# The Science of Climate Change

## What Do We Know? What Can We Do?

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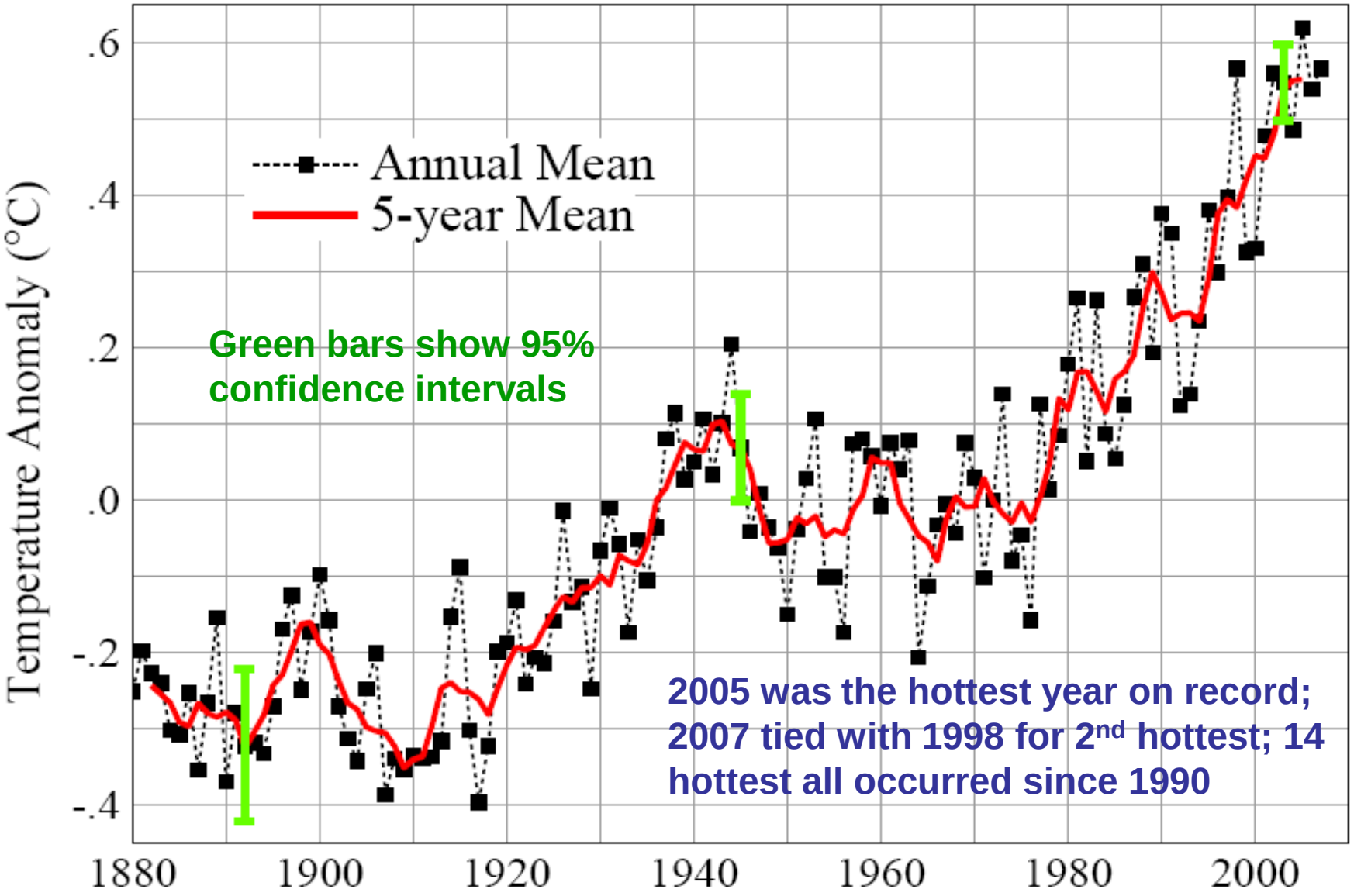
**Lecture at the**

**UNFCCC COP-15**

**Copenhagen • 16 December 2009**

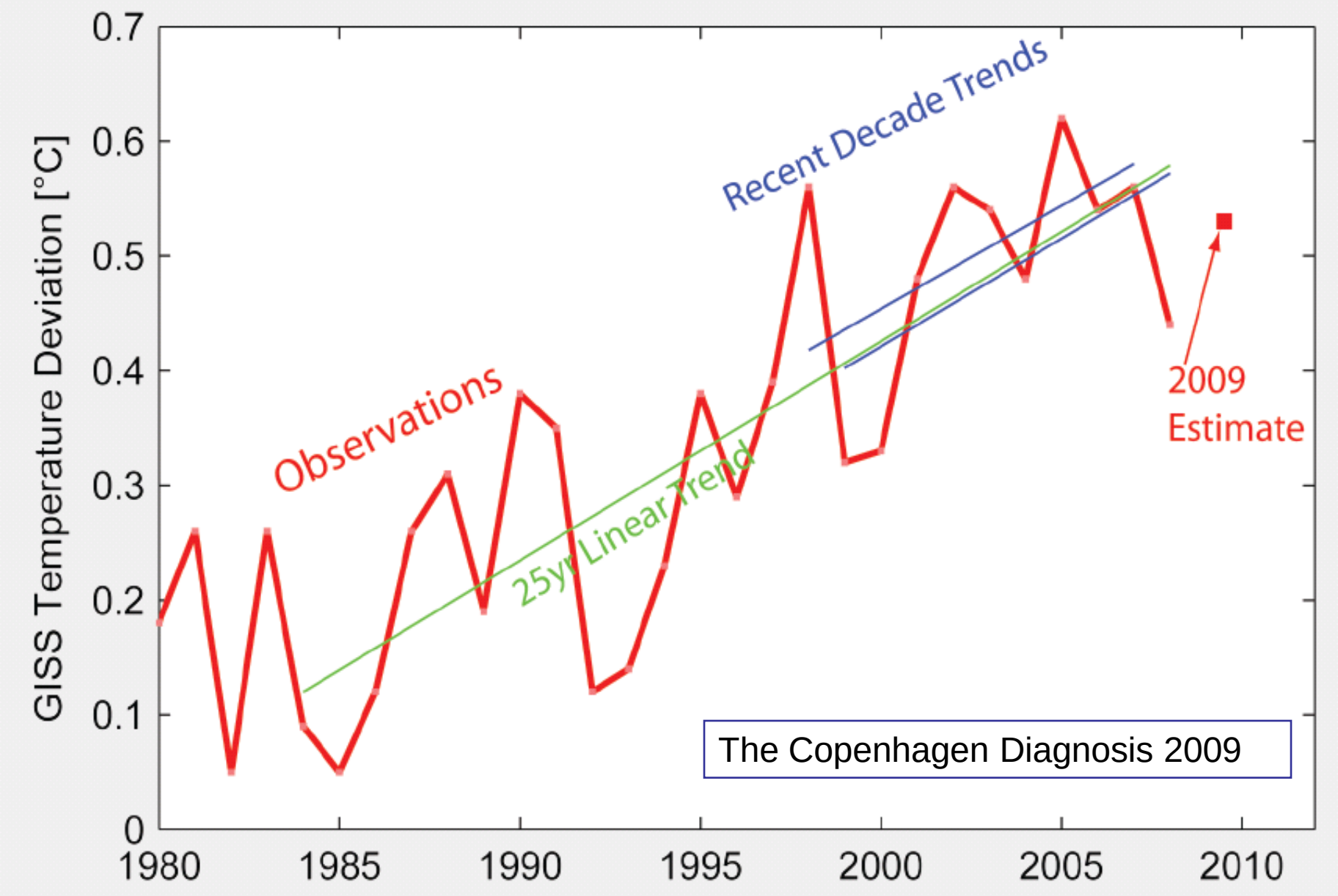
# What do we know?

# The Earth is getting hotter: the thermometer record



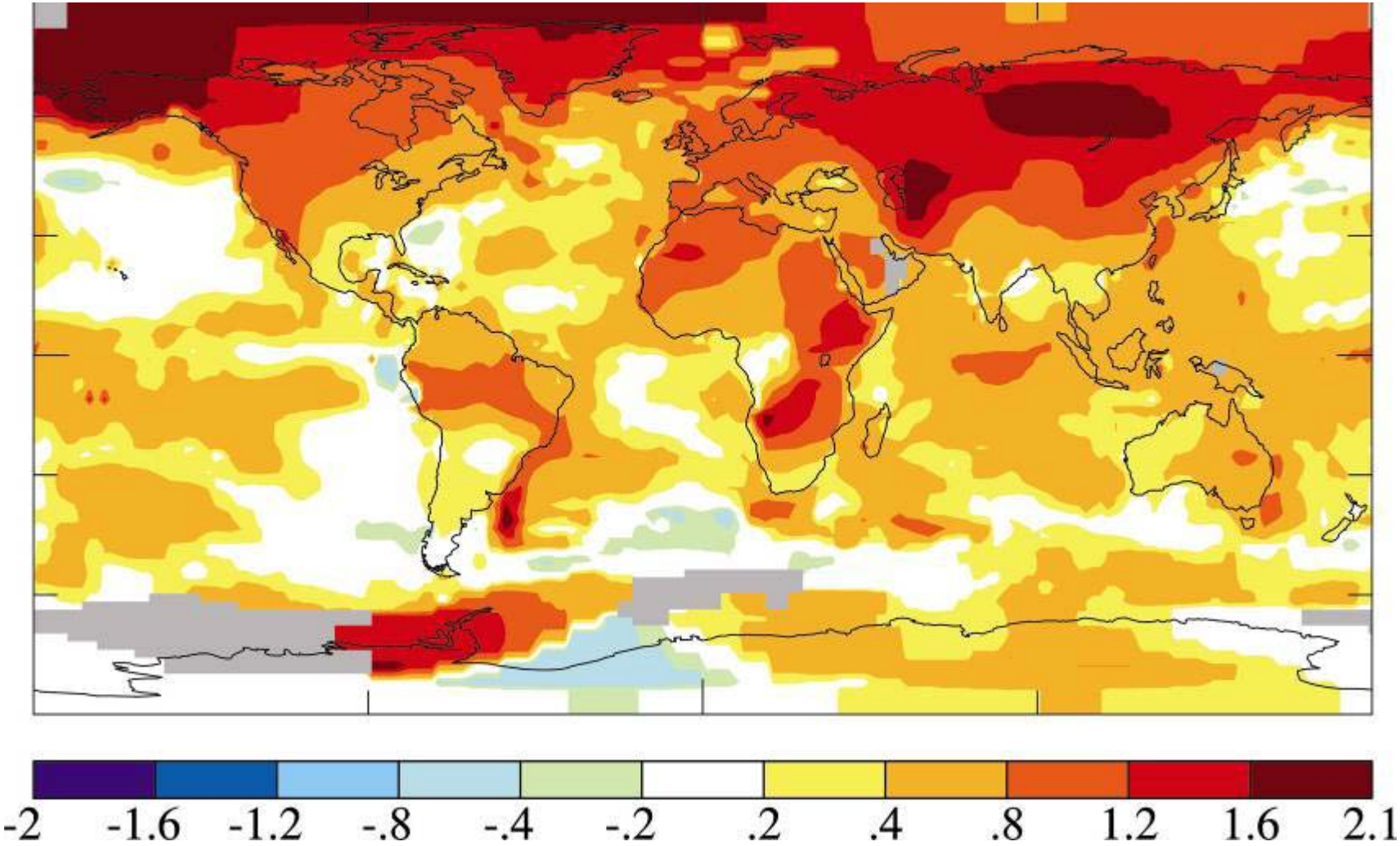

http://data.giss.nasa.gov/gistemp/graphs/

# The rate of heating is <u>not</u> slowing down



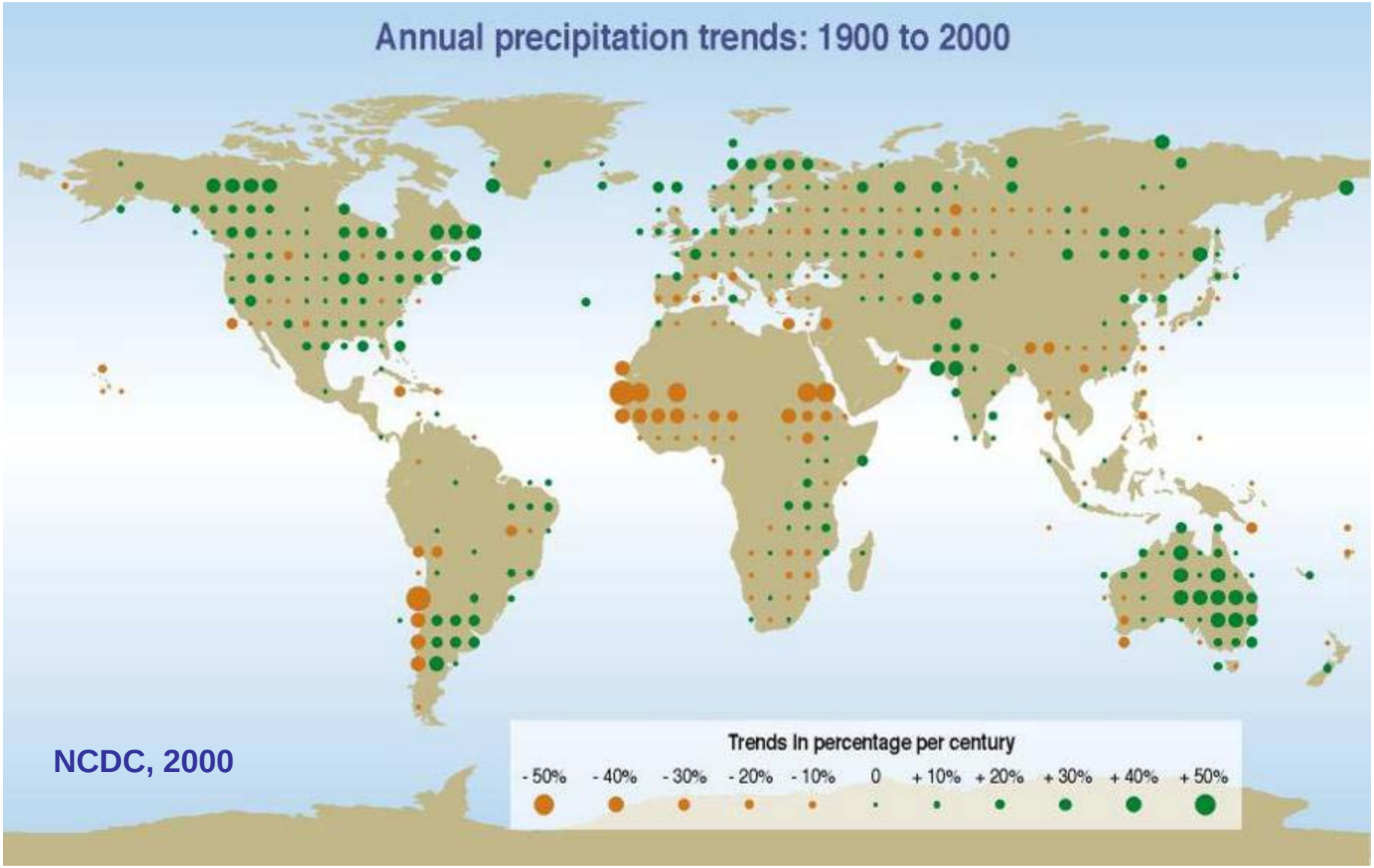
# The heating is not uniform geographically

Surface T in 2001-2005 *vs* 1951-80, averaging 0.53ºC increase




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

# Other climate indicators are changing apace




NCDC, 2000

**This too is not uniform; most places getting wetter, some drier.**

# Other indicators: glaciers retreating

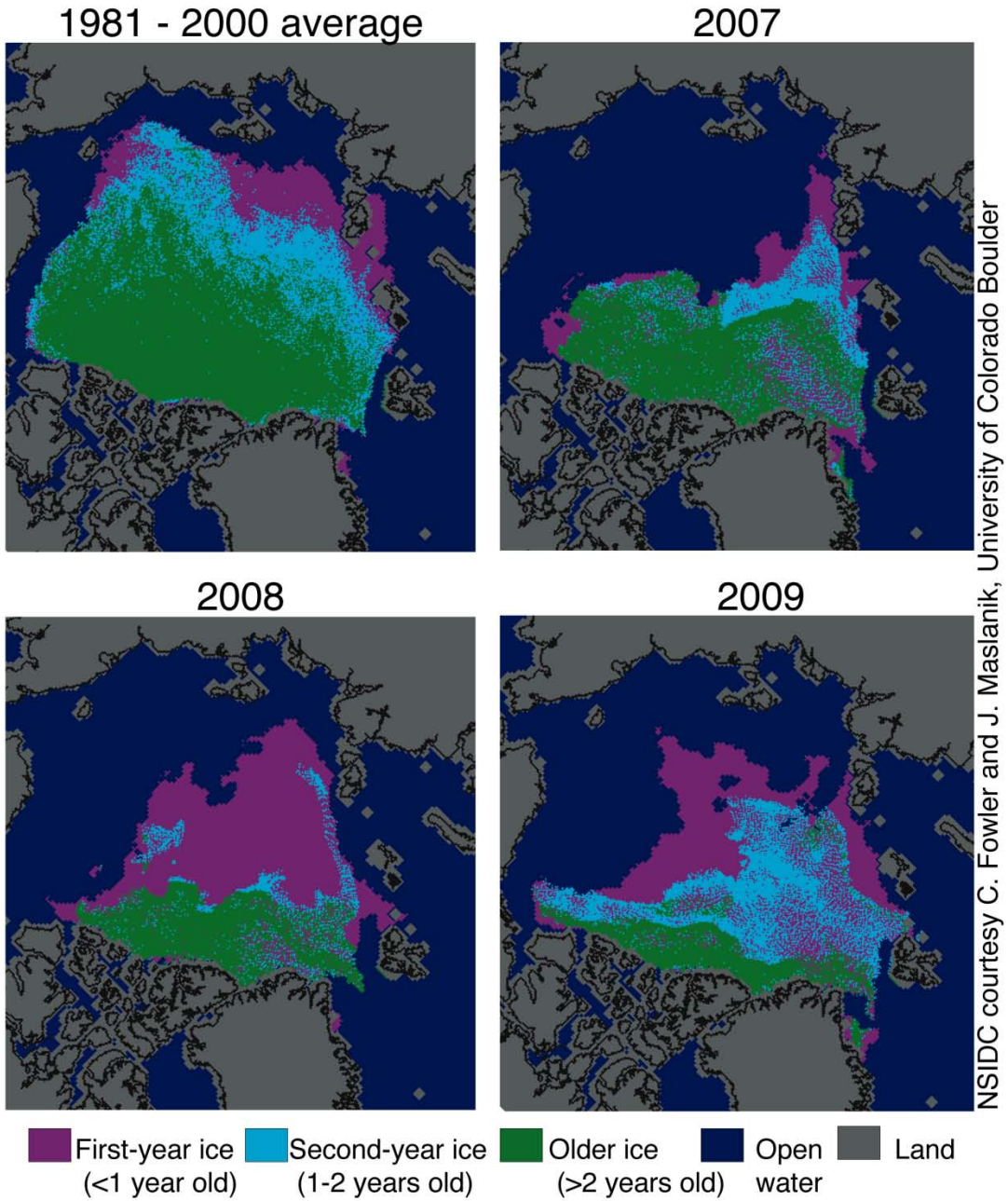
## Muir Glacier, Alaska

**August 1941**

**August 2004**

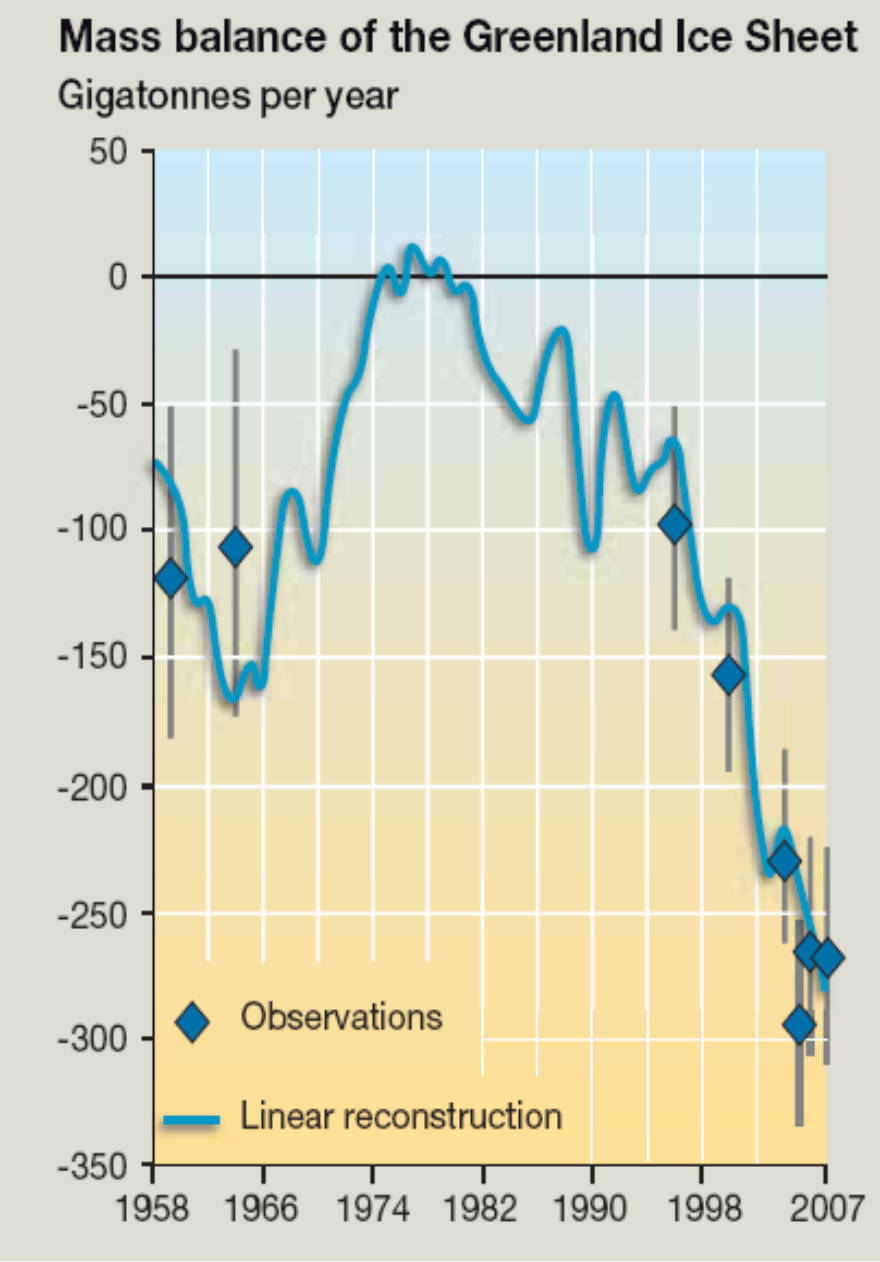
NSIDC/WDC for Glaciology, Boulder, compiler. 2002, updated 2006. *Online glacier photograph database.* Boulder, CO: National Snow and Ice Data Center.

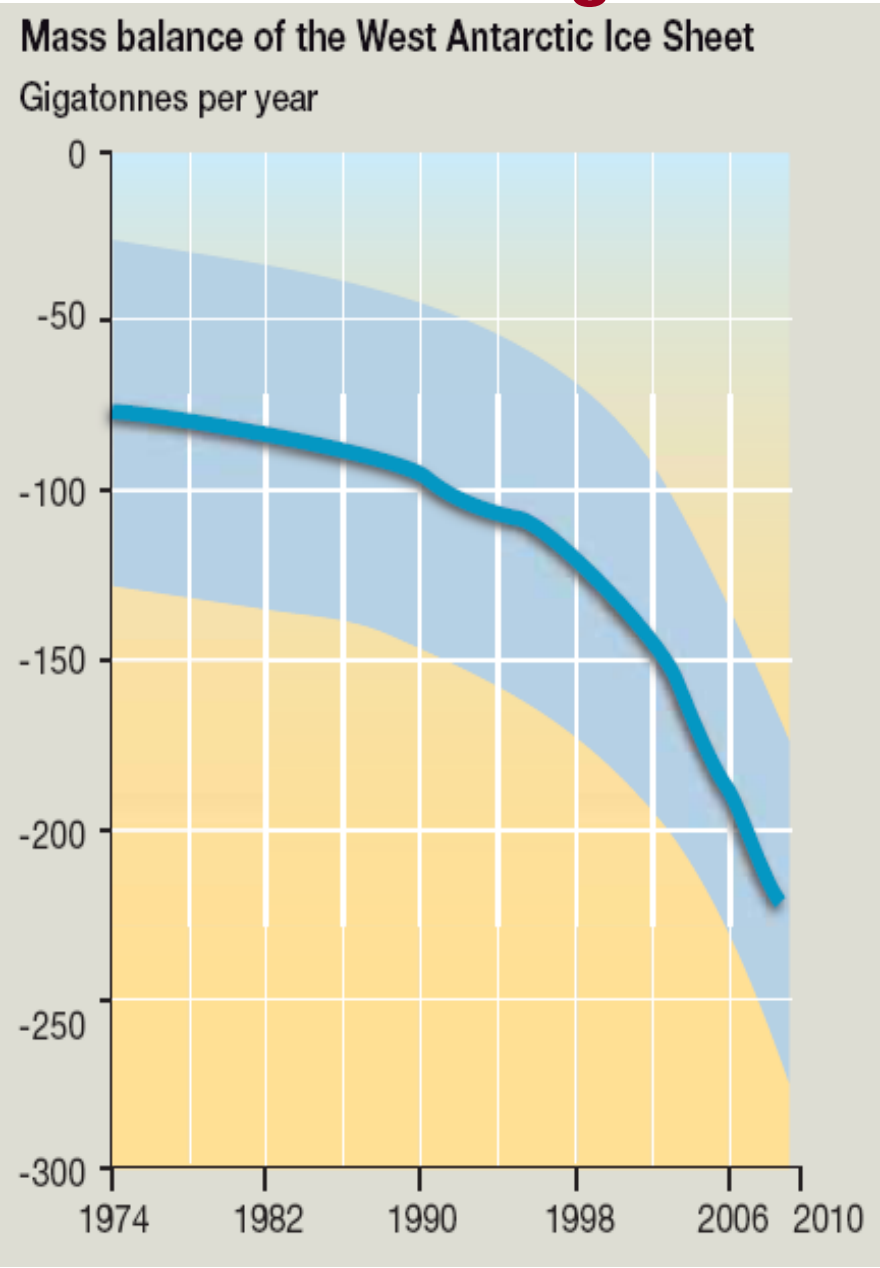
# Indicators: Arctic sea ice shrinking & thinning




NSIDC courtesy C. Fowler and J. Maslanik, University of Colorado Boulder

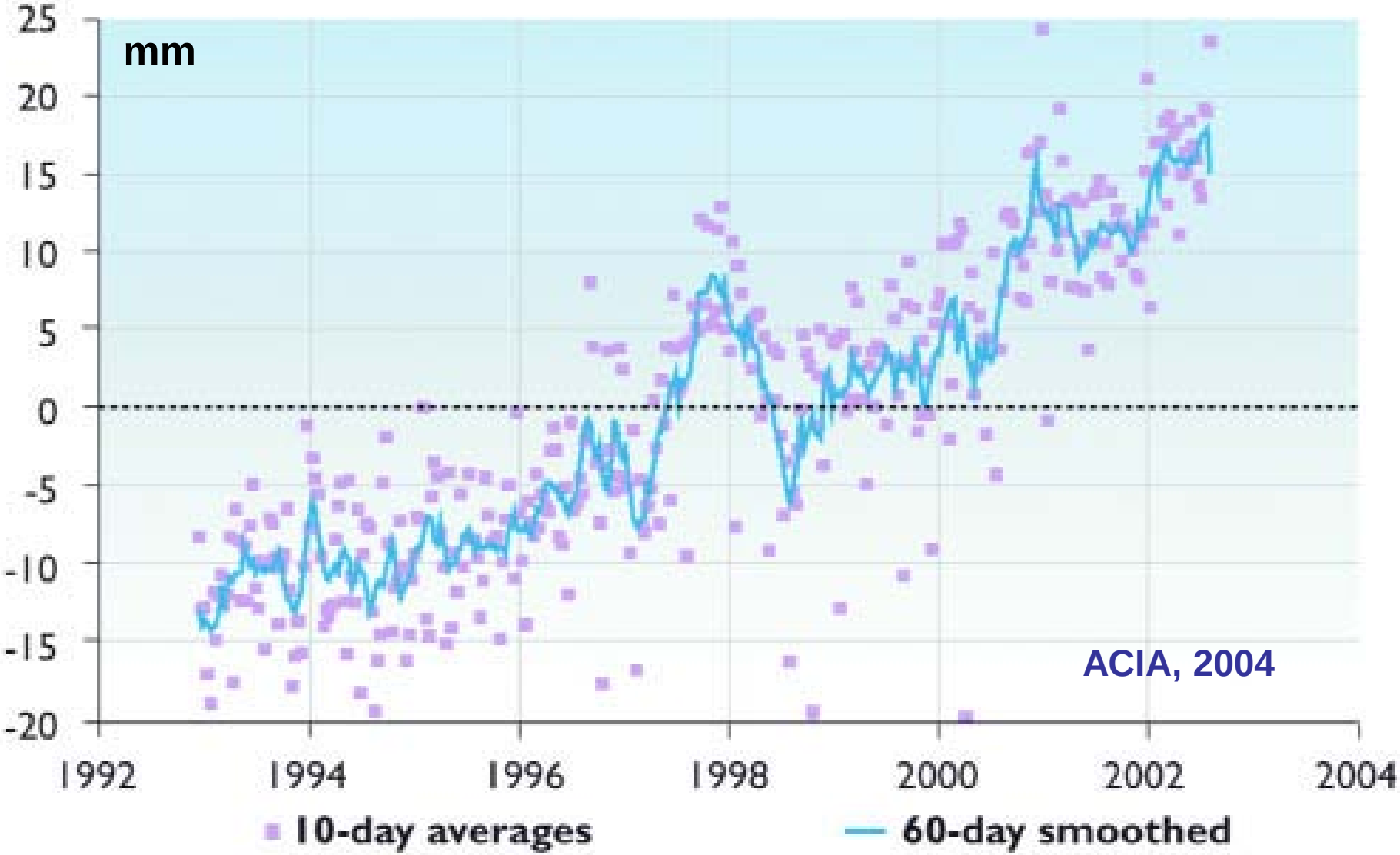
# Indicators: Greenland & Antarctic ice losing mass




The Copenhagen Diagnosis, 2009

# Indicators: sea-level is rising




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

# What we know about the human role

## 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 |

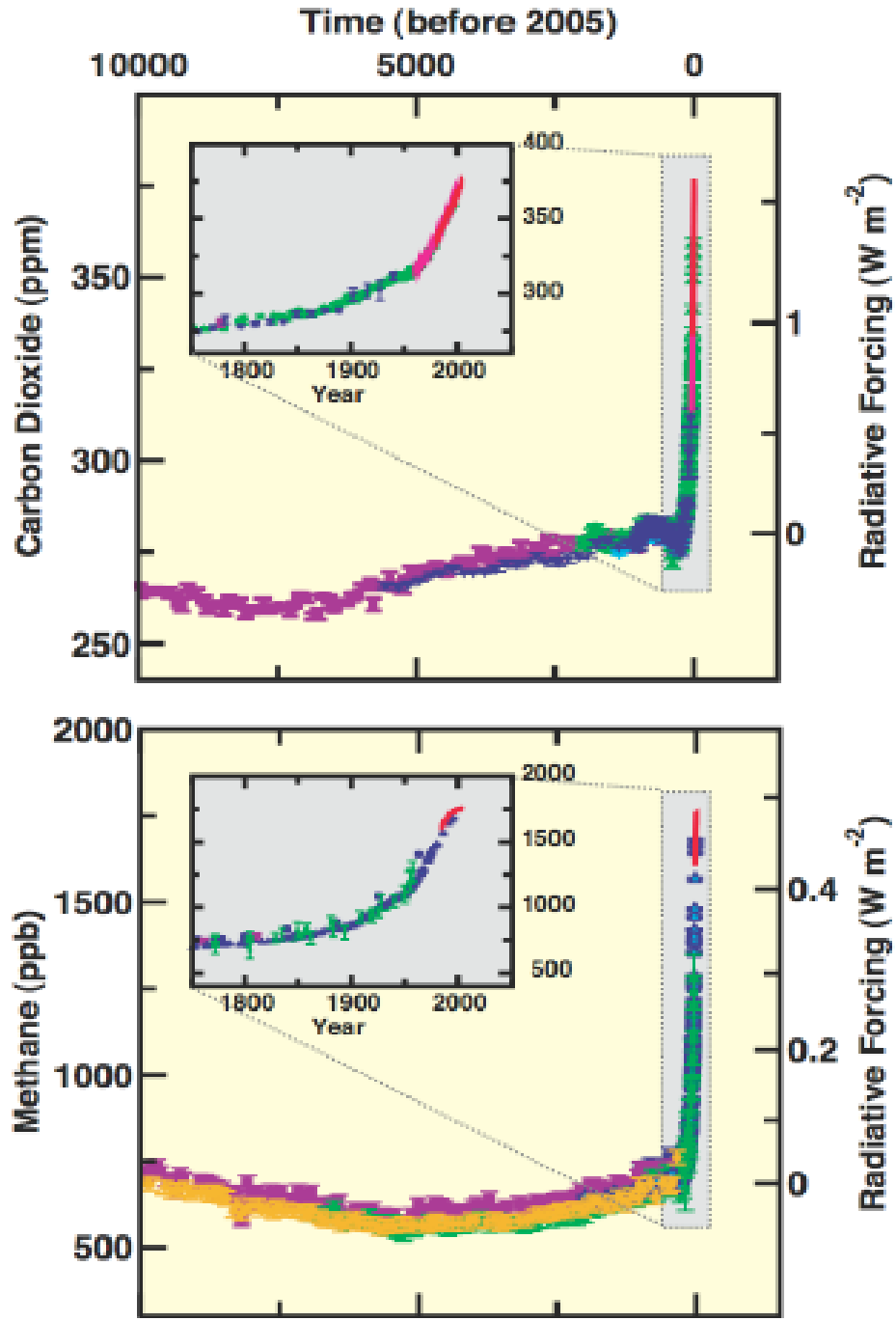
**The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.**

**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.

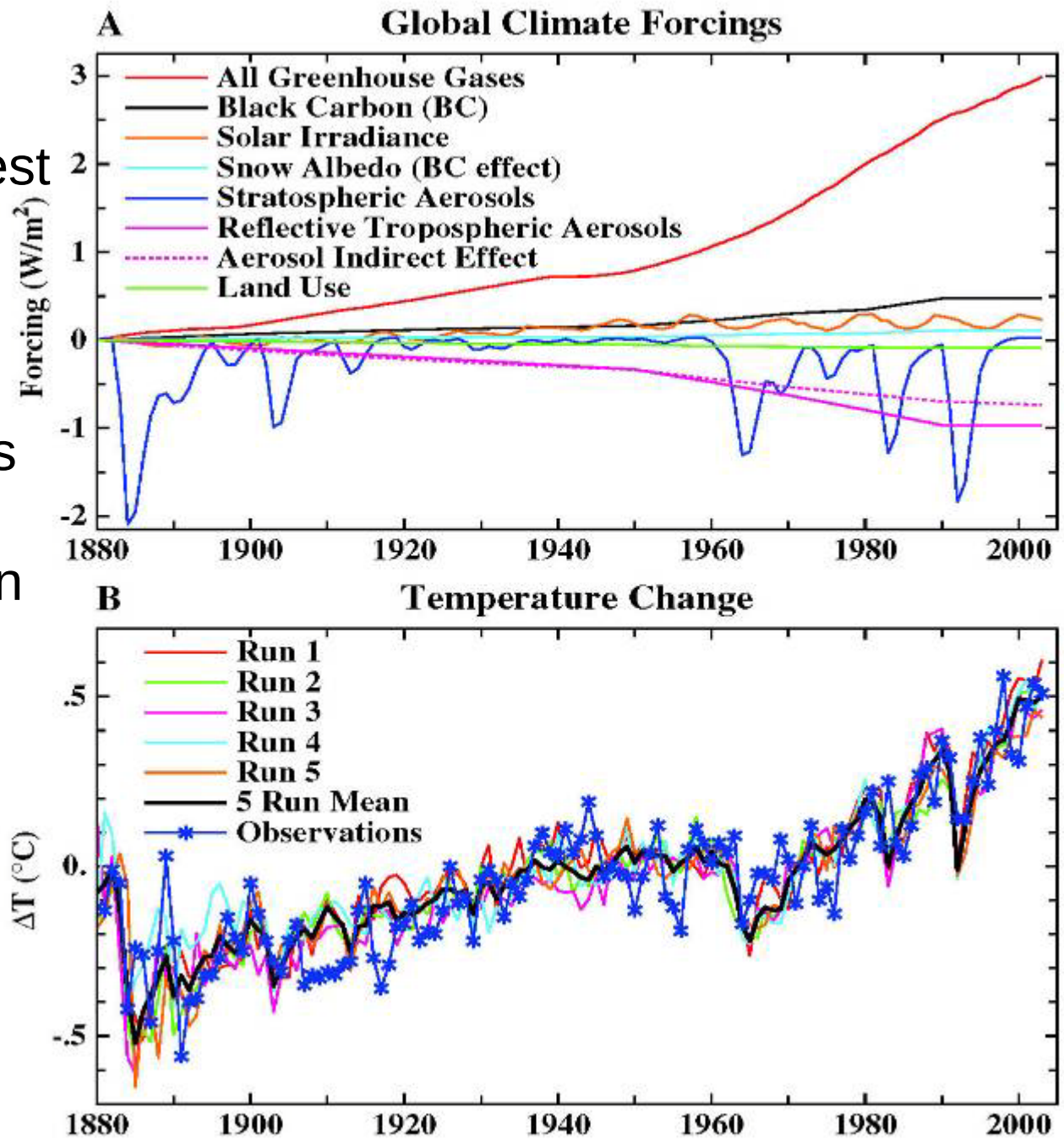



IPCC AR4, WG1 SPM, 2007

# Human influence: the "fingerprint"

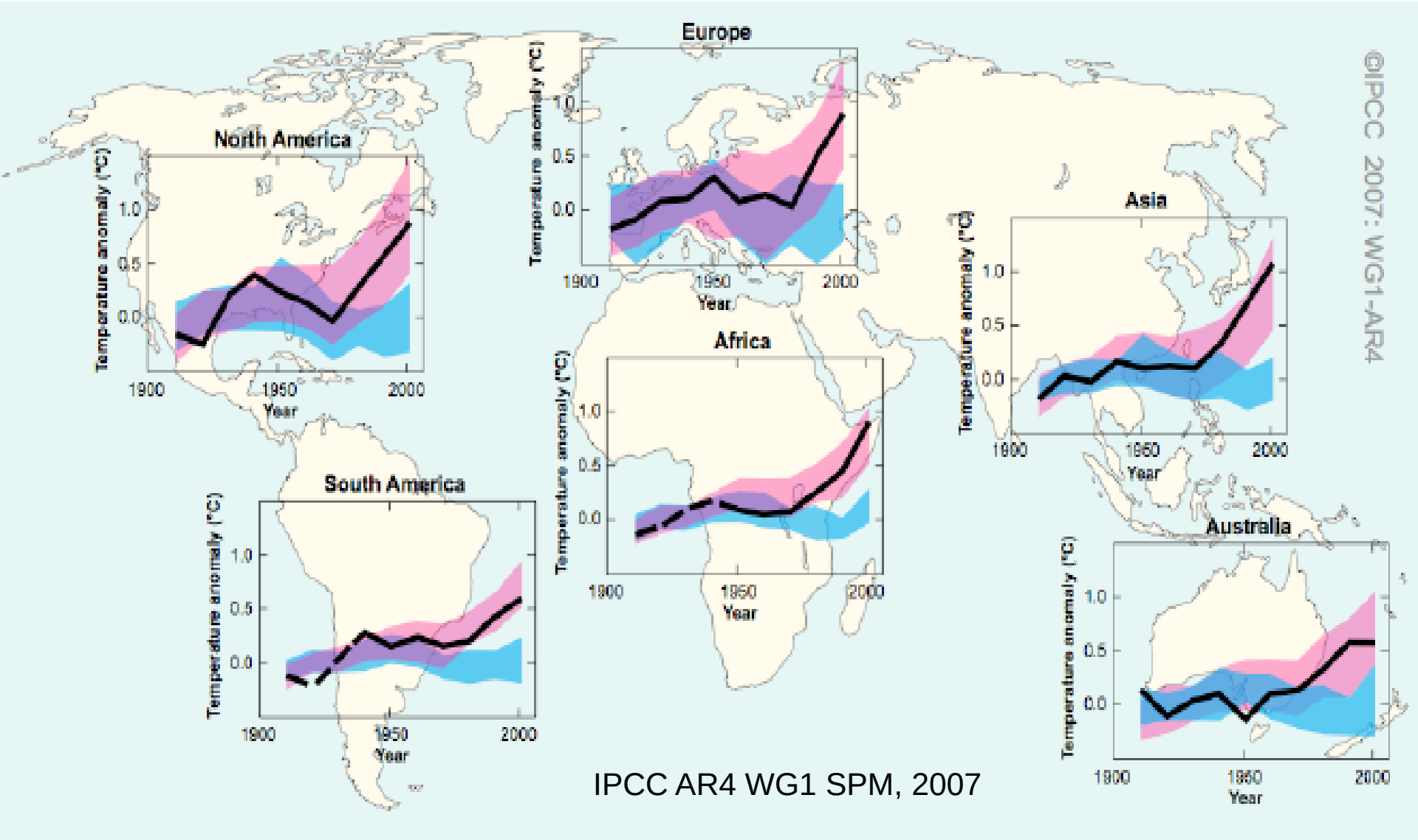
Top panel shows best estimates of human & natural forcings 1880-2005.

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




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

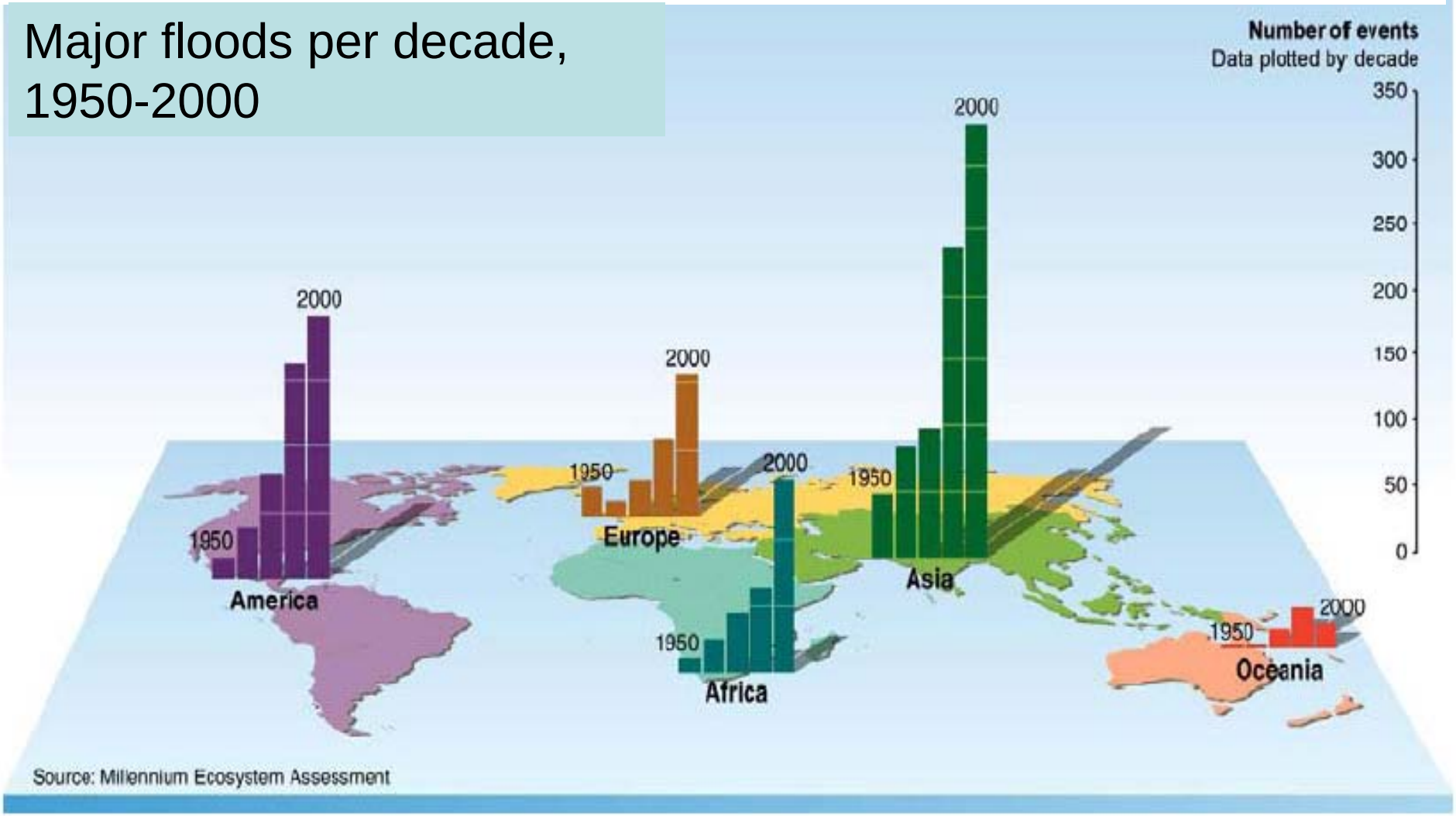
# Fingerprint: models match observed • T on all continents




IPCC AR4 WG1 SPM, 2007

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

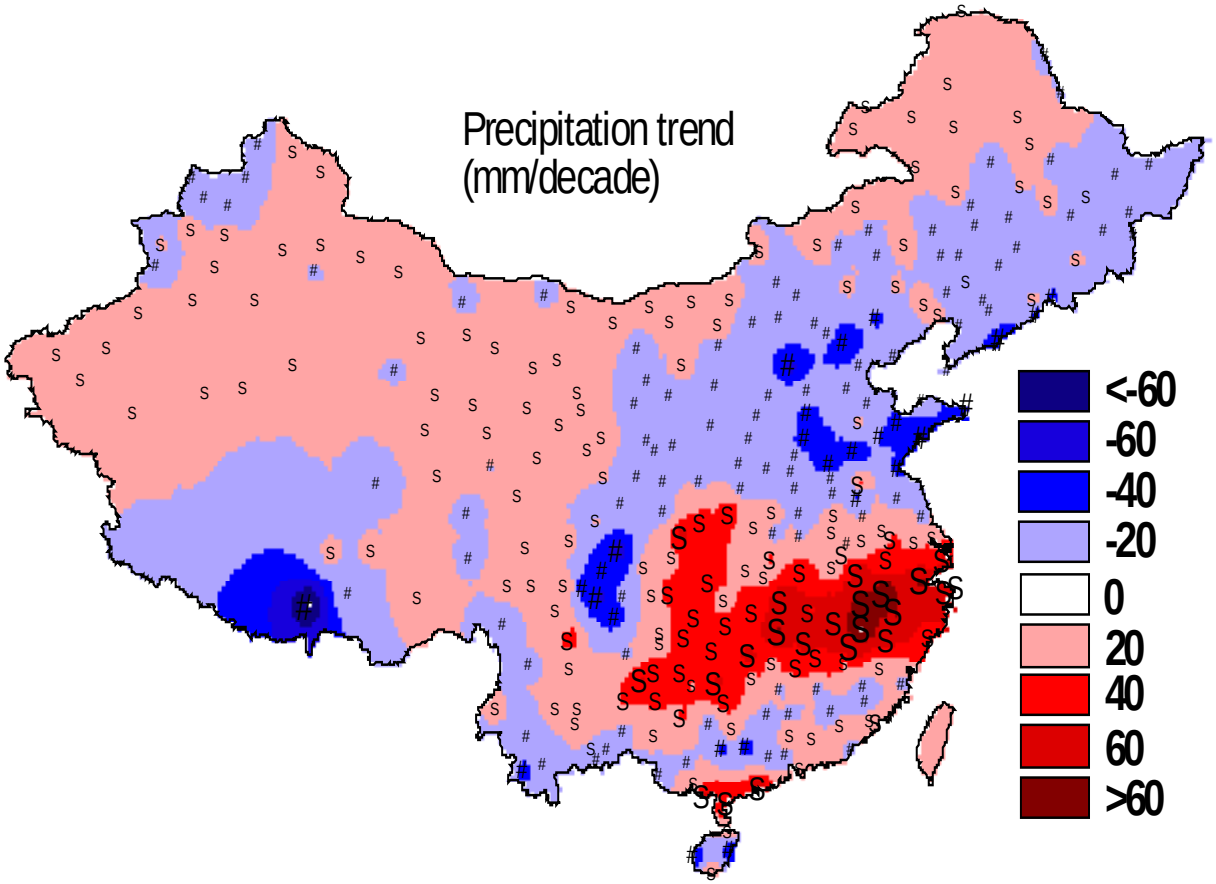
# The current climatic disruption is already causing harm




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

# Harm is already occurring: monsoon changes

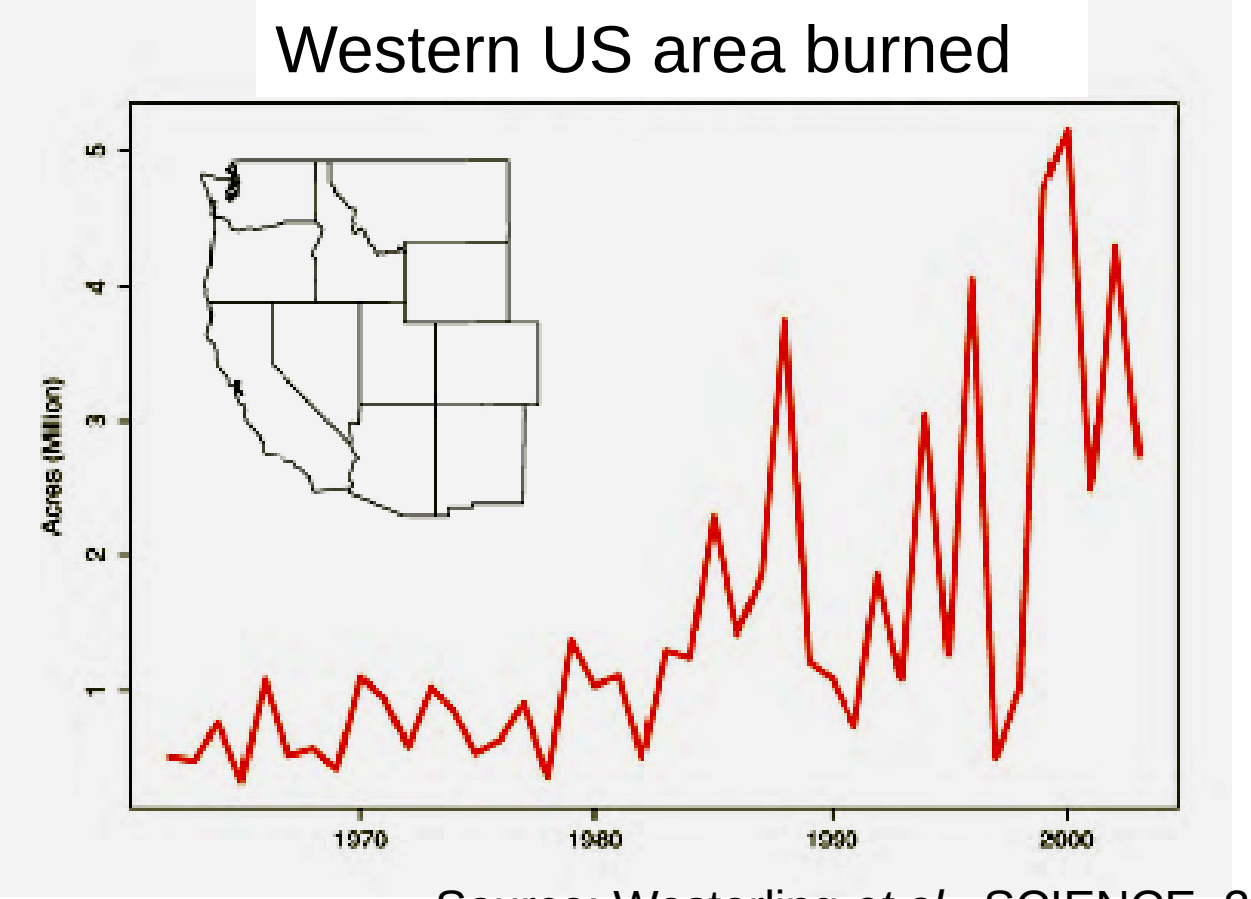
**Weakening East-Asia monsoon – attributed to global climate change -- has meant less moisture flow South to North, producing increased flooding in South, drought in North**




Qi Ye, Tsinghua University, May 2006

# Harm is already occurring: wildfires

**Wildfires in the Western USA have increased 6-fold in the last 30 years. Similar trends are evident in other fire-prone regions.**



Source: Westerling *et al*., SCIENCE, 2006

# Harm is already occurring: pest outbreaks

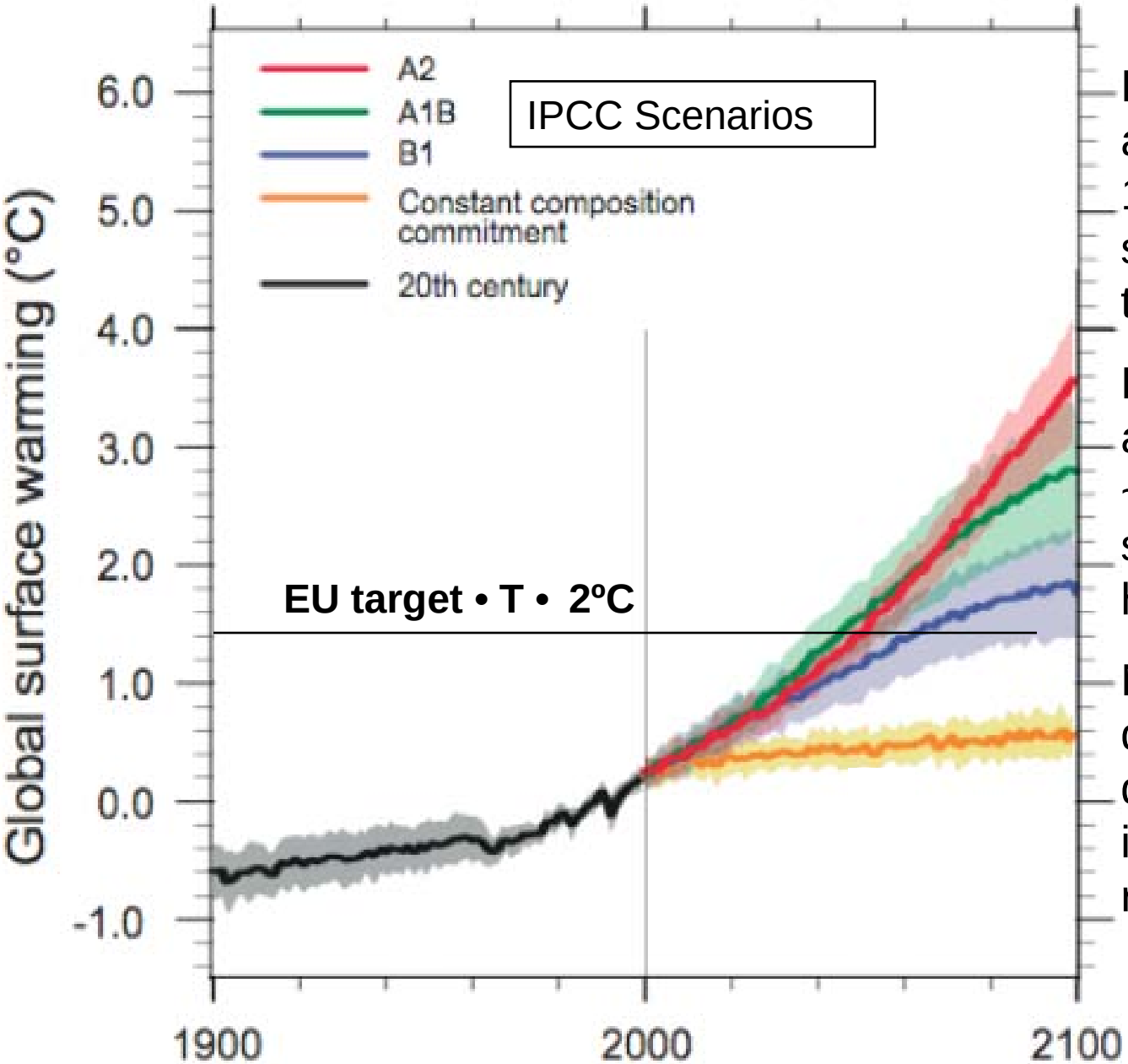
Pine bark beetles, with a longer breeding season courtesy of warming, devastate trees weakened by heat & drought in Colorado

USGCRP 2009

# Harm is already occurring: melting permafrost

Norwegian Polar Institute, 2009

# Climate change: Where are we headed?




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

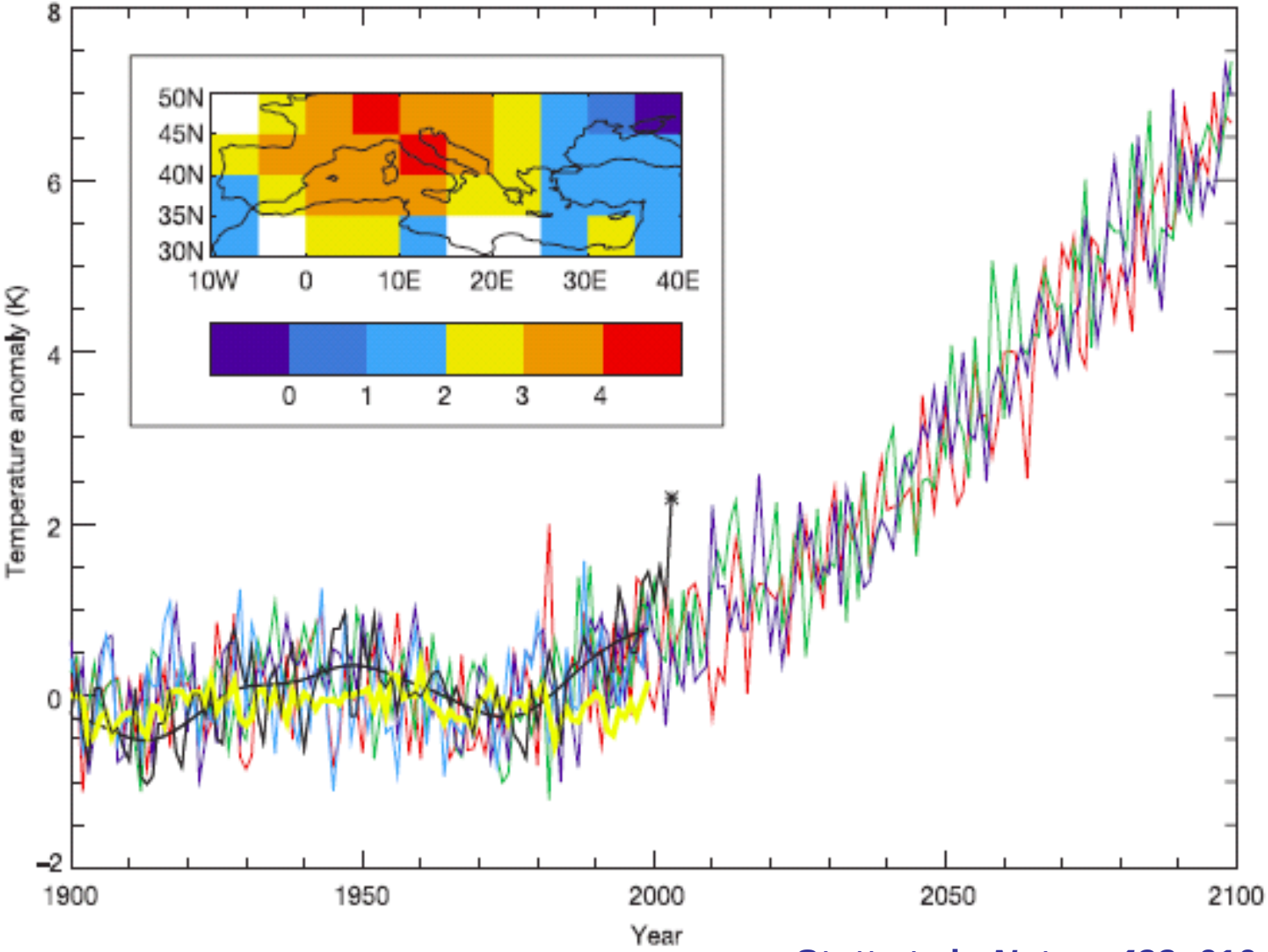
Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

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 heating, 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 • T • 1-1.5°C**

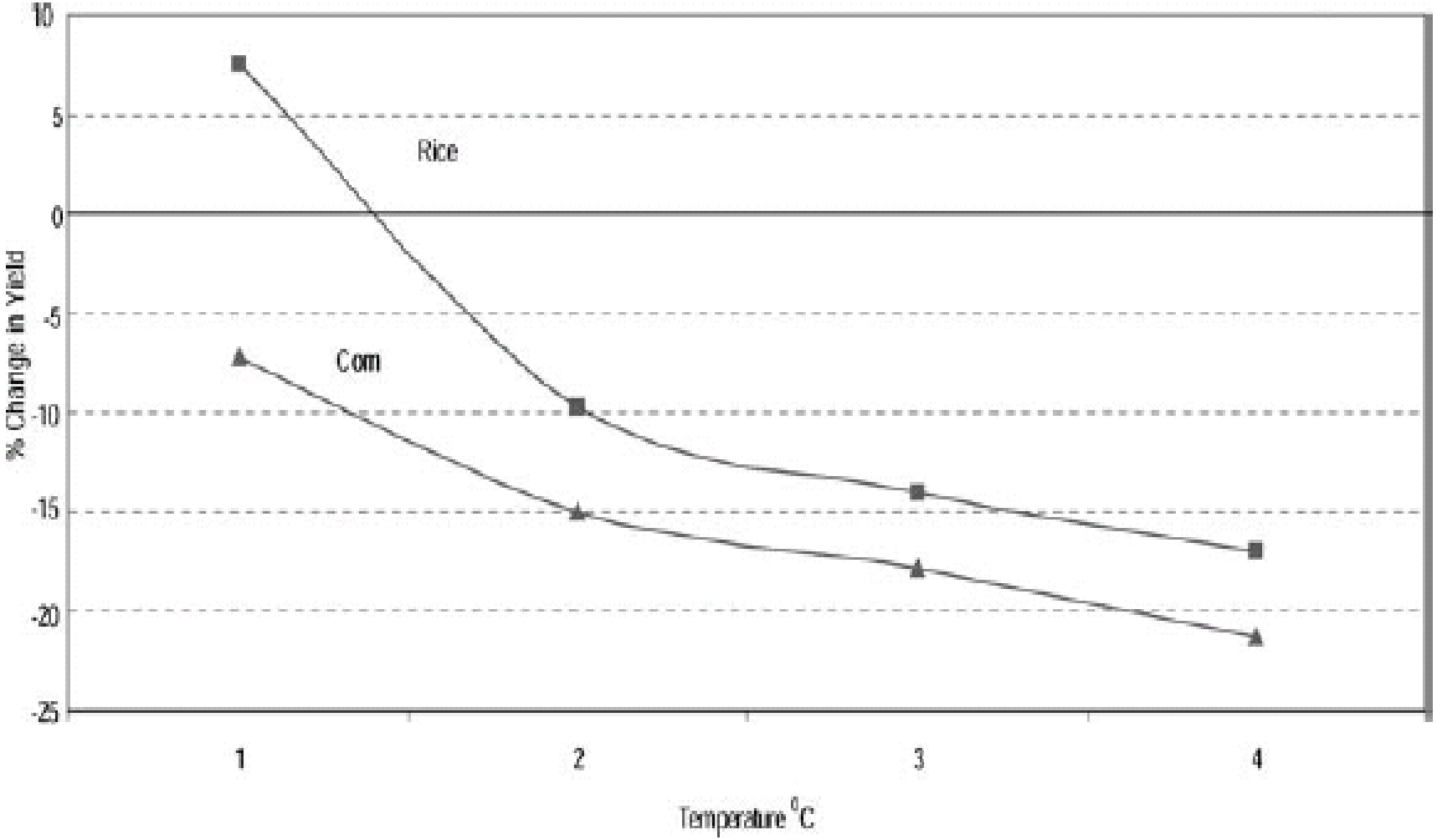



*Figure 1.* Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. $CO_2$ direct effects were included in all studies.

**Easterling and Apps, 2005**

# Where we're headed: Temperate-zone agriculture

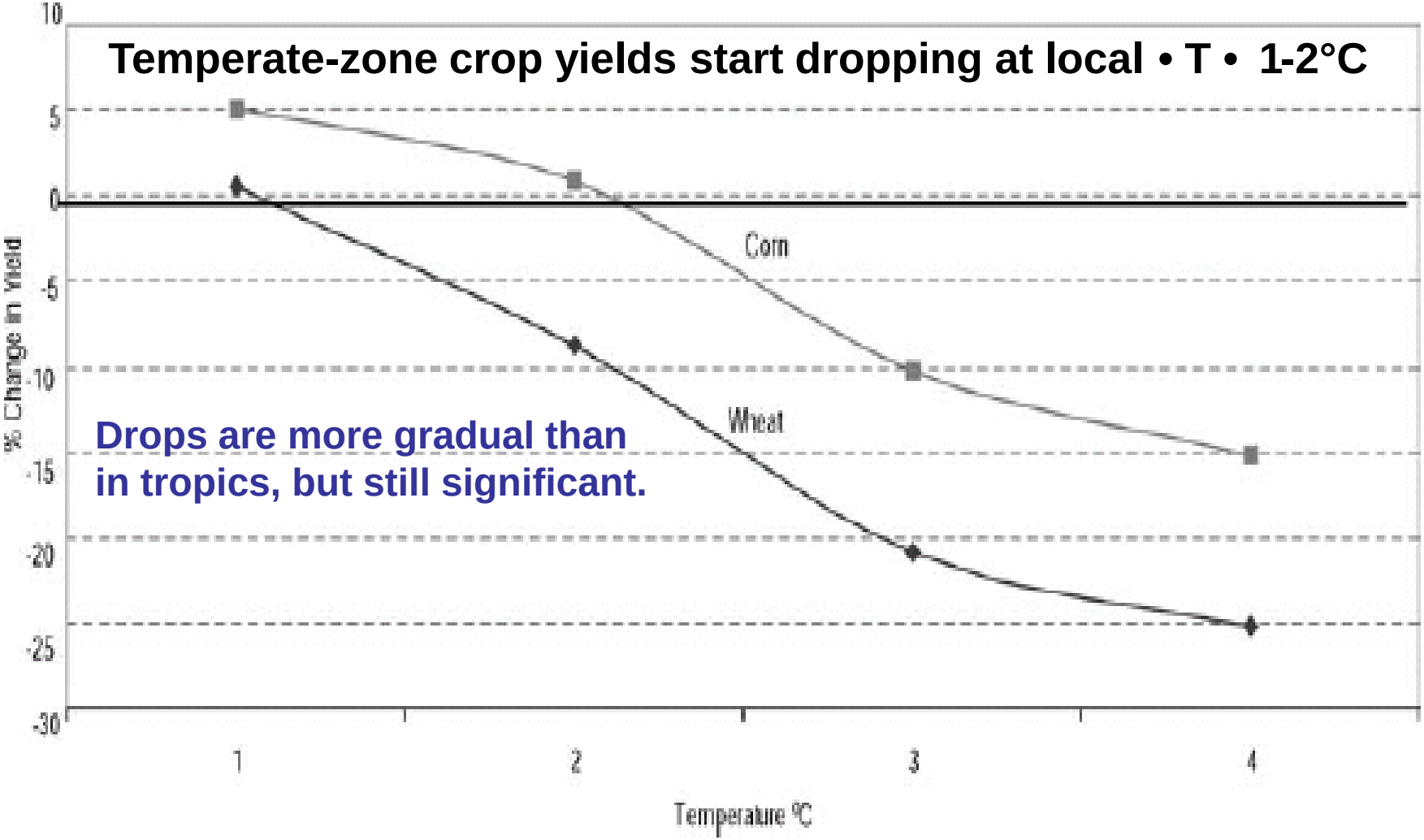
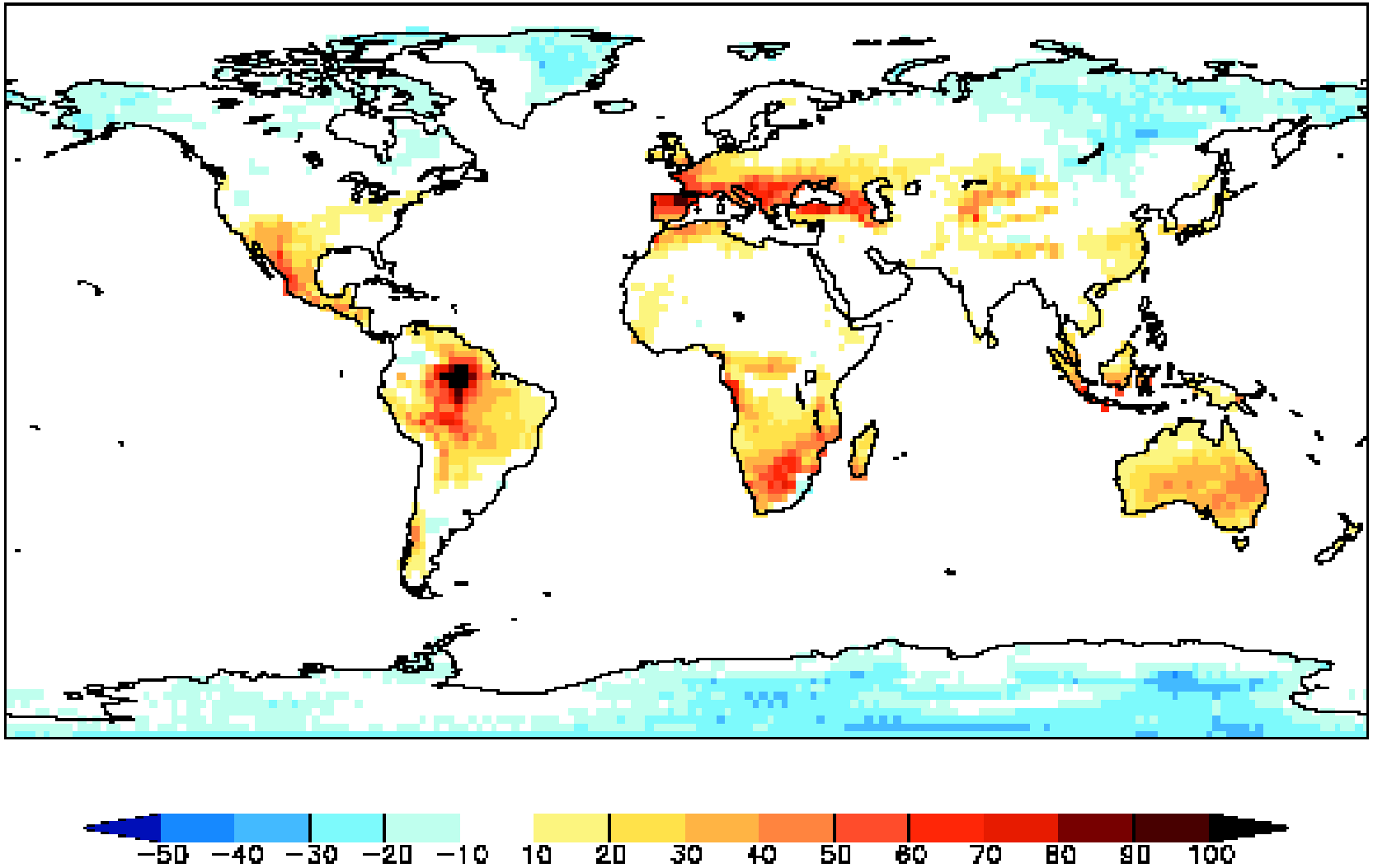



*Figure 2.* Corn and Wheat yields versus temperature increase in the temperate zone averaged across 30 crop modeling studies. All studies assumed a positive change in precipitation. $CO_2$ direct effects were included in all studies.

Easterling and Apps, 2005

# Where we're headed: droughts

## Drought projections for IPCC's A1B scenario



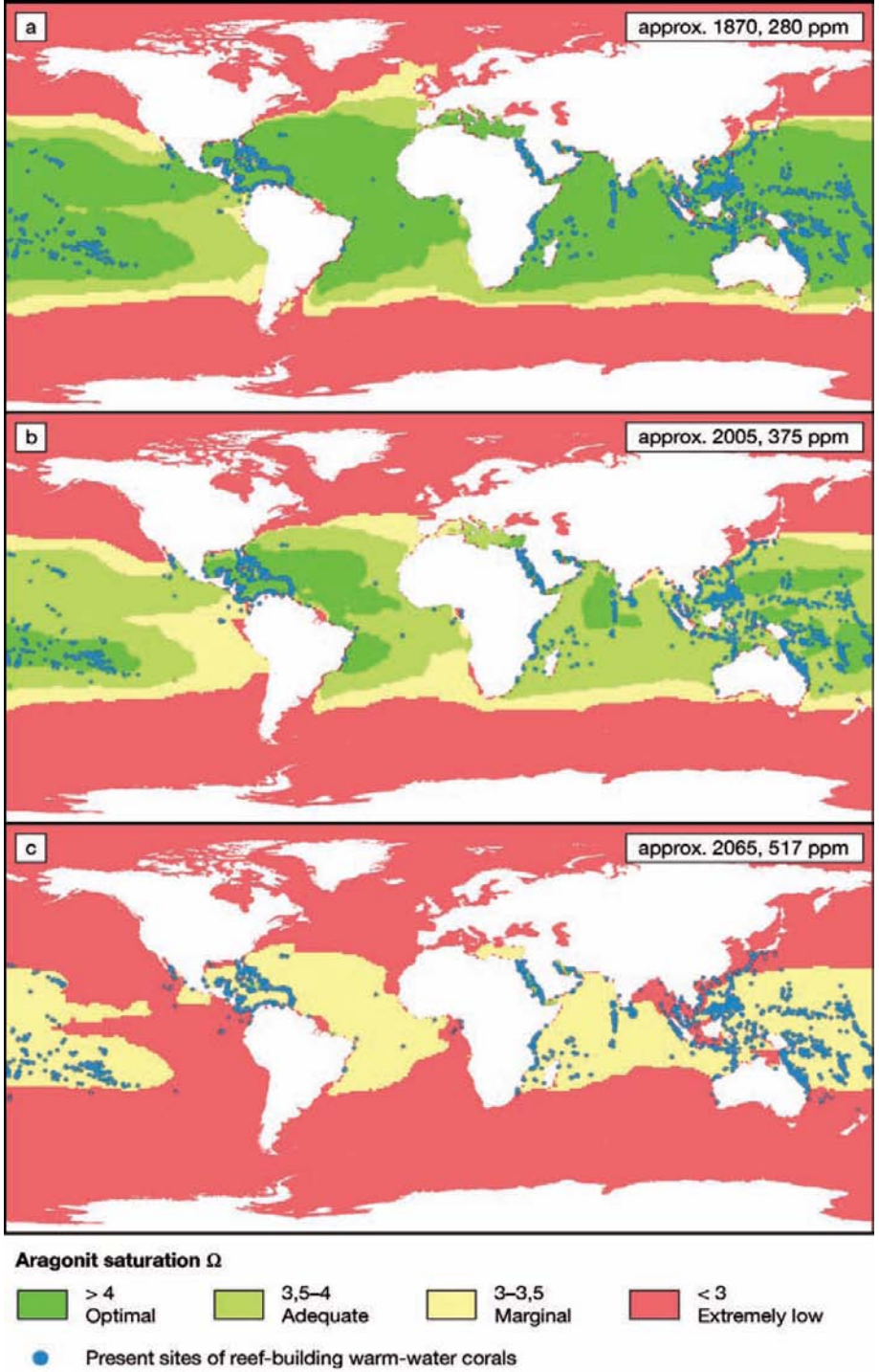

*Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.*

# Where we're headed: Pickling (as well as roasting) the oceans

About 1/3 of $CO_2$ added to atmosphere is quickly taken up by the surface layer of the oceans (top 80 meters).

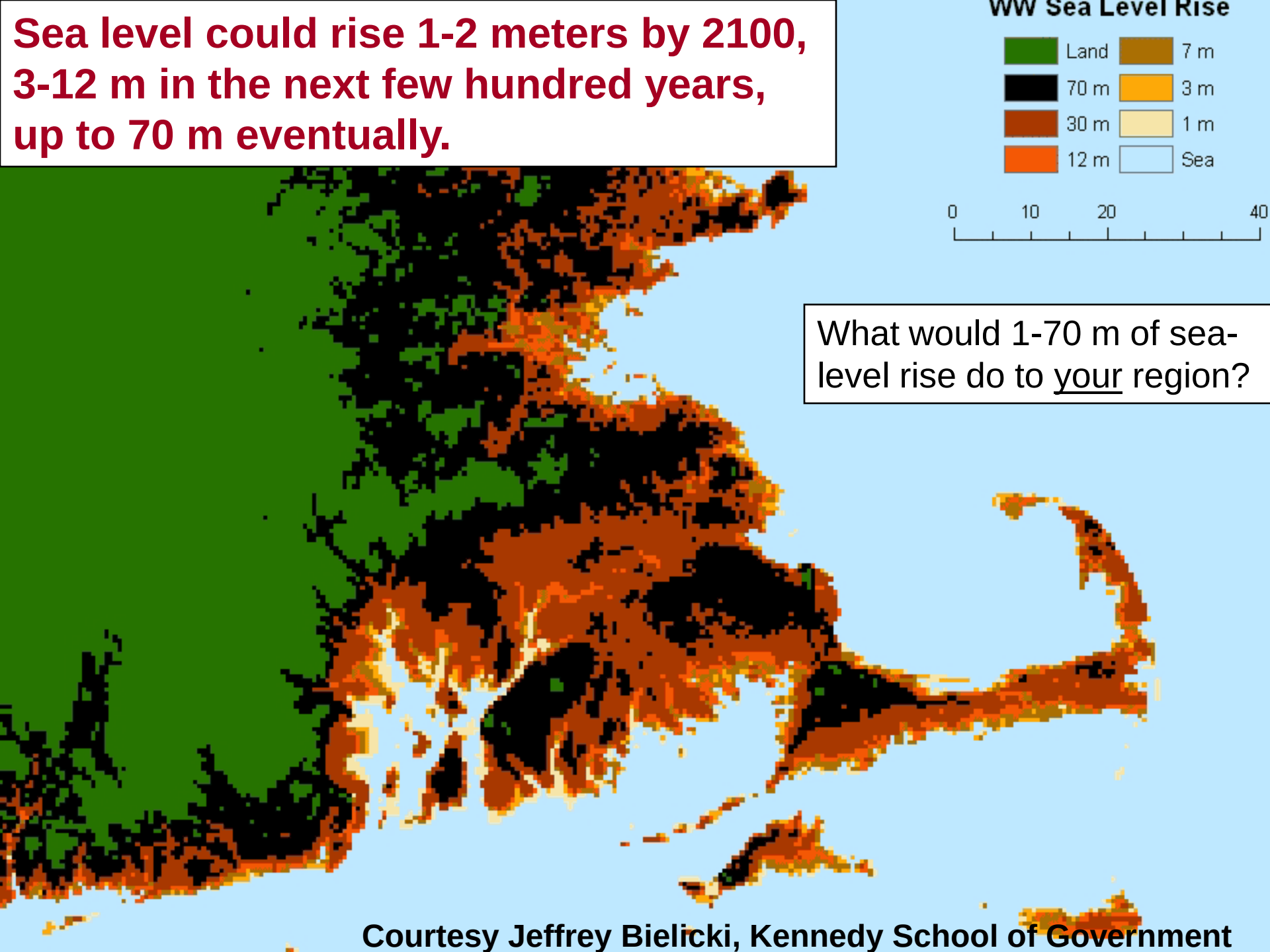
This lowers pH as dissolution of $CO_2$ forms weak carbonic acid ($H_2O + CO_2 \rightarrow H_2CO_3$).

Increased acidity lowers the availability of $CaCO_3$ to organisms that use it for forming their shells & skeletons, including corals.




Steffen et al., 2004

**Sea level could rise 1-2 meters by 2100, 3-12 m in the next few hundred years, up to 70 m eventually.**




What would 1-70 m of sea-level rise do to <u>your</u> region?

**Courtesy Jeffrey Bielicki, Kennedy School of Government**

# What can we do?

# 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 <u>some of each</u>.
- What's up for grabs is the future <u>mix.</u>
- Minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation <u>and</u> 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.

# Key mitigation realities

- Human $CO_2$ emissions are the biggest piece of the problem (50% and growing)
  - About 80% comes from burning coal, oil, & natural gas (which provide >80% of world energy)
  - Most of the rest comes from deforestation & burning in the tropics
- Industrialized & developing countries are now about equal in total $CO_2$ emissions.
- Global energy system can't be changed quickly: ~$15T is invested in it; normal turnover is ~40 yrs.
- Deforestation also isn't easy to change: forces driving it are deeply embedded in the economics of food, fuel, timber, trade, & development.

# 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

# 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 are “win-win”:  They’d make sense in any case.

# How much mitigation is needed, how soon?

- The UN Framework Convention on Climate Change of 1992 -- “the law of the land” in 191 countries -- 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 concen-trations will produce it.

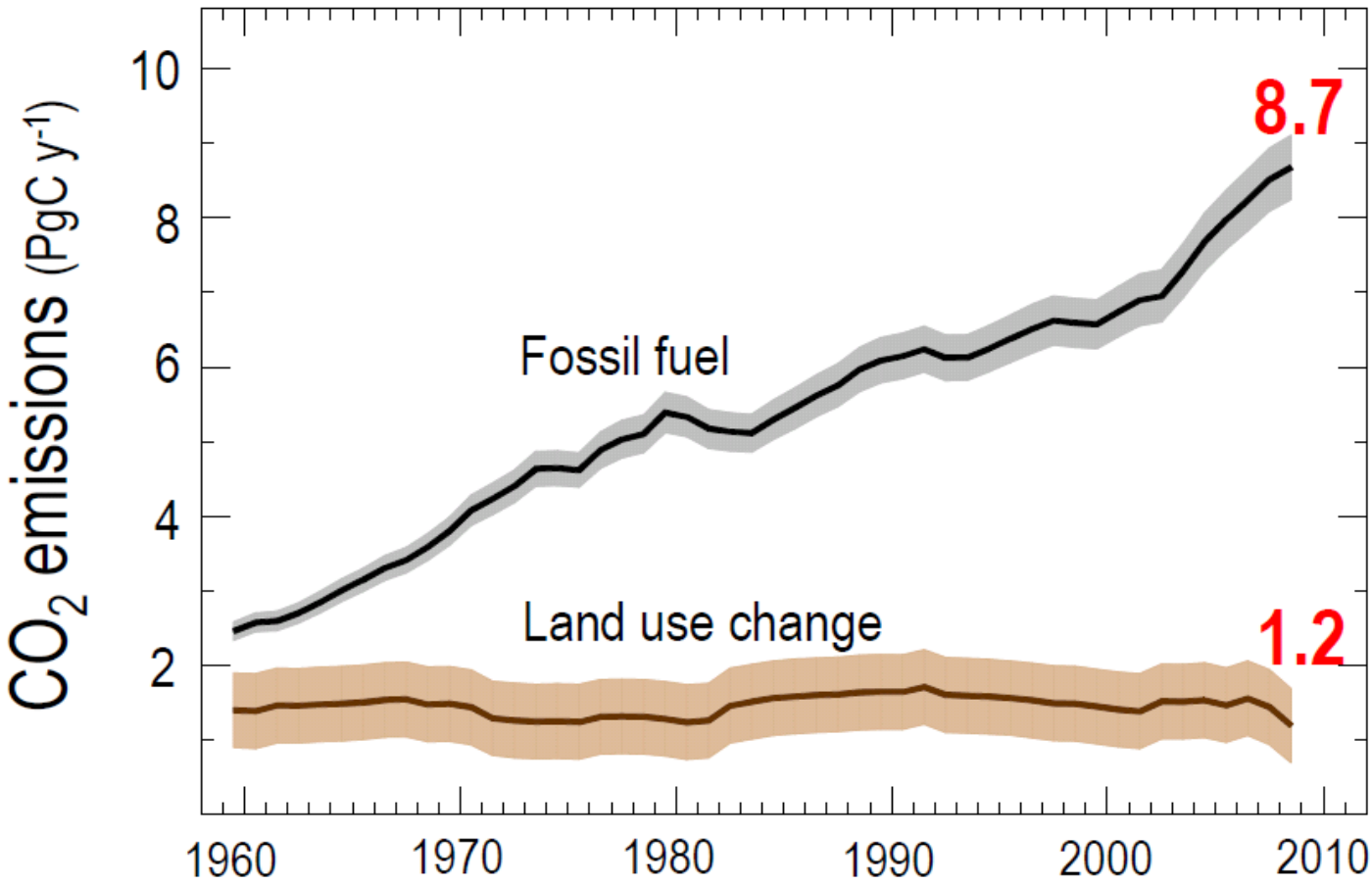
# How much, how soon? (continued)

- There's still no "official" consensus, but clearly the current level of interference is dangerous.
- Question now is, can we avoid unmanageable interference?
  - $T_{avg}$ would rise ~0.5°C more (to ~1.3ºC above pre-industrial) even if concentrations were stabilized today.
  - Potential "tipping points" into catastrophic change multiply for • $T_{avg}$ • 1.5ºC above pre-industrial, e.g.
    - rapid ice-sheet disintegration and sea-level rise
    - drastic alteration of ocean circulation & fisheries
    - huge drought & pest impacts on agriculture, forests
    - methane outpouring from warming northern soils

# How much, how soon? (continued)

- Limiting • $T_{avg}$ to • 2ºC is now considered by many the most prudent target that's still attainable.
  - EU embraced this target in 2002, G-8 in 2009
- For 50% chance of • $T_{avg}$• 2ºC, <u>sum</u> of human influences ($CO_2$, other GHG, and atmospheric particulate matter) must be stabilized at a level equivalent to 450 ppm of $CO_2$ ("450 ppm $CO_2$-e").
  - In 2005 we were at 380 ppm $CO_2$ and 430 ppm $CO_2$-e from all GHG combined.
  - Effects of particles (warming from some, cooling from others) added up to a net negative 50 ppm $CO_2$-e, so total human influence in 2005 was 430 – 50 = 380 ppm $CO_2$-e.

# The mitigation challenge: recent trends in $CO_2$ emissions

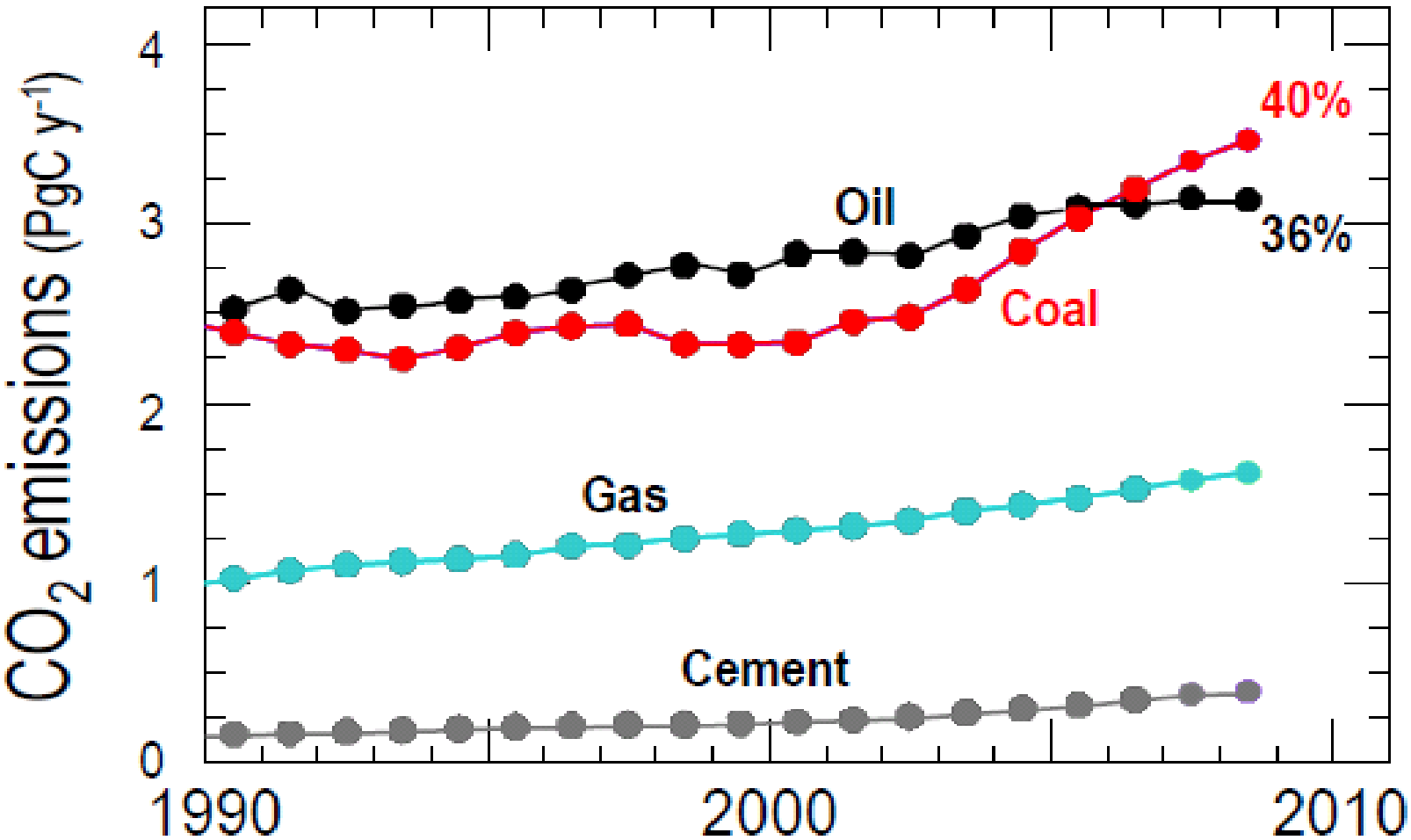


9.9 PgC

12% of total anthropogenic emissions

Global Carbon Project 2009

# The mitigation challenge: trends in $CO_2$ emissions from fossil fuels & cement




Global Carbon Project 2009

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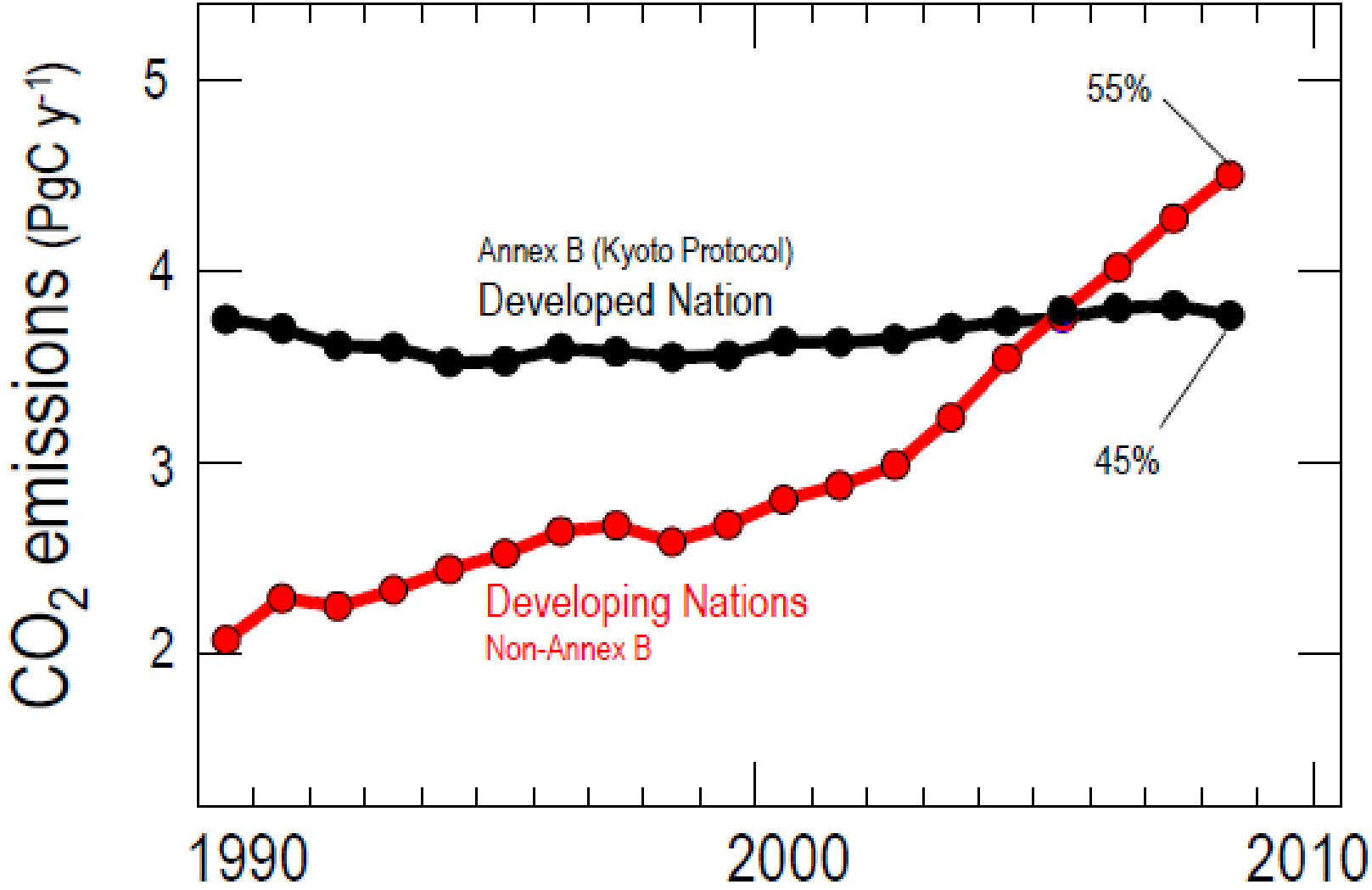
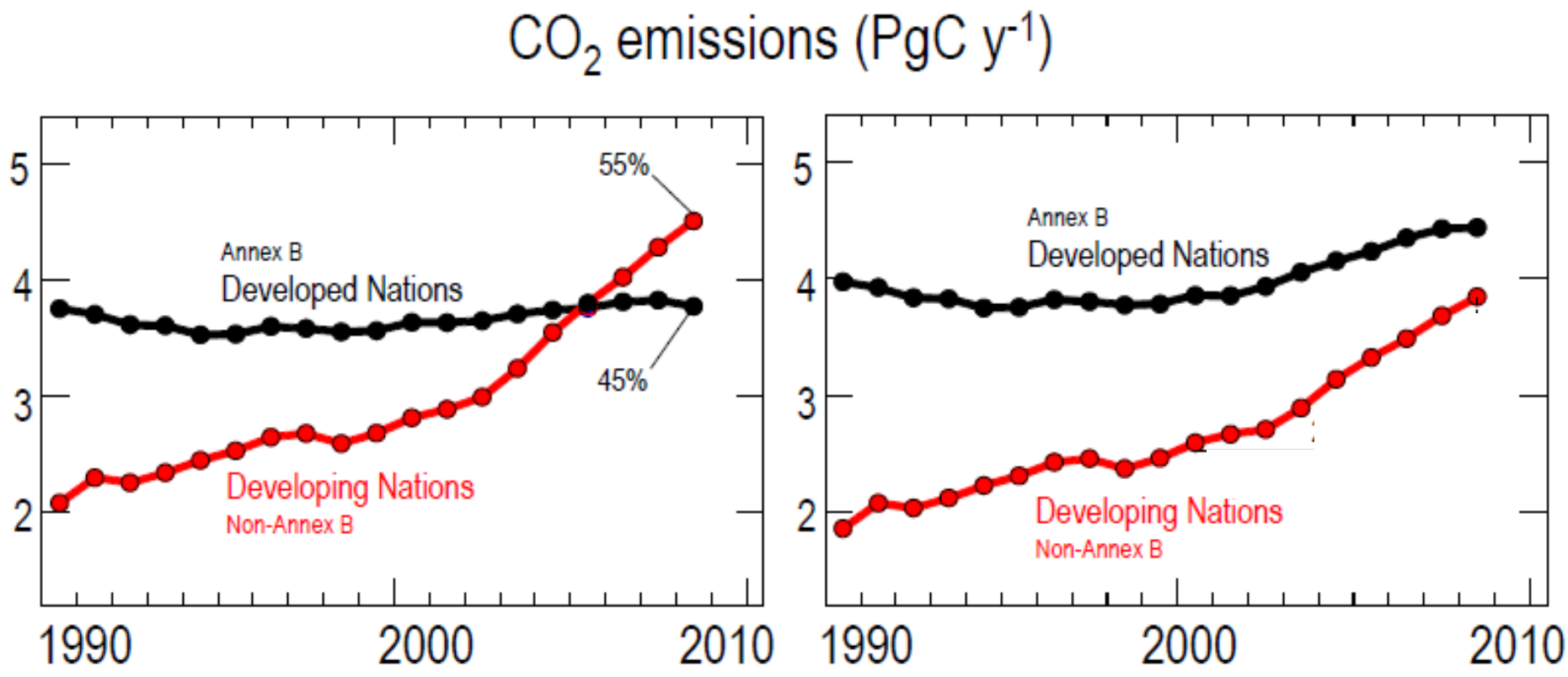



Global Carbon Project 2009

# Attribution of fossil-fuel $CO_2$ emissions

**By location of fuel use (left) and accounting for "embodied emissions" in internationally traded goods (right)**



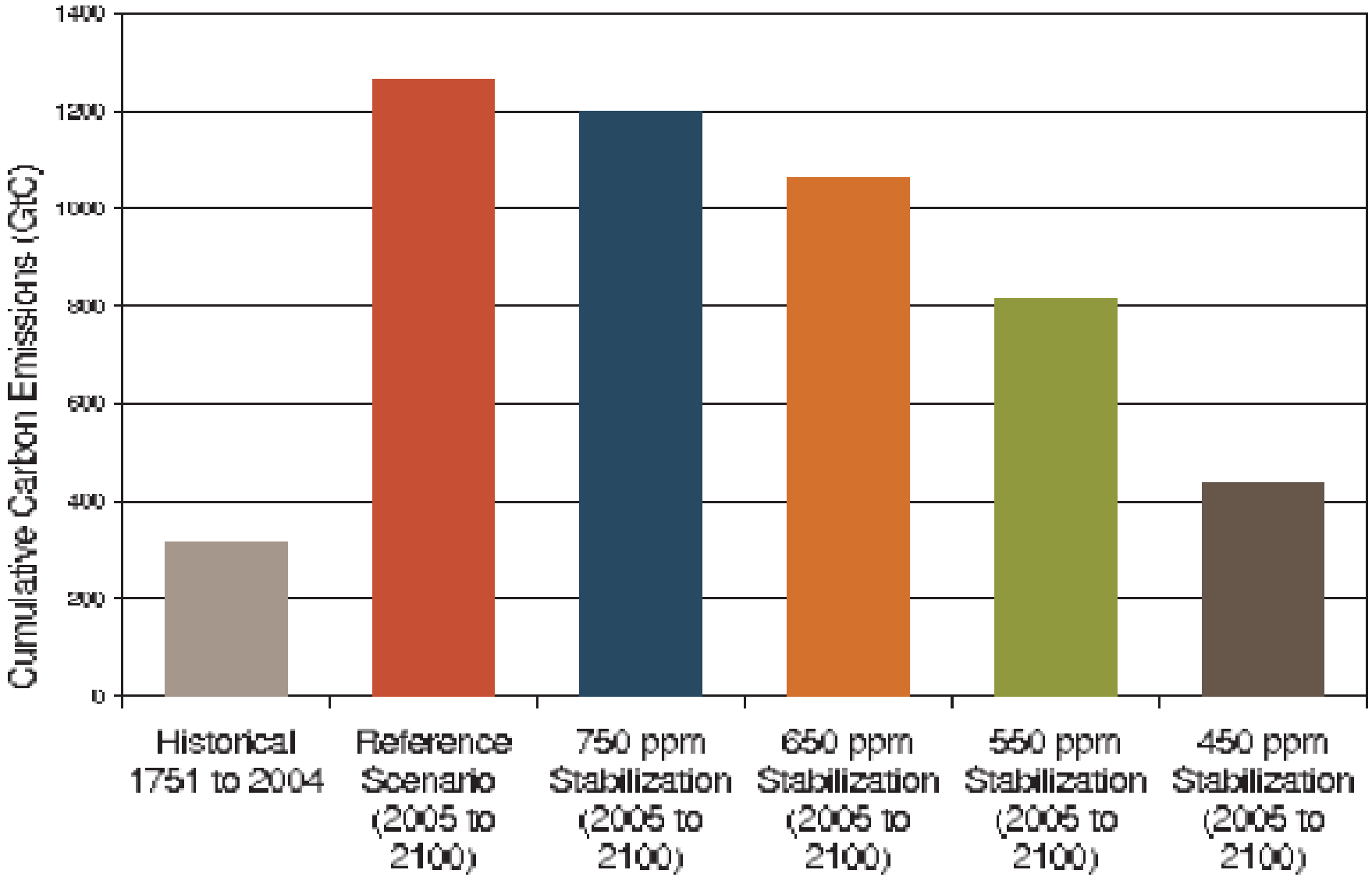

Global Carbon Project 2009

# The mitigation challenge: energy and fossil $CO_2$ in 2008

| | population (millions) | ppp-GDP (trillion $) | energy (EJ) | fossil E (percent) | fossil $CO_2$ (MtC) |
|---|---|---|---|---|---|
| **World** | 6692 | 69.7 | 545 | 82% | 8390 |
| **China** | 1326 | 7.9 | 99 | 85% | 1910 |
| **USA** | 304 | 14.2 | 105 | 86% | 1670 |
| **Russia** | 142 | 2.3 | 30 | 91% | 440 |
| **India** | 1140 | 3.4 | 29 | 64% | 390 |

World Bank 2009, BP 2009

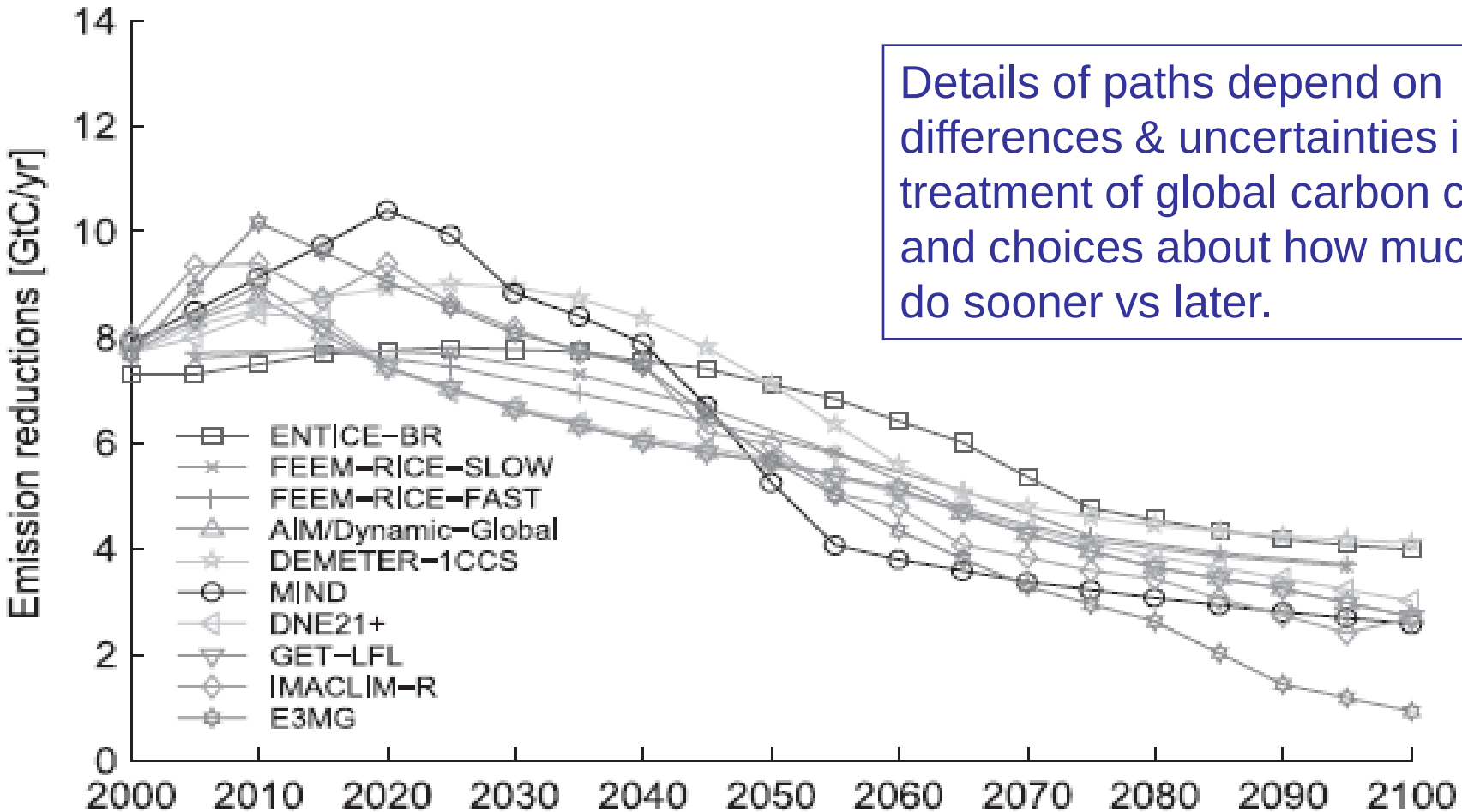
# The mitigation challenge: Cumulative 21st-century carbon emissions for stabilizing the atmosphere




Battelle GTSP 2007

# Global $CO_2$ emissions paths from 2000 that would stabilize concentration at 450 ppm

(50% chance of • T < 2°C if non-$CO_2$ effects cancel)




Details of paths depend on differences & uncertainties in treatment of global carbon cycle and choices about how much to do sooner vs later.

Grubb et al., The Energy Journal, 2006

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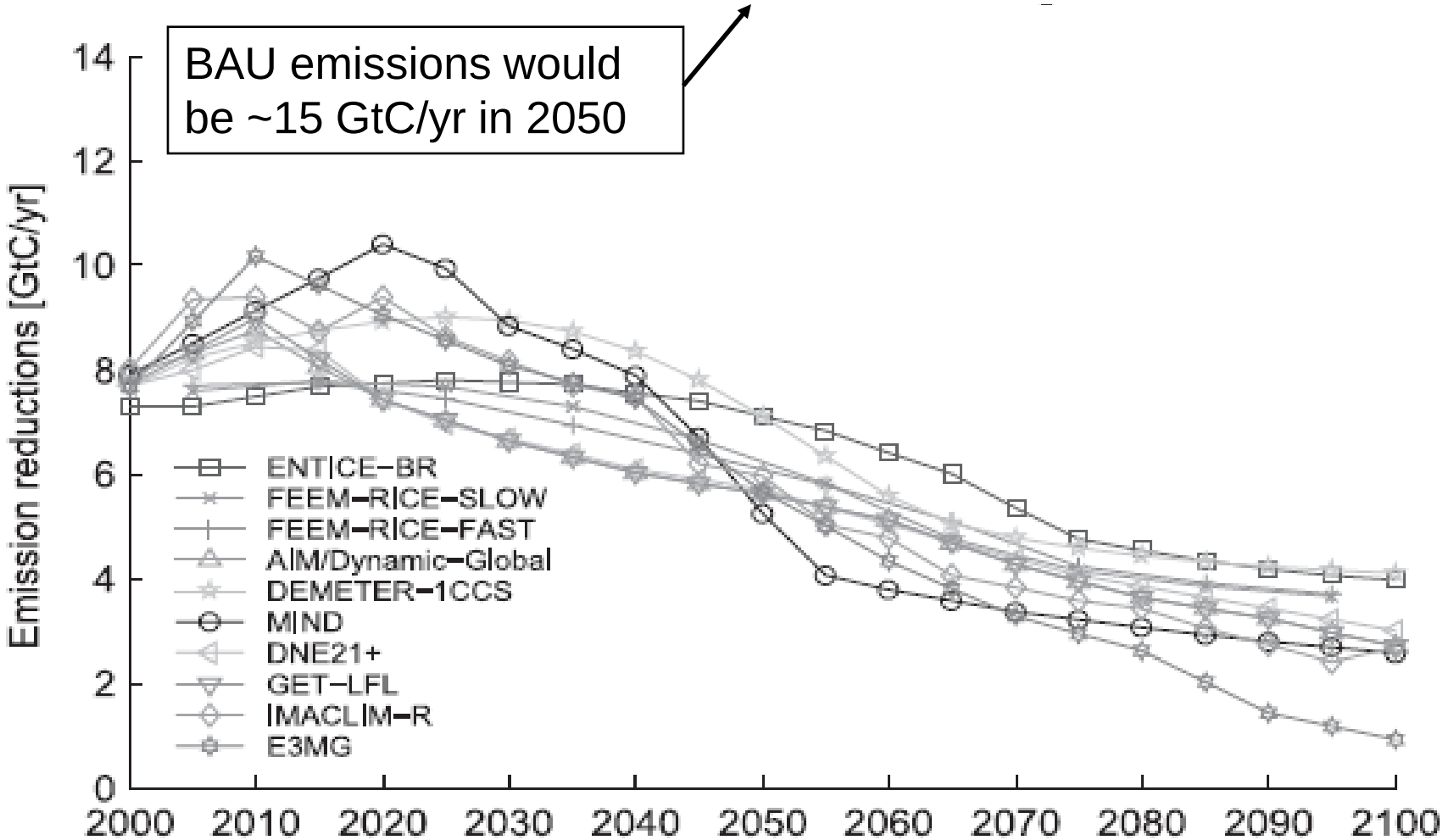


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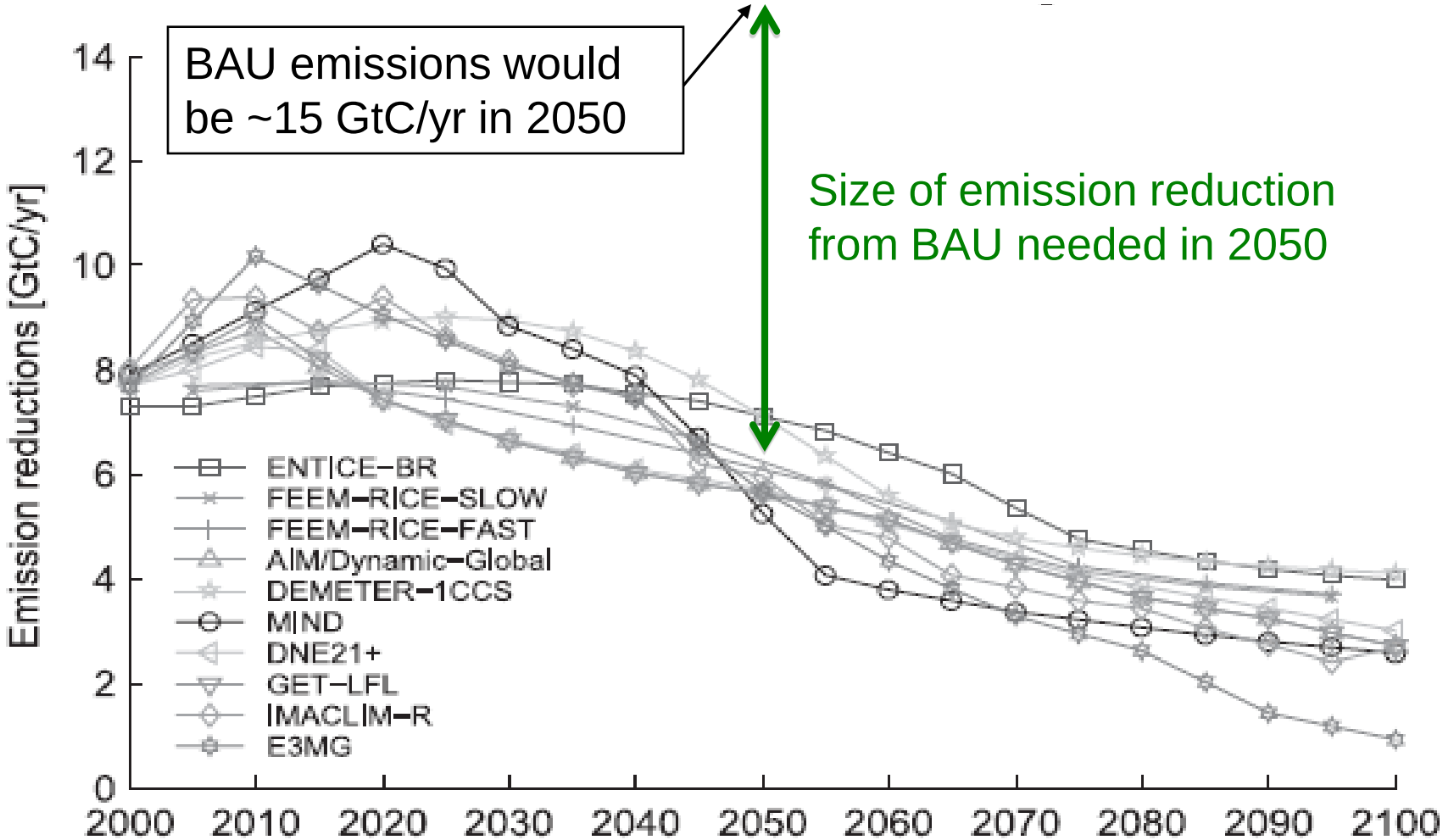



Grubb et al., The Energy Journal, 2006

# Quantitative realities of mitigation

- Stabilizing at 450 ppmv $CO_2$-e means 2050 global $CO_2$ emissions must be at least ~7-9 GtC/yr below BAU.
- Ways to avoid 1 GtC/yr in 2050 include…

- energy use in buildings cut 20-25% below BAU in 2050,
- fuel economy of 2 billion cars ~60 mpg instead of 30,
- carbon capture & storage for 800 1-GWe coal-burning power plants,
- 700 1-GWe nuclear plants replacing coal plants,
- 1 million 2-Mwe-peak wind turbines (or 2,000 1-Gwe-peak photovoltaic power plants) replacing coal power plants

Socolow & Pacala, 2004

# Qualitative realities of mitigation

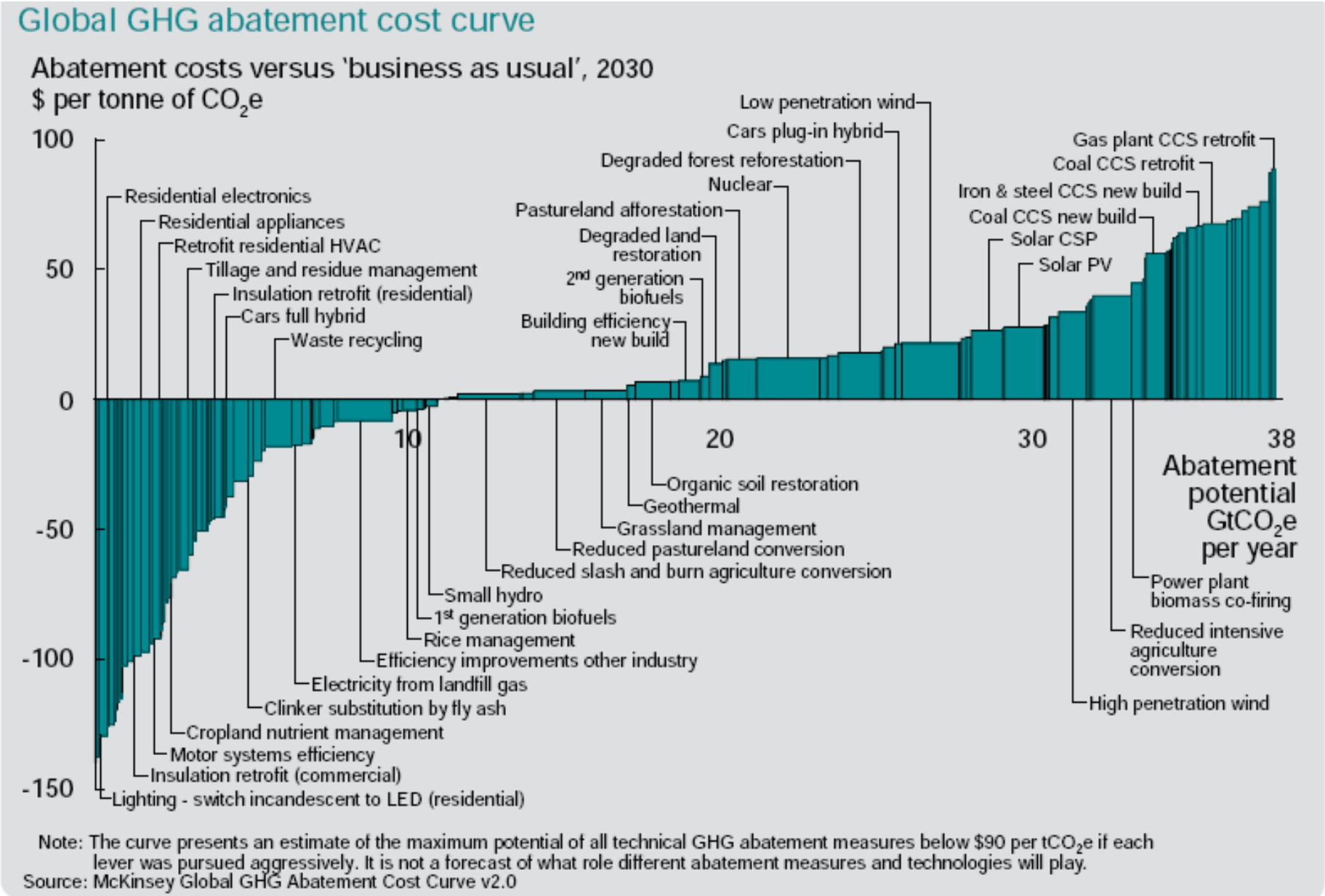
- The cheapest, fastest, cleanest emissions reductions are those available from increasing the efficiency of energy use in buildings, industry, and transport and from reductions in deforestation and forest degradation.

- Efficiency increases are often “win-win”: co-benefits in saved energy, increased domestic jobs, energy security, reduced pollution can offset costs of the measures.

- Supply-side mitigation is also sometimes “win-win”, e.g., cogeneration, wind, some biofuels incl waste-to-energy.

- The “win-win” approaches will not be enough. Adequate mitigation will require putting a price on emissions of GHG to make the costlier reduction options profitable.

# McKinsey GHG abatement *vs* cost for 2030




Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below $90 per $tCO_2e$ if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: McKinsey Global GHG Abatement Cost Curve v2.0

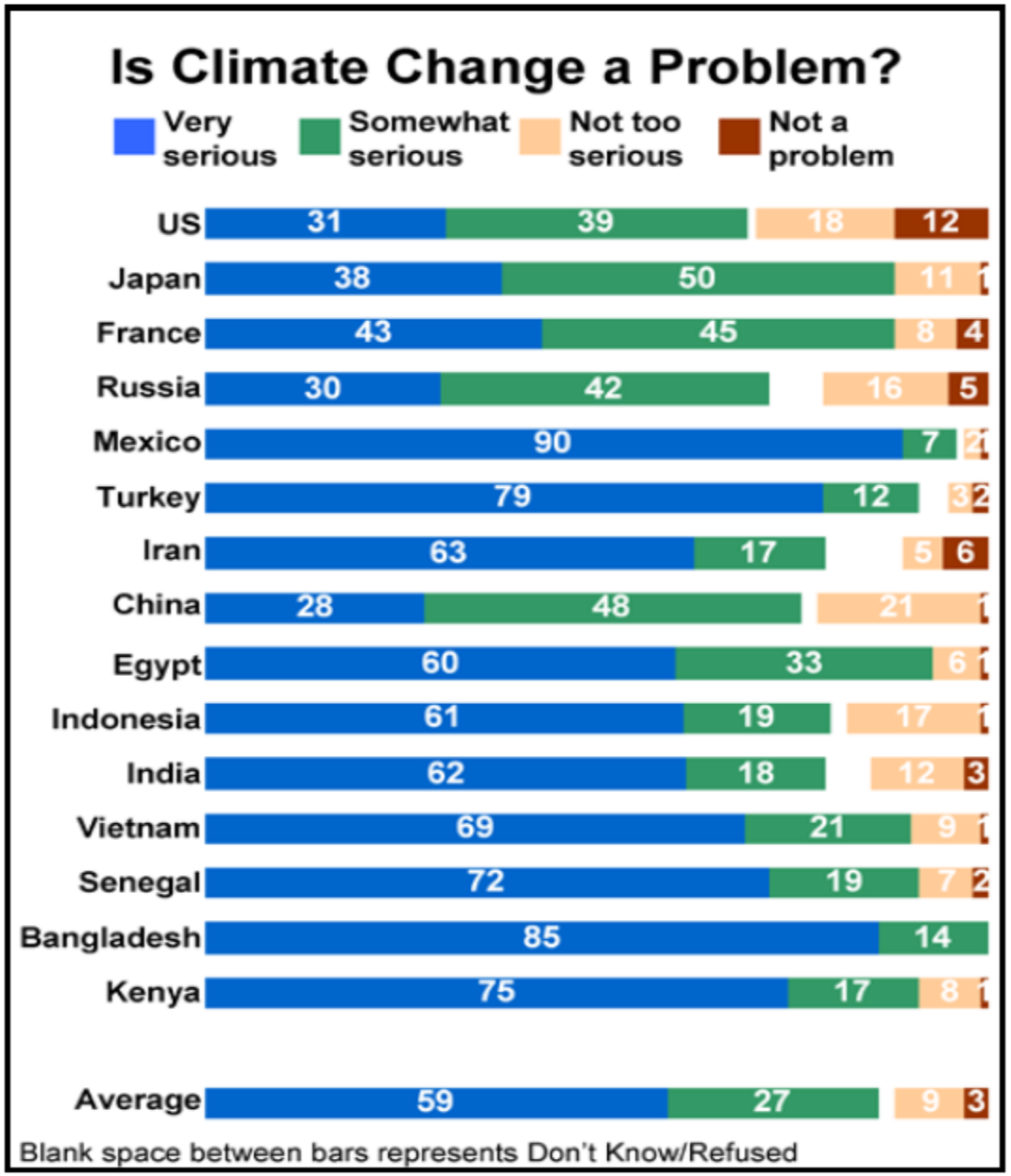
# The Obama administration's approach

- Based on recognition that it isn't "climate change policy versus the economy" but "climate change policy for the economy".
  - costs of action, for the USA and the world, will be far smaller than costs of inaction
  - we can reduce costly and risky oil imports and dangerous air pollution with the same measures we employ to reduce climate-disrupting emissions
  - the surge of innovation we need in clean-energy technologies and energy efficiency will create new businesses & new jobs and help drive economic recovery & growth.

# **Obama administration approach** (continued)

- Work with Congress to get comprehensive energy-climate legislation that will put the USA on the needed emissions trajectory with minimum economic & social cost and maximum co-benefits
- Work with other major emitting countries – industrialized & developing – and the UNFCCC process to build clean-energy technology cooperation + individual & joint climate policies consistent with “avoiding the unmanageable”
- Develop adaptation strategies and capacities domestically and internationally to “manage the unavoidable”.

# Can we get it done? Polls say "Yes, we can."




World Bank, 2009

# References


**Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis. Summary for Policy Makers.* February 2007.** http://www.ipcc.ch/SPM2feb07.pdf

**UN Scientific Expert Group on Climate Change & Sustainable Development, *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, United Nations Foundation, February 2007** http://www.unfoundation.org/SEG/

**Intergovernmental Panel on Climate Change, Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability, Summary for Policy Makers. April 2007.** http://www.ipcc.ch/

**World Bank, *World Development Report 2010: Climate Change and Development*, Nov 2009.** http://www.worldbank.org/wdr2010

**UNSW Climate Change Research Centre, *The Copenhagen Diagnosis: Updating the World on the Latest Climate Science*, Nov 2009.** http://www.copenhagendiagnosis.org

**Global Carbon Project Consortium, *Carbon Budget 2008*, Nov 2009.** http://www.globalcarbonproject.org