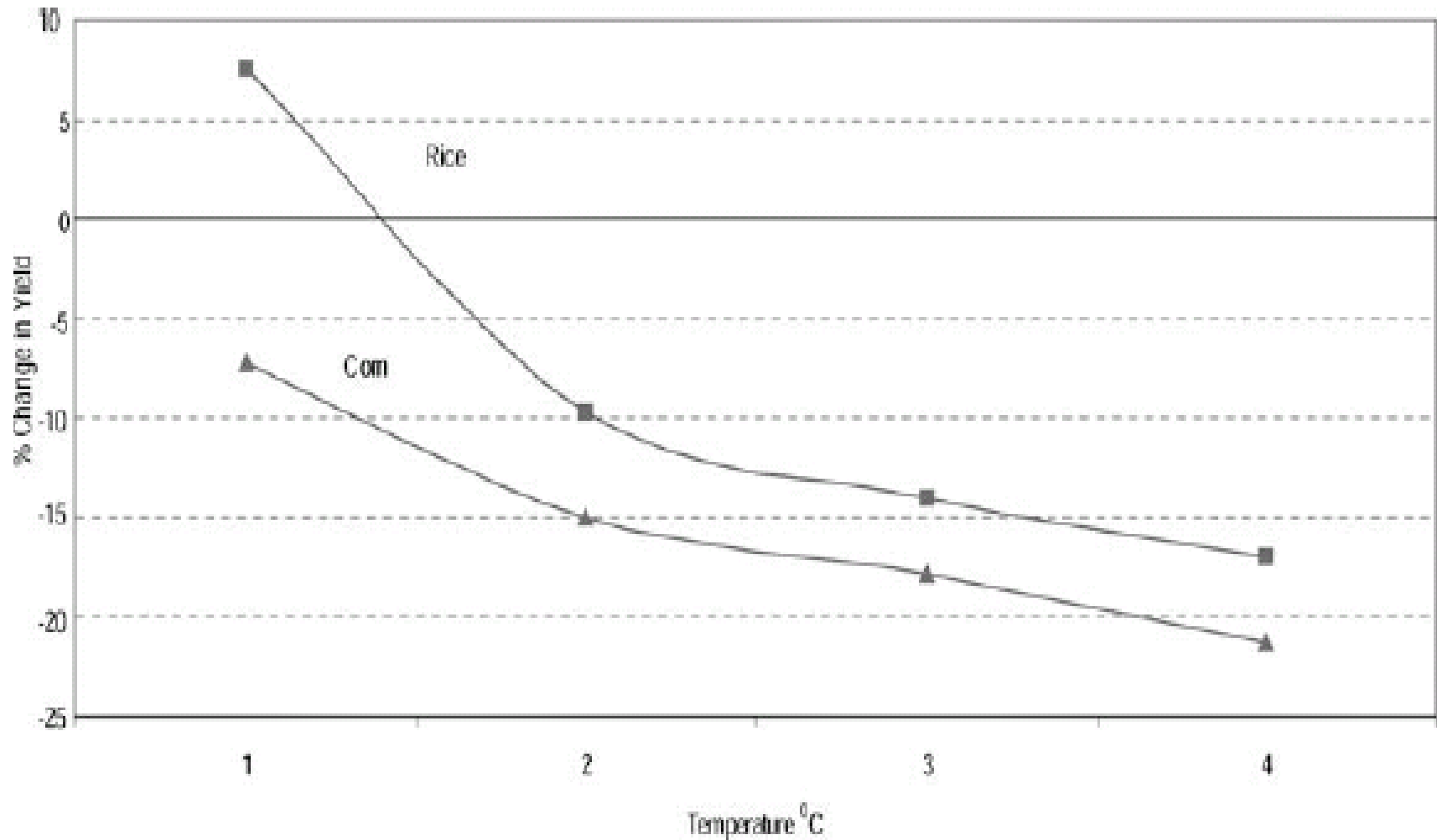


Figure 1. Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

Where we're headed: Temperate-zone agriculture

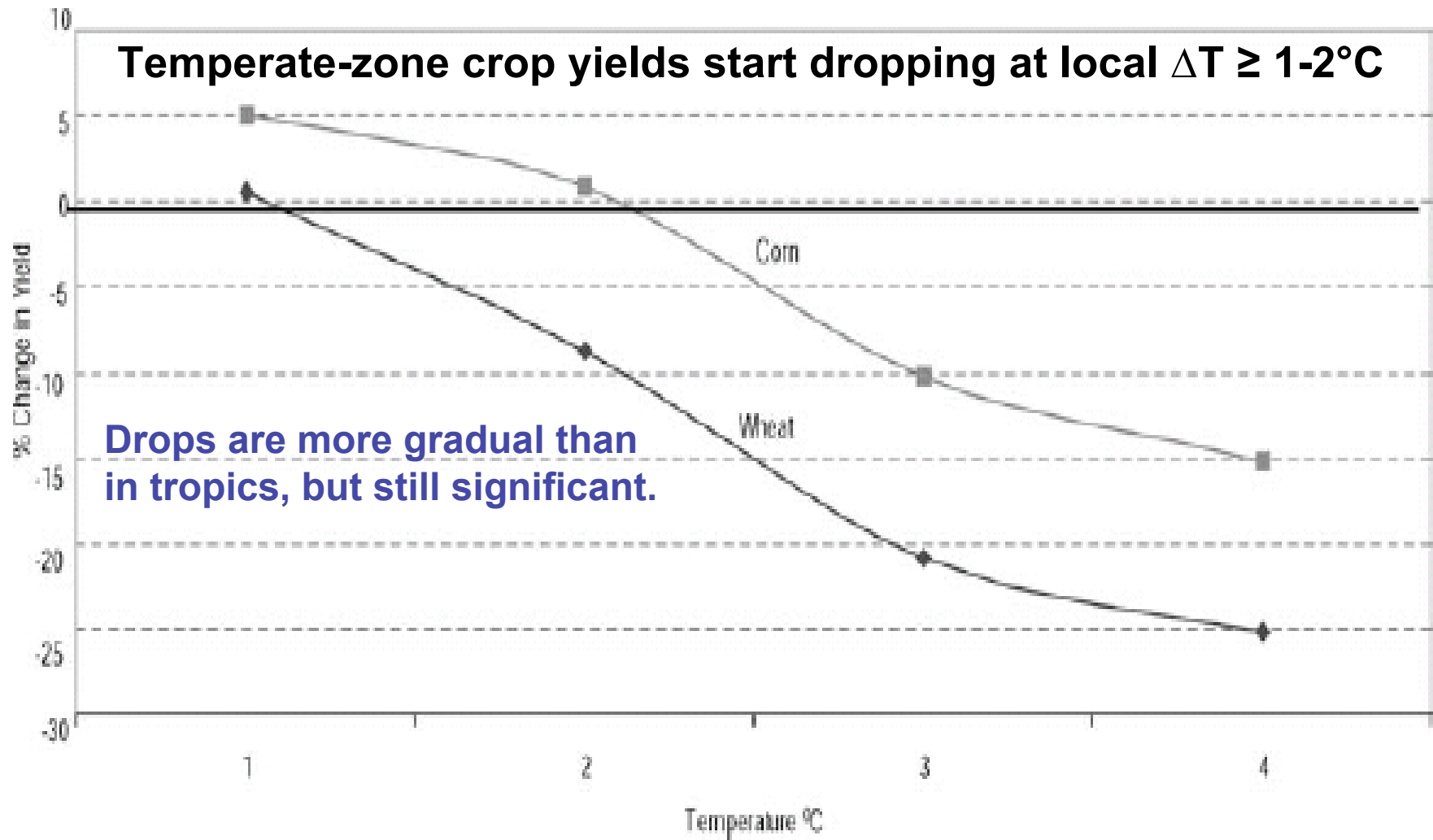
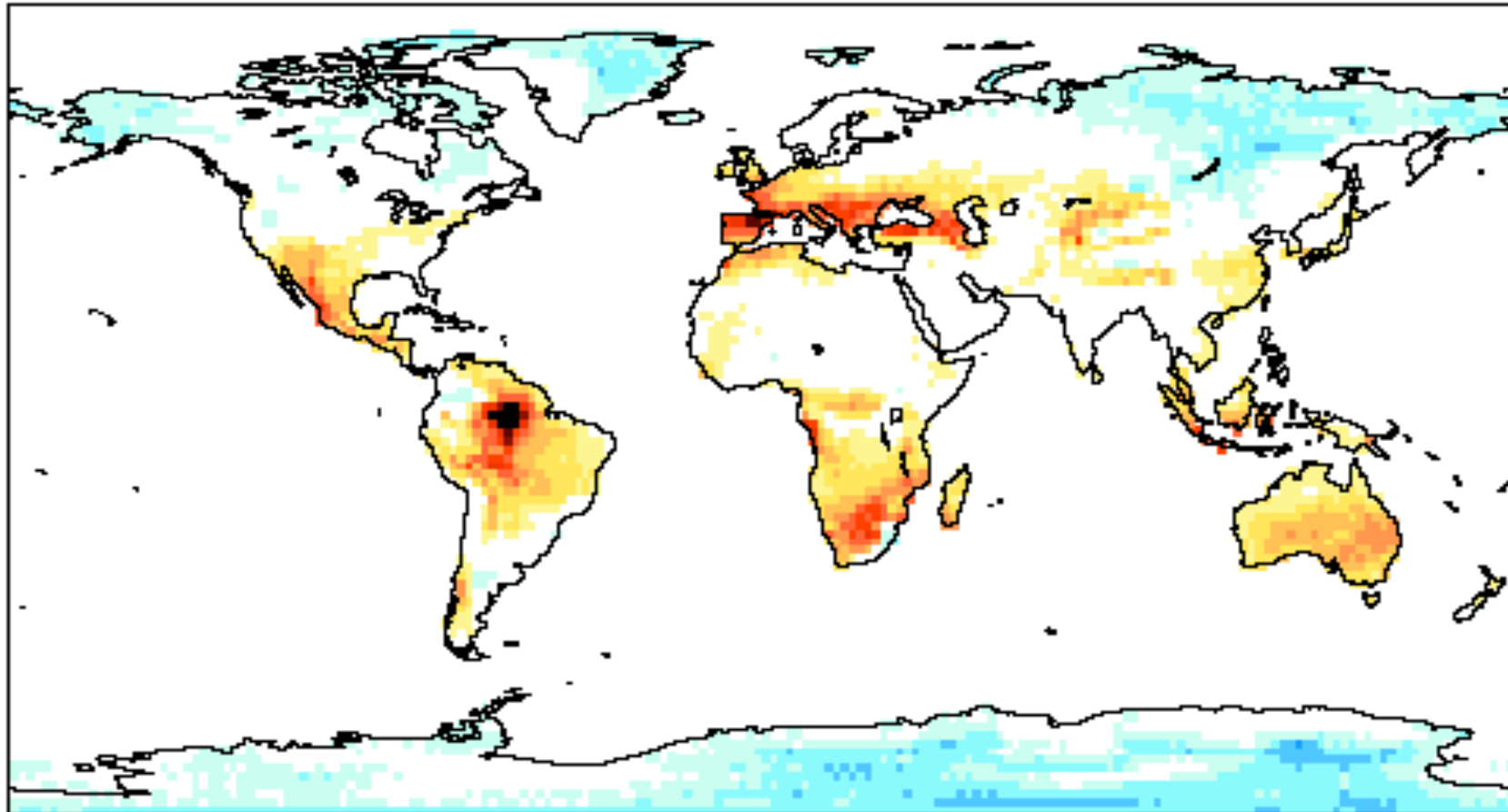


Figure 2. Corn and Wheat yields versus temperature increase in the temperate zone averaged across 30 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

Where we're headed: droughts

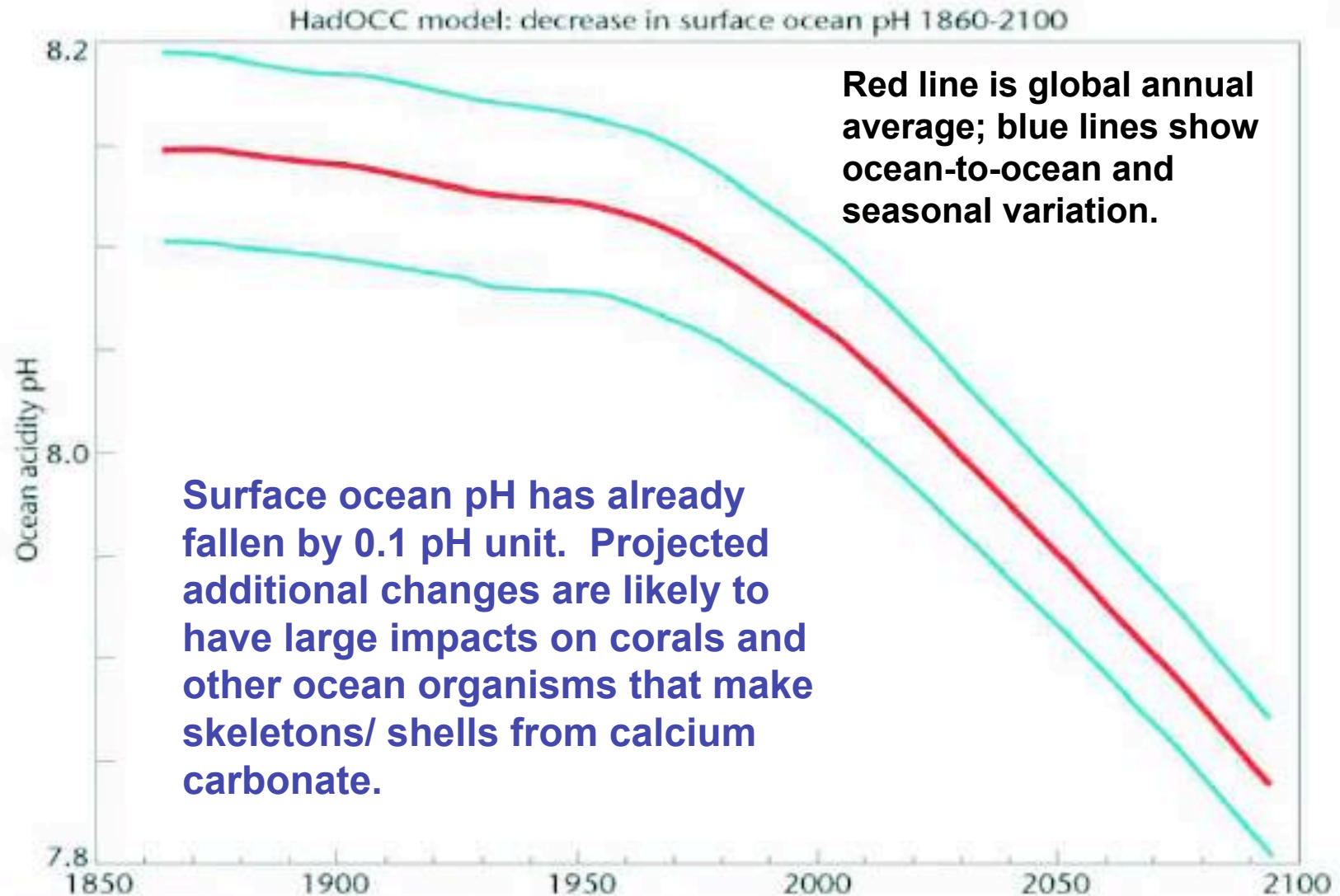
Drought projections for IPCC's A1B scenario



Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.

Where we're headed: Oceans acidifying as well as warming

pH history and "business as usual" projection



Where we're headed: sea level

Melting the Greenland and Antarctic Ice Sheets would raise sea level up to 70 meters.

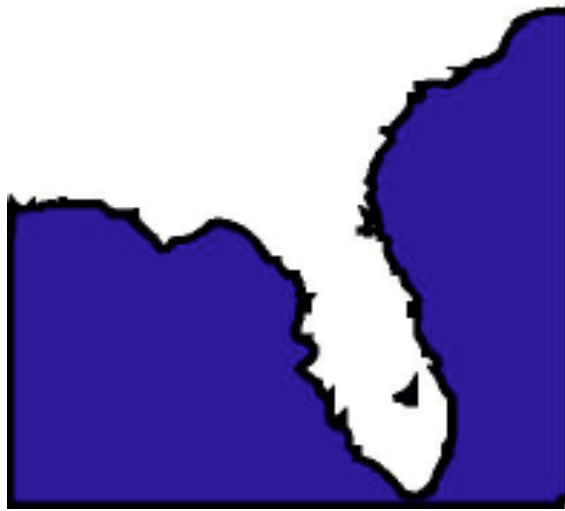
This would probably take 1000s of years, but rates of 2-5 m per century are possible.

GIS = Greenland Ice Sheet

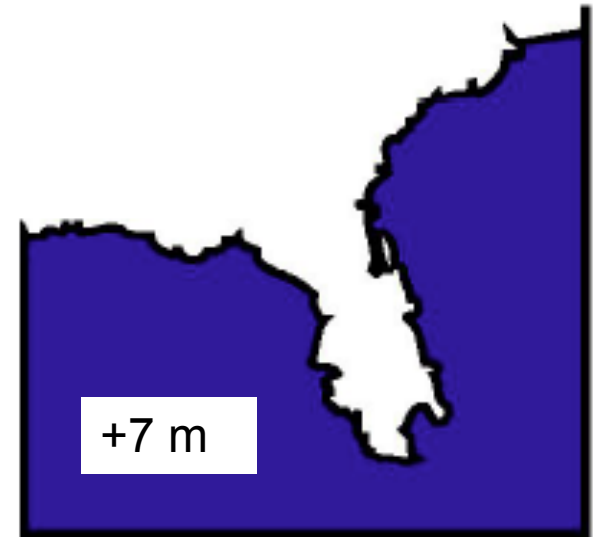
WAIS = West Antarctic Ice Sheet

EAIS = East Antarctic Ice Sheet

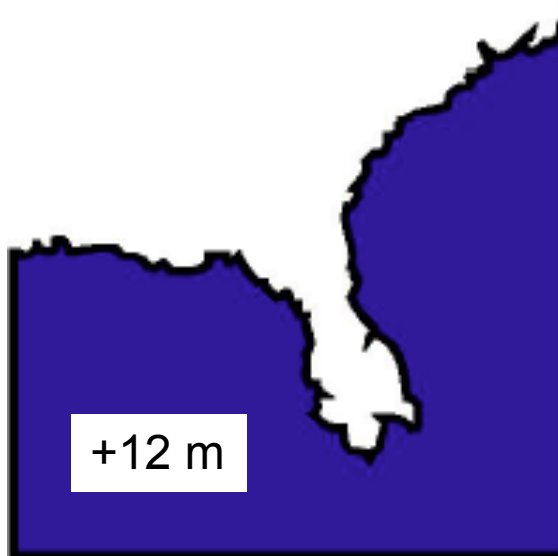
Modern Florida



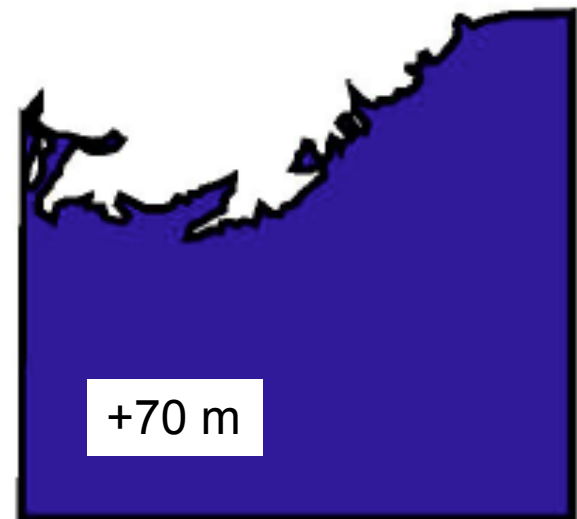
Florida w/o GIS

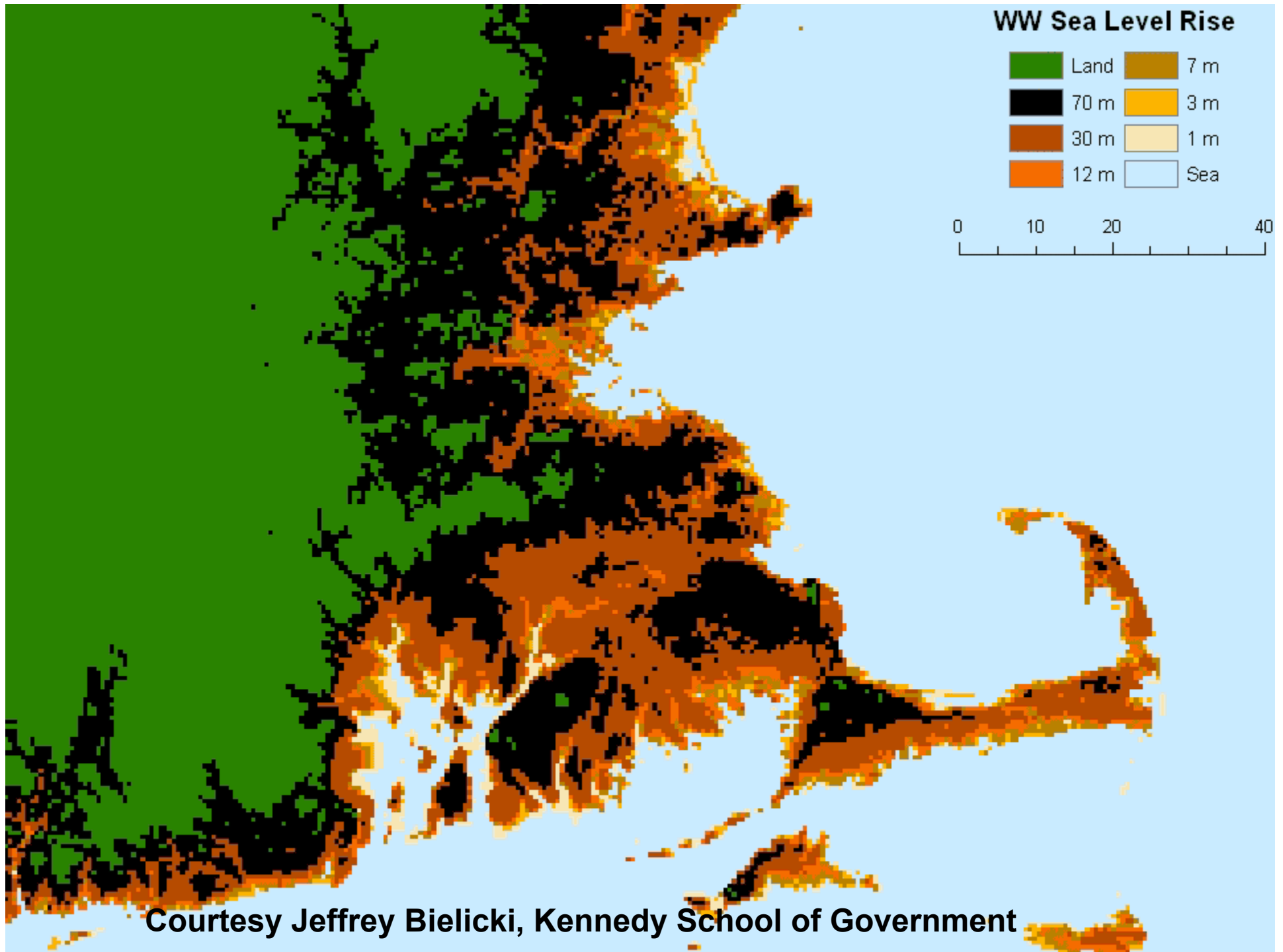


Florida w/o WAIS+GIS



Florida w/o WAIS+GIS+EAIS





Courtesy Jeffrey Bielicki, Kennedy School of Government

Facing the dangers from climate change...

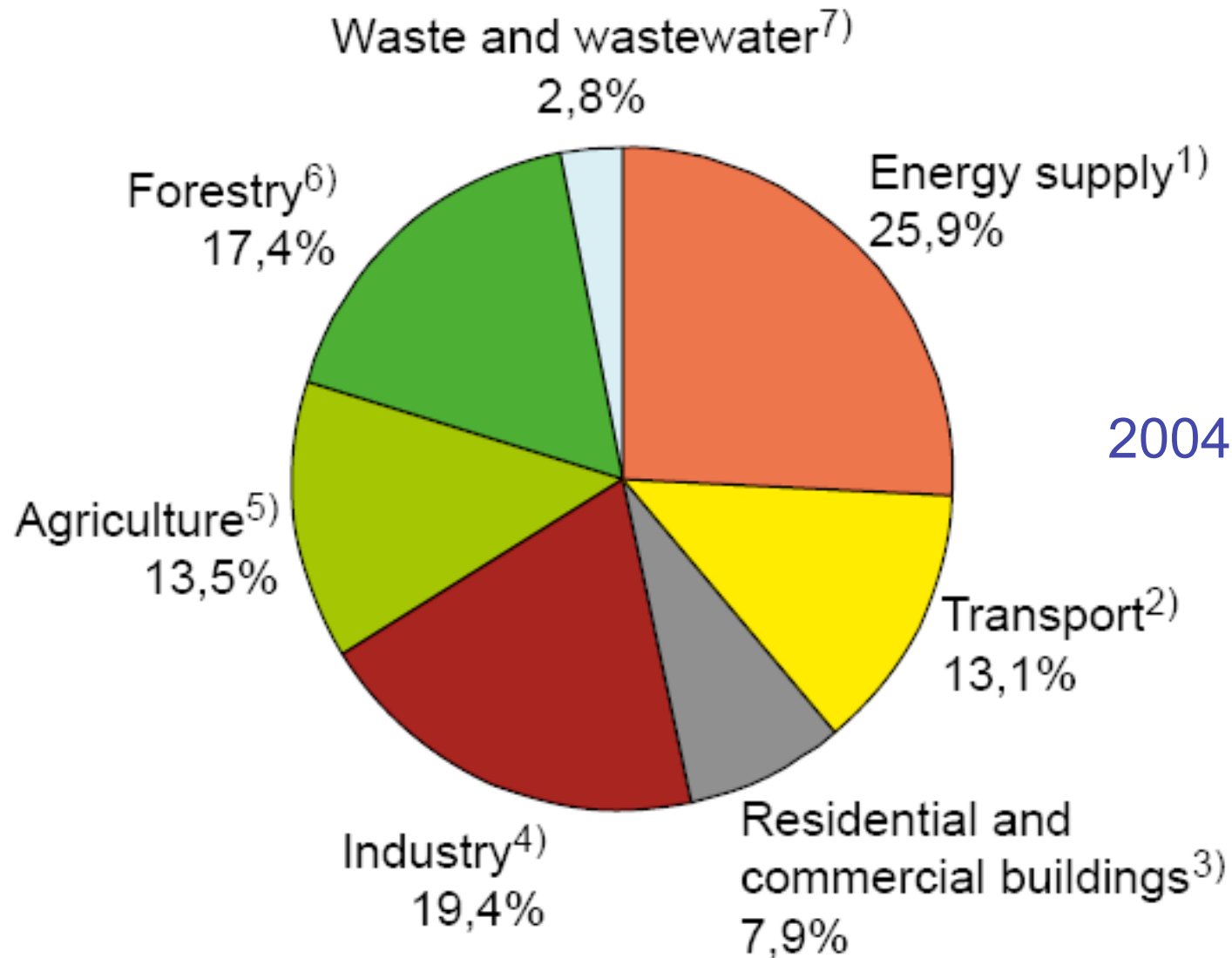
...there are only three options:

- Mitigation, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.
- Adaptation, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.
- Suffering the adverse impacts that are not avoided by either mitigation or adaptation.

Concerning the three options...

- We're already doing some of each.
- What's up for grabs is the future mix.
- Minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation and a lot of adaptation.
 - Mitigation alone won't work because climate change is already occurring & can't be stopped quickly.
 - Adaptation alone won't work because adaptation gets costlier & less effective as climate change grows.
 - We need enough mitigation to avoid the unmanageable, enough adaptation to manage the unavoidable.

Mitigation leverage: The sources of GHG emissions



Mitigation possibilities include...

(CERTAINLY)

- Reduce emissions of greenhouse gases & soot from the energy sector
- Reduce deforestation; increase reforestation & afforestation
- Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon

(CONCEIVABLY)

- “Scrub” greenhouse gases from the atmosphere technologically
- “Geo-engineering” to create cooling effects offsetting greenhouse heating

How much mitigation is needed, how soon?

- The UN Framework Convention on Climate Change of 1992 is “the law of the land” in 191 countries (including the United States).
- It calls for
“stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”.
- But there was no formal consensus in 1992 as to what constitutes “dangerous anthropogenic interference” or what level of GHG concentrations will produce it.

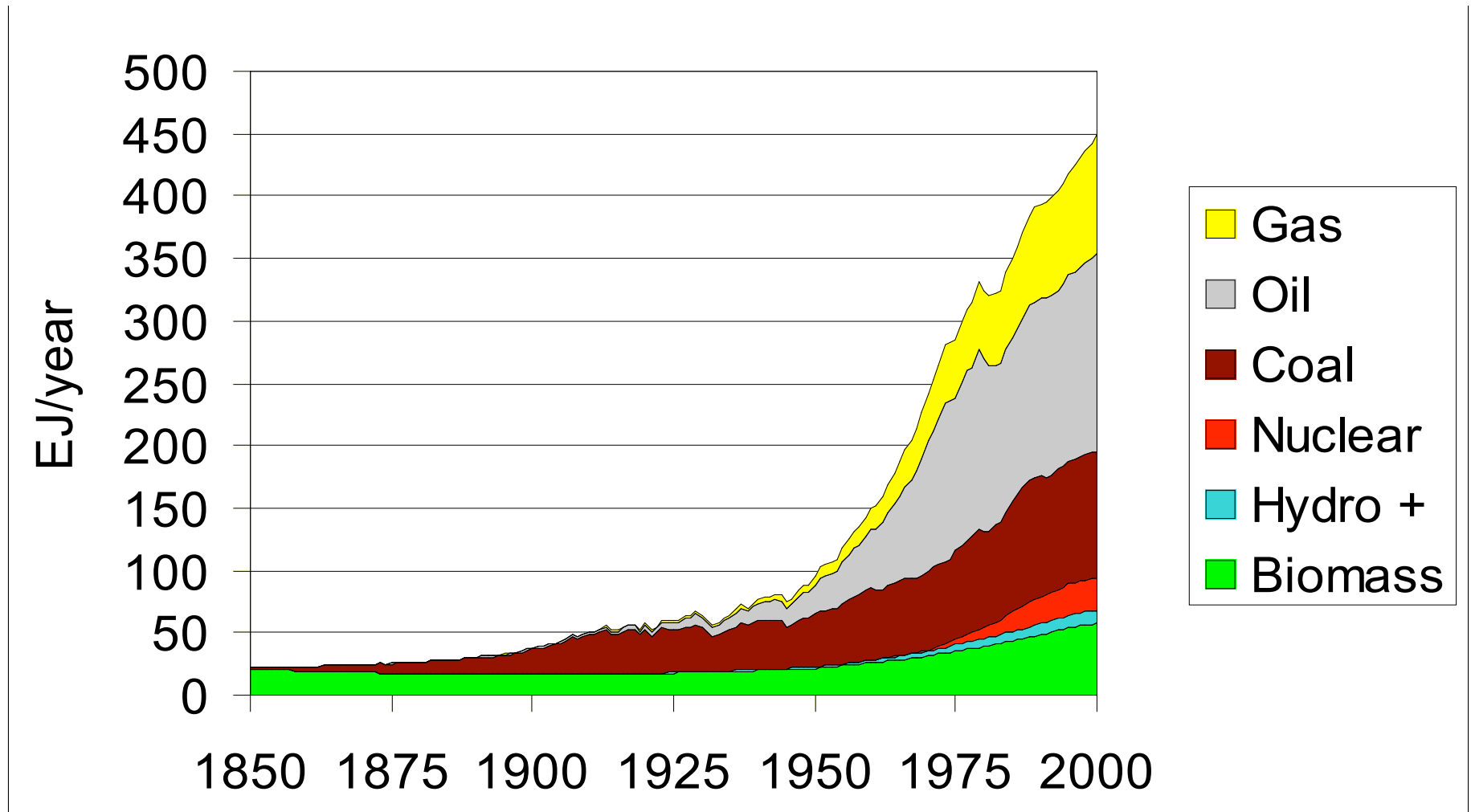
How much, how soon? (continued)

- There's still no "official" consensus, but it's becoming clear that the current level of interference is dangerous.
- Can we avoid catastrophic interference?
 - T_{avg} would rise 0.6°C more (to 1.4°C above pre-industrial) even if concentrations were stabilized today.
 - Chance of a tipping point into catastrophic change grows rapidly for T_{avg} more than 2°C above pre-industrial (IPCC 2007, UNSEG 2007).
- Limiting ΔT_{avg} to $\leq 2^{\circ}\text{C}$ is the most prudent target that still might be attainable; as a fallback, 2.5°C gives better odds of avoiding catastrophe than 3°C.

Key mitigation realities

- Human CO₂ emissions are the biggest piece of the problem (50% and growing)
 - 3/4 comes from burning coal, oil, & natural gas (80% of world energy)
 - 1/4 comes from deforestation & burning in the tropics
- While 60% of fossil CO₂ still came from industrialized countries in 2006, developing countries will dominate after 2015.
- Global energy system can't be changed quickly: \$15T is invested in it, w normal turnover ~40 yrs.
- Deforestation isn't easy to change either: forces driving it are deeply embedded in the economics of food, fuel, timber, trade, & development.

The biggest cause: 150+ years of world energy growth driven by fossil fuels



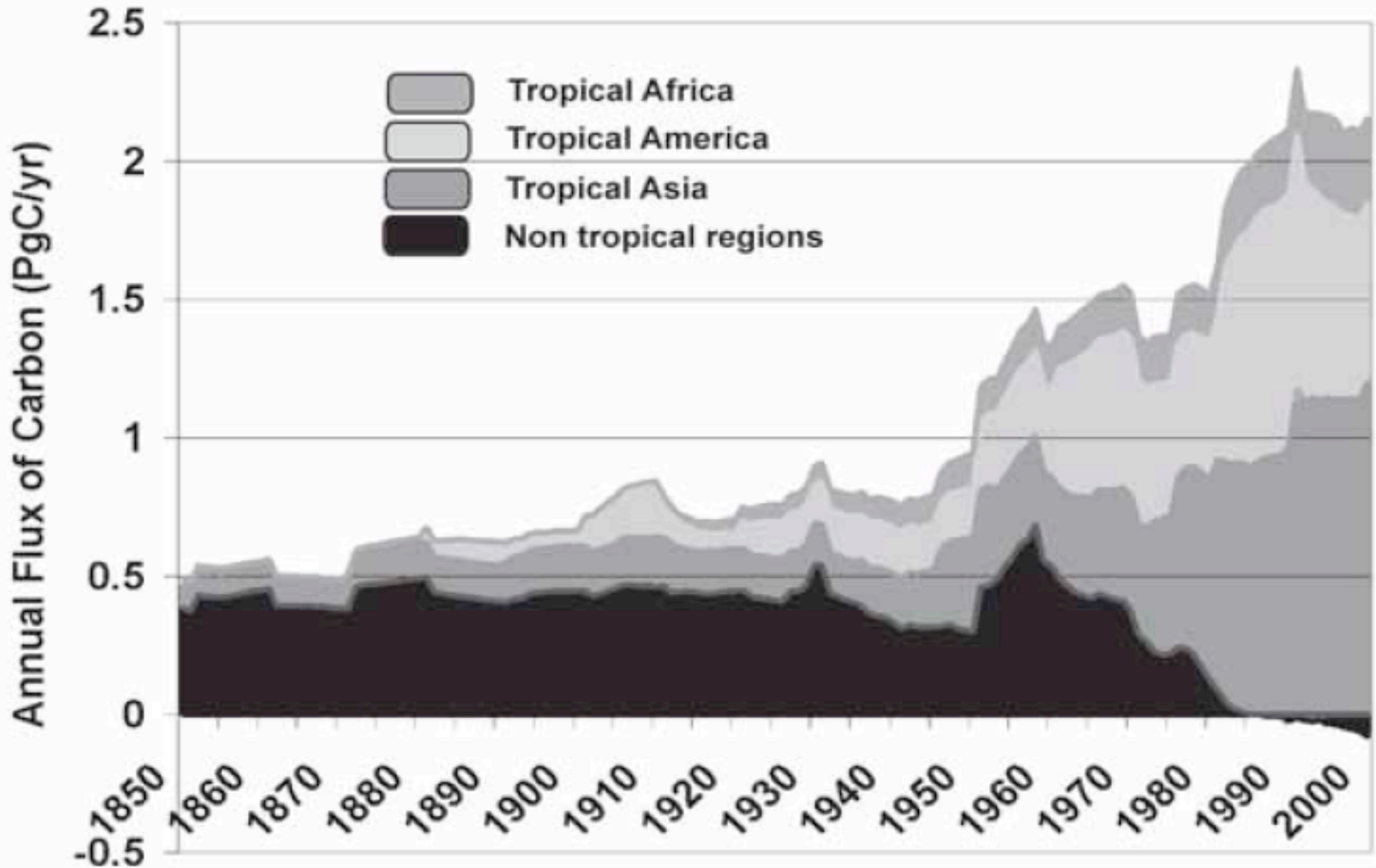
The 20-fold increase in world energy use in this period came mostly from coal (1850-1950) and oil & gas (1950-2000).

World energy system is huge, costly, long-lived



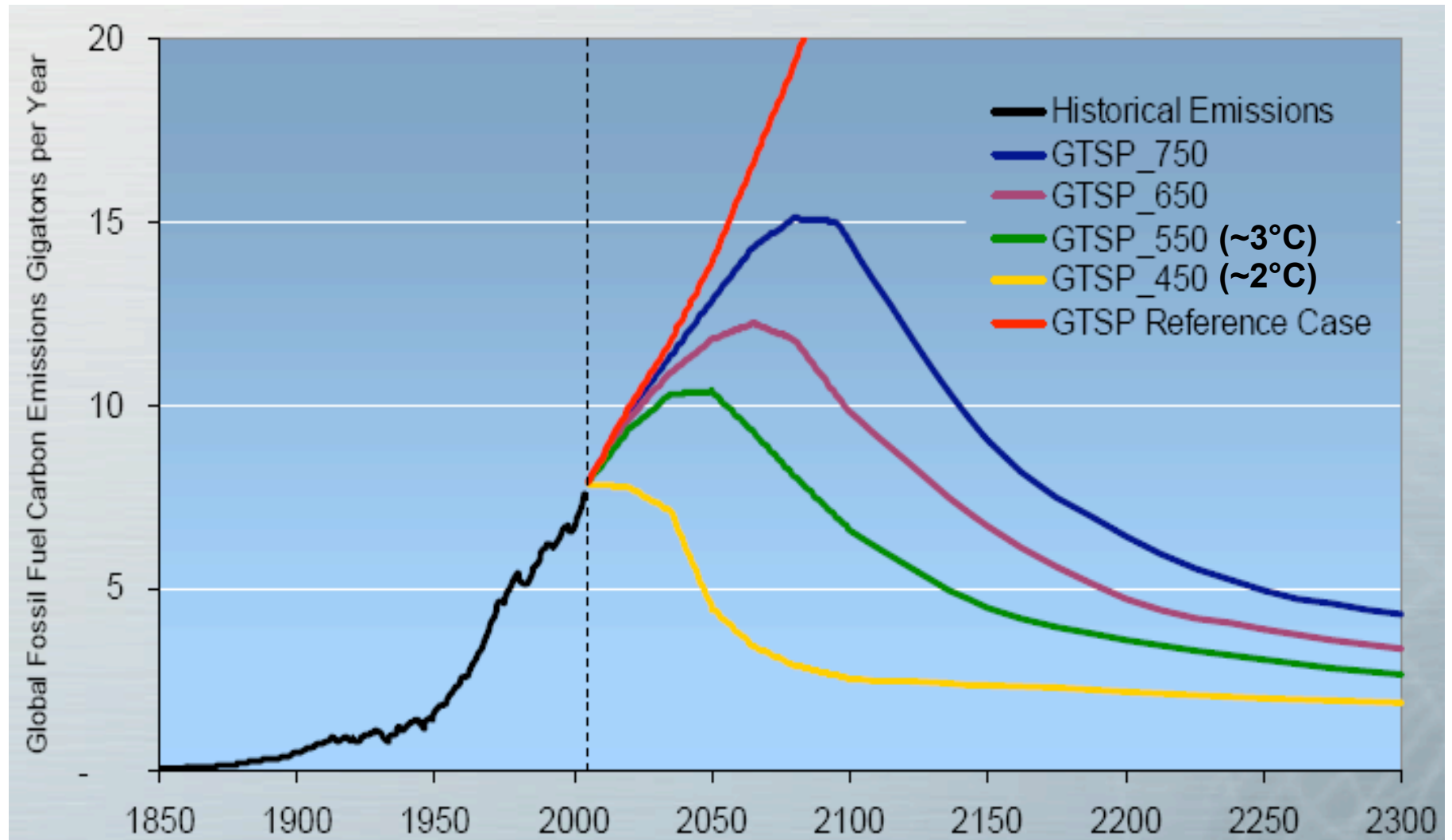
Capital investment is ~\$15 trillion, turnover time is ~40 years.

2nd biggest cause: 150 years of deforestation



Houghton in Moutinho & Schwartzman, 2005

Fossil CO₂ emissions paths: BAU versus stabilizing CO₂ concentration to limit ΔT_{avg}



Global Energy Technology Strategy, Battelle, 2007

Leverage on fossil-fuel CO₂ emissions

The emissions arise from a 4-fold product...

$$C = P \times \text{GDP} / P \times E / \text{GDP} \times C / E$$

where C = carbon content of emitted CO₂ (kilograms),
and the four contributing factors are

P = population, persons

GDP / P = economic activity per person, \$/pers

E / GDP = energy intensity of economic activity, GJ/\$

C / E = carbon intensity of energy supply, kg/GJ

For example, in the year 2000, the world figures were...

$$\begin{aligned} &6.1 \times 10^9 \text{ pers} \times \$7400/\text{pers} \times 0.01 \text{ GJ}/\$ \times 14 \text{ kgC}/\text{GJ} \\ &= 6.4 \times 10^{12} \text{ kgC} = 6.4 \text{ billion tonnes C} \end{aligned}$$

Options for reductions

Reduce growth of energy use by...

- reducing population growth
- reducing growth of GDP/person
- reducing E/GDP ratio by
 - increasing efficiency of conversion to end-use forms
 - increasing technical efficiency of energy end-use
 - changing mix of economic activities

Reduce CO₂/E ratio by...

- substituting natural gas for oil & coal
- replacing fossil fuels with renewables
- replacing fossil fuels with nuclear energy
- capturing & sequestering CO₂ from fossil-fuel use

There is no panacea

All of the options have limitations & liabilities.

- limiting population: social & political sensitivities
- slowing GDP/person: economic aspirations
- expanding natural gas: resource size & distribution
- wind: intermittency, siting (NIMBY→BANANA)
- biofuels: net energy, land, food/ecosystem impacts
- photovoltaics: intermittency, cost, toxics
- nuclear fission: cost, waste, safety, proliferation
- nuclear fusion: doesn't work yet
- CO₂ capture/sequestration: cost, scale, complexity
- end-use efficiency: education, other barriers

Note: H₂ is not a stand-alone option; one has to make it.

Big problem & lack of panacea mean...

- We'll need a portfolio of approaches
 - Not just one or two, but many;
 - although not necessarily everything on the menu, as developing the better options to their full potential may allow foregoing some that prove very costly or risky.
- We need increased research & development on all of the options to try to
 - improve their performance,
 - lower their costs, and
 - reduce their adverse side effects,so that the future menu can be better than today's.

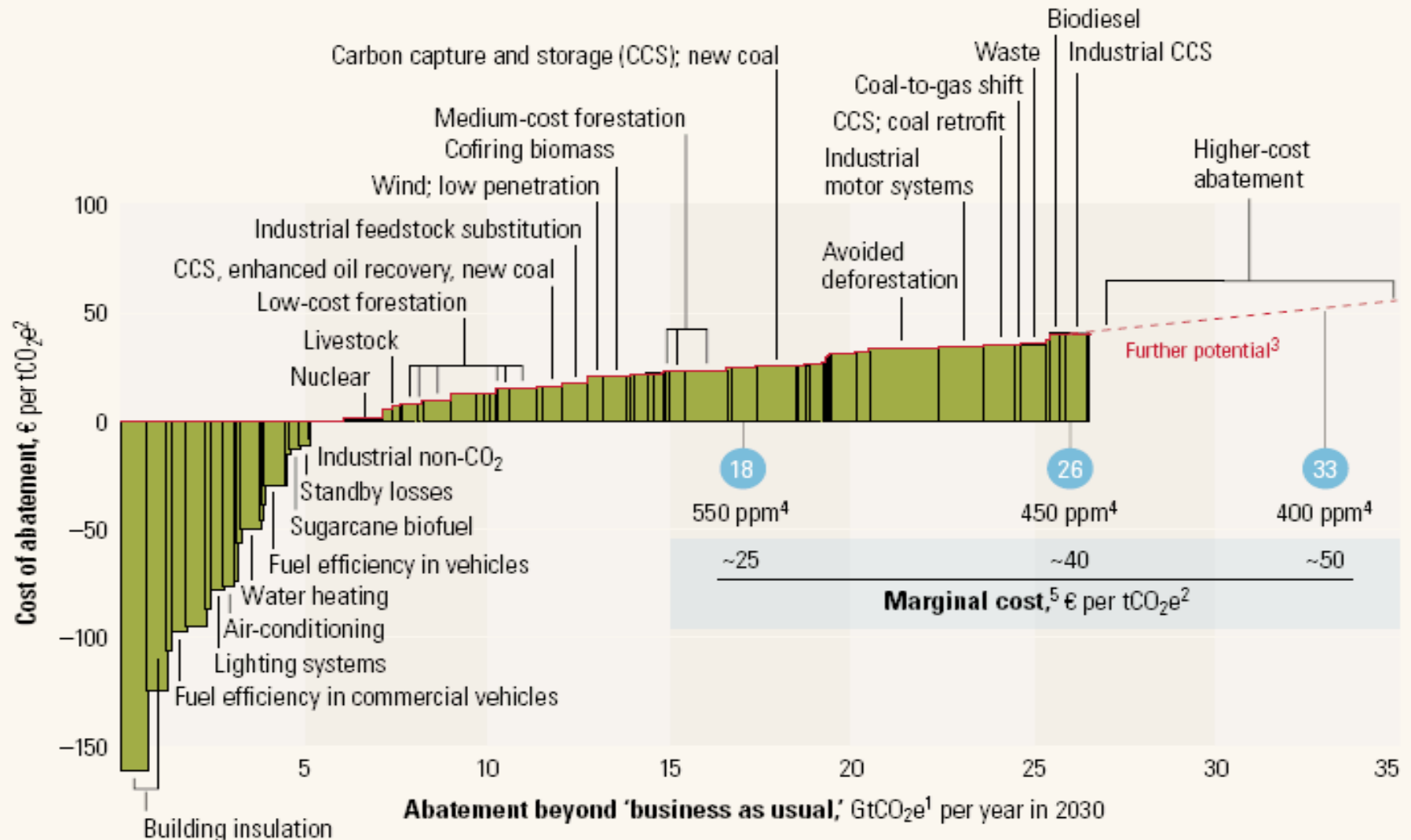
Good & bad news re mitigation

- G: The cheapest, fastest, cleanest, surest source of emissions reductions is to increase the efficiency of energy use in buildings, industry, and transport.
- G: Many such approaches are “win-win”: their co-benefits in saved energy, increased energy security, reduced conventional pollution, etc., are more than worth their costs.
- G: Some supply-side mitigation options (wind, some bio-fuels) are also “win-win”, as are many adaptation options.
- B: The “win-win” approaches will not be enough. Adequate mitigation will require putting a price on emissions of GHG (via emissions tax or tradable emissions permits).

Supply curve for GHG abatement in 2030

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in GtCO₂e¹

● Approximate abatement required beyond 'business as usual,' 2030



McKinsey, 2007

The challenge of scale

Stabilizing at 500 ppmv CO₂-e requires reducing global CO₂ emissions by ~7 GtC/yr in 2050 compared to BAU. Avoiding 1 GtC/yr requires...

- energy use in buildings cut 20-25% below BAU in 2050, or
- fuel economy of 2 billion cars increased from 30 to 60 mpg, or
- carbon capture & storage for 800 1-GWe coal-burning power plants, or
- 700 1-GWe nuclear plants replacing coal plants, or
- 1 million 2-MWe(peak) wind turbines replacing coal power plants.

Some mitigation-policy realities

- In applying the costlier solutions, the industrialized nations must lead – going first, paying more of the up-front costs, offering assistance to developing countries.

This is a matter of historical responsibility, capacity, equity, and international law (the UNFCCC).

- Developing countries will need to be compensated for reducing/avoiding deforestation.
- Without a formal & binding global agreement on the allocation of emissions in the post-Kyoto period, the needed global reductions will not be achieved.
- The best basis for such an agreement in the short term is probably reductions in emission intensity (GHG/GDP); in the longer run, the only politically acceptable basis will be equal per-capita emissions rights.

Economics of mitigation

- Current global CO₂ emission rate from fossil fuels + deforestation ≈ 9-10 billion tonnes of C per year.

Paying \$100/tC to avoid half of it would be \$0.5 trillion/year, about 1% of the Global World Product (much of it a transfer, not money down a black hole).

- World spends 2.5% of GWP on defense; USA spends 5% of GDP on defense, 2% on environmental protection.
- More sophisticated analyses of economic impact of mitigation to stabilize at 550 ppmv CO₂e → ~1% GWP loss (range 0.5-2%) in 2100 (Stern review); mid-range IPCC 2007 estimates are ~0.5% GWP loss in 2030.

Adaptation possibilities include...

- Changing cropping patterns
- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Building new water projects for flood control & drought management
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

Many of these are “win-win”.

The most important next steps

- Accelerate “win-win” mitigation and adaptation measures; integrate adaptation with development
- Put a price on GHG emissions so marketplace can work to find cheapest reductions
- Pursue a new global framework for mitigation and adaptation in the post-Kyoto period
- Sharply increase investments in energy-technology research, development, demonstration
- Expand international cooperation on deploying advanced energy technologies

The United States must lead!

Some references

John P. Holdren, “The energy innovation imperative”,
Innovations: Technology/ Globalization/Governance,
Vol. 1, No. 2, Spring 2006

http://bcsia.ksg.harvard.edu/BCSIA_content/documents/Innovations_The_Imperative_6_06.pdf

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Change: Avoiding the Unmanageable and Managing
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<http://www.unfoundation.org/SEG/>

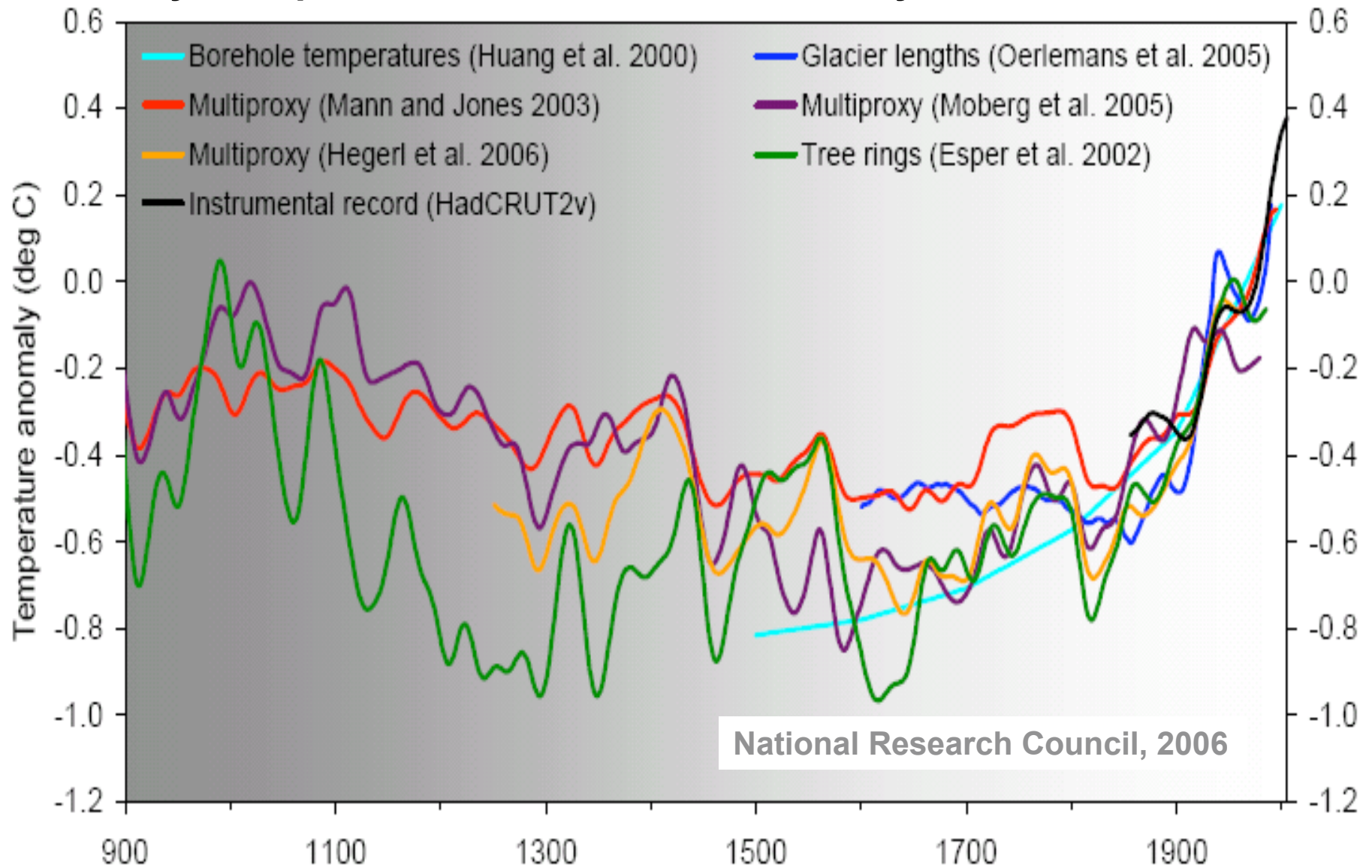
Intergovernmental Panel on Climate Change, *Climate
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KSG Belfer Center, *Energy Technology Innovation Policy
website*: <http://www.belfercenter.org/energy/>

Supplementary materials

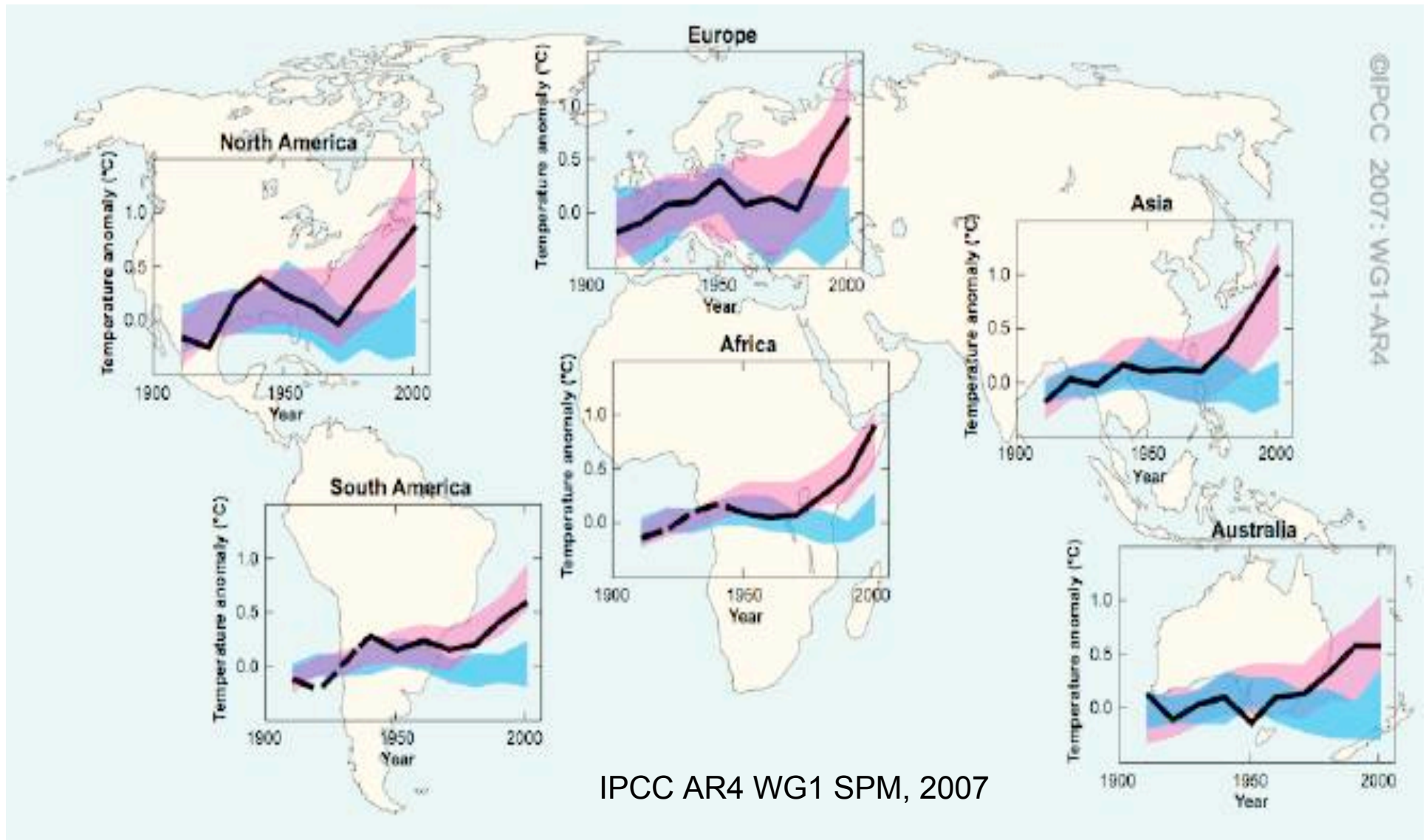
What's happening reverses a long cooling trend

“Proxy” temperature reconstructions + 125-yr thermometer record



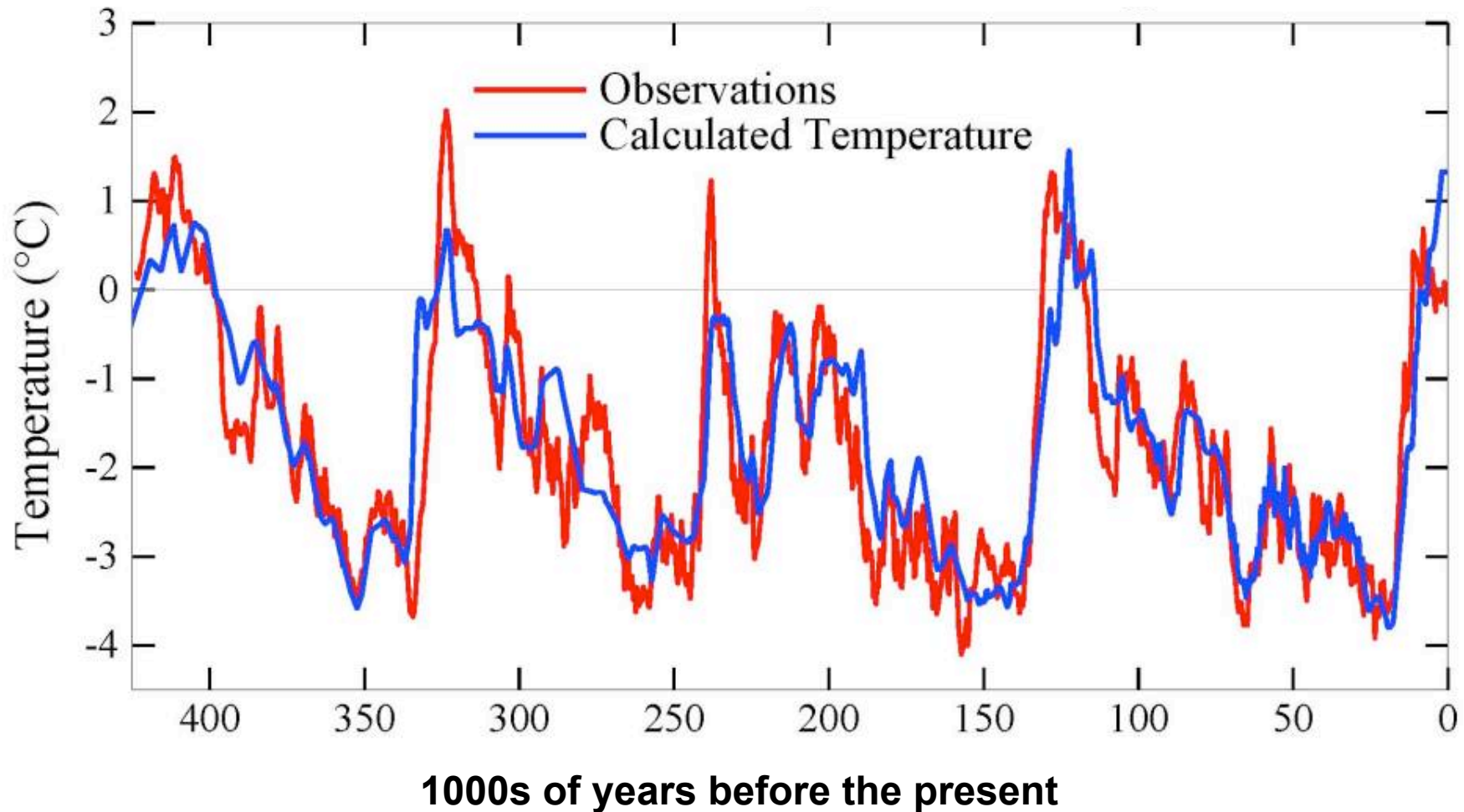
T leveled off ~1600, started to rise after 1700 & more sharply after 1800.

Computer models match observed ΔT on all continents



Black lines are decadal averaged observations. Blue bands are computer models with natural forcings only. Pink bands are computer models with human + natural forcings.

The same computer models capture the essentials of long-term climate change from natural causes.



Observations are Antarctic temperature anomaly (derived from ice-core δD) divided by 2 to give global-average T change. Calculated T is based on known forcings assuming sensitivity of 0.75°C per W/m^2 . From J. Hansen 2005.

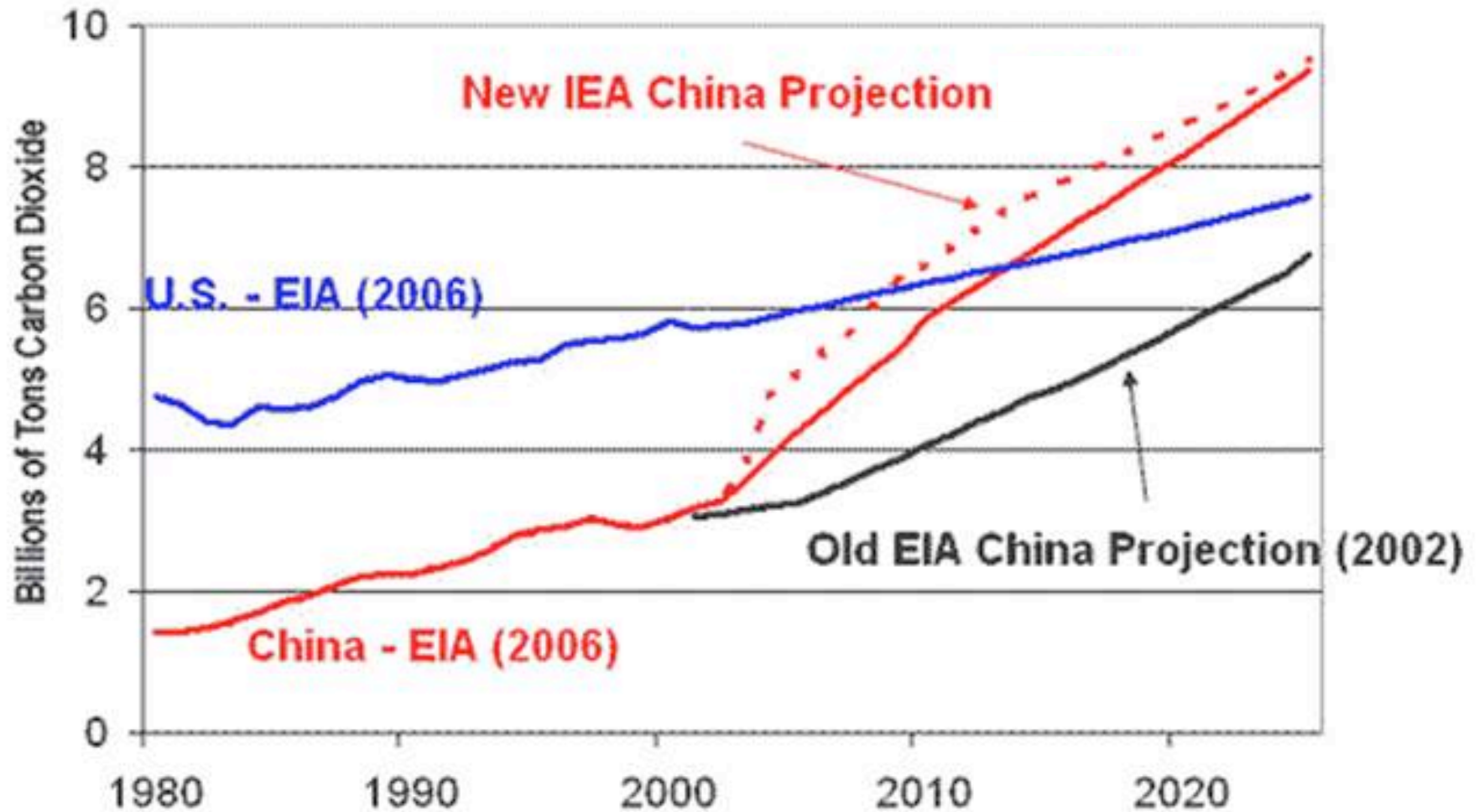
Fossil-fuel dominance in detail

	2005	World	USA	China
Primary Energy (exajoules)		514	106	80
of which... Oil		34%	40%	18%
Natural Gas		21%	24%	2%
Coal		26%	25%	62%
Nuclear Energy		6%	8%	0.6%
Hydropower		2%	1%	2%
Biomass and Other		11%	3%	15%

In 2005, fossil fuels were 81% of world energy, 88% in USA, 82% in China.

“Leadership” in emissions shifting to LDCs

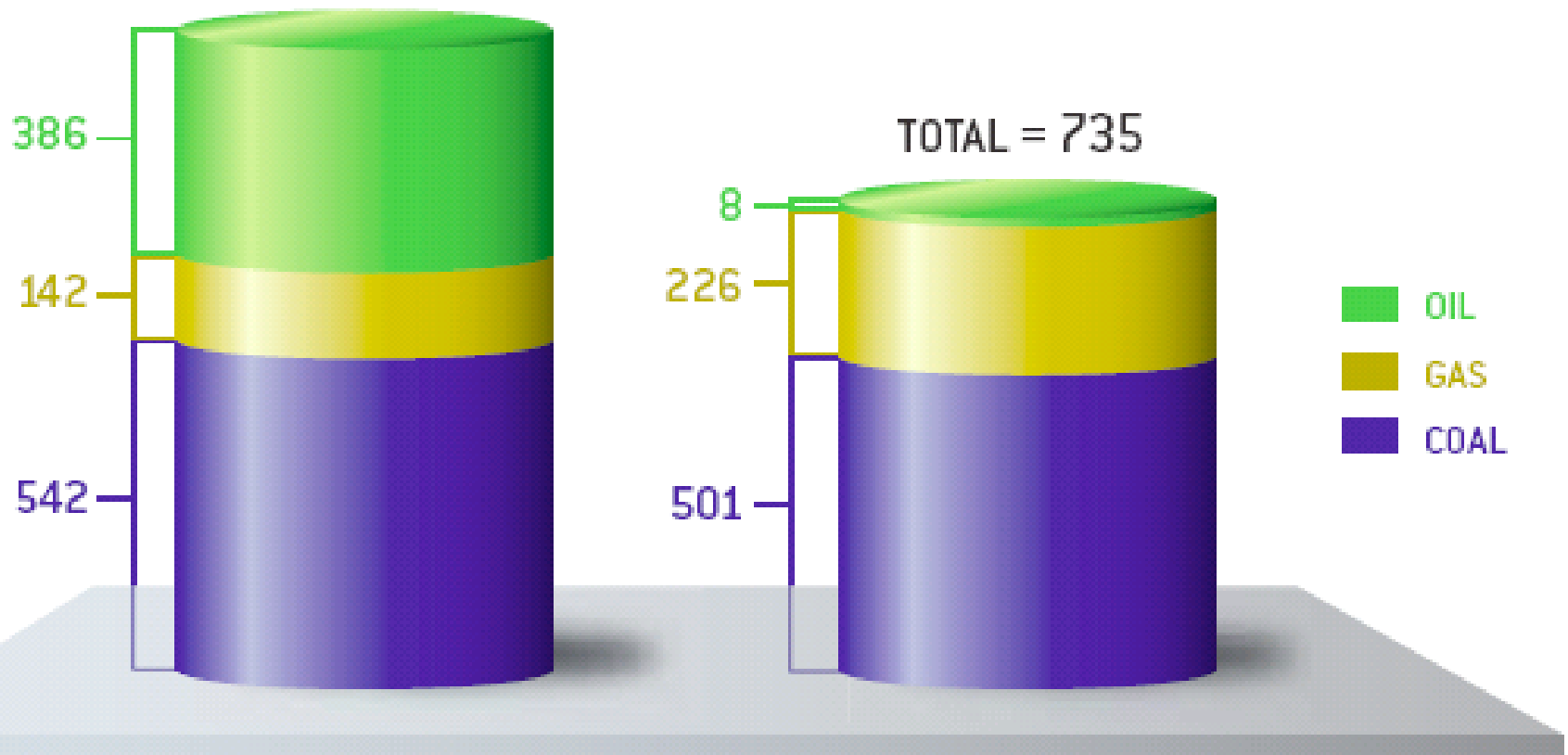
Chinese and U.S. Carbon Dioxide Emission Comparisons, 1980-2025



Sources: U.S. EIA *International Energy Outlook 2006*; World Resources Institute; Oak Ridge National Laboratory.

Capturing CO₂ from power plants will be costly, but concentrations can't be stabilized soon enough unless we do it.

TOTAL = 1,070 (billions of tons of carbon dioxide)



All CO₂ emissions from 1750 to 2002

Lifetime CO₂ emissions from power plants built 2003-2030

LIFETIME FOSSIL-FUEL EMISSIONS from power plants projected to be built during the next quarter of a century will be comparable to all the emissions during the past 250 years.

Courtesy David Hawkins, Rob Socolow, & Scientific American

The impending US political tipping point

- Drumbeat of climate science about pace & impacts
- People's everyday experience (and news reports) of floods, droughts, heat, fires; Katrina
- Changing corporate attitudes & publicity: BP, Shell, GE, Dupont, Duke Energy, Exelon, Alcoa, PG&E...
- Shifting position of labor & religious communities
- Bipartisan, multi-sectoral consensus on policy reflected in high-profile US reports (e.g., Energy Futures Coalition, National Commission on Energy Policy)
- 2005 Sense of Senate resolution
- 2006 elections → Congress changes hands
- Al Gore's "Inconvenient Truth", Oscar, Nobel Prize
- 2007 IPCC, UNSEG reports underscore science, urgency
- Climate policies embraced by cities (~300) & states (~30)

What about China?

- China is the world's largest coal burner & now the 1st or 2nd largest emitter of GHG overall.
- Expectations have been that China would not sacrifice economic growth to reduce GHG emissions.
- Prospect that China, India, Brazil, and other large developing countries wouldn't participate has been the nightmare of architects of a global climate framework.
- This has recently been changing in China (and India)
- Chinese leaders now recognize that climate change is already harming China, leading to...
 - **sharp changes in rhetoric about the climate issue;**
 - **increased impetus behind actions to raise vehicle fuel efficiency;**
 - **potential for switch to carbon-capture ready coal technologies.**