Meeting the Climate-Change Challenge

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Main messages

- “Global warming” is a misnomer; we should be calling it “global climatic disruption”.
- The disruption & its impacts are now growing more rapidly than was expected just a few years ago.
- The world is already experiencing “dangerous anthro-pogenic interference in the climate system”. The question now is whether we can avoid catastrophic interference.
- Our options are mitigation, adaptation, & suffering. If we do less mitigation & adaptation, we’ll do more suffering.
- In mitigation and adaptation, there is a lot of “low-hanging fruit”, but it’s not enough. We need a price on GHG emissions to motivate reaching higher in the tree, as well as R&D to bring more fruit into reach.
- 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 <u>pattern</u> 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 <u>altered patterns</u>.

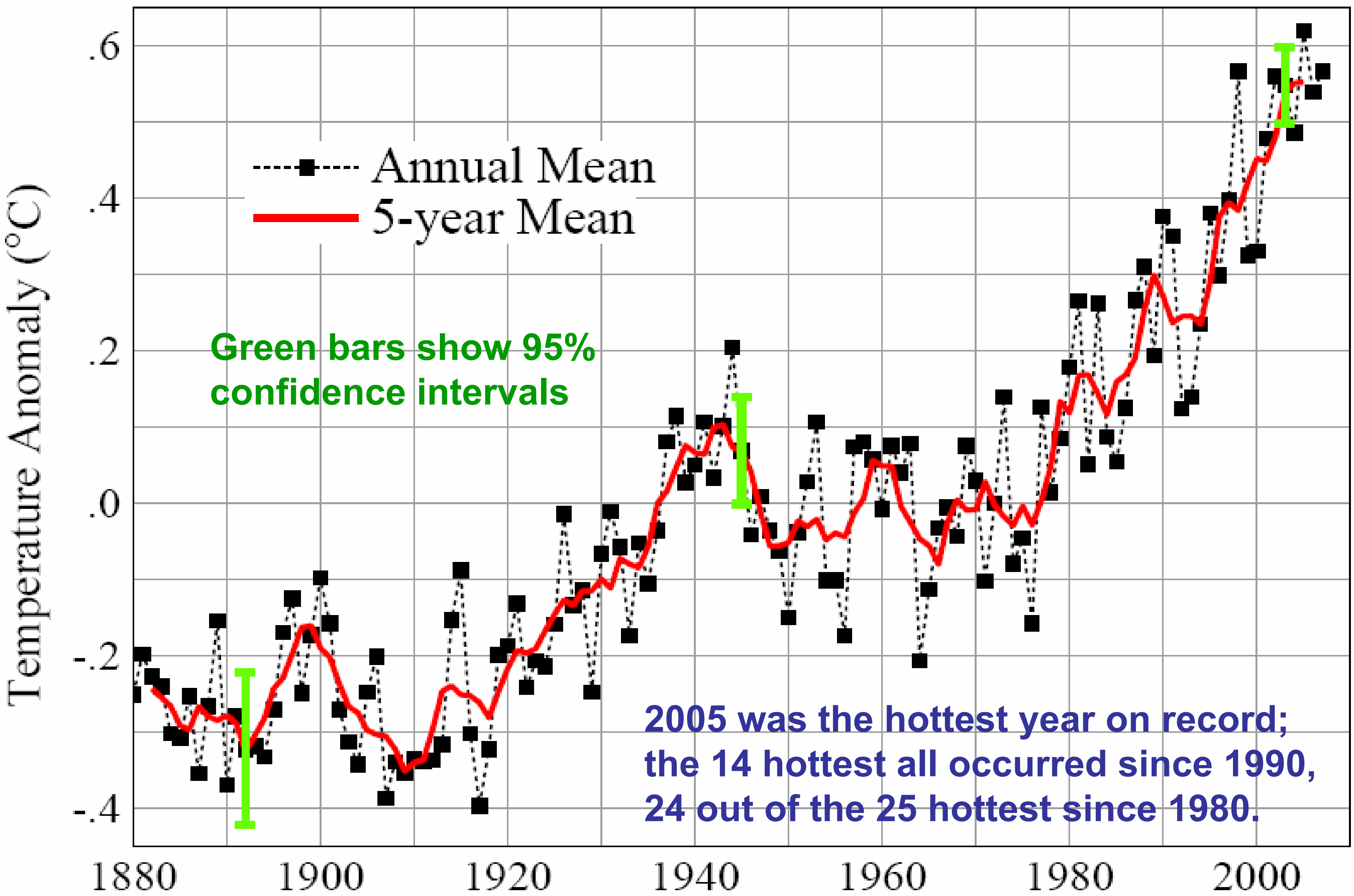
Global average temperature is just an <u>index</u> of the state of the global climate as expressed in these patterns. Small changes in the index → big changes in the patterns.

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

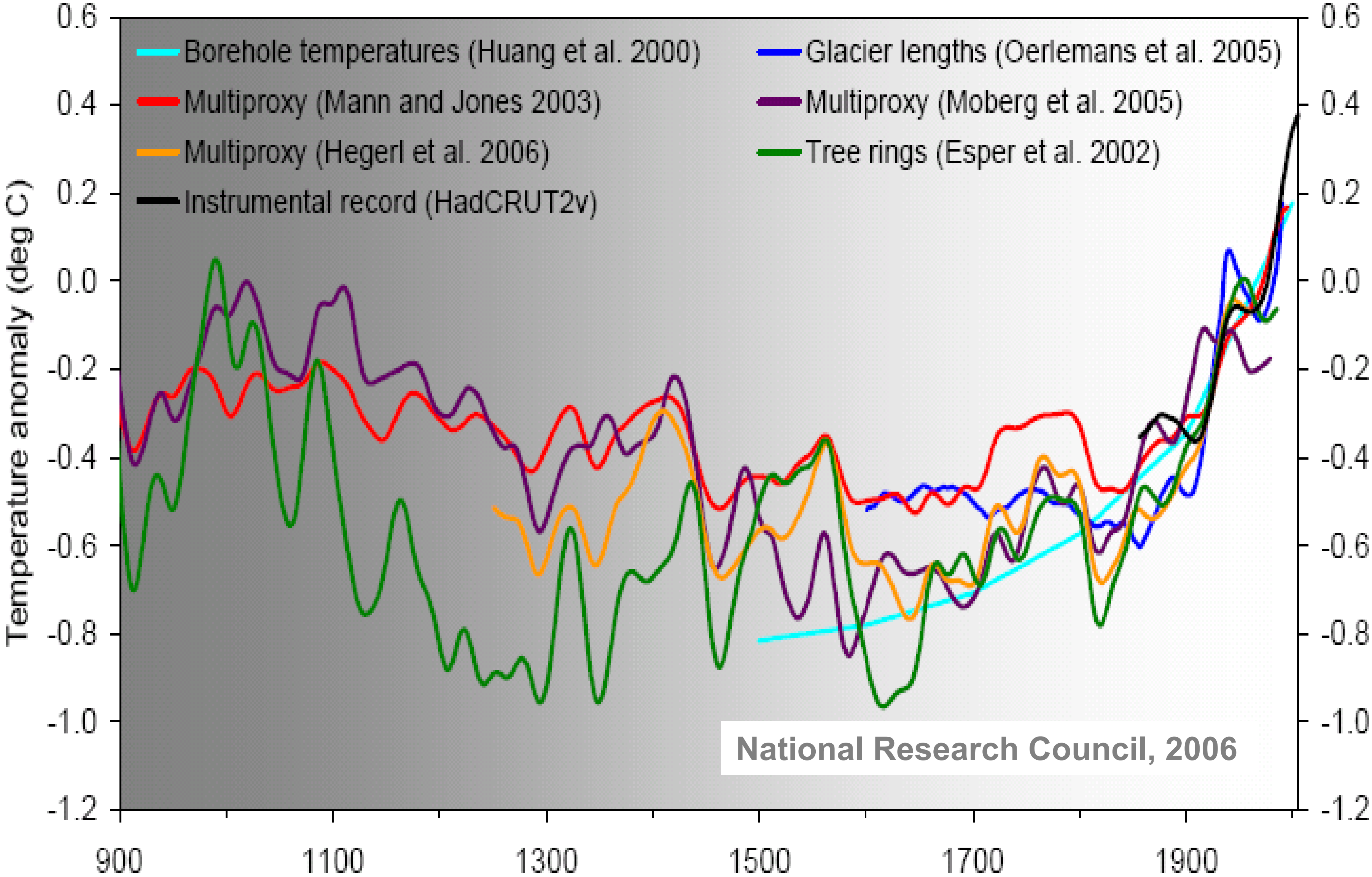
The Earth is getting hotter.



http://data.giss.nasa.gov/gistemp/graphs/

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.

We know why:

Human vs natural influences 1750-2005 (watts/m^2)

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

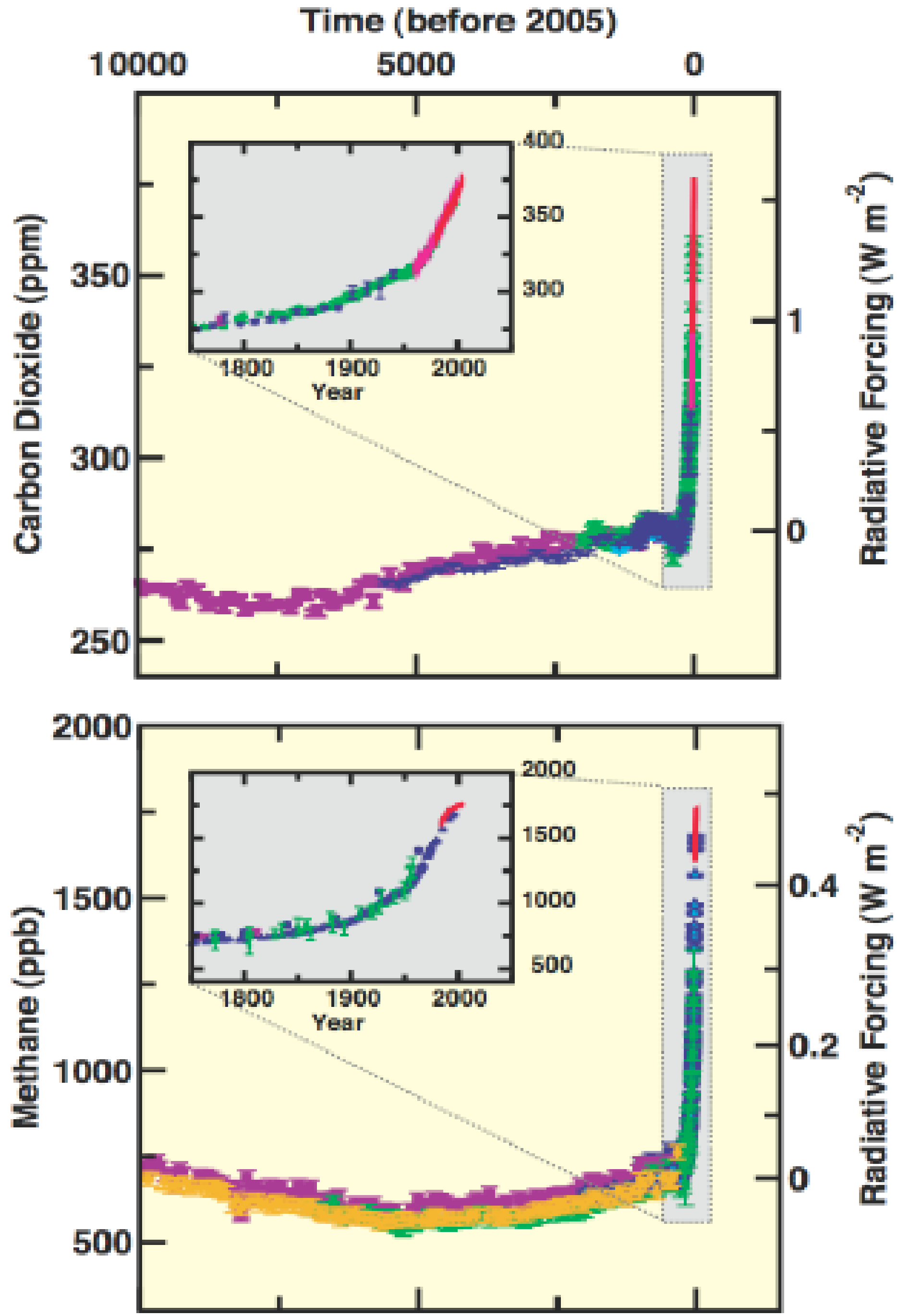
The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

IPCC AR4, WG1 SPM, 2007

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 CO_2 & CH_4 in the past 250 years is extraordinary.

We know humans are responsible for the CO_2 spike because fossil CO_2 lacks carbon-14, and the drop in atmospheric C-14 from the fossil-CO_2 additions is measurable.

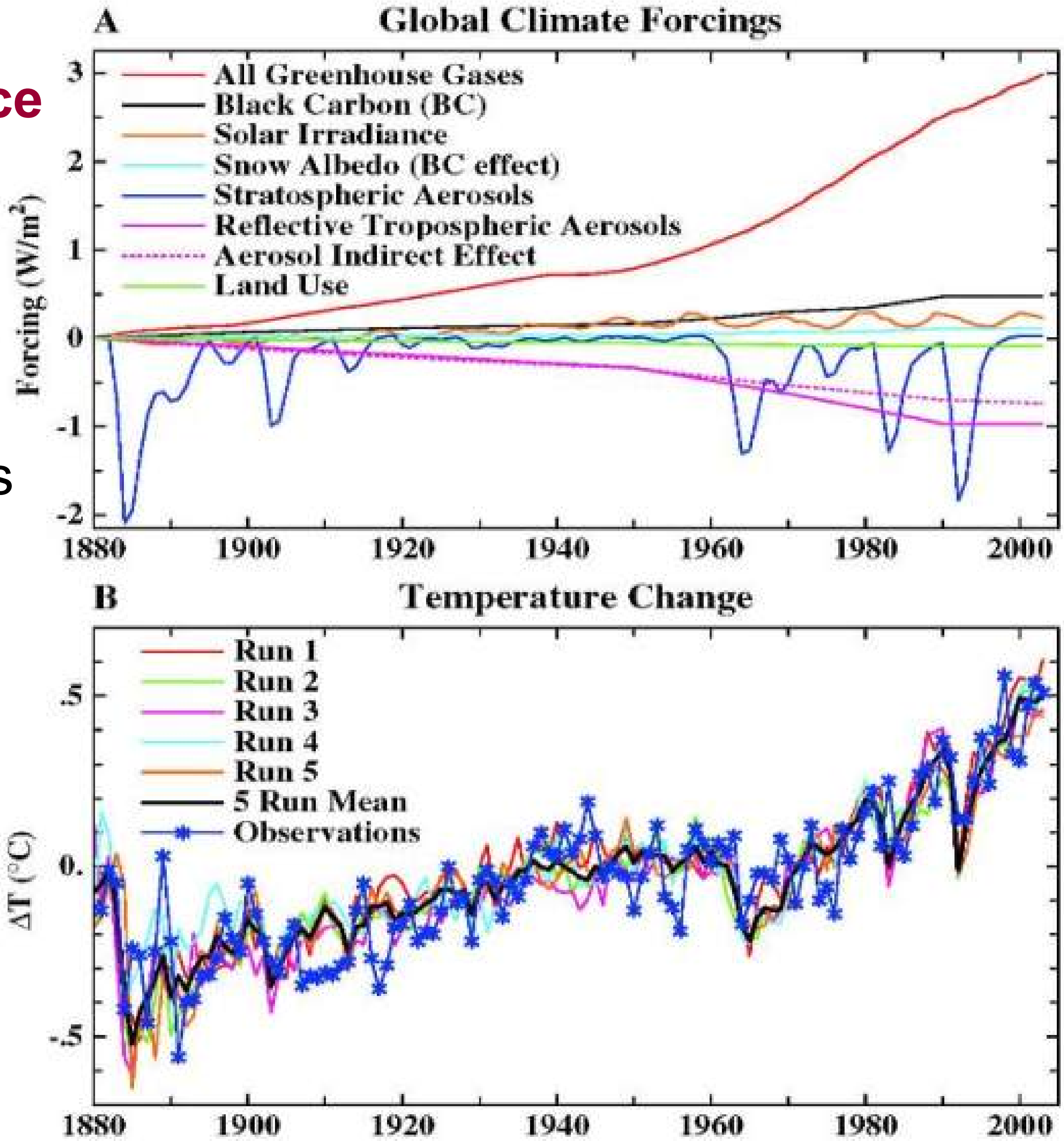


IPCC AR4, WG1 SPM, 2007

The smoking gun for human influence

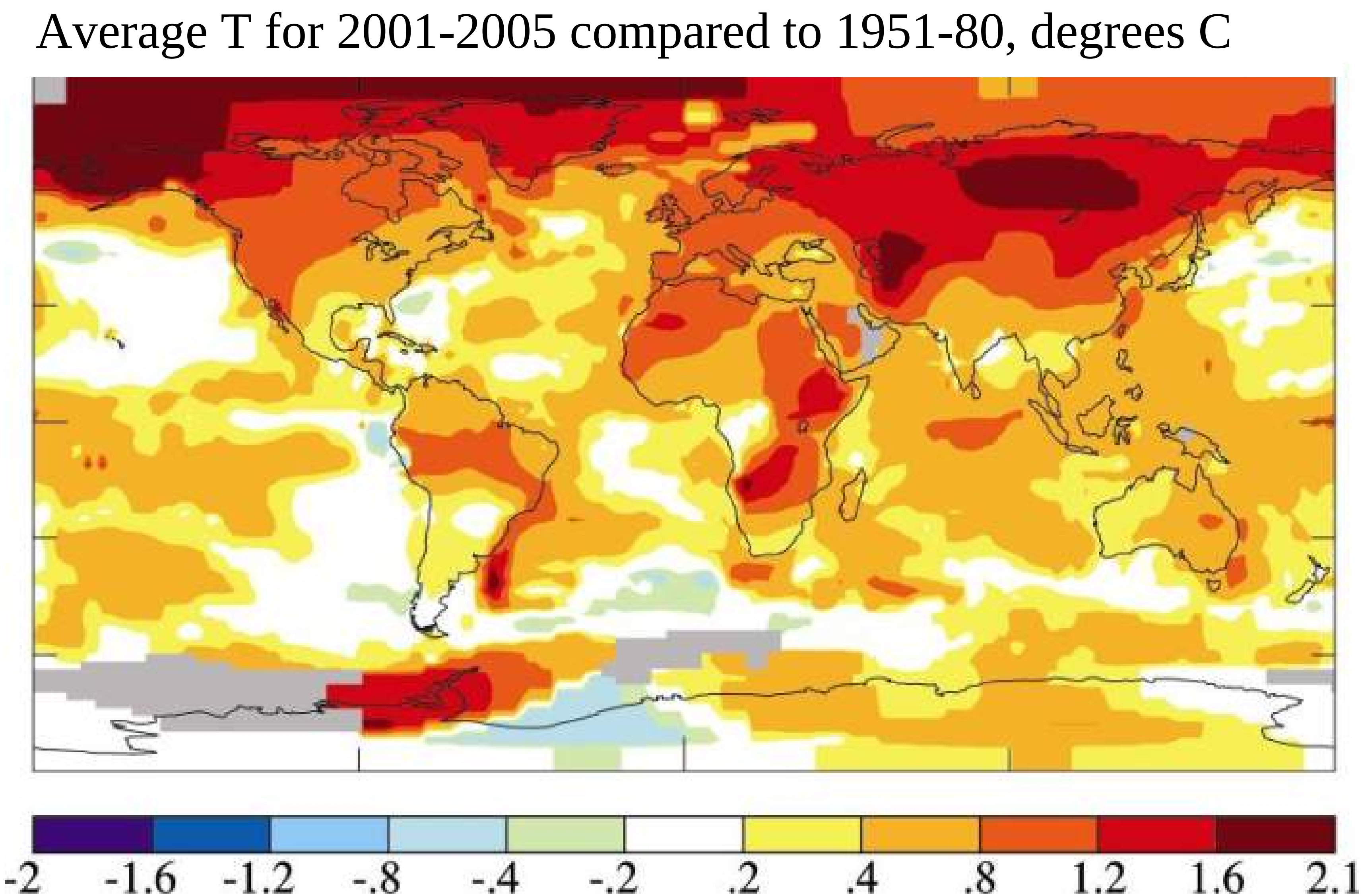
Top panel shows best estimates of human & natural forcings 1880-2005.

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.

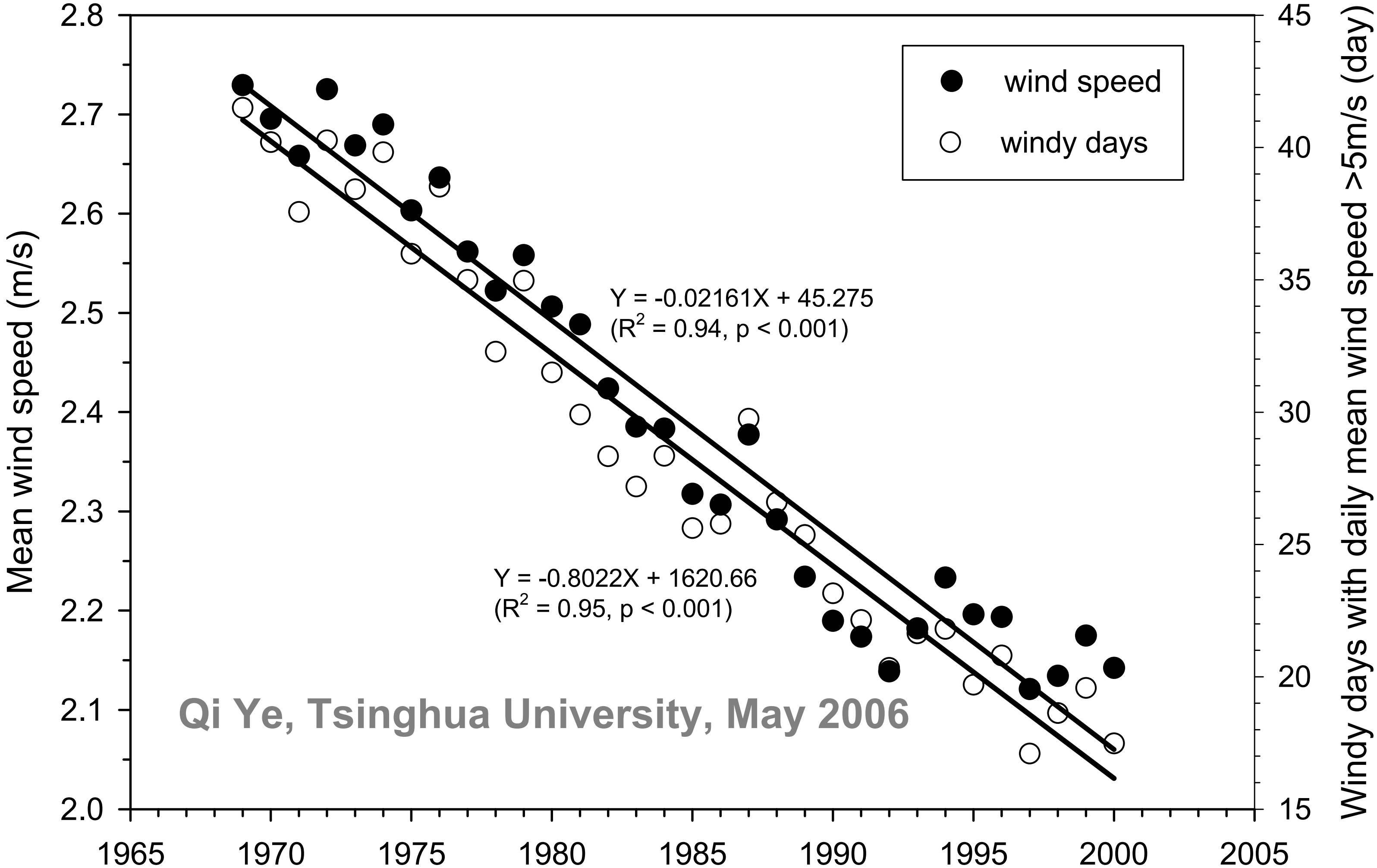
The current heating is not uniform geographically



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

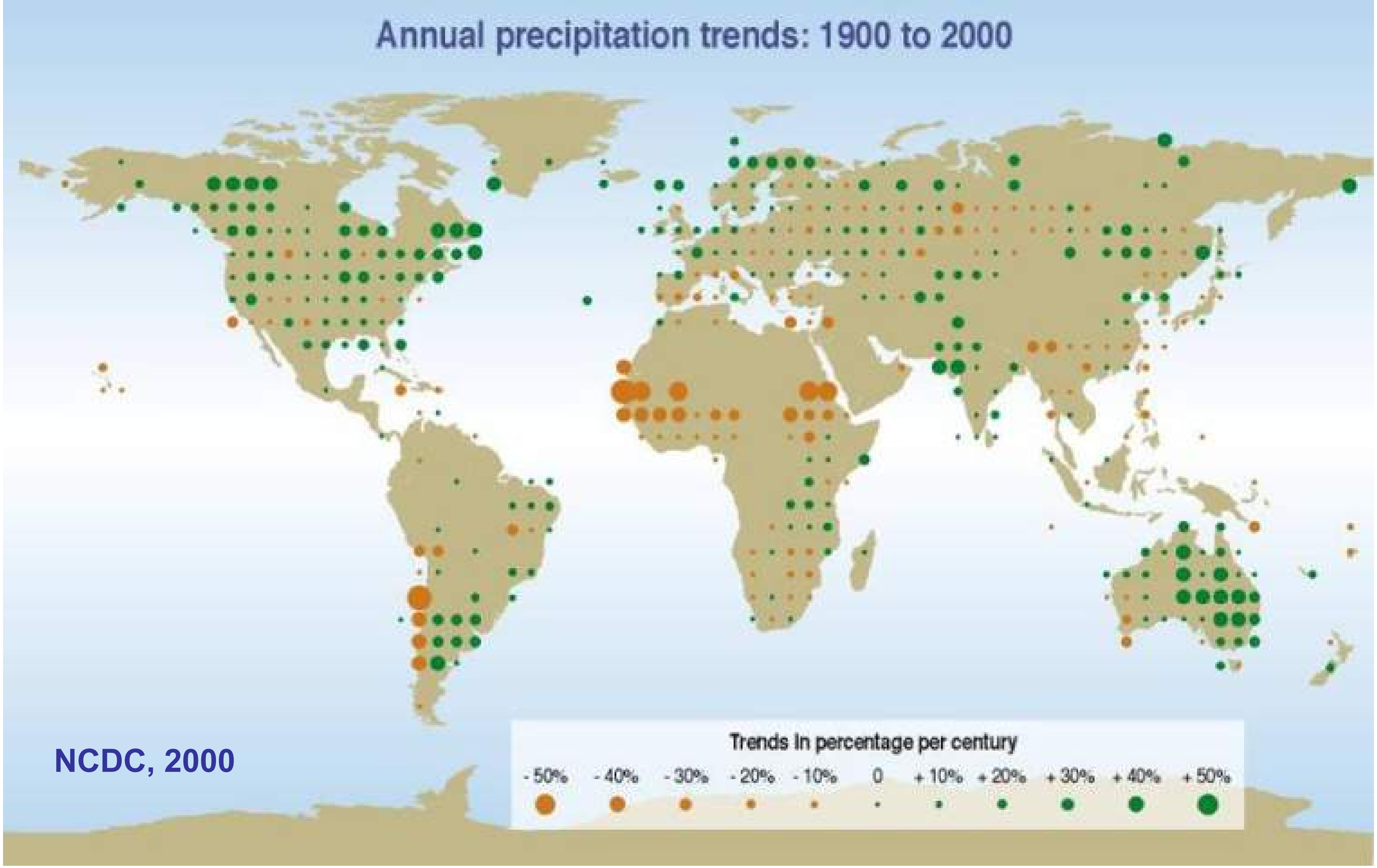
Circulation patterns are changing

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.

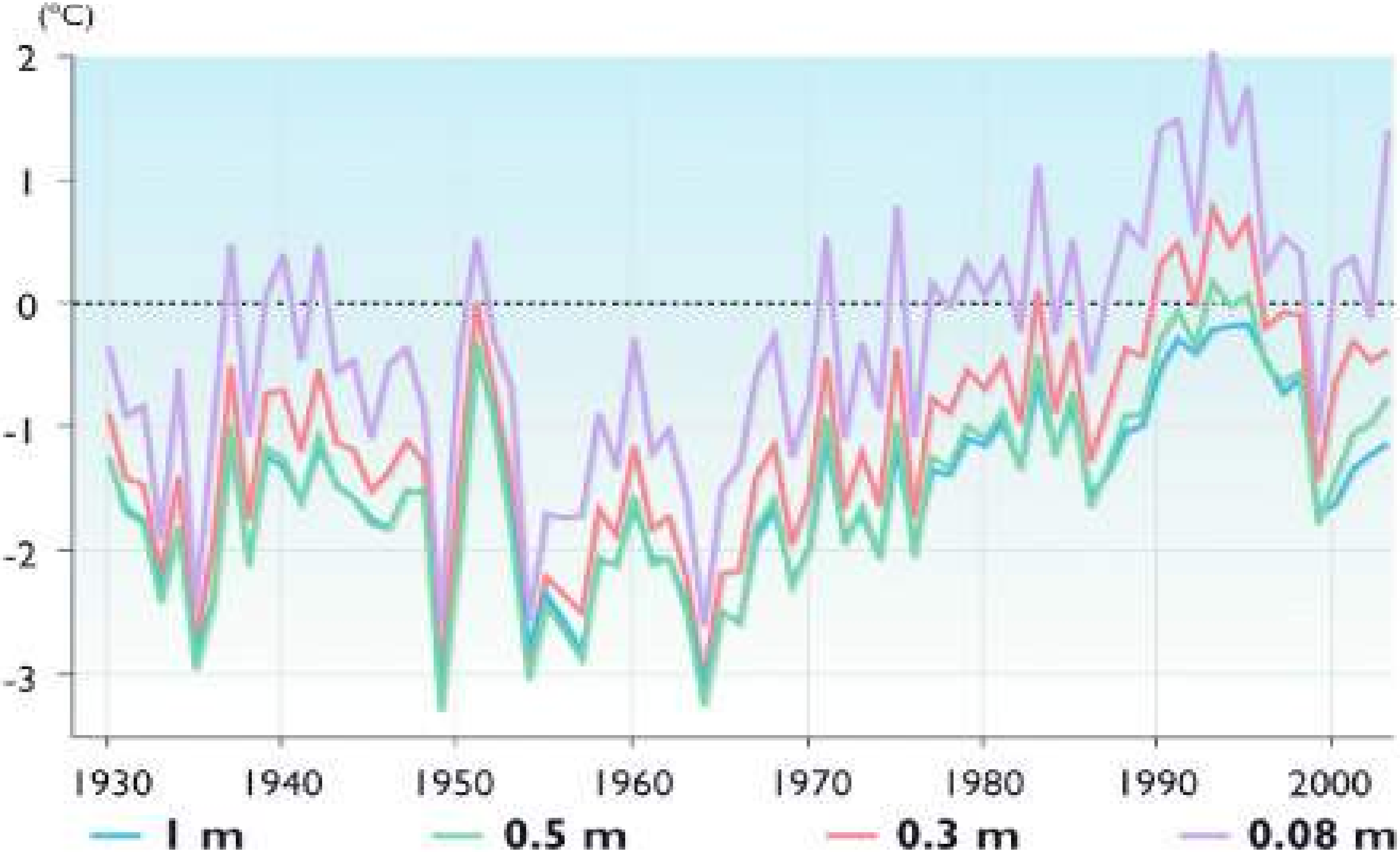
Evaporation & precipitation are increasing



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

Permafrost is thawing

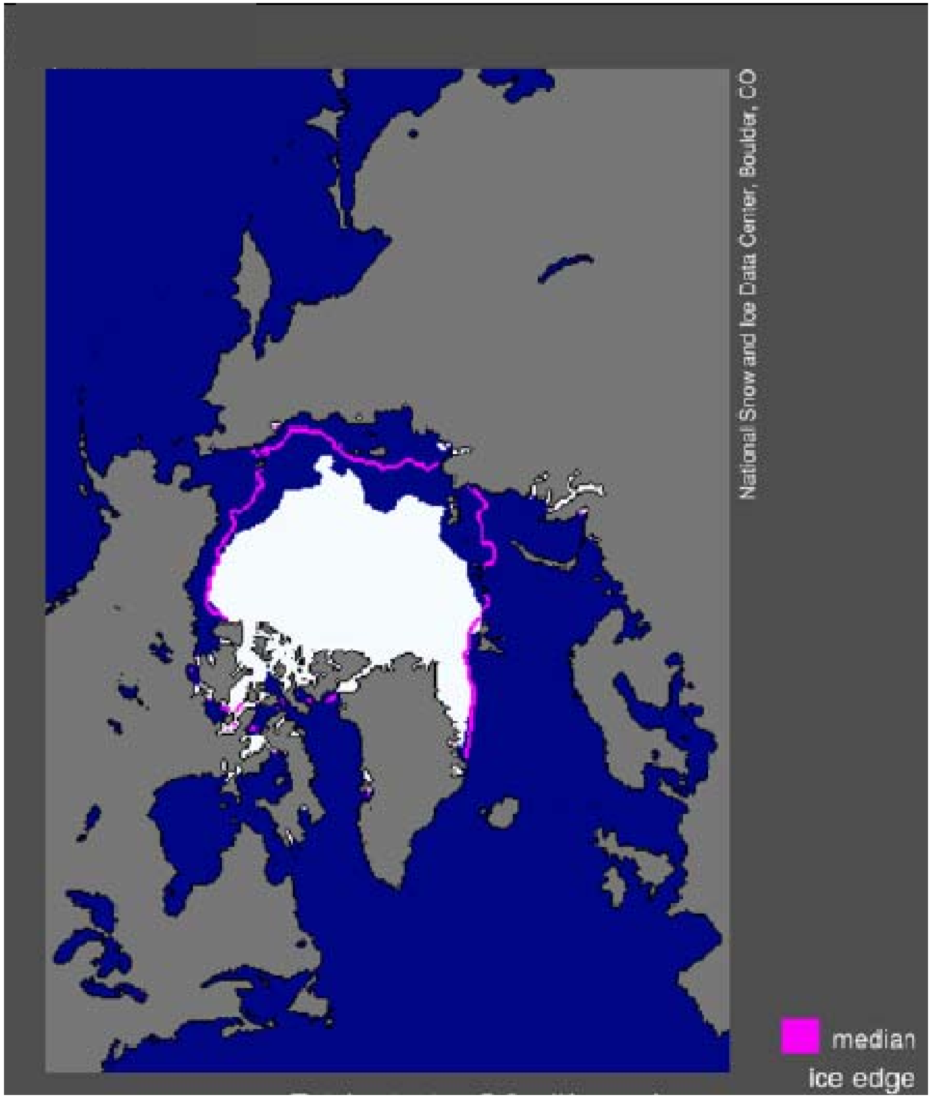
Average ground temperature near Fairbanks, Alaska, degrees C



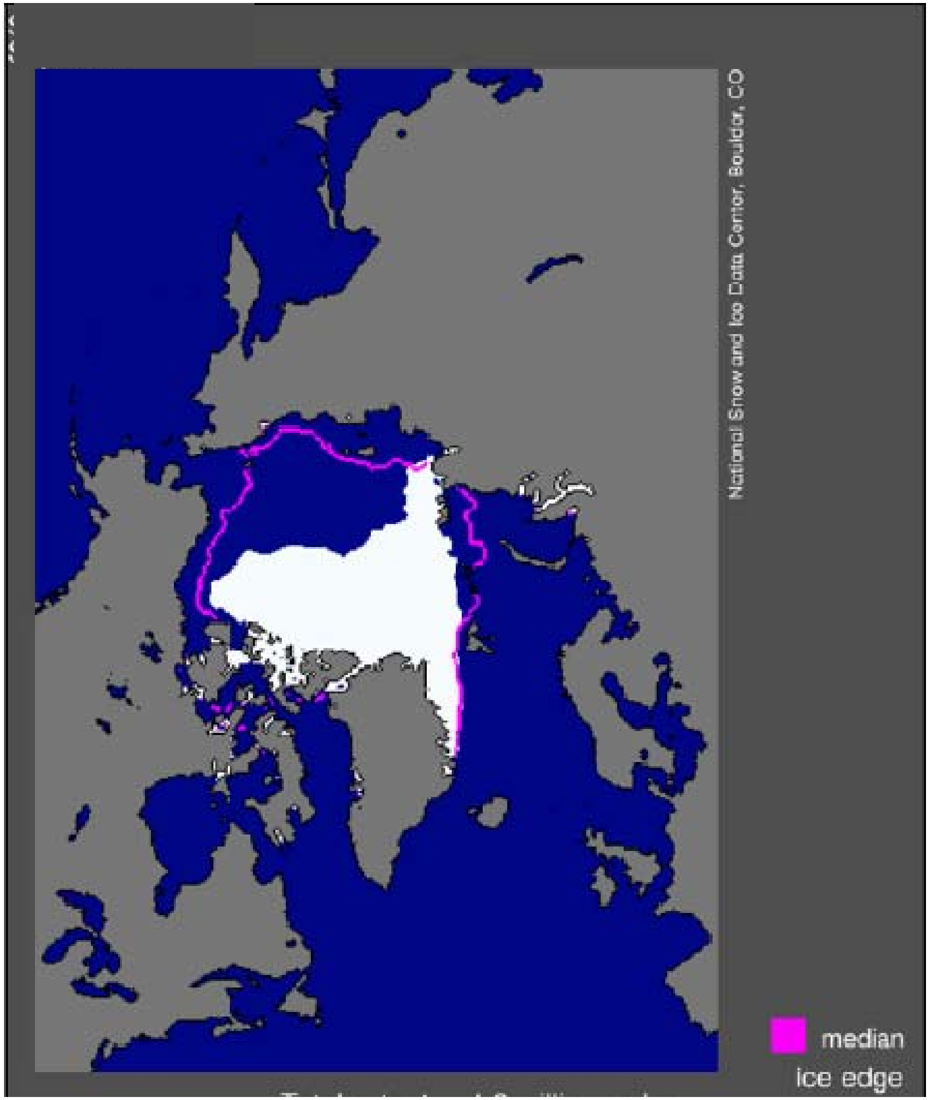
Permafrost thaws when T ≥ 0°C

ACIA 2004

Arctic summer sea ice is disappearing



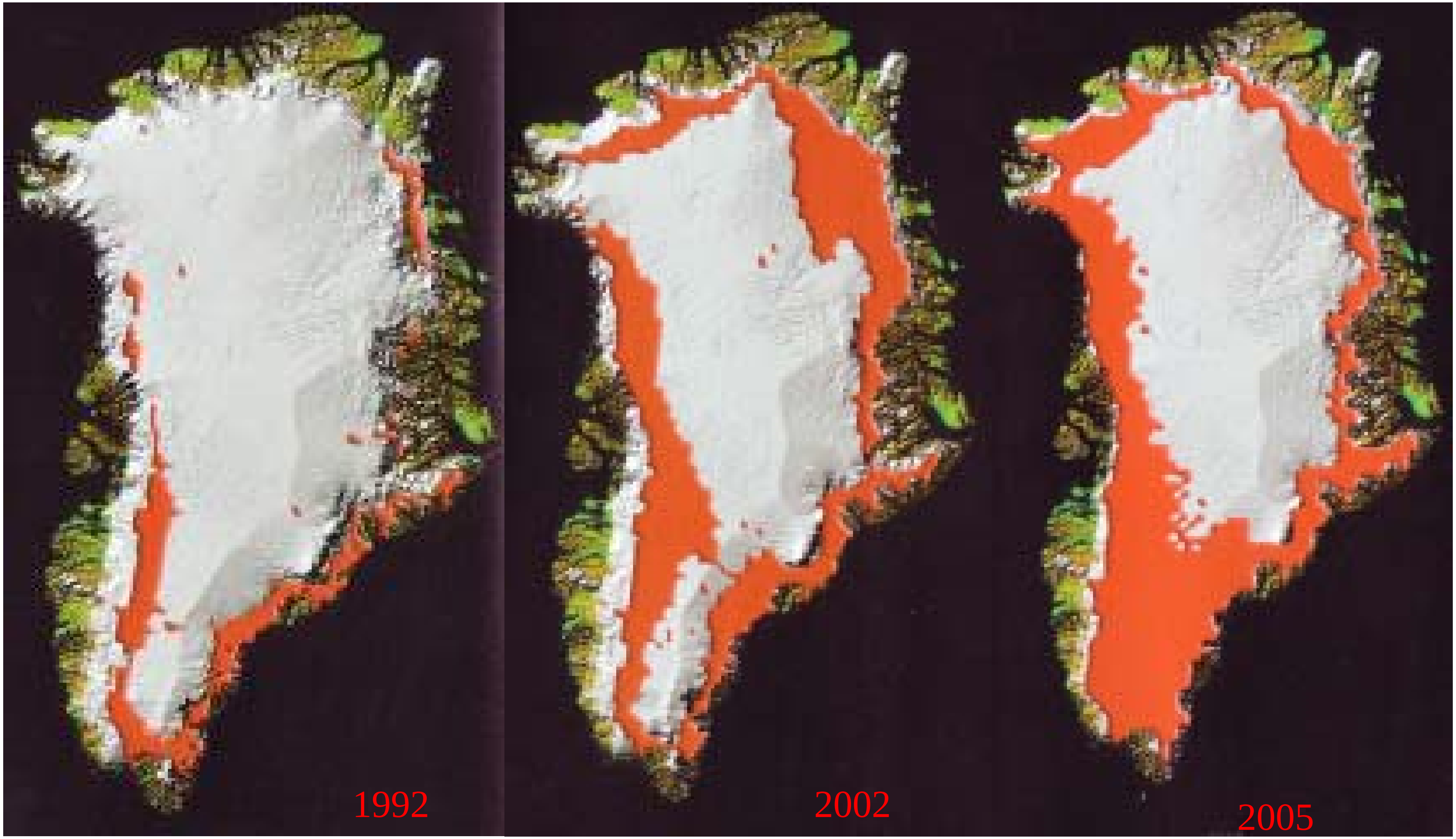
September 2005



September 2007

US National Snow & Ice Data Center, 2007

Surface melting on Greenland is expanding



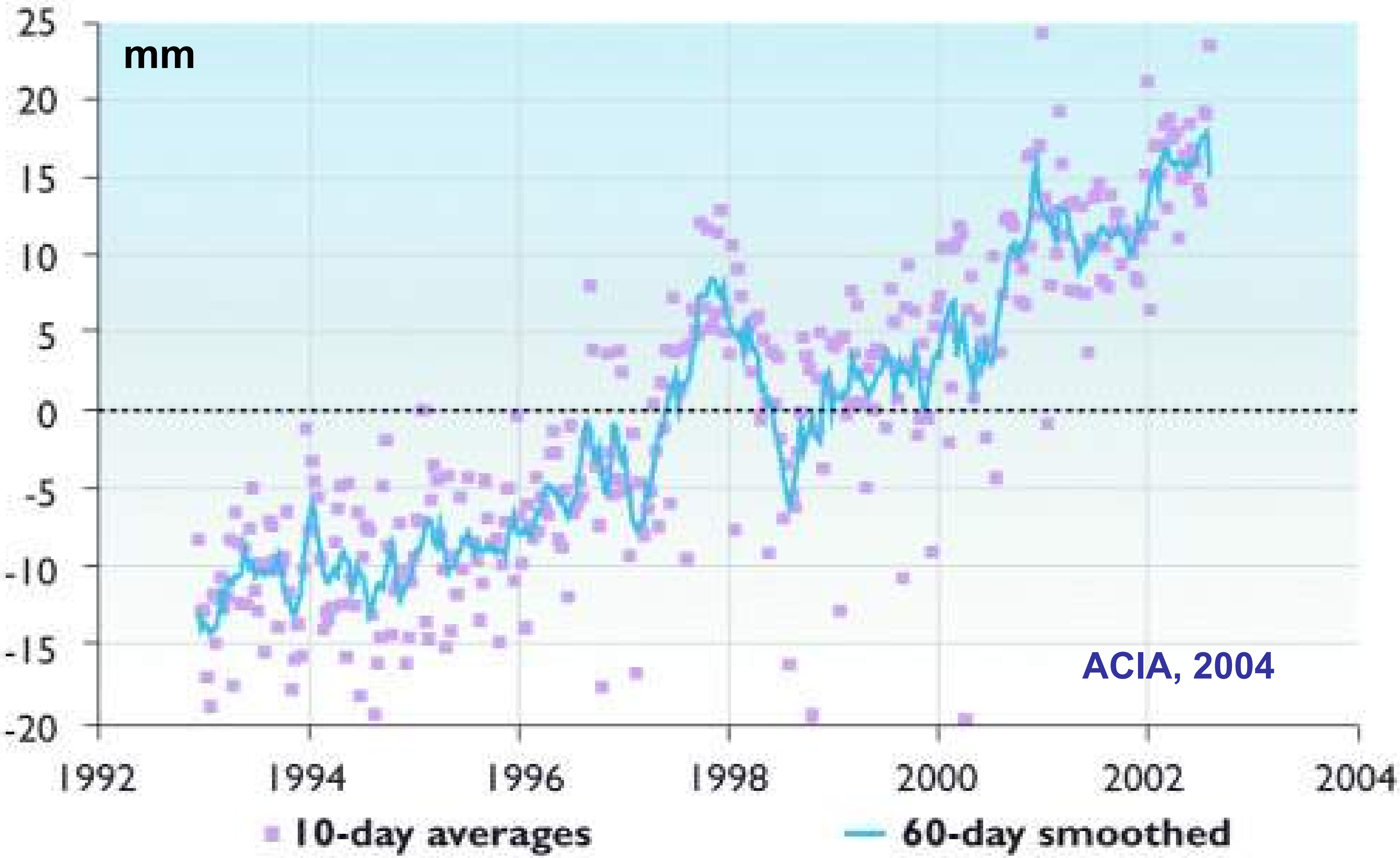
In 1992 scientists measured this amount of melting in Greenland as indicated by red areas on the map

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

And in 2005, it accelerated dramatically yet again

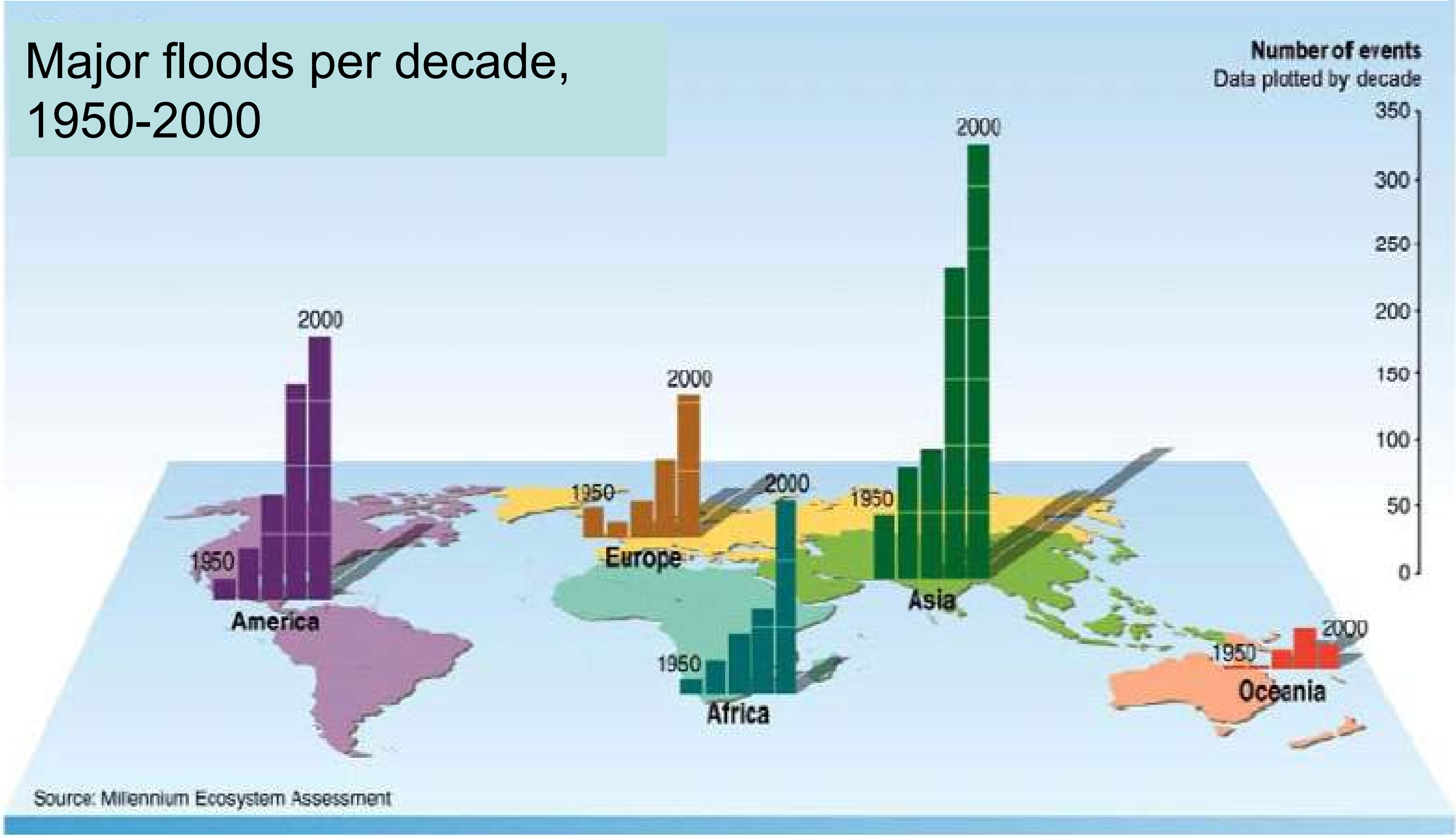
Source: ACIA, 2004 and CIRES, 2005

Sea-level is rising



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

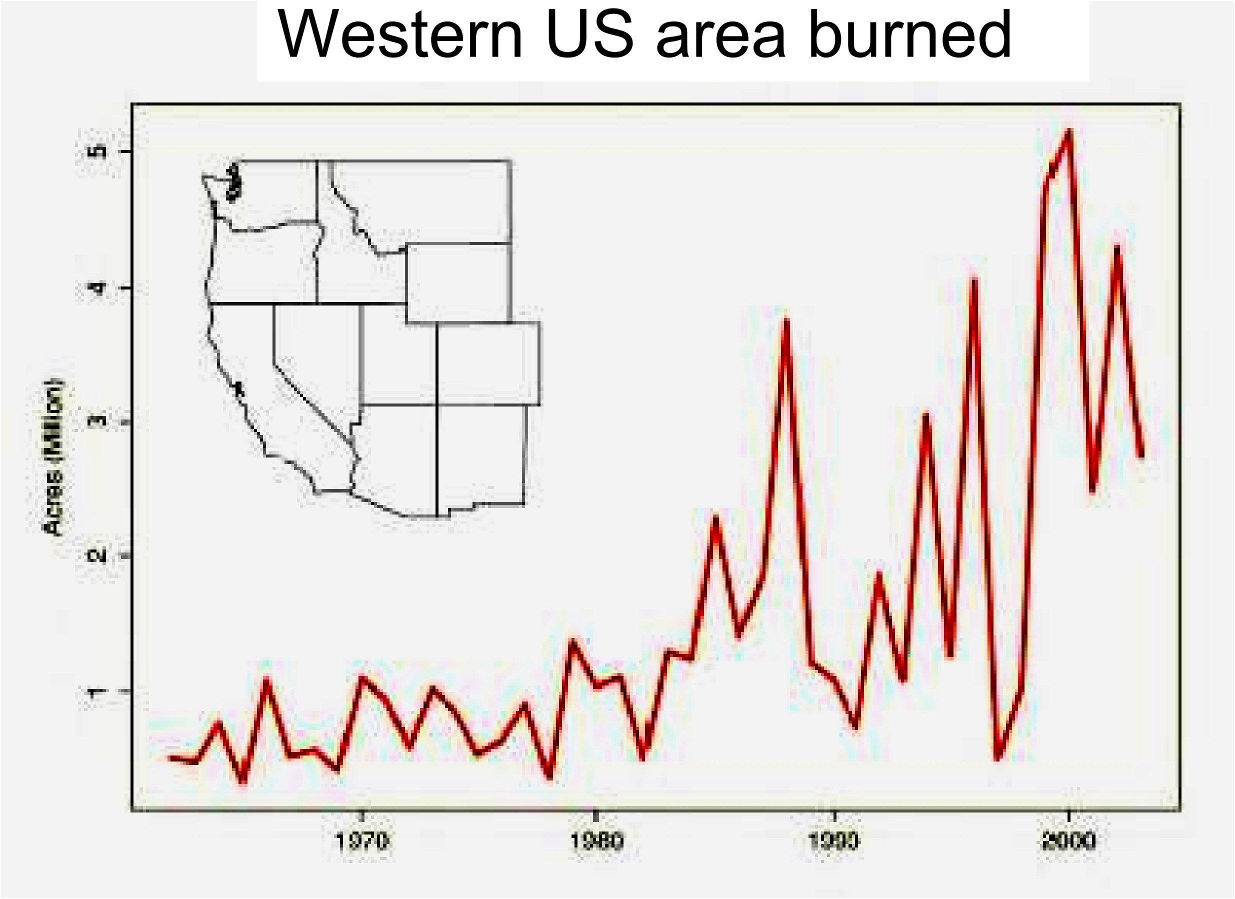
These changes are already causing harm



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

Harm is already occurring (continued)

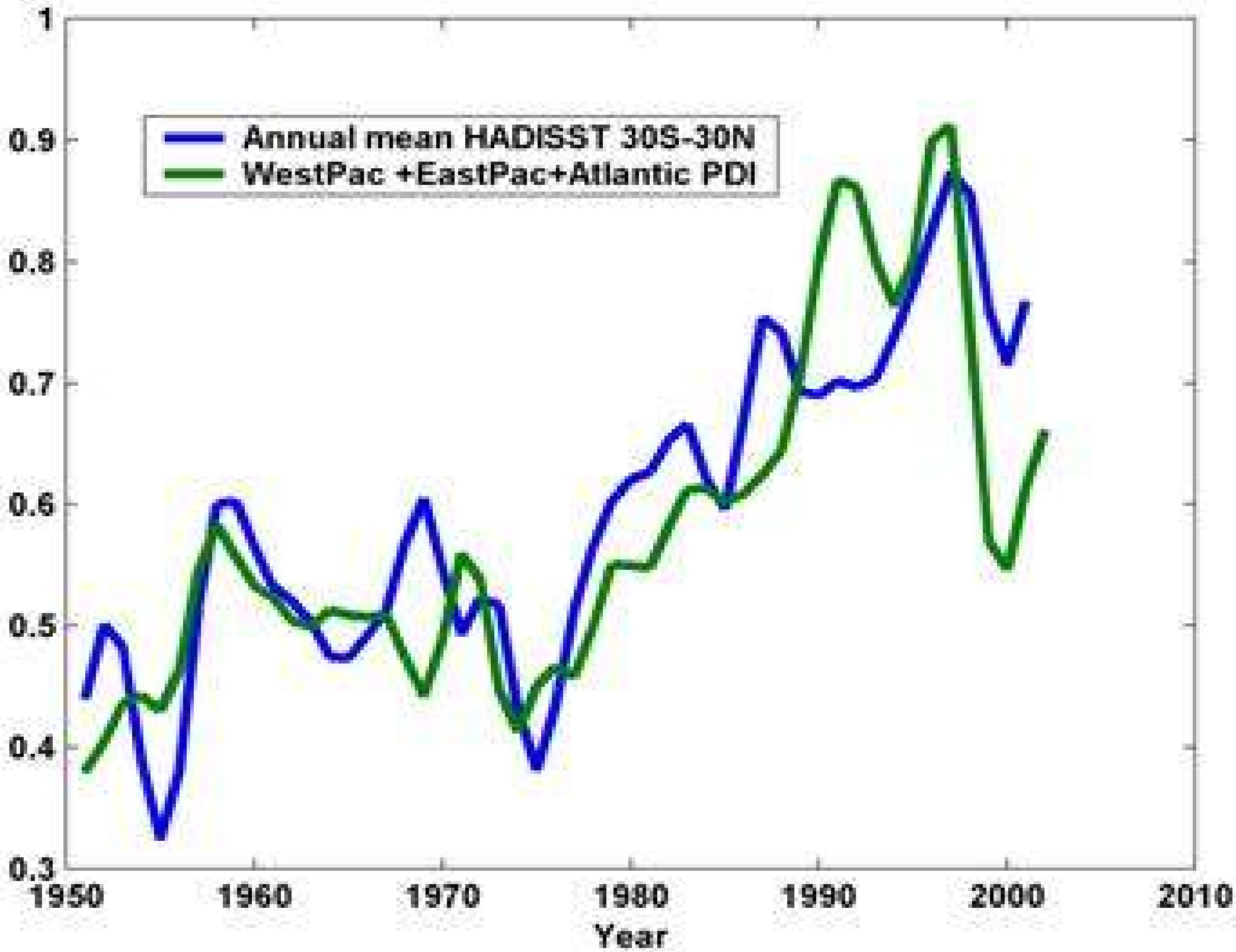
Wildfires in the Western USA have increased 4-fold in the last 30 years.



Source: Westerling et al. 2006

Harm is already occurring (continued)

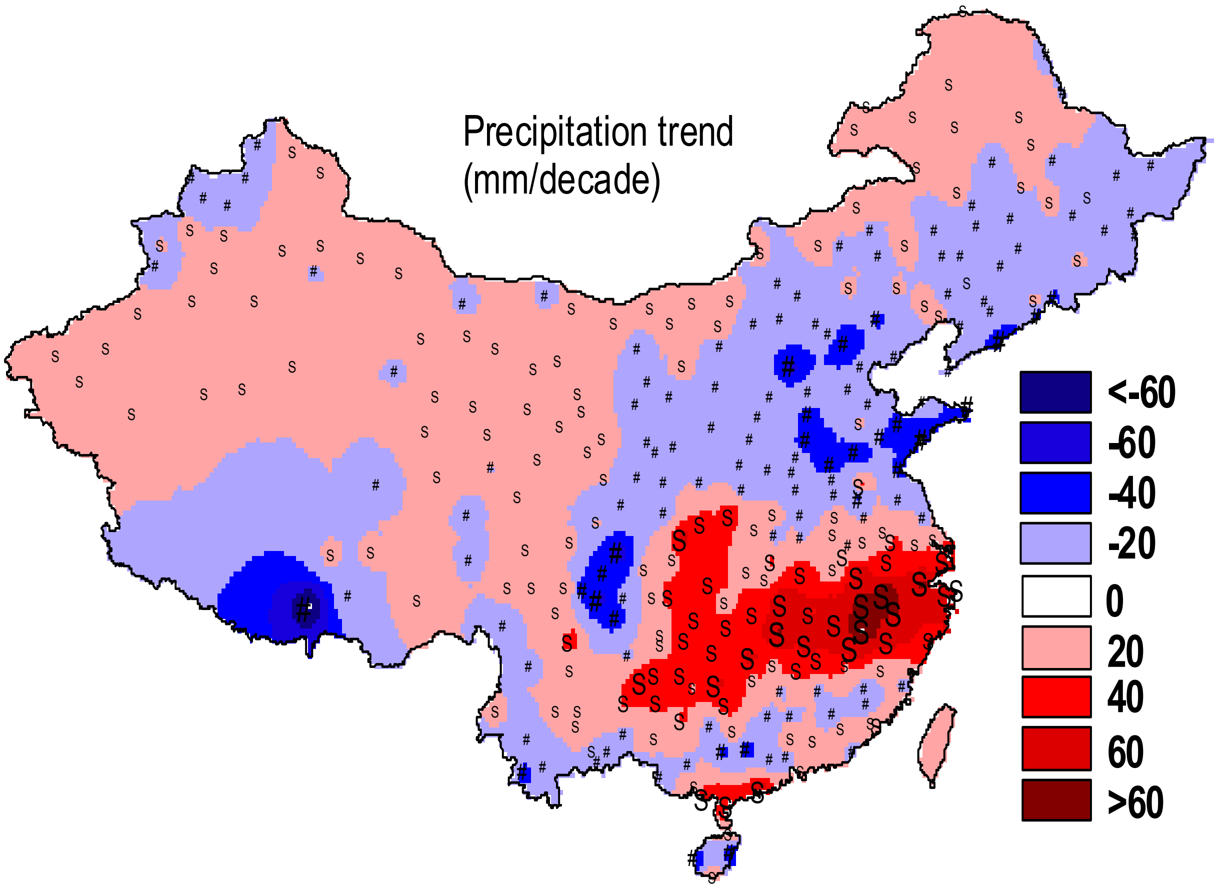
Total power released by tropical cyclones (green) has increased along with sea surface temperatures (blue).



Kerry Emanuel, MIT, 2006

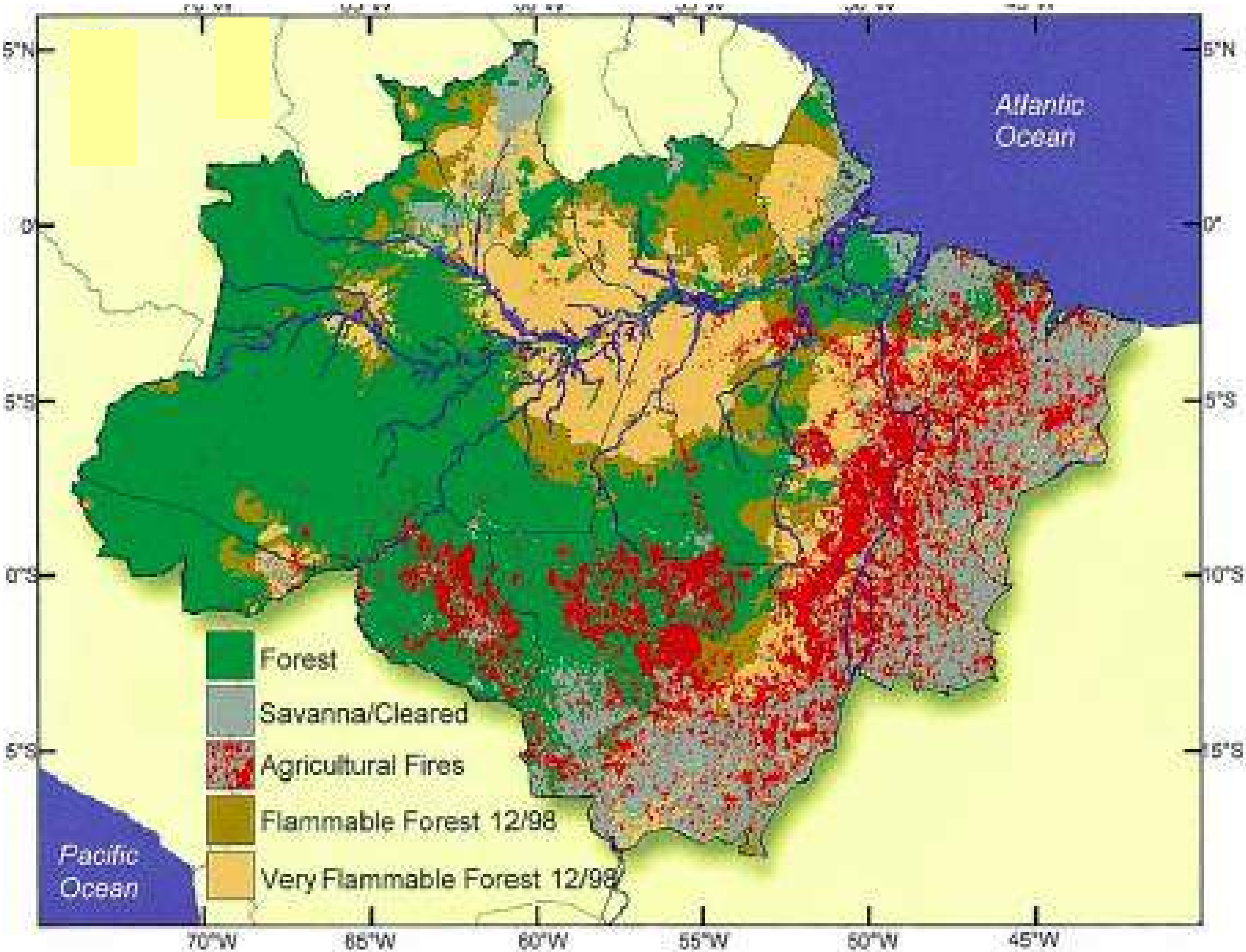
Harm is already occurring (continued)

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.

Nepstad et al., Forest Ecology & Management 154, 2001

Harm is already occurring (concluded)

WHO estimates climate change already causing ≥150,000 premature deaths/yr in 2000

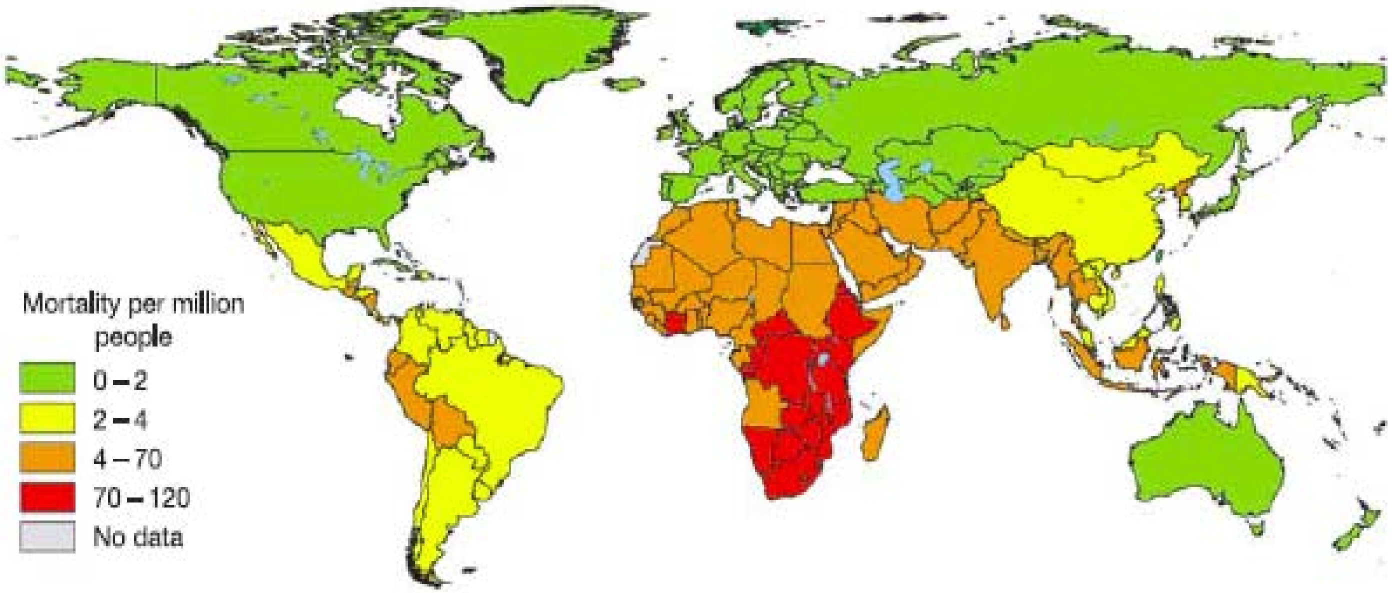
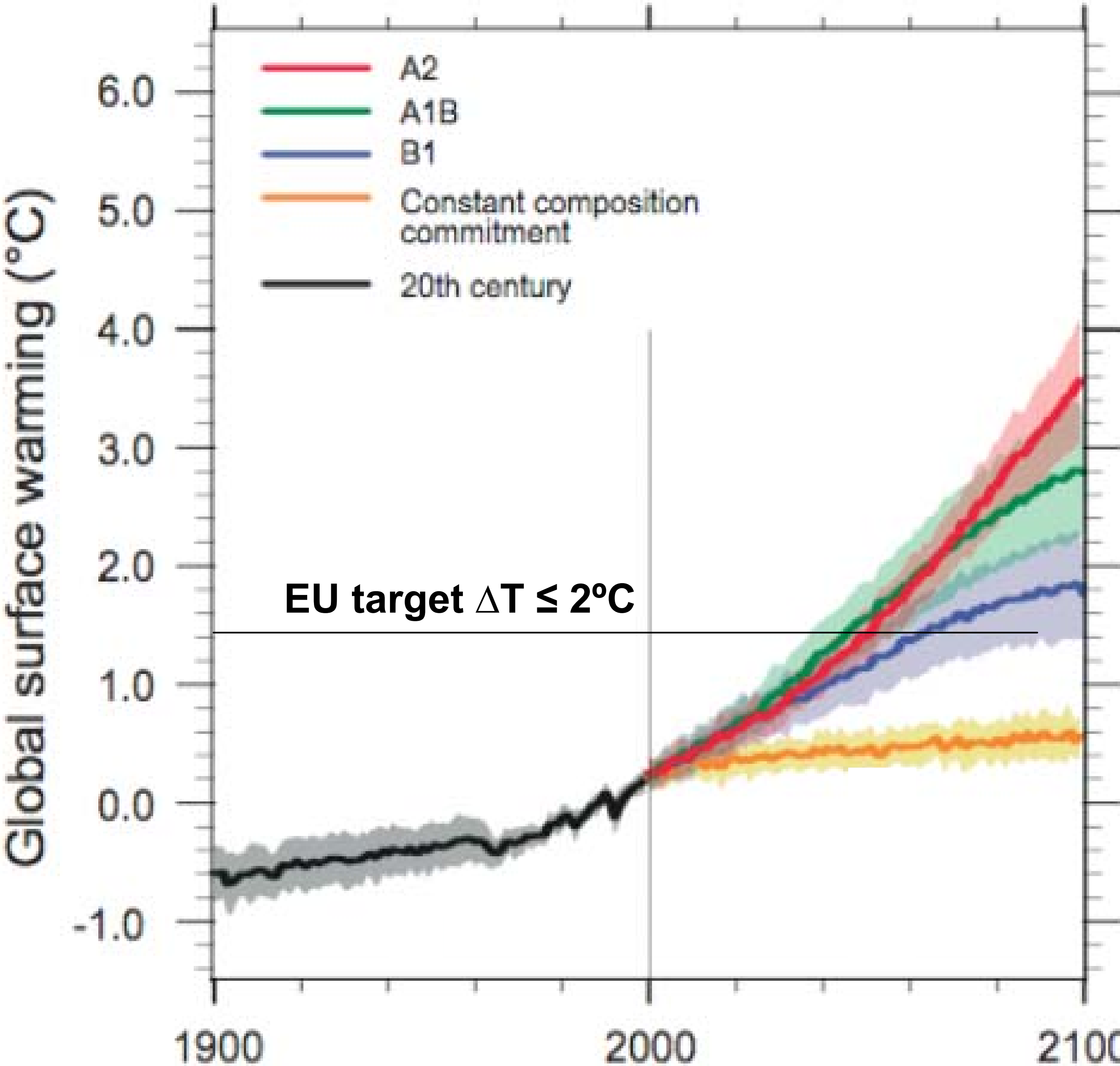


Figure 2 | WHO estimated mortality (per million people) attributable to climate change by the year 2000. The IPCC 'business as usual' greenhouse gas emissions scenario, 'IS92a' and the HadCM2 GCM of the UK Hadley Centre were used to estimate climate changes relative to 'baseline' 1961–1990 levels of 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



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

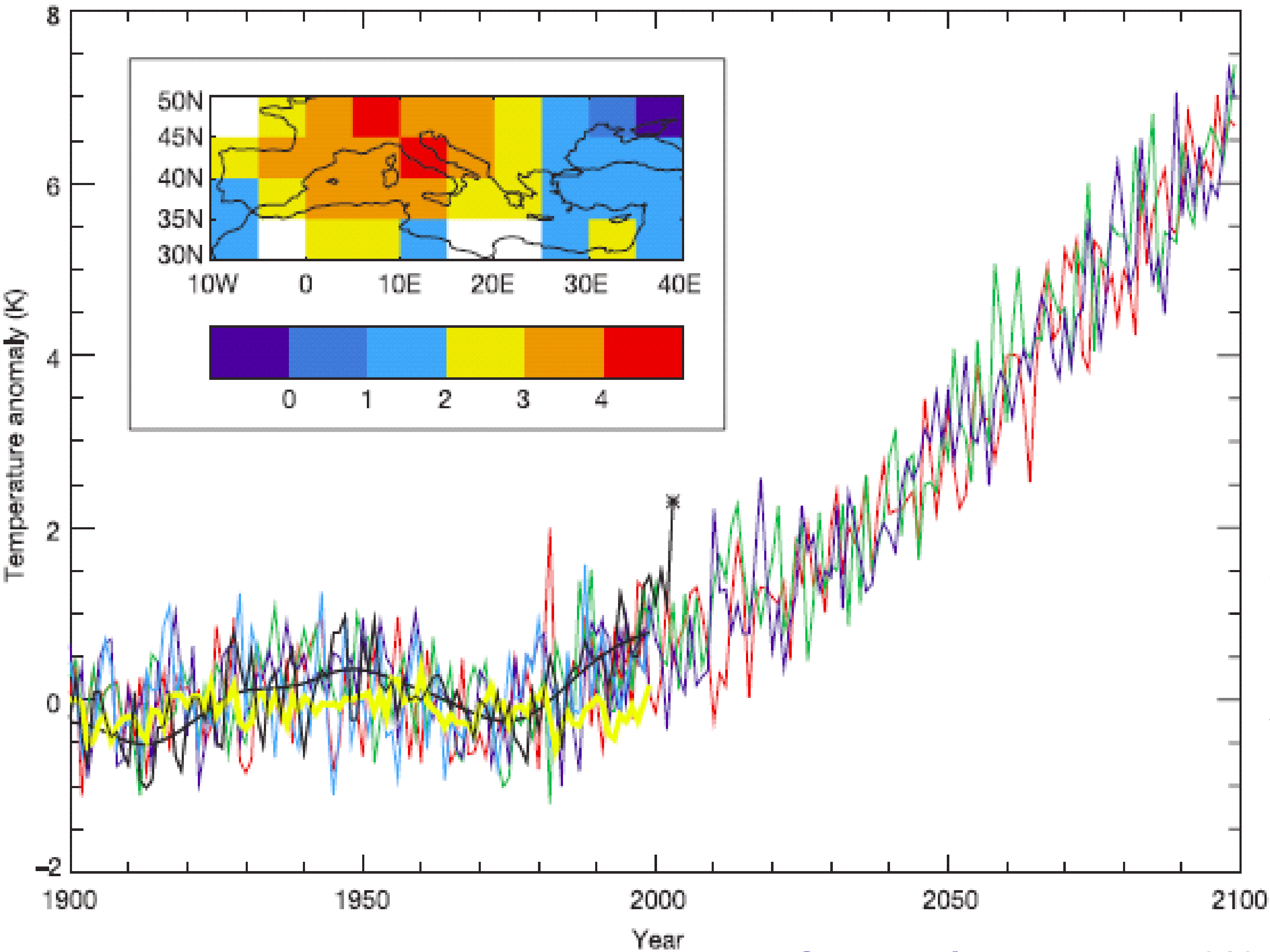
Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

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

IPCC 2007

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

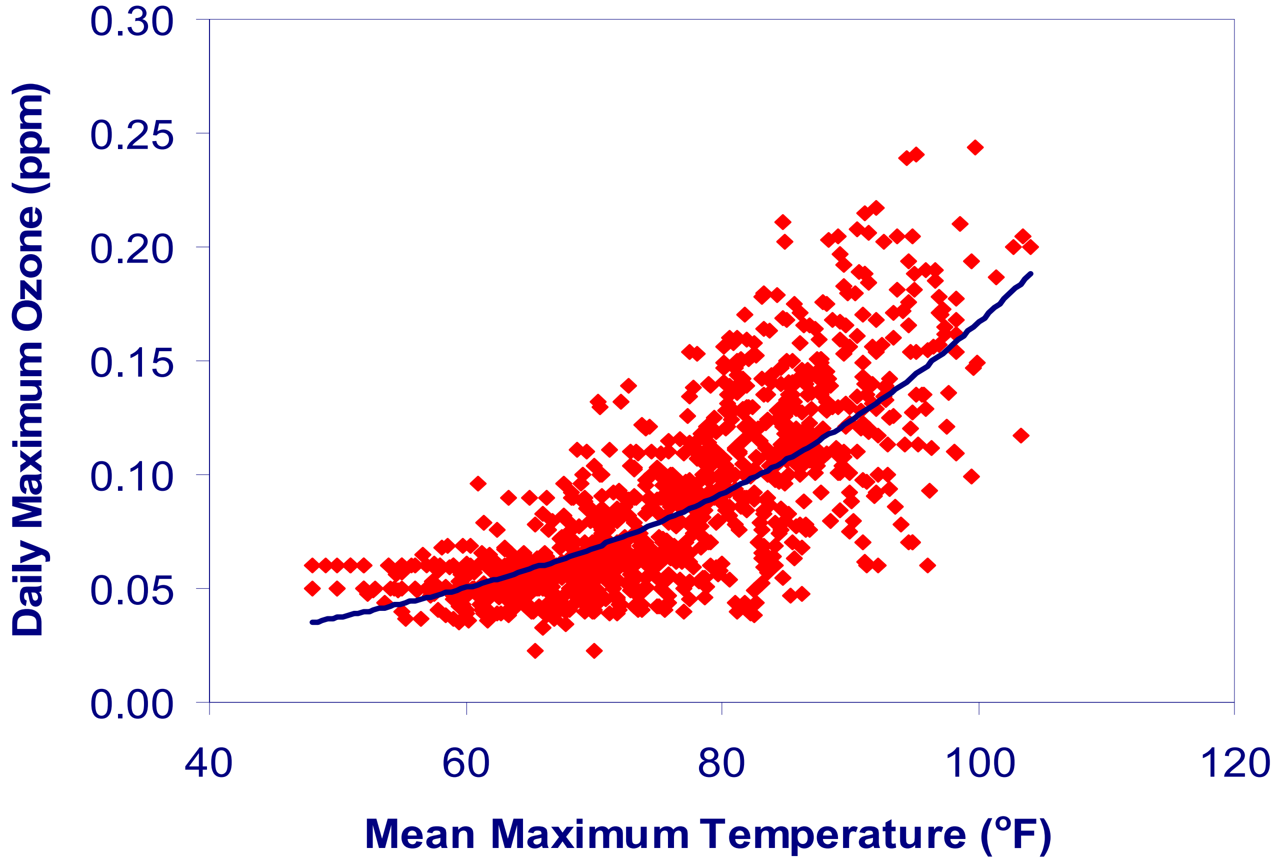


Black lines are observed temps, smoothed & unsmoothed; red, blue, & green lines are Hadley Centre simulations w natural & anthropogenic forcing; yellow is natural only.

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

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

Higher temperatures also mean more smog



South Coast Air Basin

Ozone Levels

(1996-1999)

Our Changing Climate: Assessing the Risks to California (2006),

www.climatechange.ca.gov. Source: Air Resources Board, 2000

Where we're headed: Agriculture in the tropics

Crop yields in tropics start dropping at local ∆T ≥ 1-1.5°C

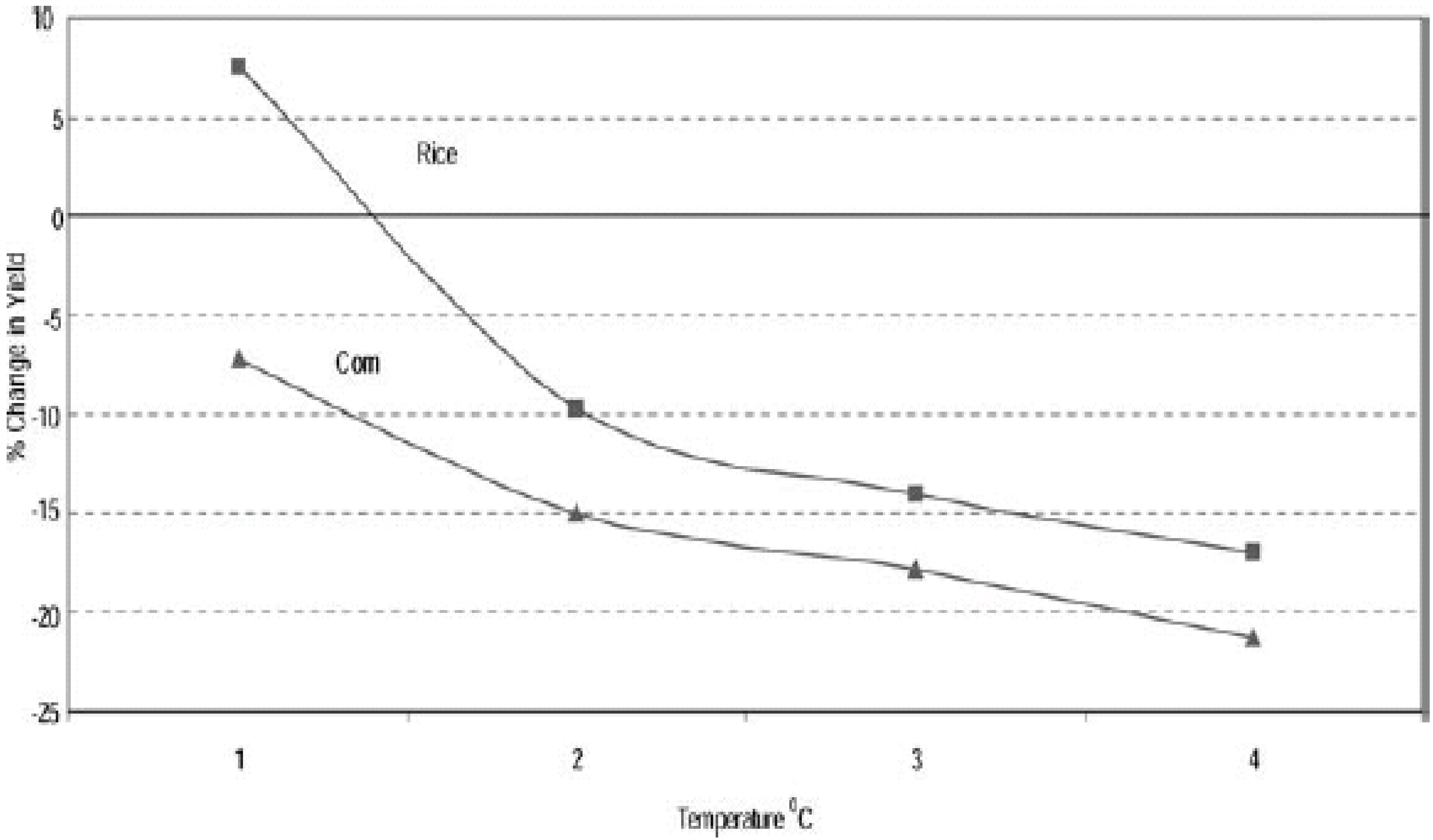


Figure 1. Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

Where we're headed: Temperate-zone agriculture

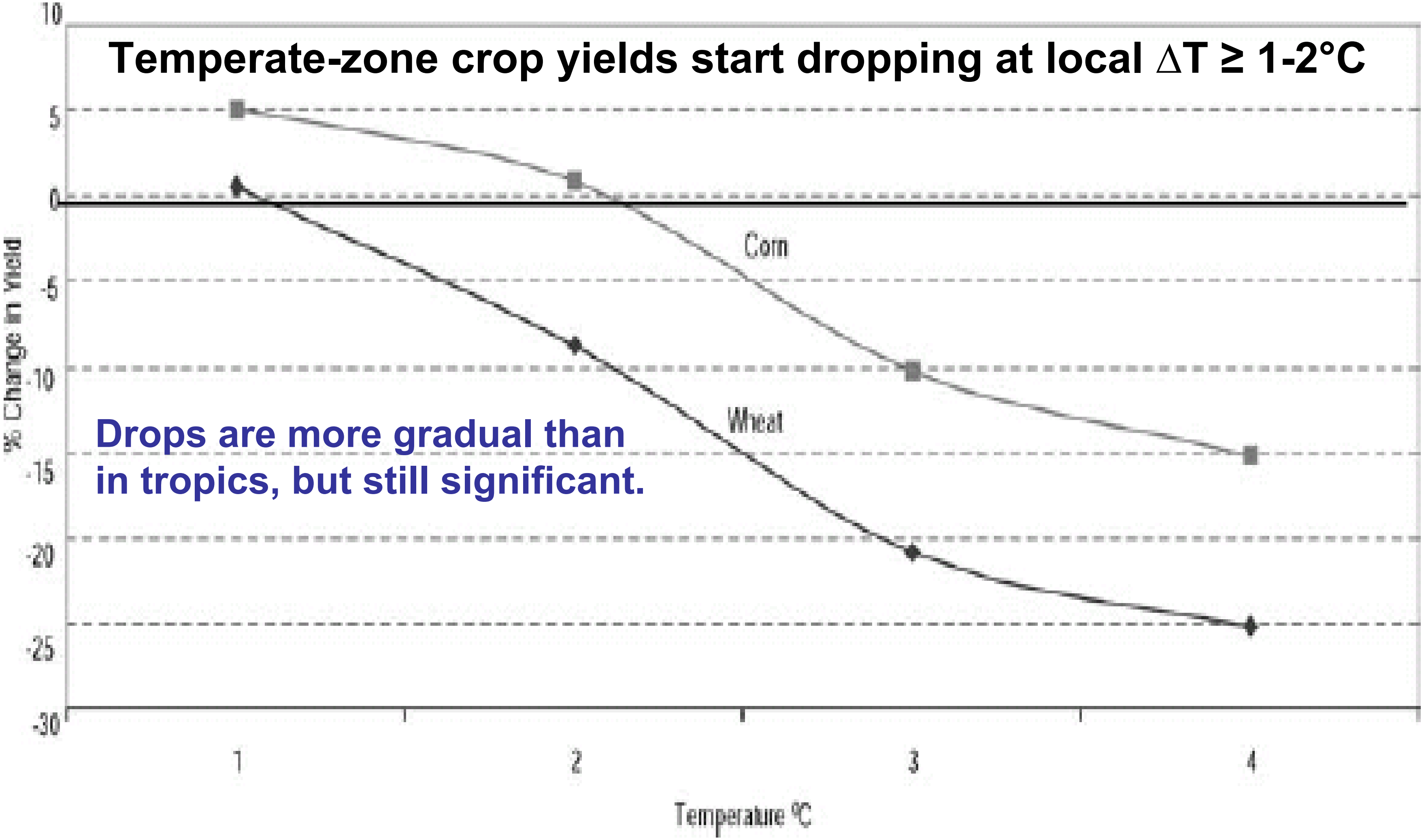
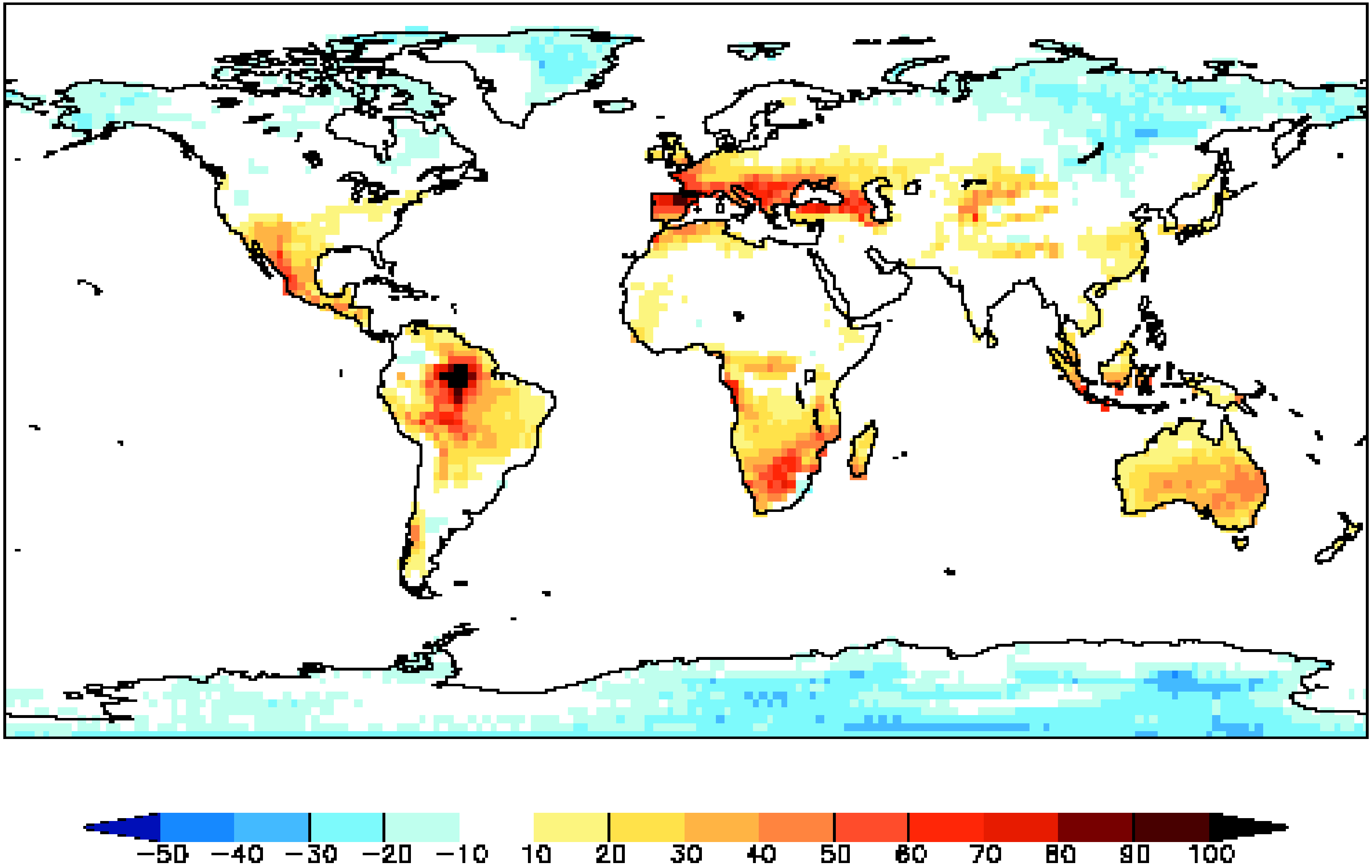


Figure 2. Corn and Wheat yields versus temperature increase in the temperate zone averaged across 30 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

Where we're headed: droughts

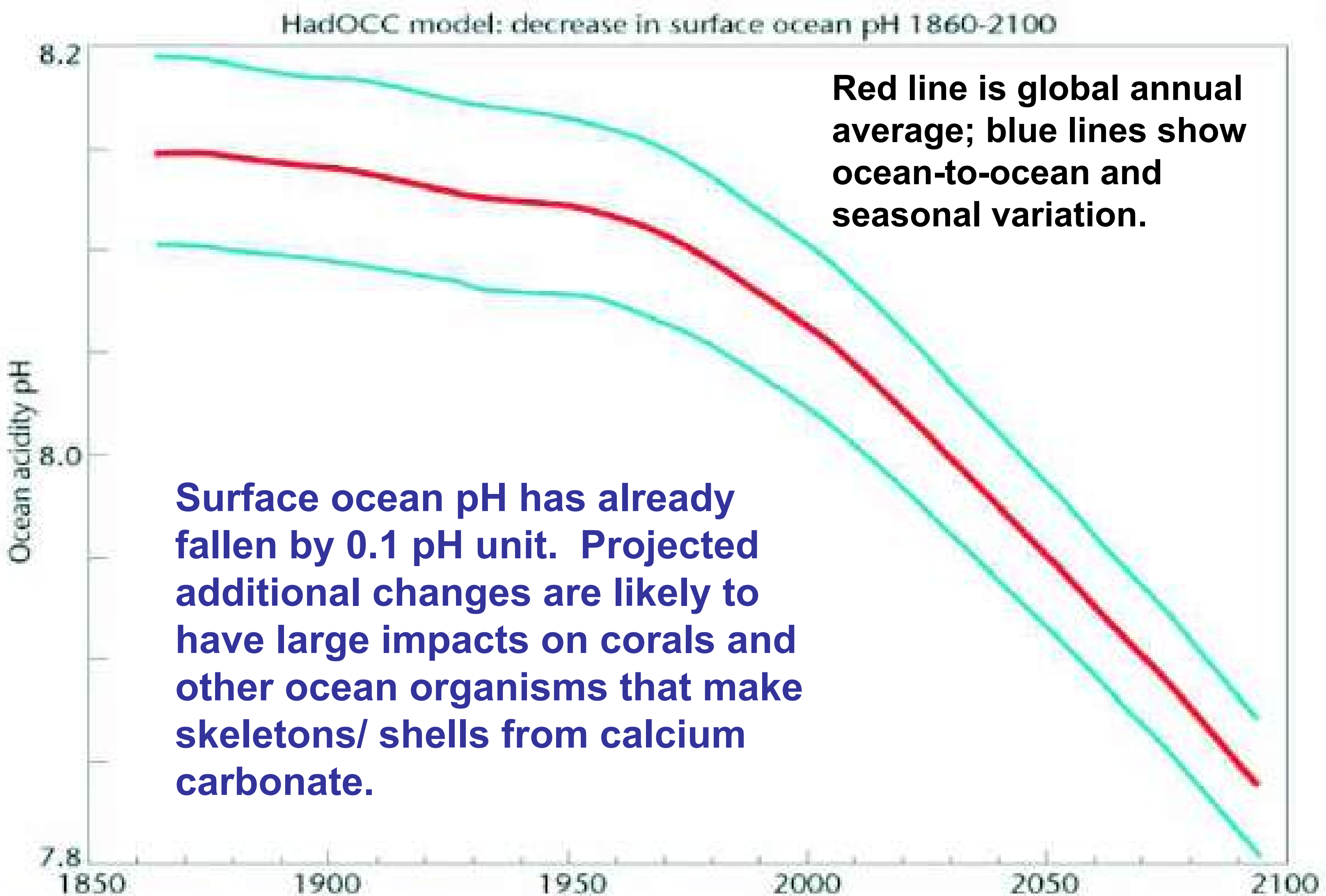
Drought projections for IPCC's A1B scenario



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



Hadley Centre for Climate Prediction and Research

Where we're headed: sea level

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

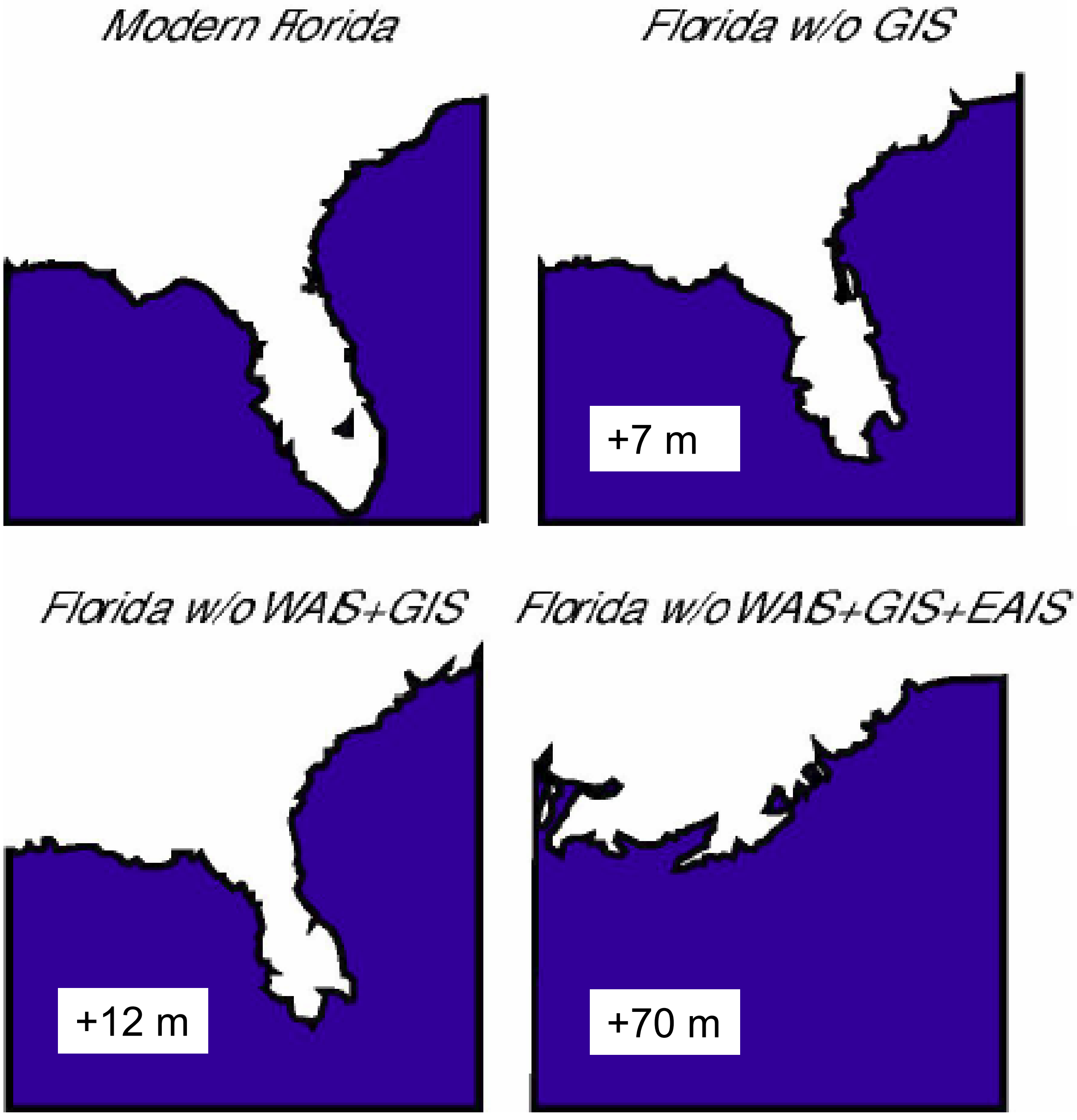
This would probably take 1000s of years, but rates of 2-5 m per century are possible.

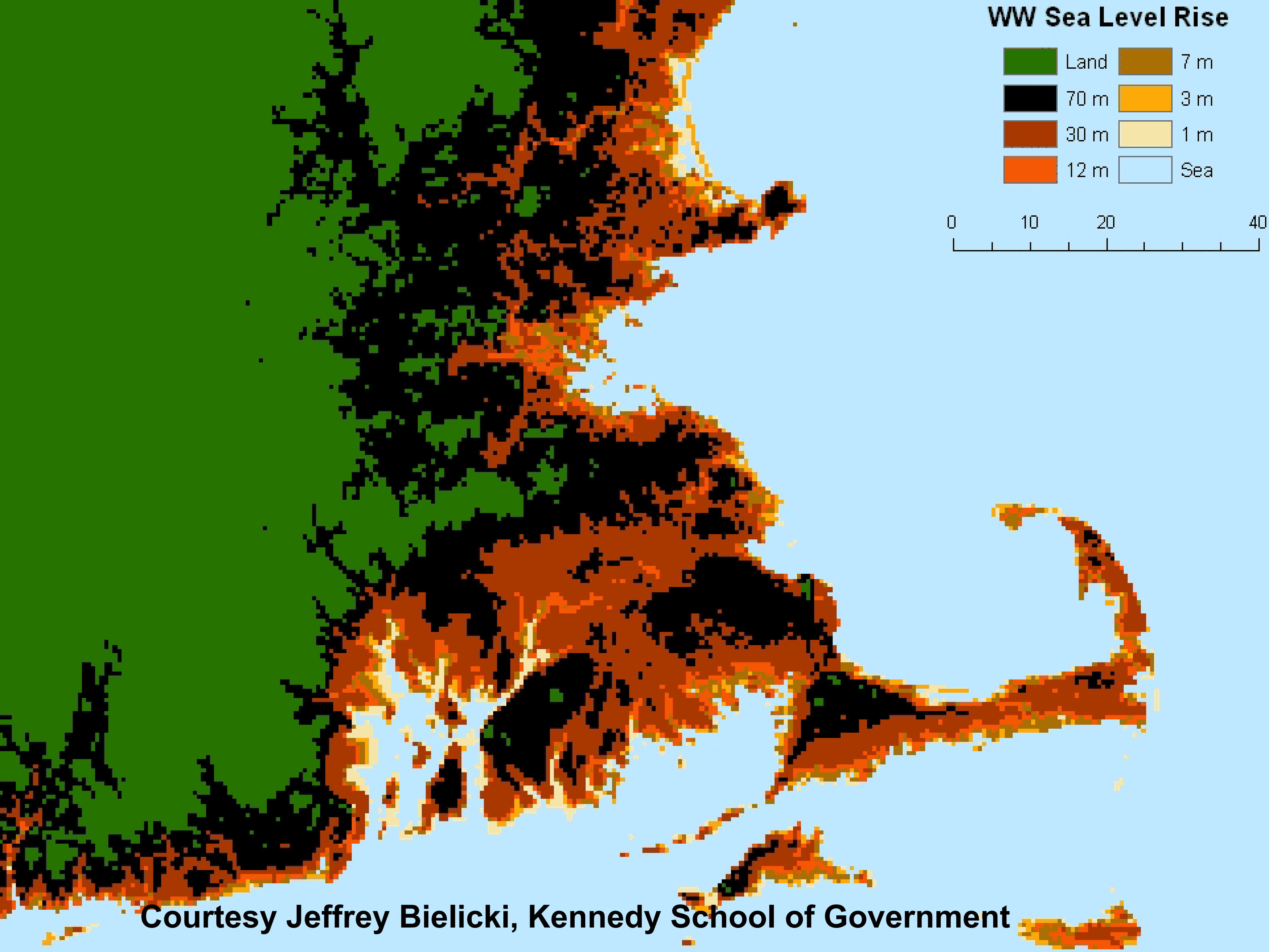
GIS = Greenland Ice Sheet

WAIS = West Antarctic Ice Sheet

EAIS = East Antarctic Ice Sheet

Dr. Richard Alley, 2005





Courtesy Jeffrey Bielicki, Kennedy School of Government

Facing the dangers from climate change…

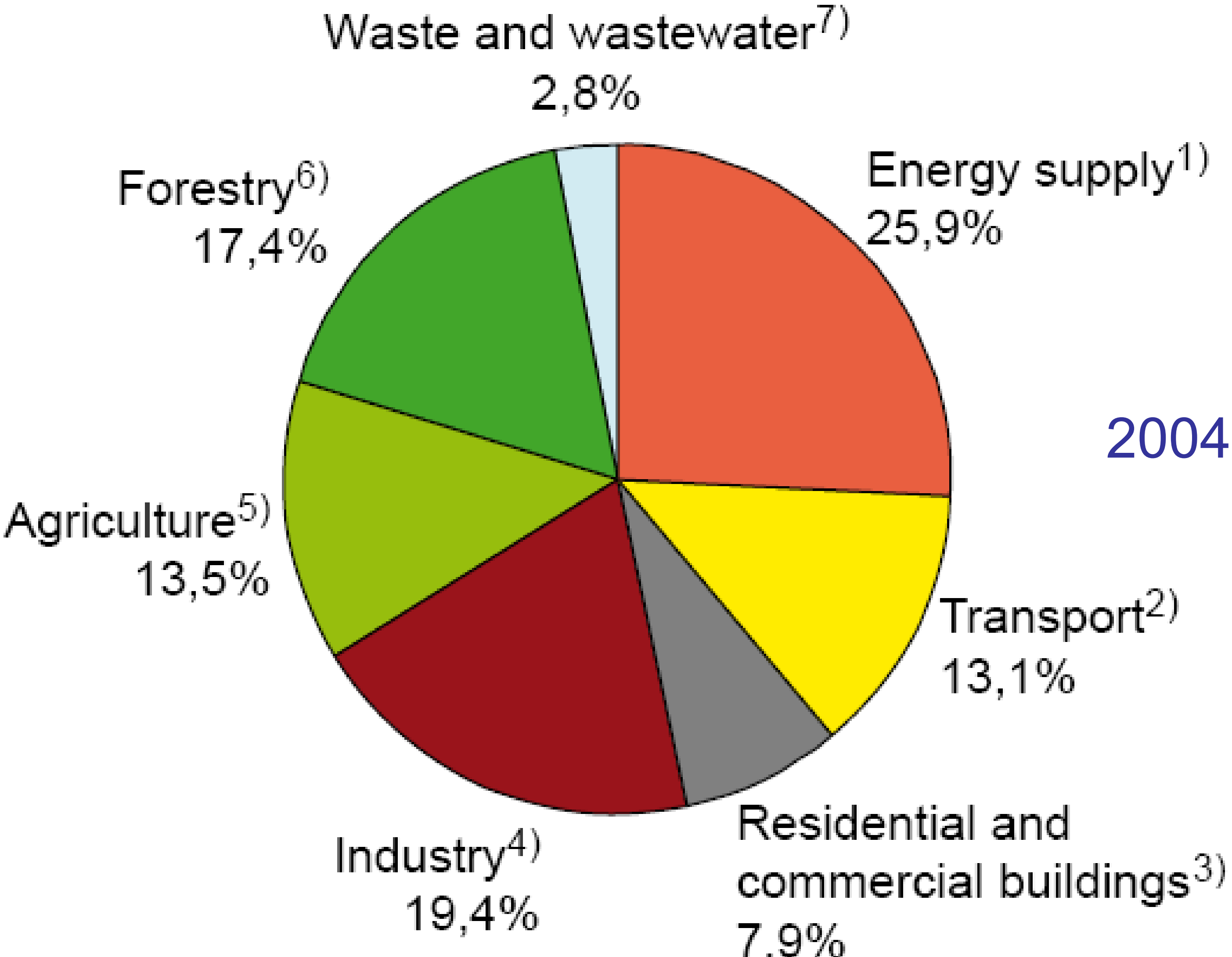
…there are only three options:

- 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 unmanage-able, enough adaptation to manage the unavoidable.

Mitigation leverage: The sources of GHG emissions



2004

IPCC WG3, 2007

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

(POSSIBLY)

- "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.

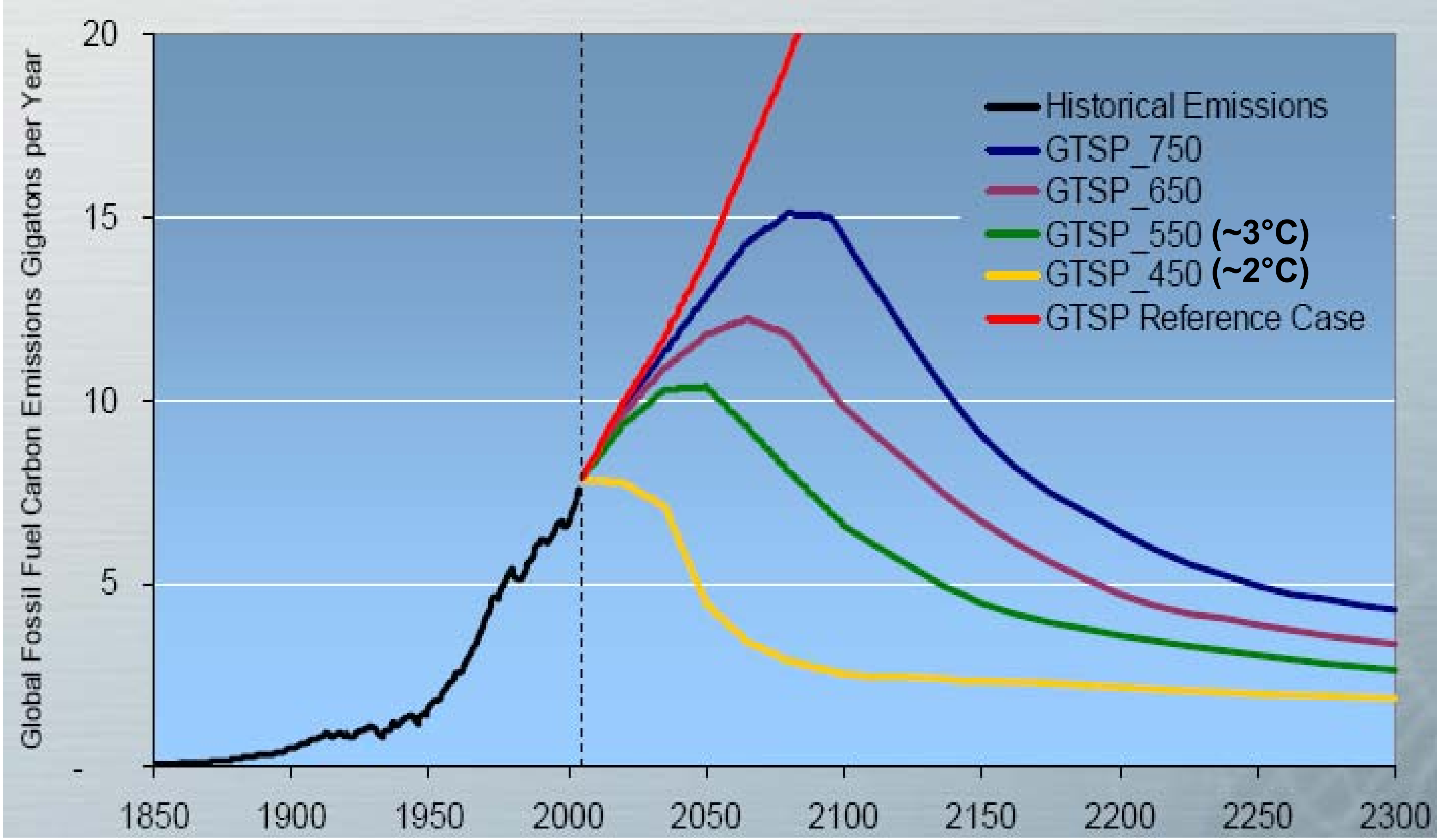
How much, how soon? (continued)

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

Key mitigation realities

- Human CO_2 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 CO_2 still came from industrial-ized 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.

Fossil CO_2 emissions paths: BAU versus stabilizing CO_2 concentration to limit ΔT_{avg}



Global Energy Technology Strategy, Battelle, 2007

Leverage on fossil-fuel CO_2 emissions

The emissions arise from a 4-fold product…

$$C = P \times GDP / P \times E / GDP \times C / E$$

where C = carbon content of emitted CO_2 (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 2005, the world figures were…

6.4×10^9 pers x $6500/pers x 0.012 GJ/$ x 15 kgC/GJ

= 7.5×10^{12} kgC = 7.5 billion tonnes C

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 CO_2/E ratio by…

- substituting natural gas for oil & coal
- replacing fossil fuels with renewables
- replacing fossil fuels with nuclear energy
- capturing & sequestering CO_2 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
- CO_2 capture/sequestration: cost, scale, complexity
- end-use efficiency: education, other barriers

Note: H_2 is not an energy source; it comes from other sources

Big problem & lack of panacea mean…

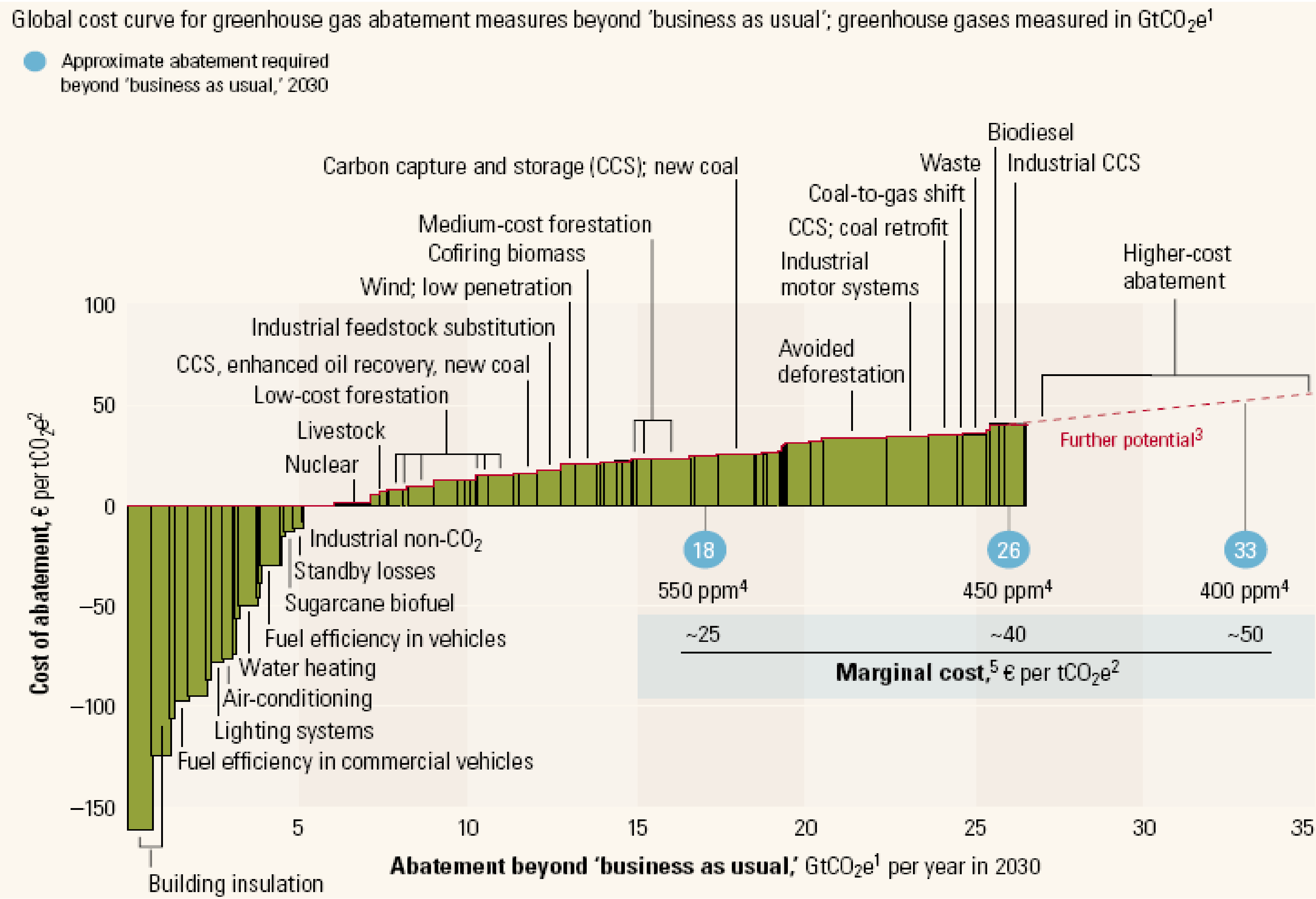
- We'll need a portfolio of approaches
  - Not just one or two, but many;
  - although not necessarily everything on the menu, as developing the better options to their full potential may allow foregoing some that prove very costly or risky.
- We need increased research & development on all of the options 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

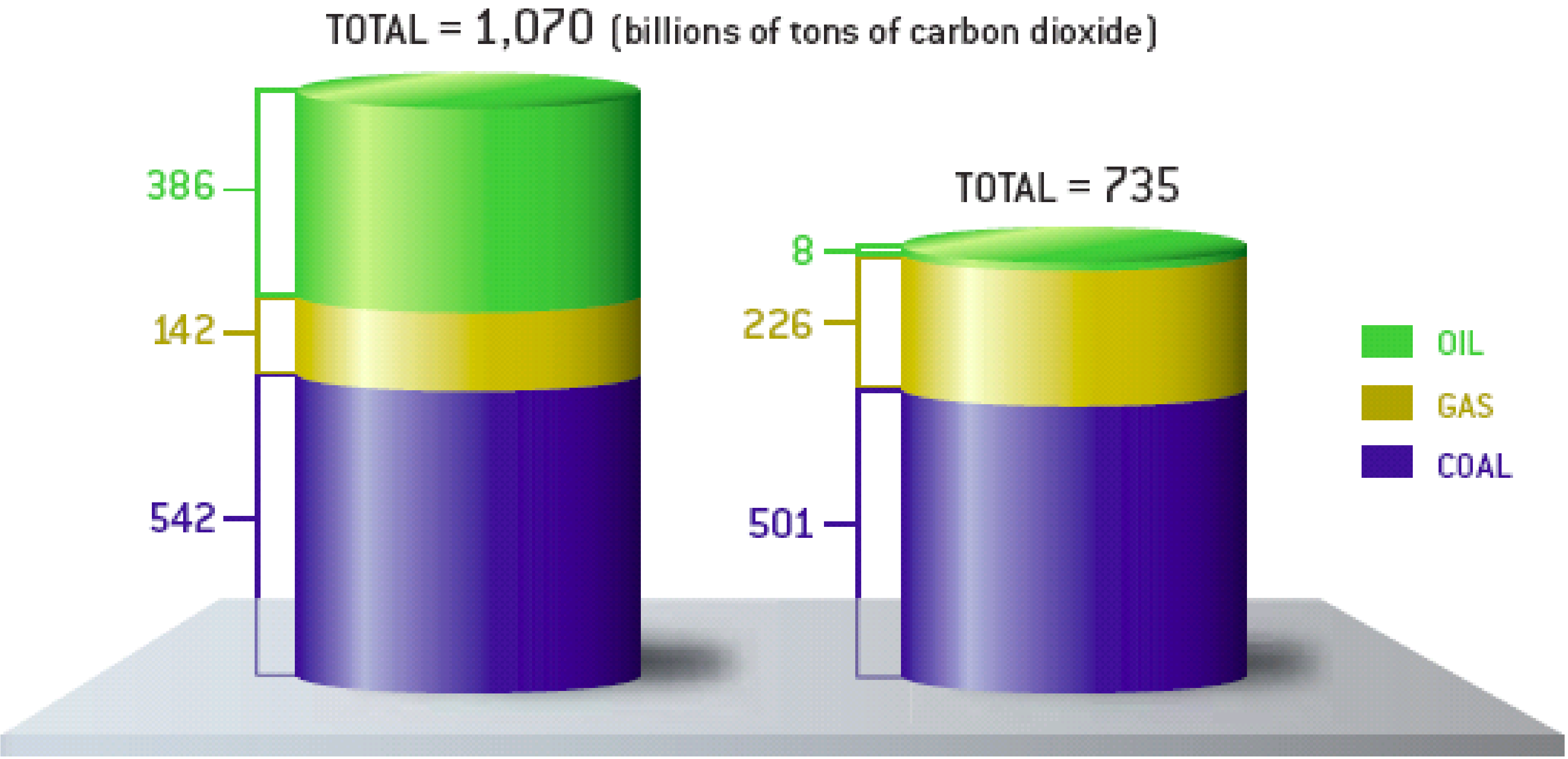
- G: The cheapest, fastest, cleanest, surest source of emissions reductions is to increase the efficiency of energy use in buildings, industry, and transport.
- G: Many such approaches are “win-win”: their co-benefits in saved energy, increased energy security, reduced conventional pollution, etc., are 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



McKinsey, 2007

Capturing CO_2 from power plants will be costly, but concentrations can't be stabilized soon enough unless we do it.



All CO_2 emissions from 1750 to 2002

Lifetime CO_2 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 challenge of scale

- Stabilizing at 500 ppmv CO_2-e means global CO_2 emissions must be ~7 GtC/yr below BAU in 2050.
- Avoiding 1 GtC/yr requires…
  - energy use in buildings cut 20-25% below BAU in 2050, or
  - fuel economy of 2 billion cars ~60 mpg instead of 30, 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 or
  - 2,000 1-GWe(peak) photovoltaic power plants replacing coal power plants

Socolow & Pacala, 2004

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 <u>intensity</u> (GHG/GDP); in the longer run, the only politically acceptable basis will be equal per-capita emissions rights.

Economics of mitigation

- Current global CO_2 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 CO_2e → ~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-2012 period
- Ramp up investments in energy-technology research, development, & demonstration by 2-5X
- Expand international cooperation on deploying advanced energy technologies

The United States <u>must</u> lead!

Some references

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