Meeting the Energy-Climate Challenge

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The essence of the challenge

- Without energy there is no economy
- Without climate there is no environment
- Without economy <u>and</u> environment there is no material well-being, no civil society, no personal or national security

Alas, the world is getting most of the energy its economies need in ways that are wrecking the climate its environment needs.

Climate change is <u>not</u> just "global warming"

That term implies something…

- uniform across the planet,
- mainly about temperature,
- gradual,
- quite possibly benign.

What's actually happening is…

- highly nonuniform,
- not just about temperature,
- rapid compared to capacities for adjustment
- harmful for most places and times

We should call it "global climate disruption".

Why average temperature isn't everything

Climate = weather patterns, meaning averages, extremes, timing, spatial distribution of…

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

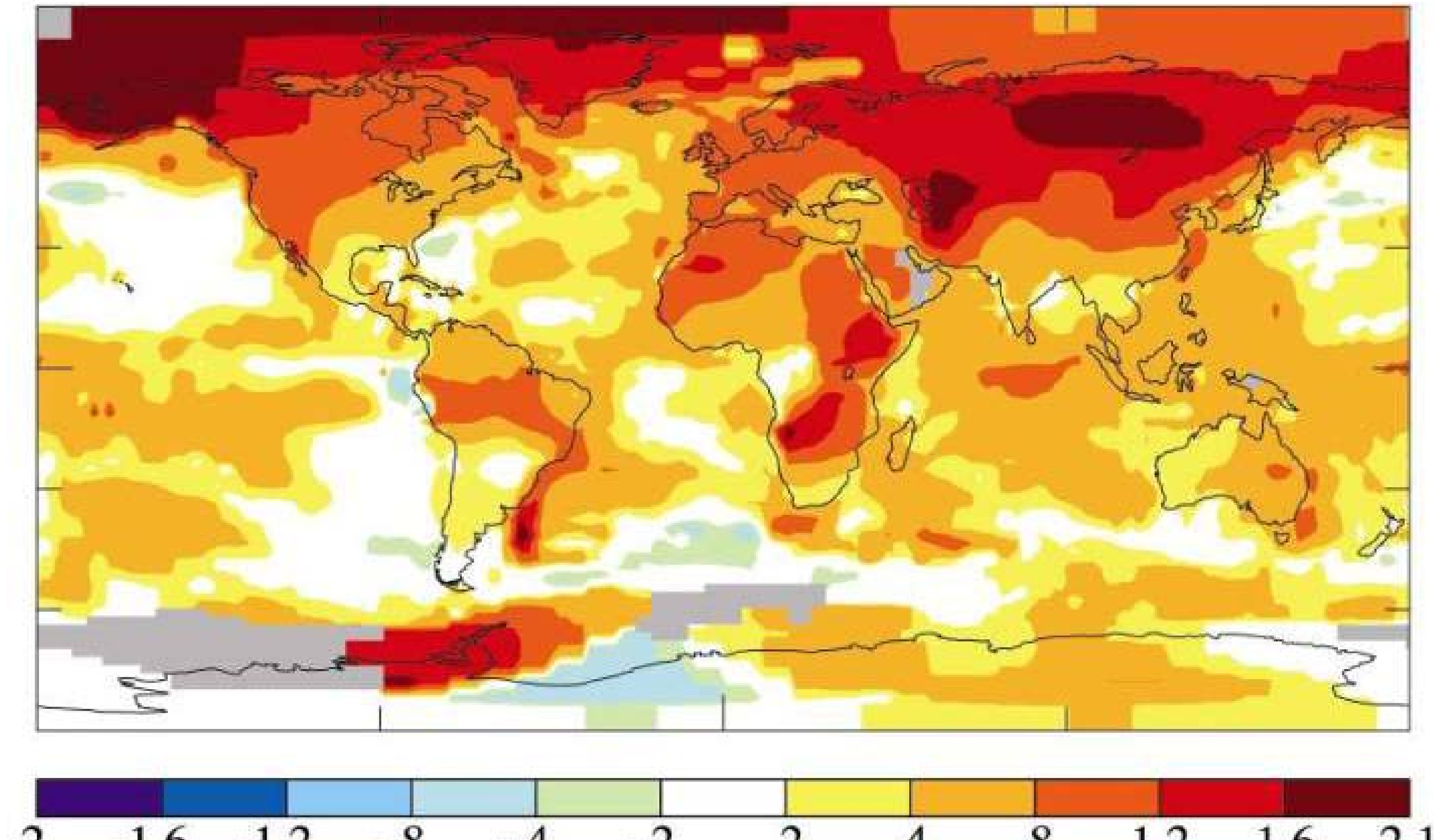
Climate change means disruption of the patterns.

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.

Spatial distribution: highly uneven heating

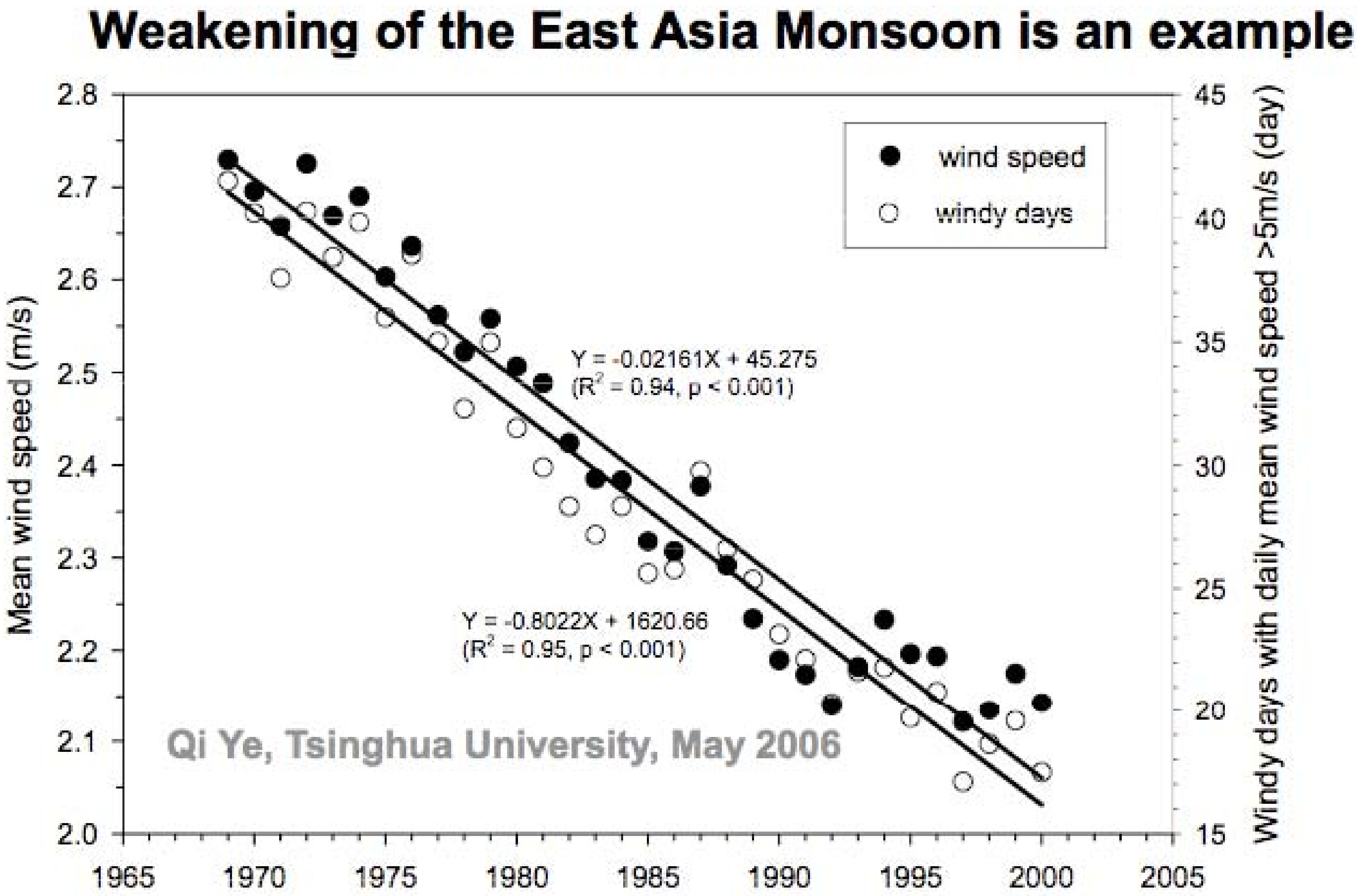
(Biggest ΔTs are in far North & Antarctic peninsula)

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



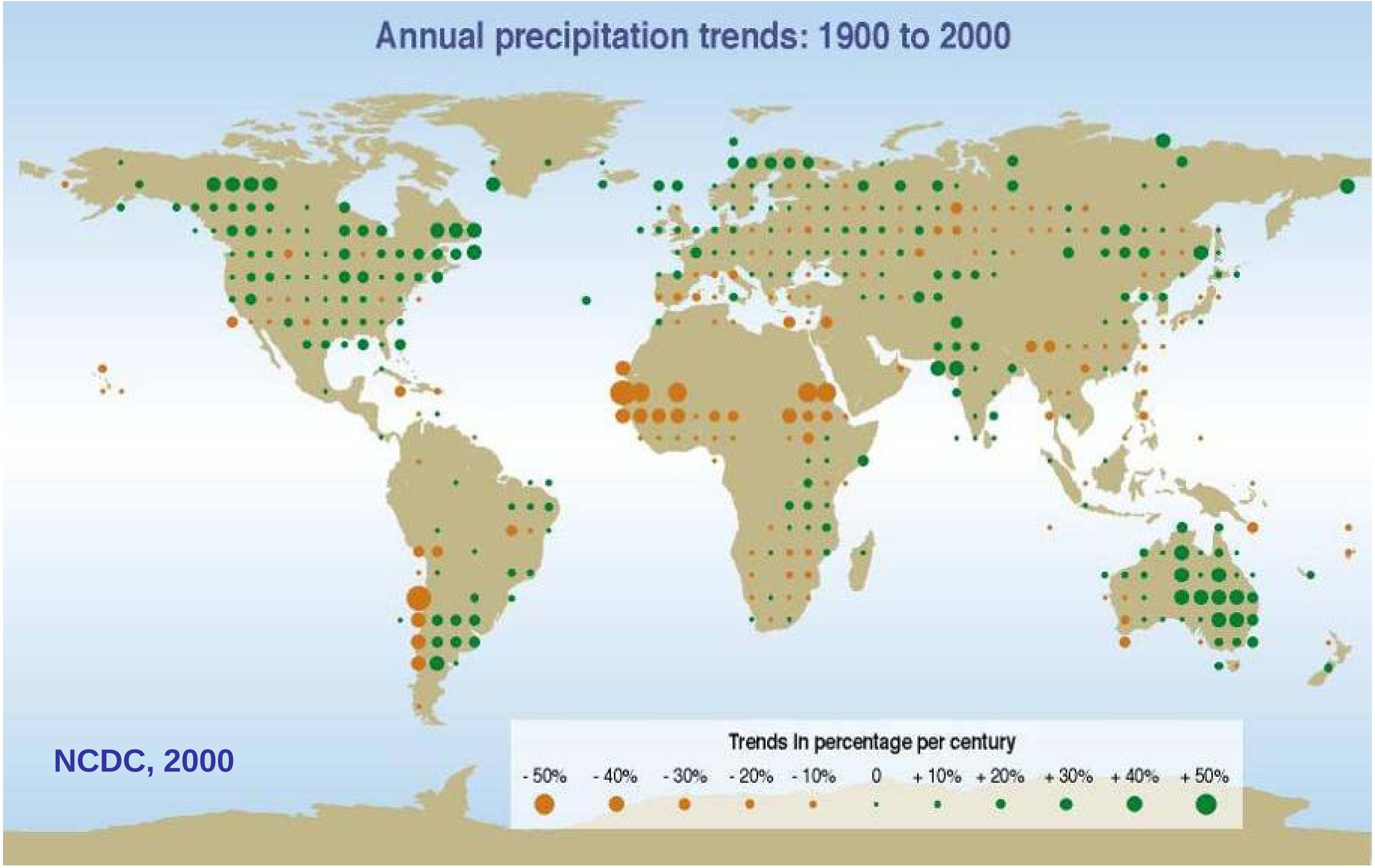
J. Hansen et al., *PNAS 103*: 14288-293 (2006)

Uneven heating changes wind patterns…



The observations match model predictions, by Chinese researchers, for greenhouse-gas-driven disruption.

…and precipitation patterns



Global average is an increase, but some places are getting drier.

What's at risk?

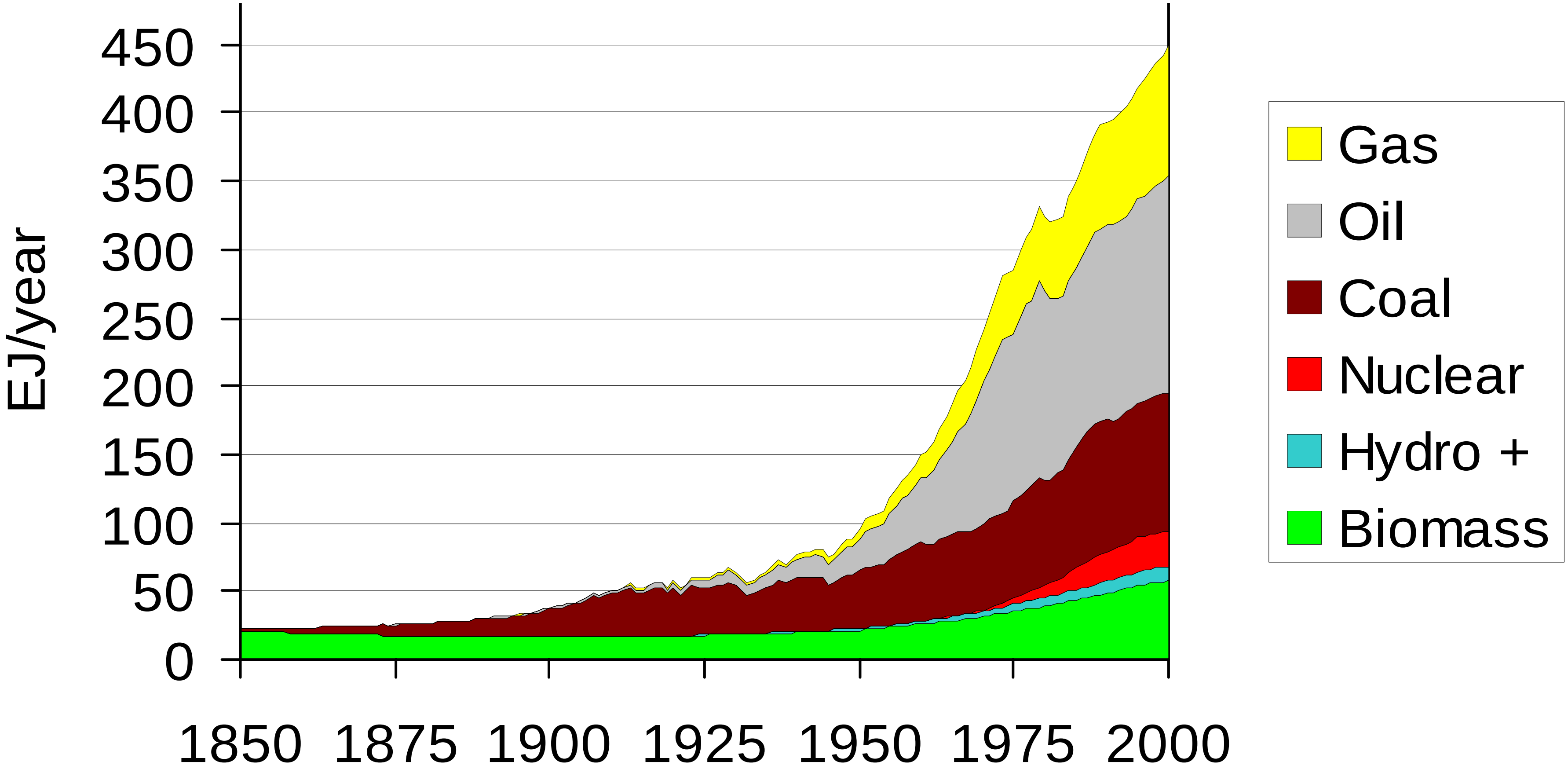
Climate governs (so climate disruption affects)

- 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 rest of the story

- How we got where we are
- Where we're headed
- Current climate-science understanding of ...
  - what's already happening
  - what's likely to happen absent a course change
- The options going forward
  - adaptation
  - mitigation
- The Obama Administration's strategy

How we got here: Growth of world population & prosperity 1850-2000 → 20-fold growth in energy, nearly all of it from fossil fuels



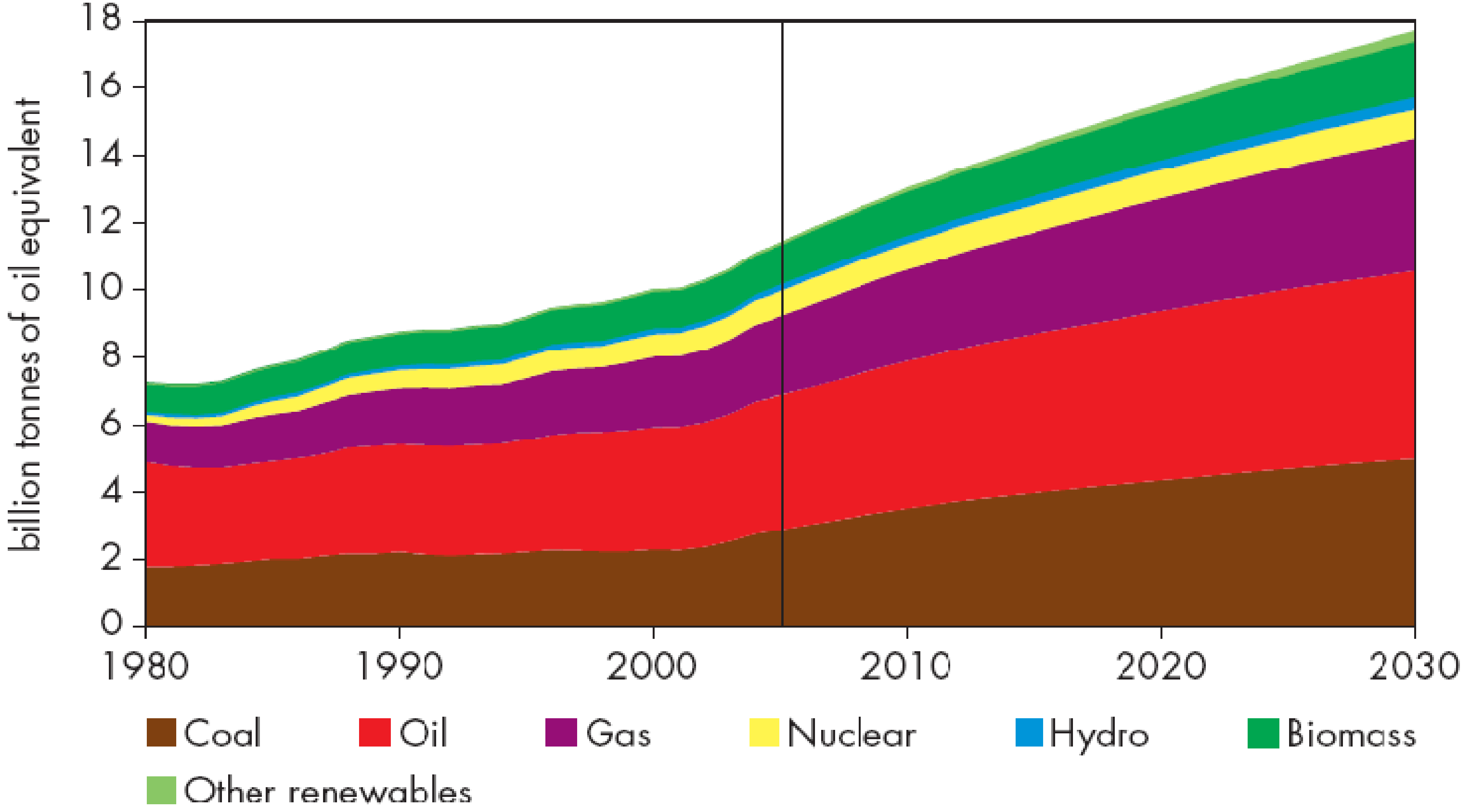
Growth rate 1850-1950 was 1.45%/yr, driven mainly by coal.
From 1950-2000 it was 3.15%/yr, driven mainly by oil & natural gas.

Where we are: 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

Where we're headed: continued high growth & continued dominance of fossil & biomass fuels



WEO 2007

What's wrong with this picture?

- Reasons to want to change course include
  - rising US oil imports, increasing internat'l competition for oil → economic, nat'l security liabilities;
  - conventional air pollution, water pollution, and eco-system impacts from fossil-fuel harvesting & use;
  - impacts of current biofuels approaches (woodstoves, corn ethanol) on health, ecosystems, food supply
- But most compelling reason -- requiring fastest, biggest course change -- is dominant contribution of energy system to global climate-disruption.

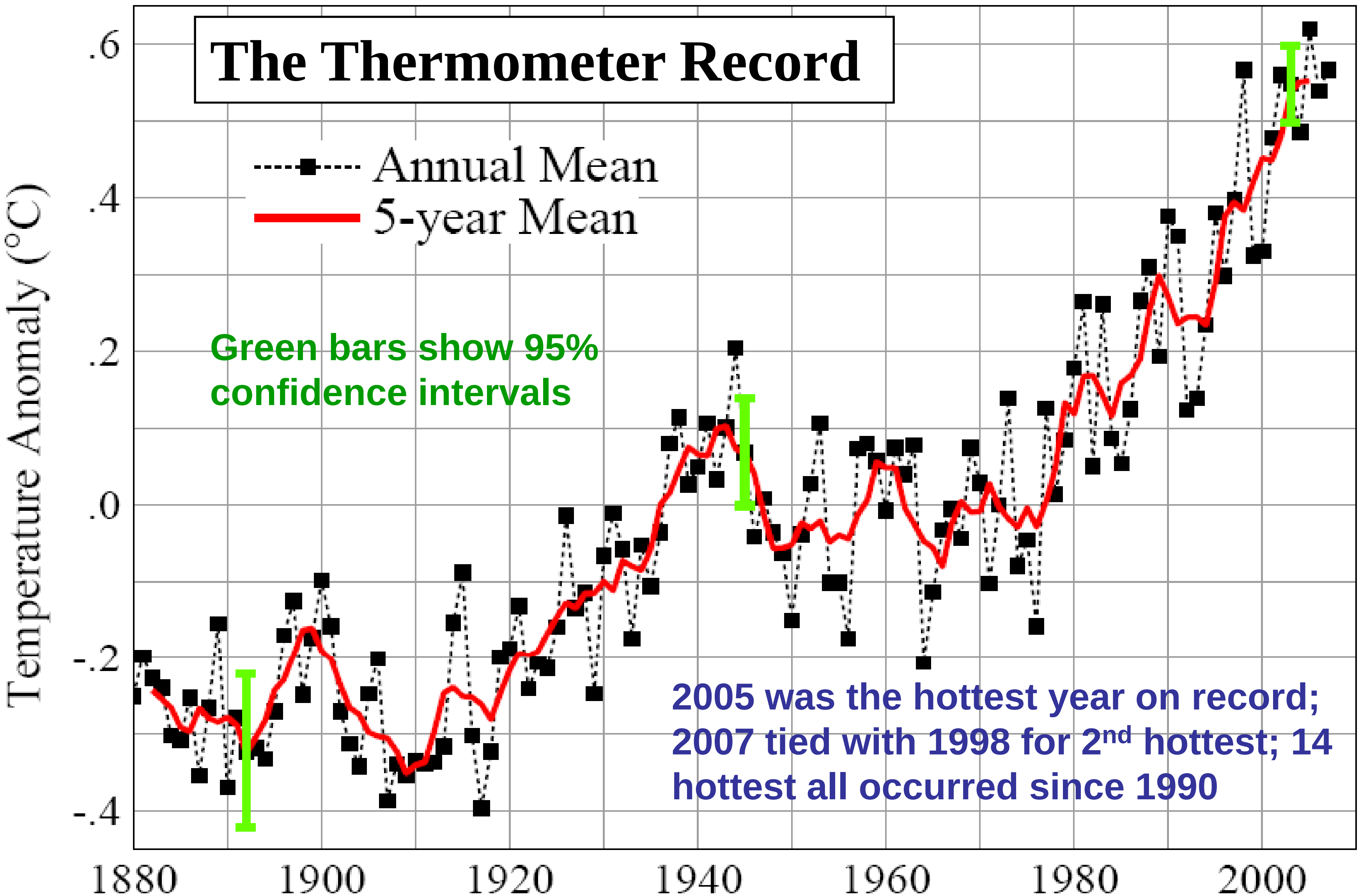
Energy accounts for ~70% of global emissions of the heat-trapping gases & particles wrecking the climate

Climate Science

What's happening?

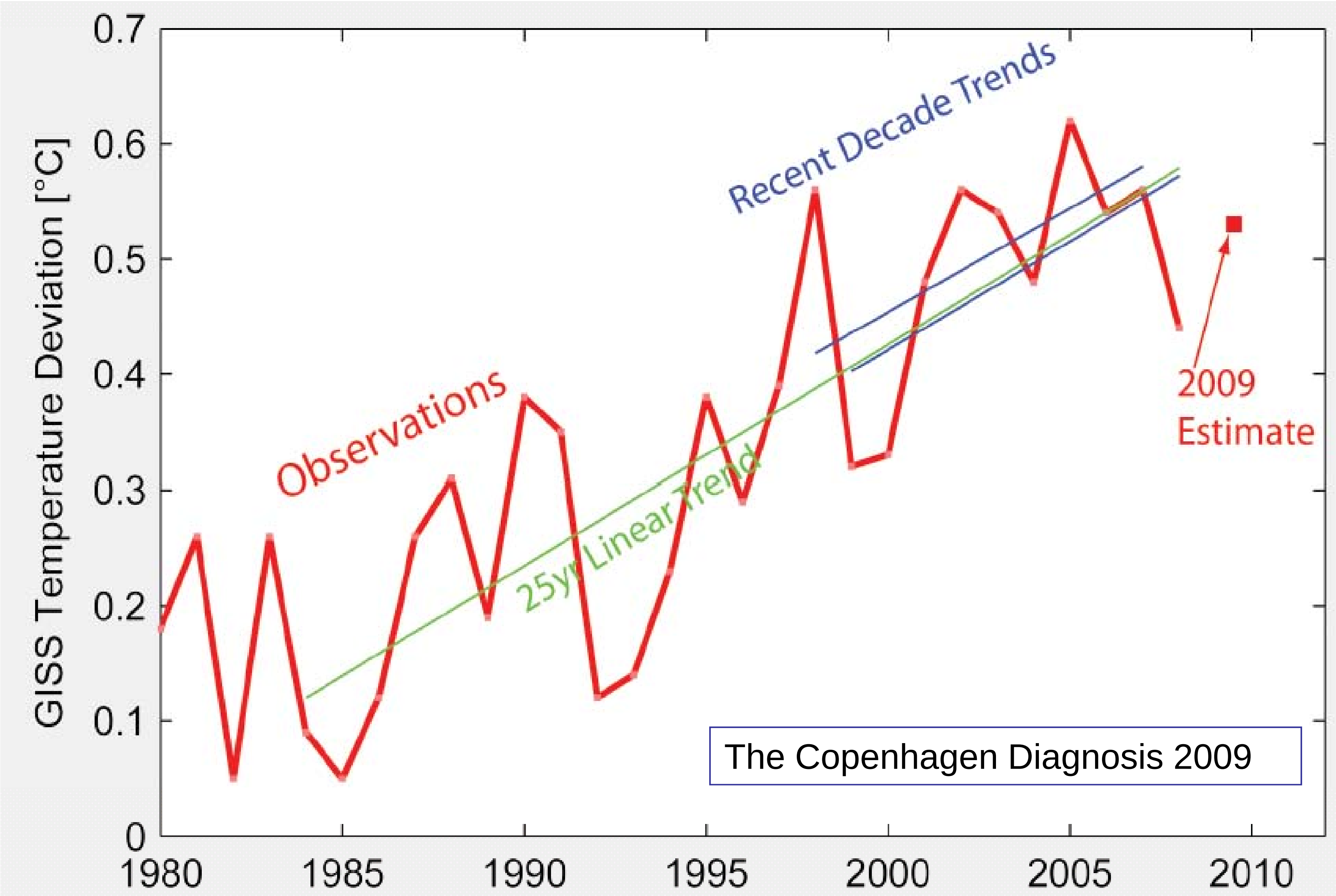
What's likely to happen absent remedial action?

What's happening: the Earth is getting hotter



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

The rate of heating is not slowing down



Other indicators are tracking temperatures: retreating glaciers

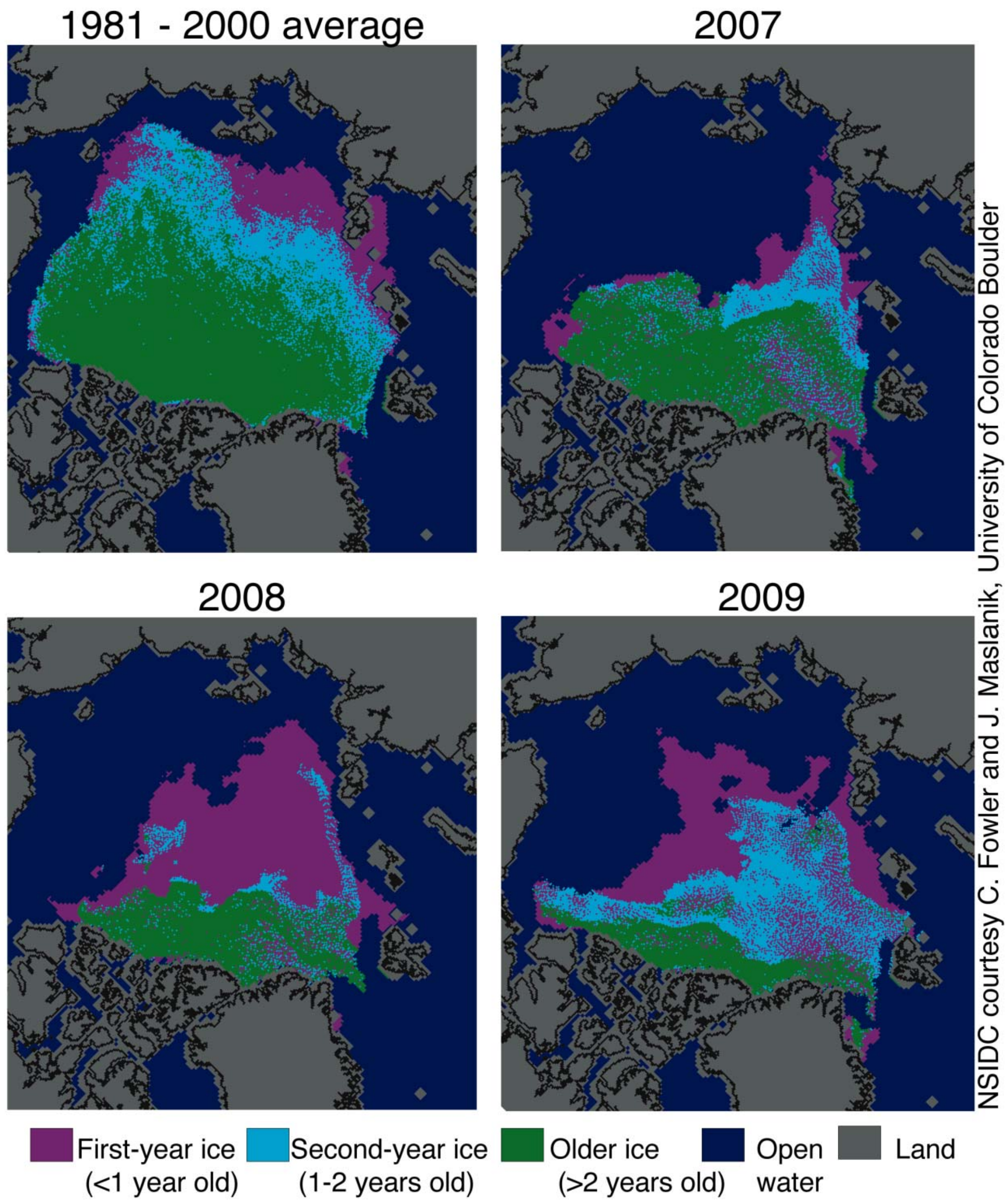
Muir Glacier, Alaska

August 1941

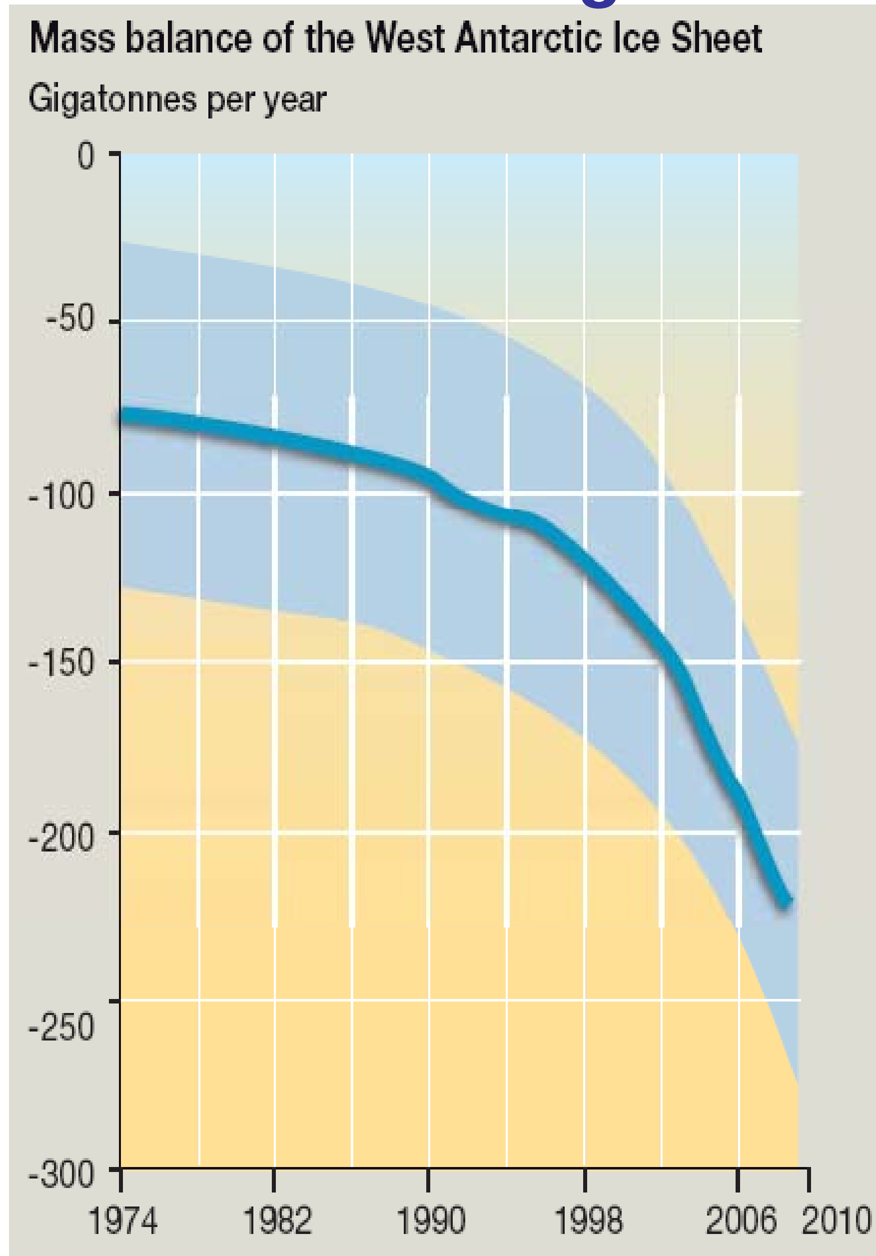
August 2004

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

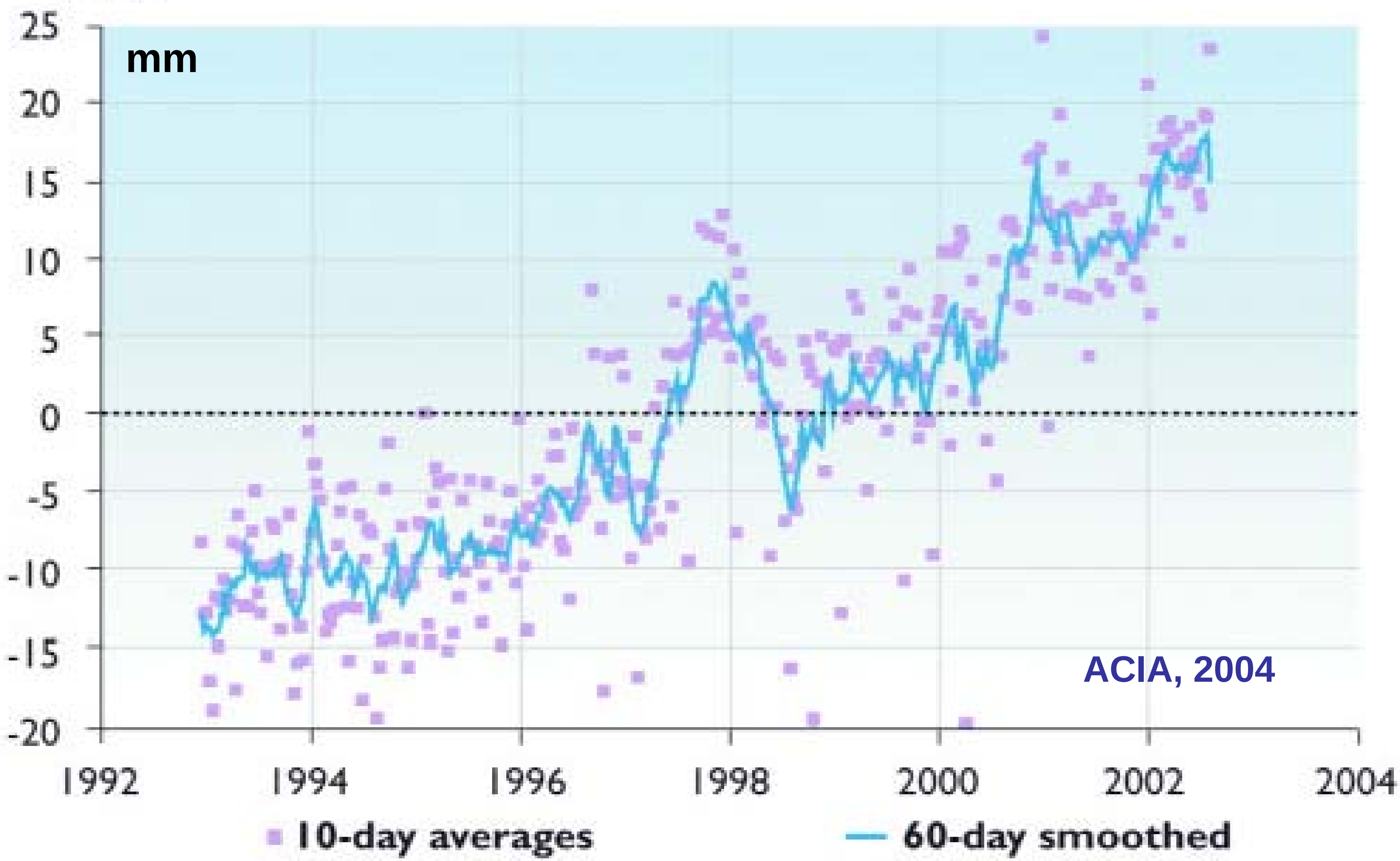


Indicators: Greenland & Antarctic ice losing mass



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/m²)

Human emissions leading to increases in…	
atmospheric carbon dioxide	+ 1.7
methane, nitrous oxide, CFCs	+ 1.0
absorptive particles (soot)	+ 0.4
net ozone (troposphere↑, stratosphere↓)	+ 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

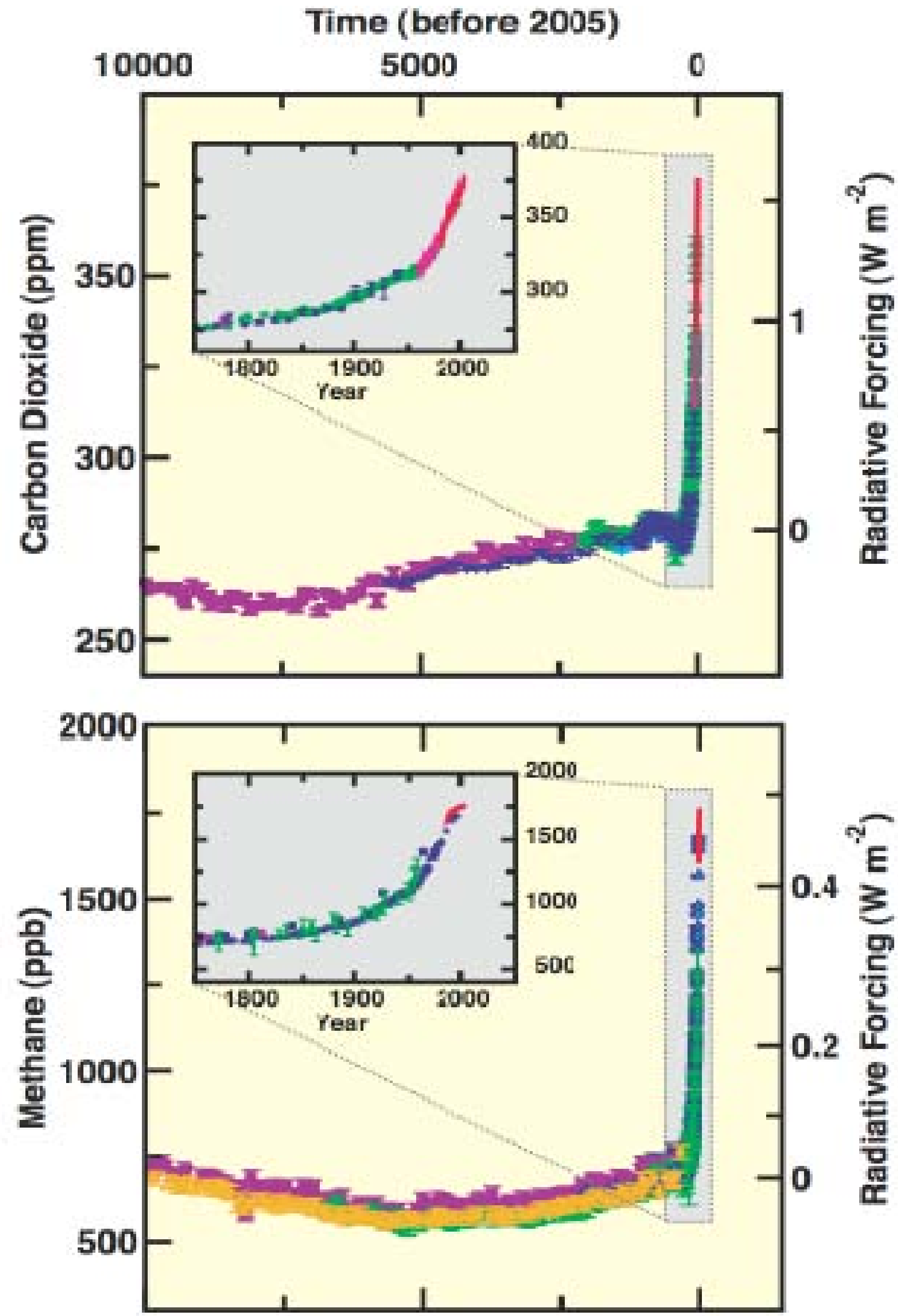
The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

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.

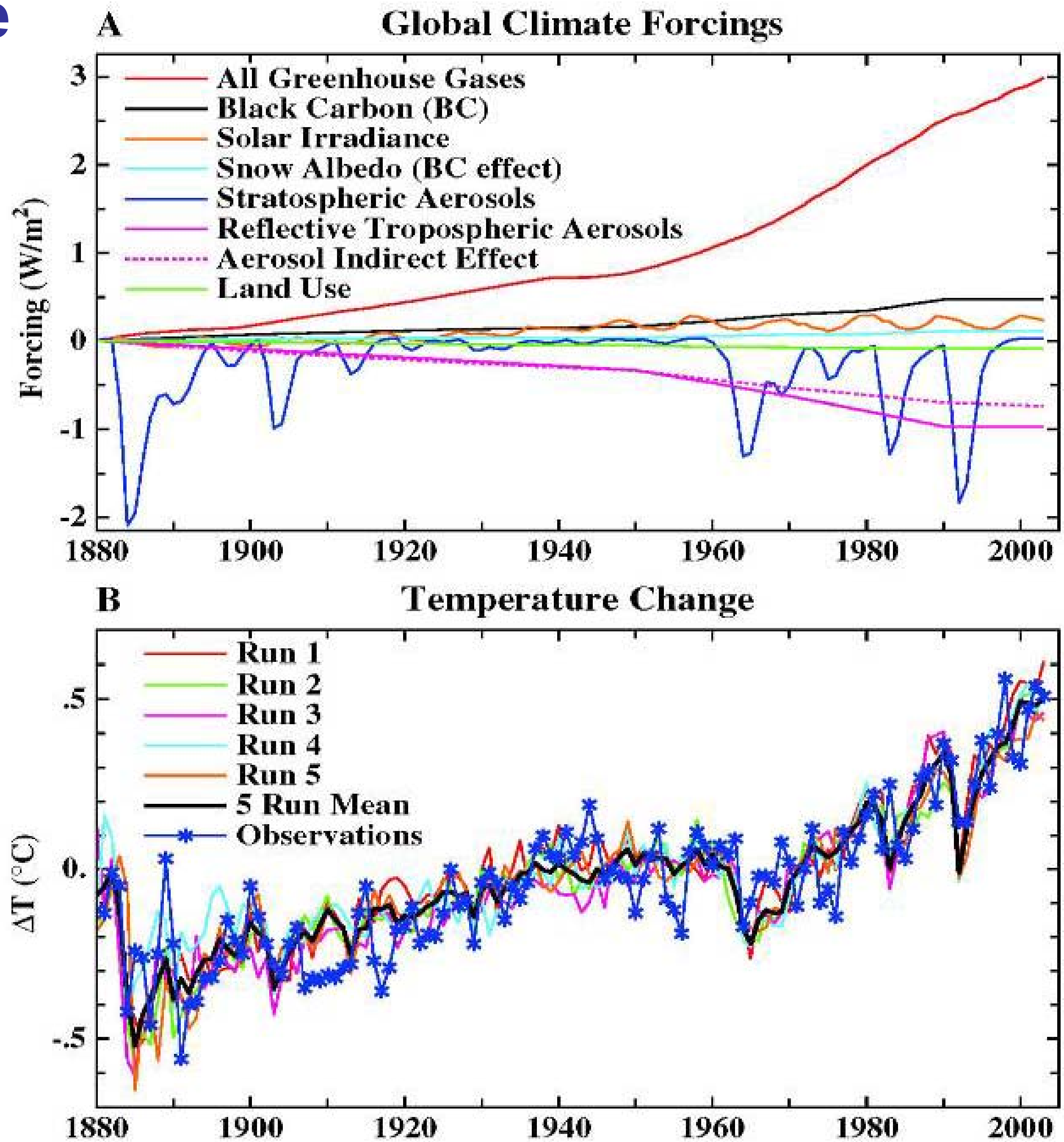


IPCC AR4, WG1 SPM, 2007

Human role: the "fingerprint"

Top panel: Best estimates of human & natural forcings 1880-2005.

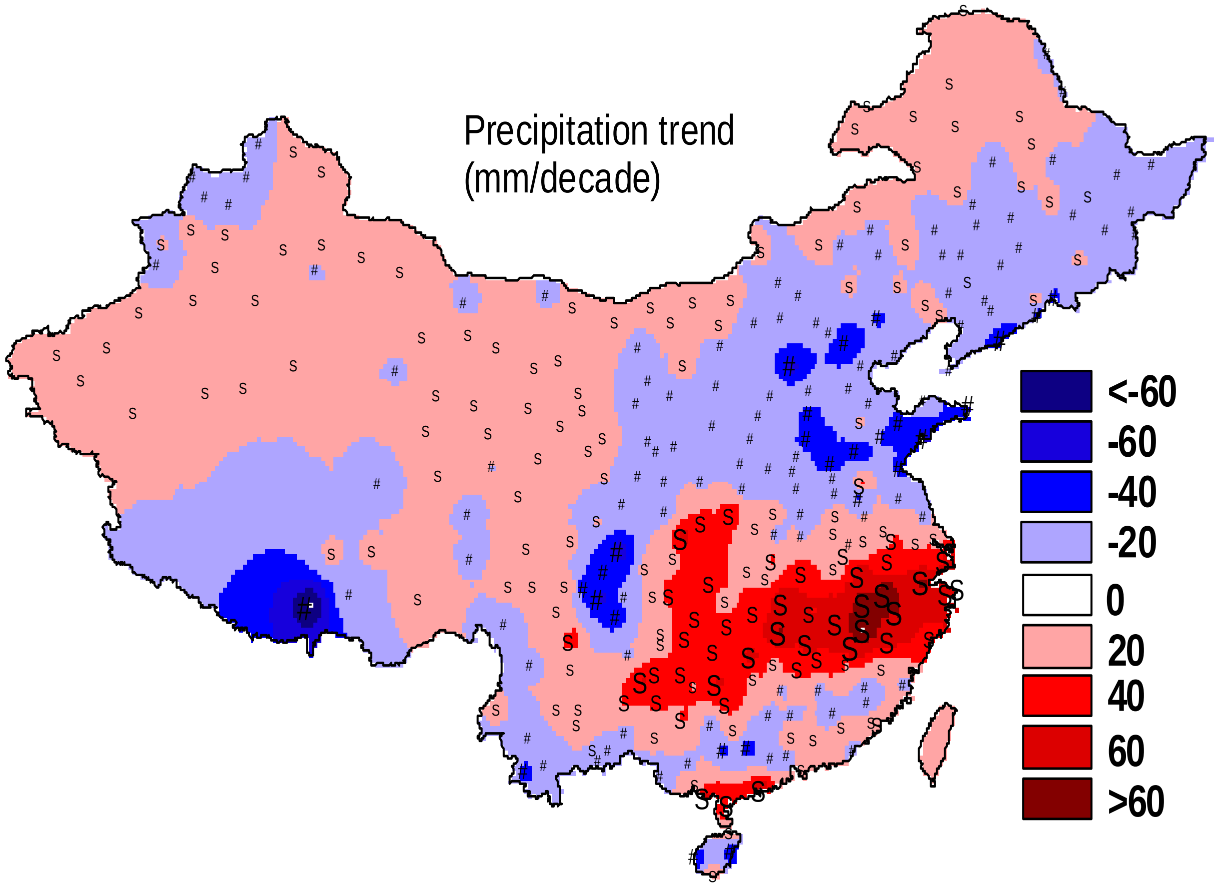
Bottom panel: <u>State-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.</u>



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

Harm is already occurring: floods & droughts

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

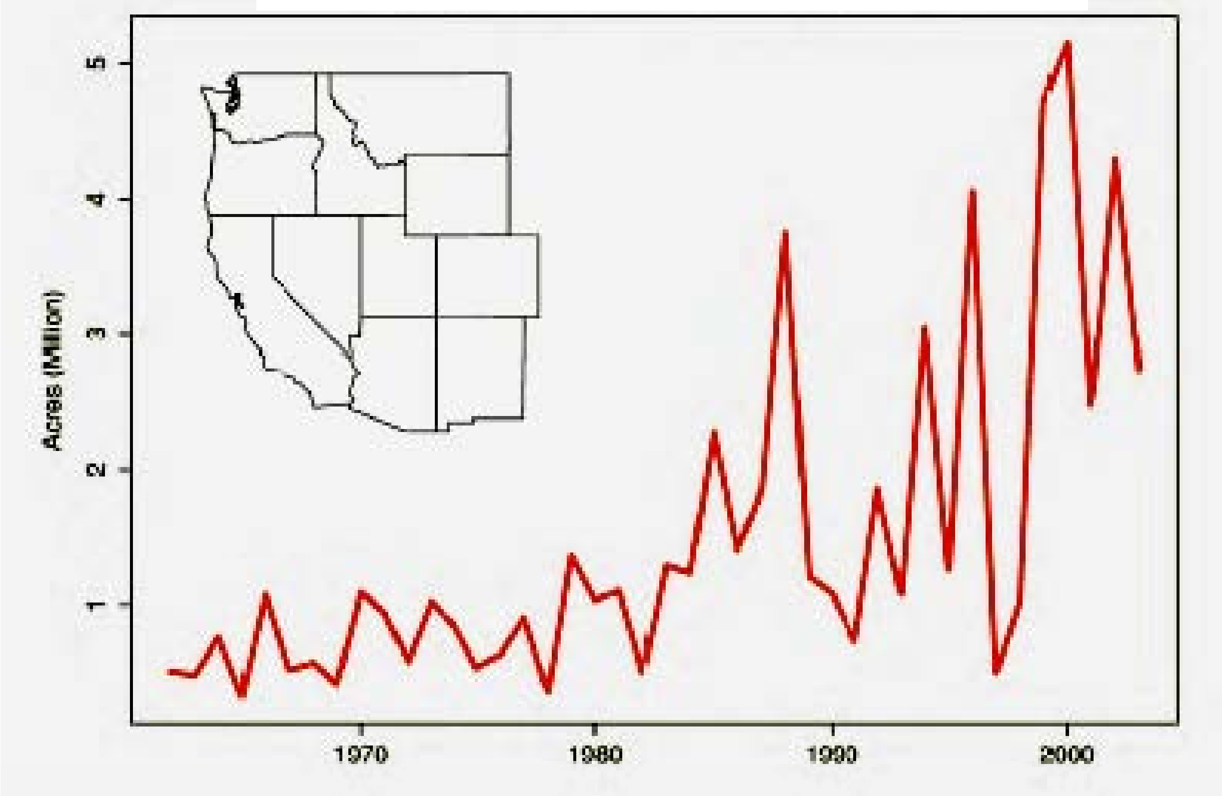


Qi Ye, Tsinghua University, May 2006

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.

Western US area burned



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

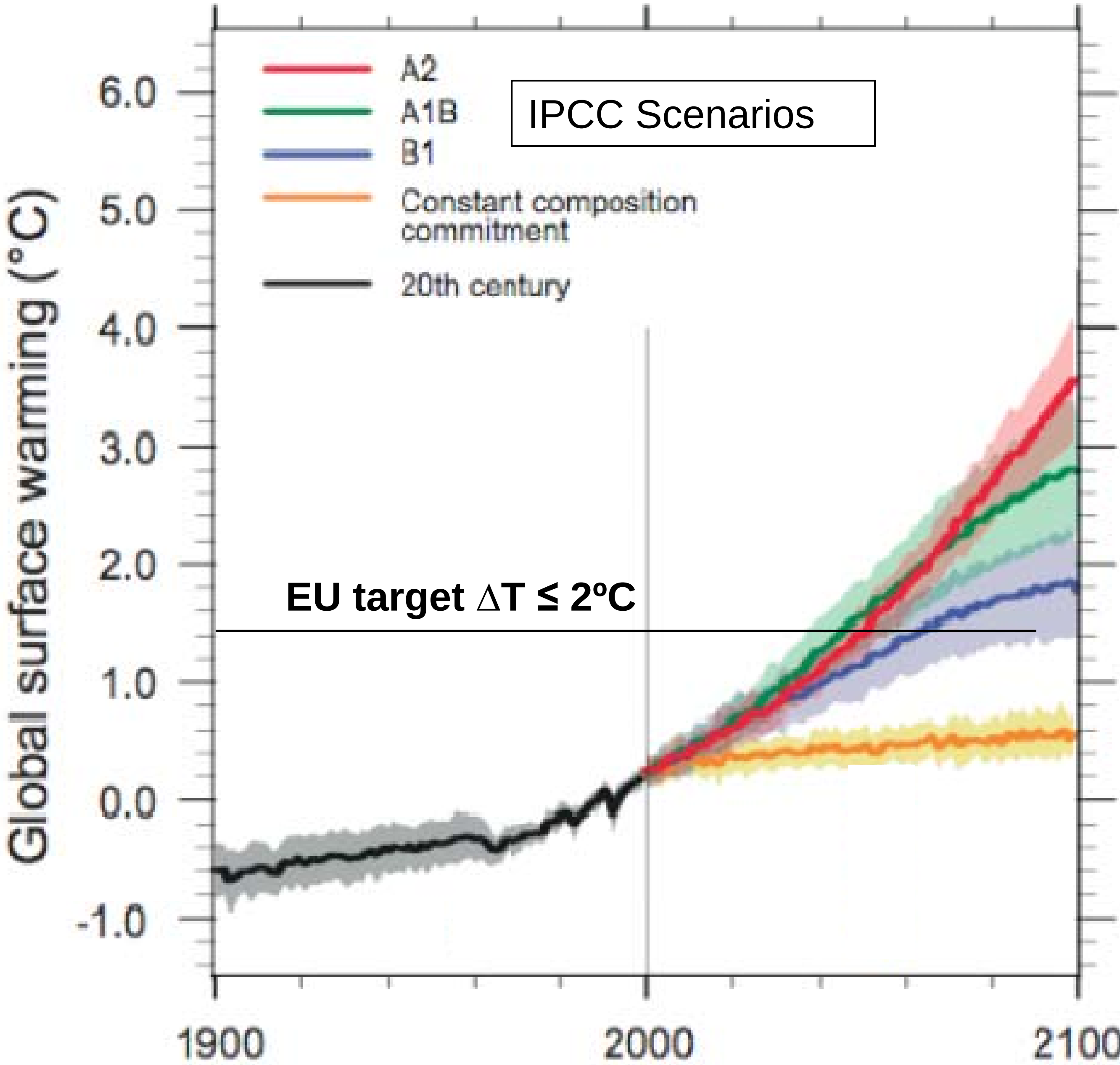
Harm is already occurring widely

Worldwide we're seeing, variously, increases in

- floods
- wildfires
- droughts
- heat waves
- pest outbreaks
- coral bleaching events
- power of typhoons & hurricanes
- geographic range of tropical pathogens

All plausibly linked to climate change by theory, models, observed "fingerprints"

Science: What's likely absent a course change



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

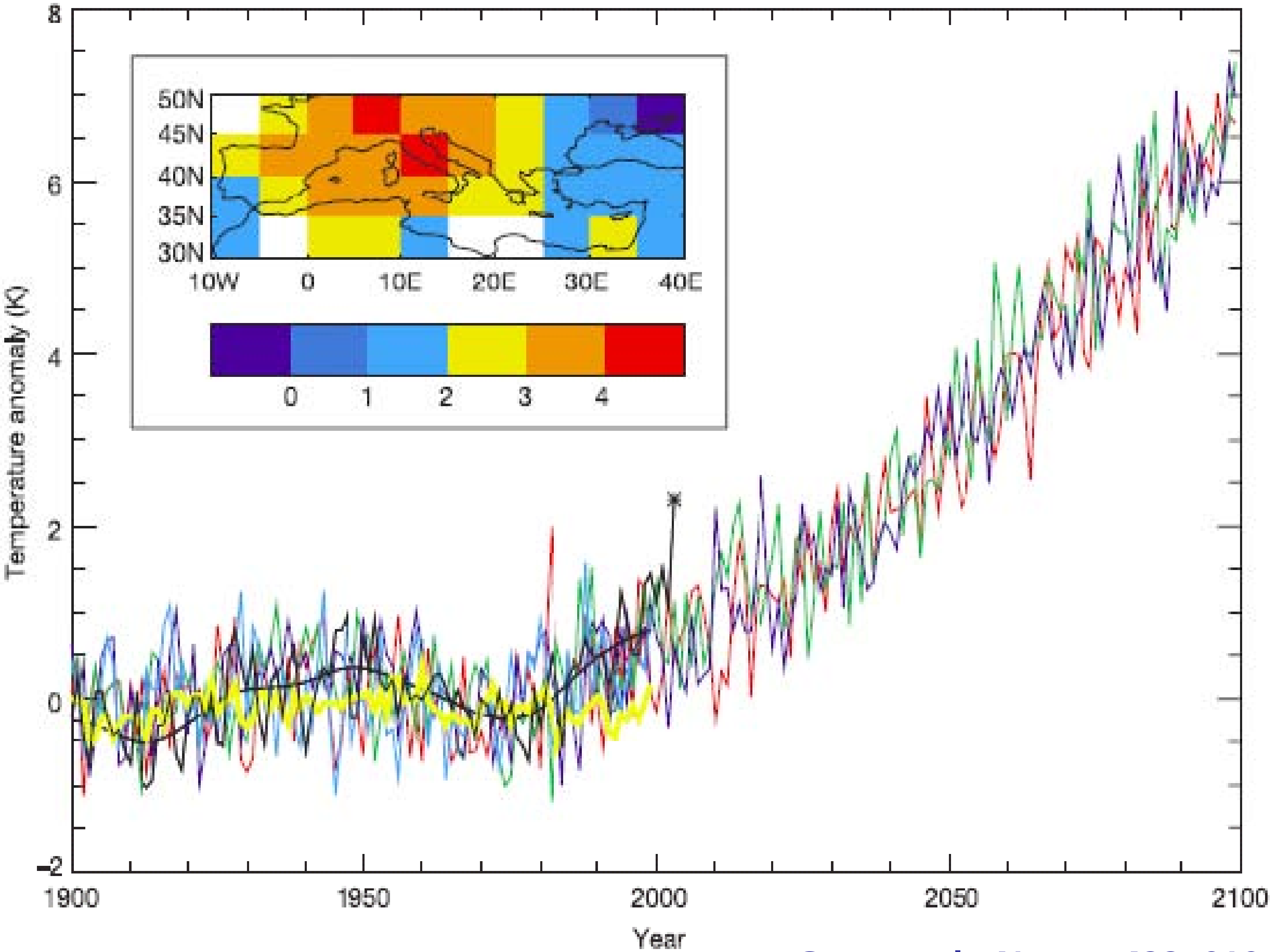
Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

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

IPCC 2007

What's likely: Worse 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)

What's likely: falling crop yields

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

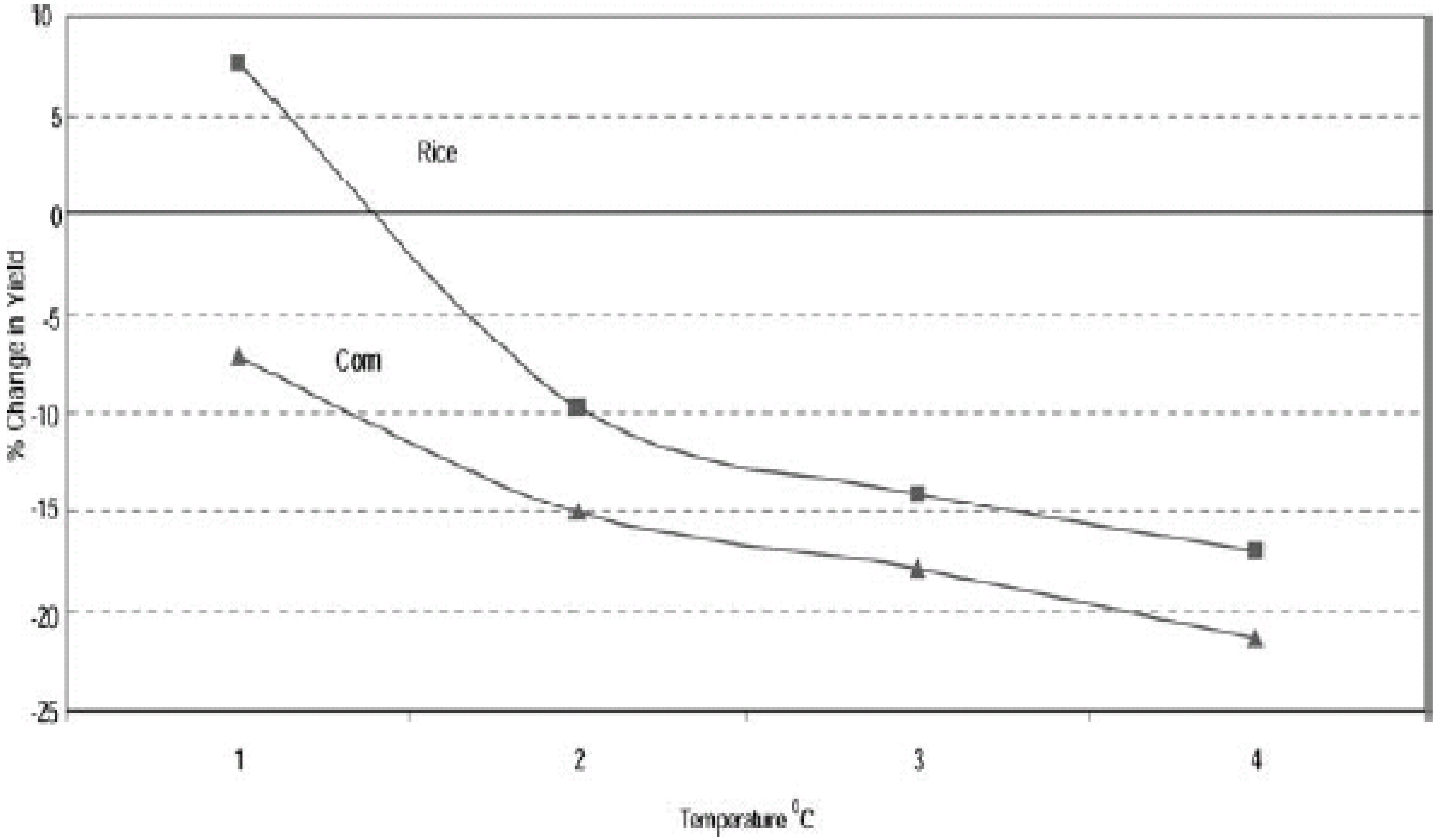
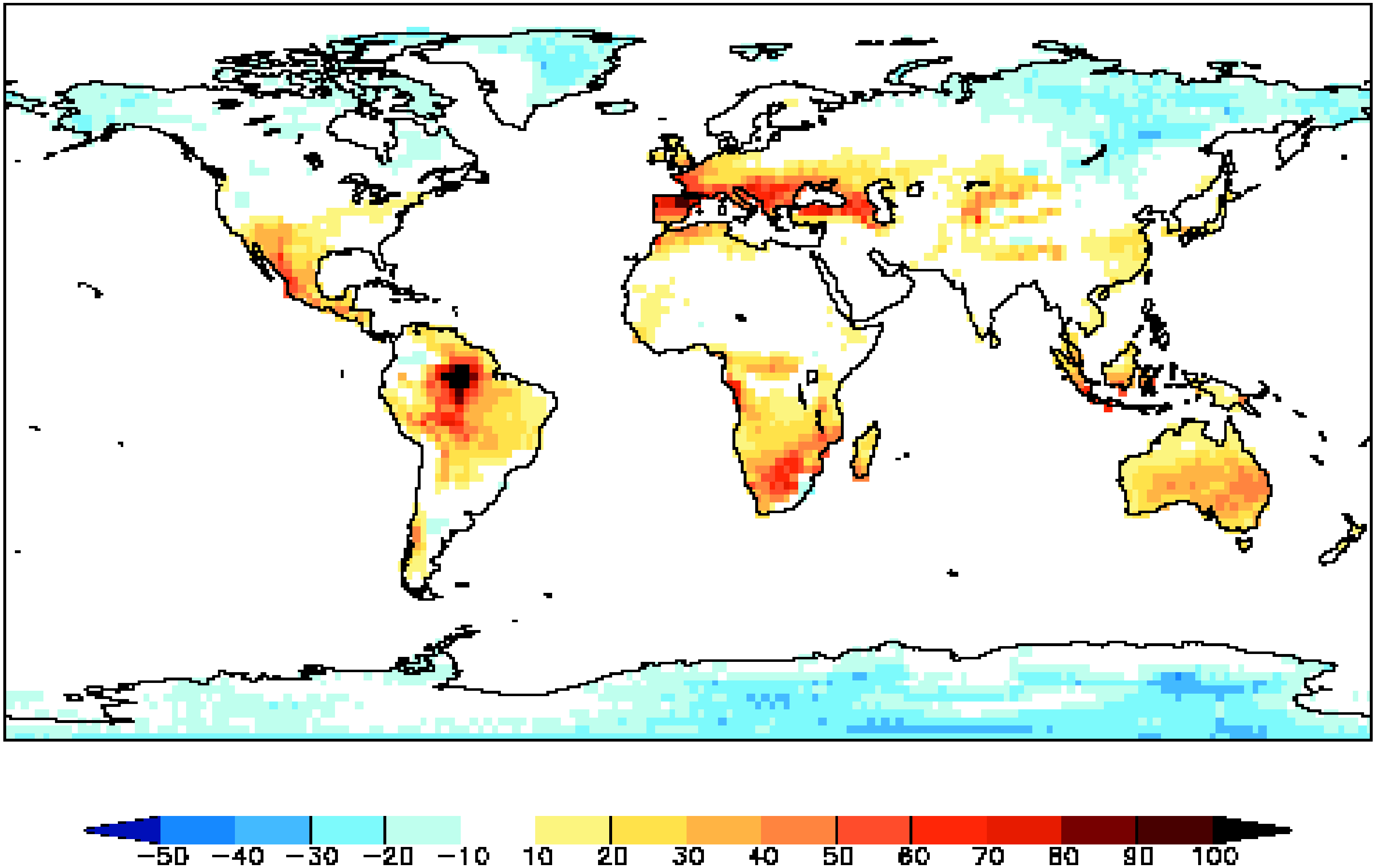


Figure 1. Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

What’s likely: worse droughts

Drought projections for IPCC‘s A1B scenario



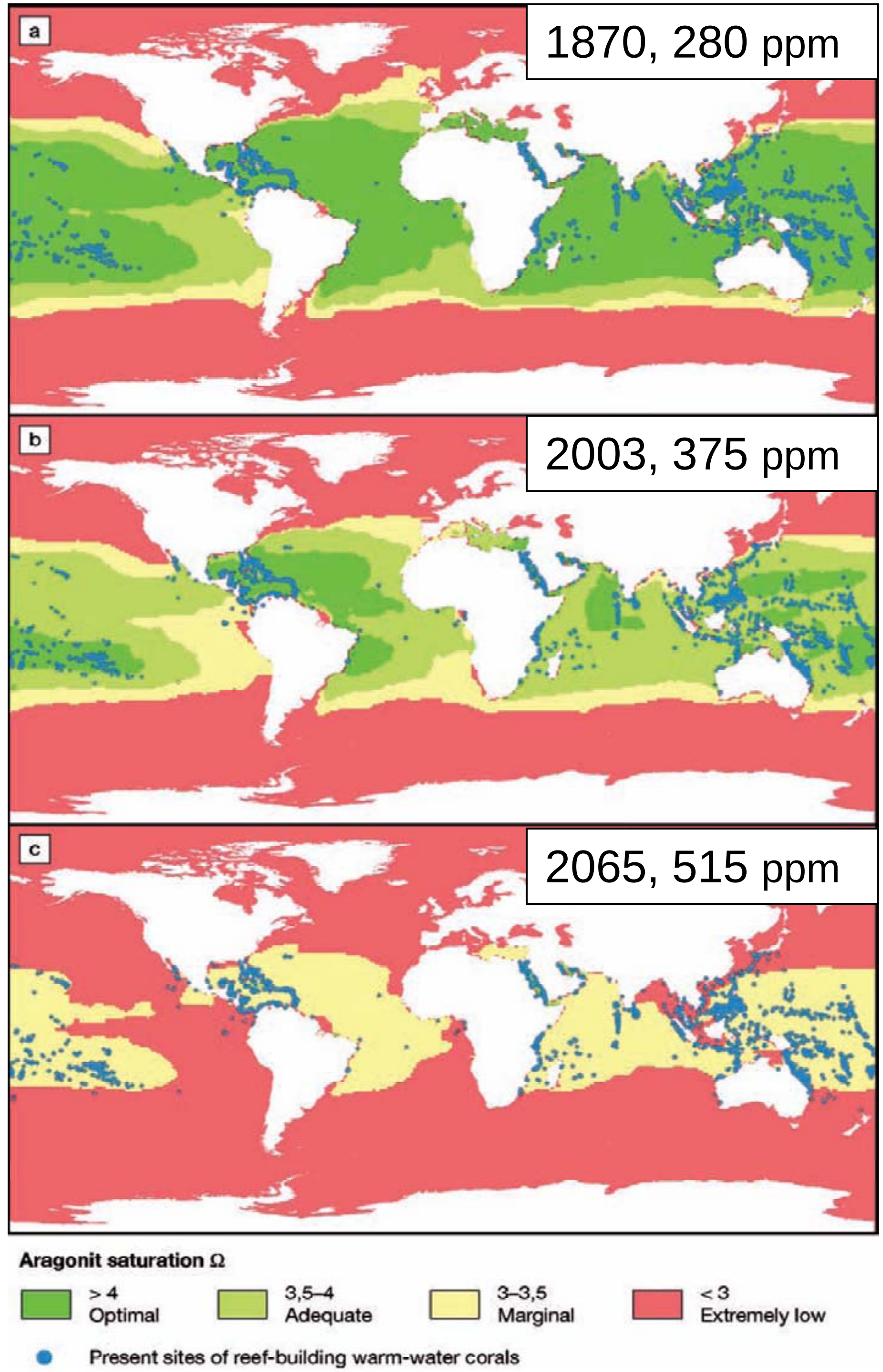
Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.

What 's likely: pickling 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

What <u>might</u> happen: Tipping points

- If Arctic sea ice disappears entirely and doesn’t re-form, climate of N hemisphere would change drastically.
- Changes in ocean chemistry and currents could devastate marine productivity.
- Rapid ice-sheet disintegration (1-2 m per century sea-level rise) more likely as $\Delta T_{avg} \geq 1.5^{o}C$.
- Tundra & permafrost are warming & thawing, with potential for CO_2 & CH_4 outpouring that would accelerate climate disruption overall and onset of any or all of the above.

Do recent disclosures about e-mails and IPCC missteps cast doubt on these conclusions?

- E-mails show climate scientists are human, too, and that increased efforts to ensure openness & transparency in conduct of climate science are warranted (consistent with Obama scientific-integrity principles enunciated a year ago)
- IPCC missteps show need for increased attention to following review procedures rigorously – and perhaps strengthening them further – but errors discovered so far are few in number and small in importance.
- IPCC is not the source of scientific understanding of climate change – it's just one of the messengers. The sources are the global community of climate scientists and the mountain of peer-reviewed research they've produced over decades.

Recent disclosures (continued)

- Nothing that has come to light in e-mails or controversies about the IPCC rises to a level that would call into question the core understandings from climate science about what is going on.
- All science is contingent, and there are always uncertainties and needs for refinement. There's always a chance that new observations and analyses will not just refine but overturn previous conclusions.
- But overturnings are far rarer than most people imagine, and the larger, more diverse, & more consistent the body of data and analyses underpinning a branch of science, the less likely are its main conclusions to be overturned.

Recent disclosures (continued)

- The body of data & analysis underpinning climate science is immense; highly diverse in discipline, approach, geographic focus, and nationality of investigators; and remarkably consistent.
- In part because of their relevance to policy choices of great importance, moreover, the key findings from climate science have been subjected to an absolutely unprecedented multiplicity and depth of peer reviews.
- It’s therefore very unlikely that new data or insights will alter these findings in a fundamental way. Policy makers should not bet with the public’s welfare against such long odds, and the public should punish at the polls those who do.

What are our options?

There are only three:

- 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.

Mitigation & adaptation are both essential

- No feasible amount of mitigation can stop climate change in its tracks.
- Adaptation efforts are already taking place and must be expanded.
- But adaptation becomes costlier & less effective as the magnitude of climate changes grows.
- We need enough mitigation to avoid the unmanageable, enough adaptation to manage the unavoidable.

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

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

Mitigation possibilities

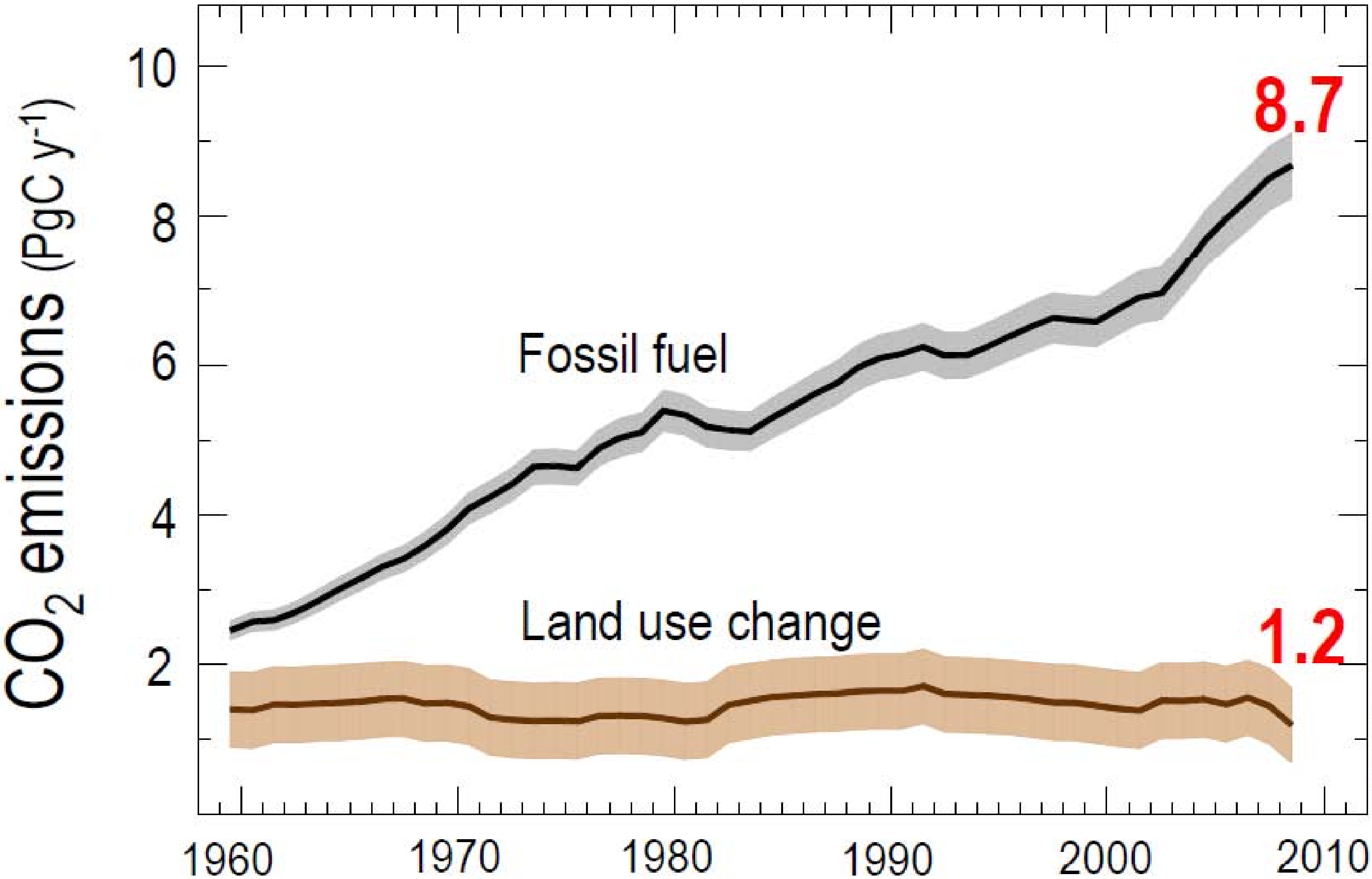
CERTAINLY

- 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

- “Geo-engineering” to create cooling effects offsetting greenhouse heating (white roofs...)
- “Scrub” greenhouse gases from the atmosphere technologically

The mitigation challenge: recent trends in CO_2 emissions

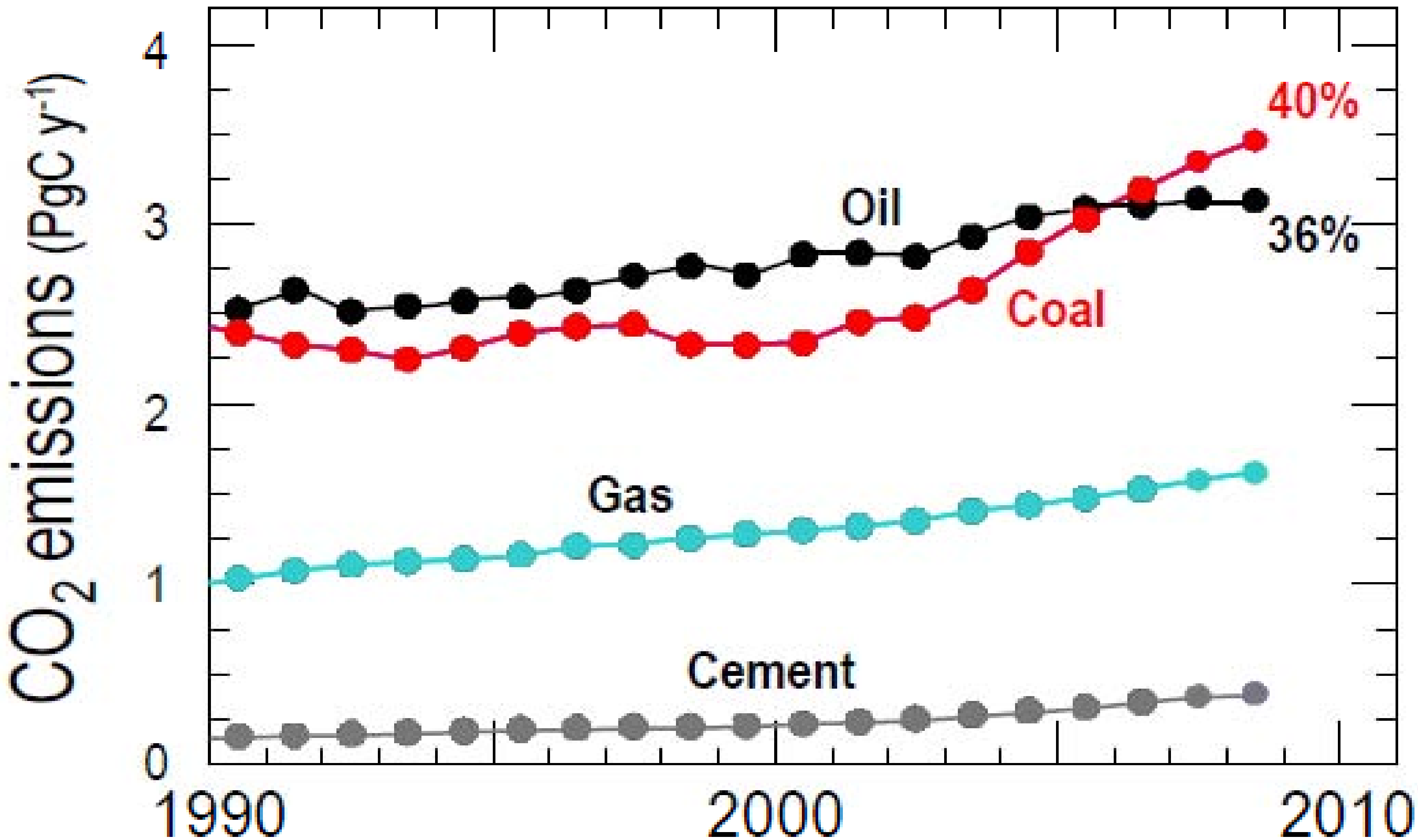


9.9 PgC

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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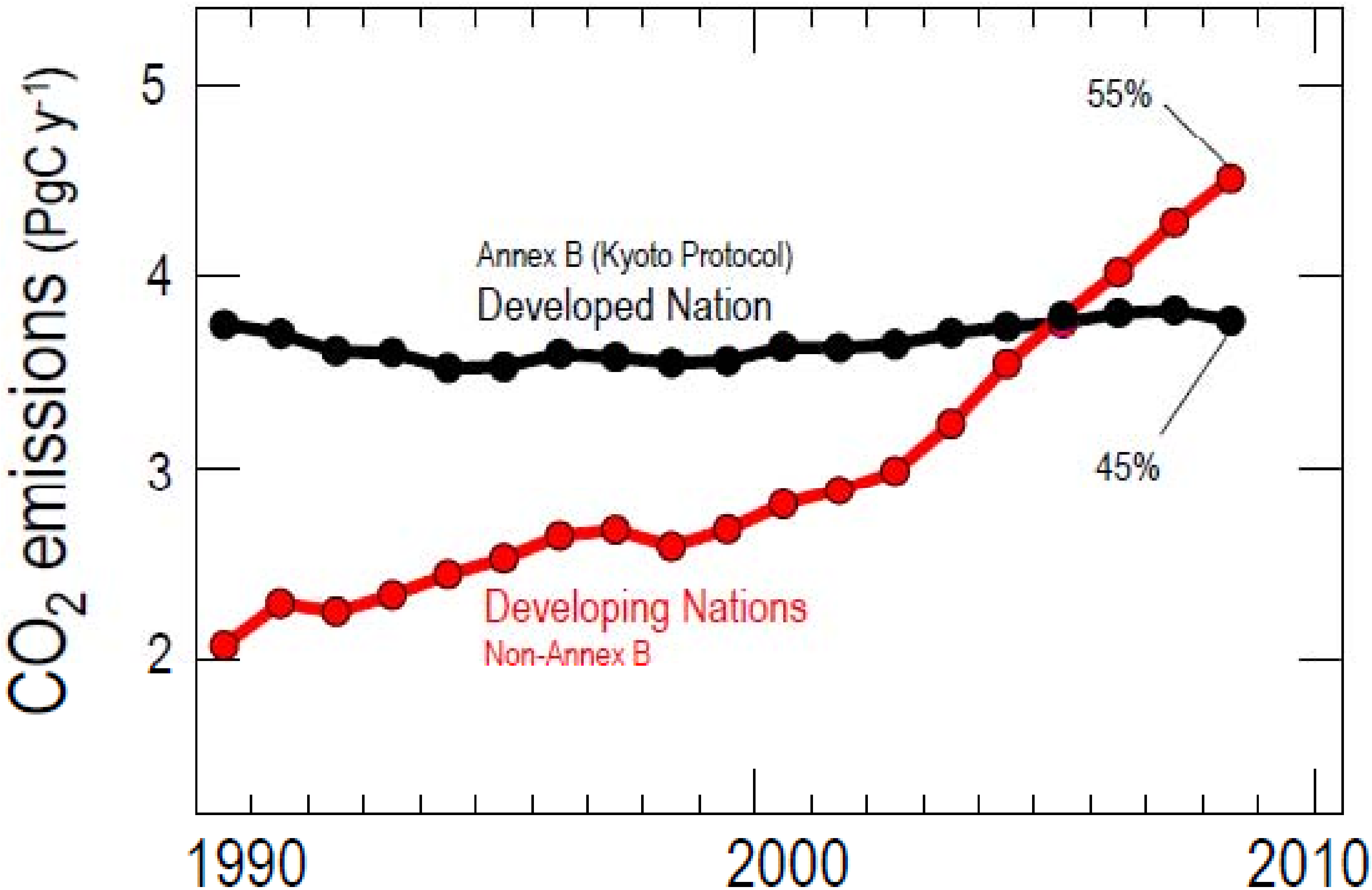


Global Carbon Project 2009

How much mitigation is enough?

- 550 ppmv CO_2-e (50% chance of $\Delta T_{avg} < 3^0C$) looks unlikely to avoid unmanageable change
- 450 ppmv CO_2-e (50% chance of $\Delta T_{avg} < 2^0C$) would be more prudent (but still no guarantee)
- Achieving 450 ppmv requires that...
  - global emissions level off by ~2020 and decline thereafter to ~50% below 2000 emissions by 2050.
  - emissions in USA & other industrial countries level off by 2015 and decline thereafter to ~80% below 2000 emissions by 2050.

Some realities about mitigation

- Stabilizing at 450 ppmv CO_2-e means 2050 global CO_2 emissions must be at least ~7-9 GtC/yr below BAU (i.e., a cut of 50% or more 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

More mitigation realities

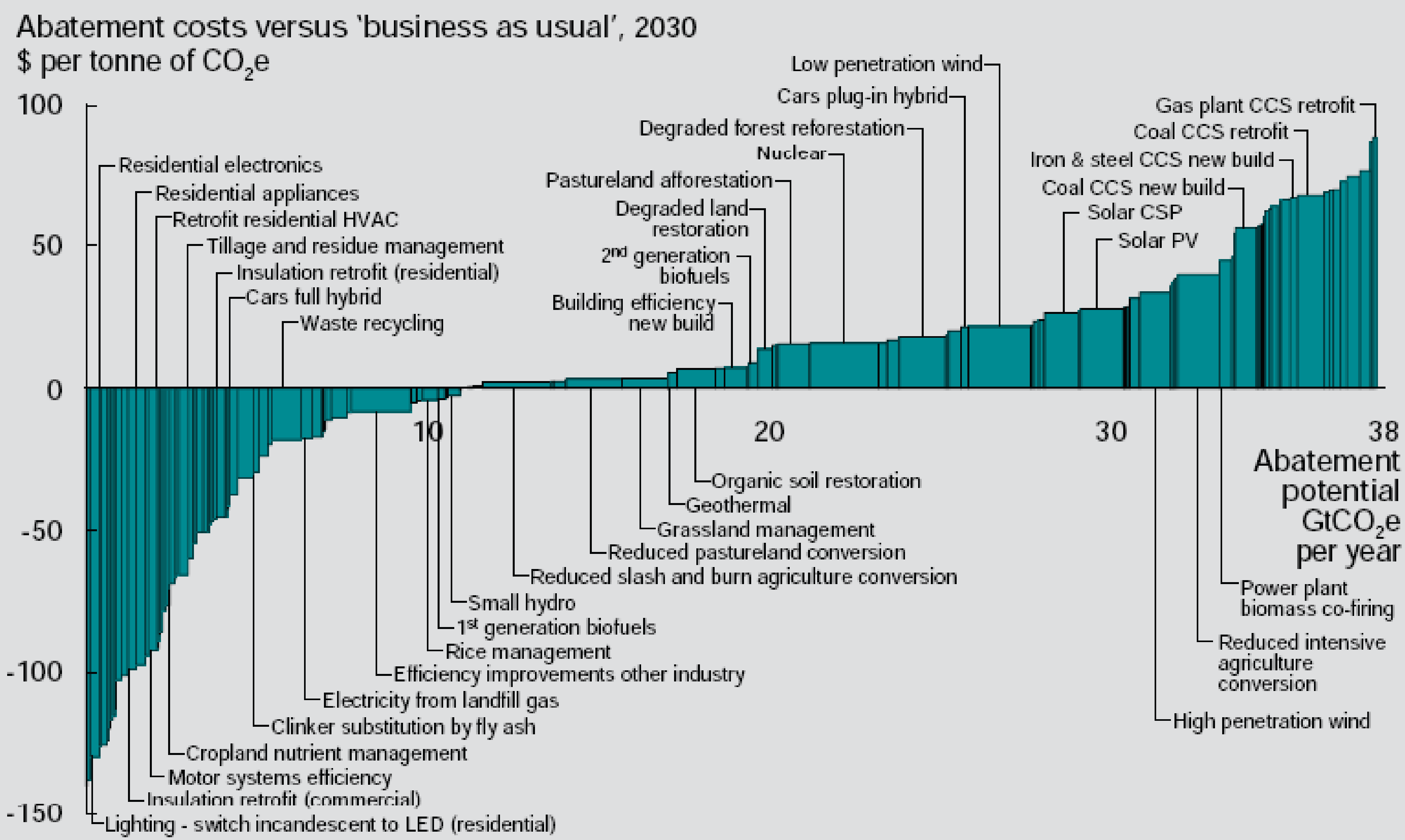
- The cheapest, fastest, cleanest emissions reductions are those available from increasing the efficiency of energy use in buildings, industry, and transport and from reductions in deforestation and forest degradation.

- 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.

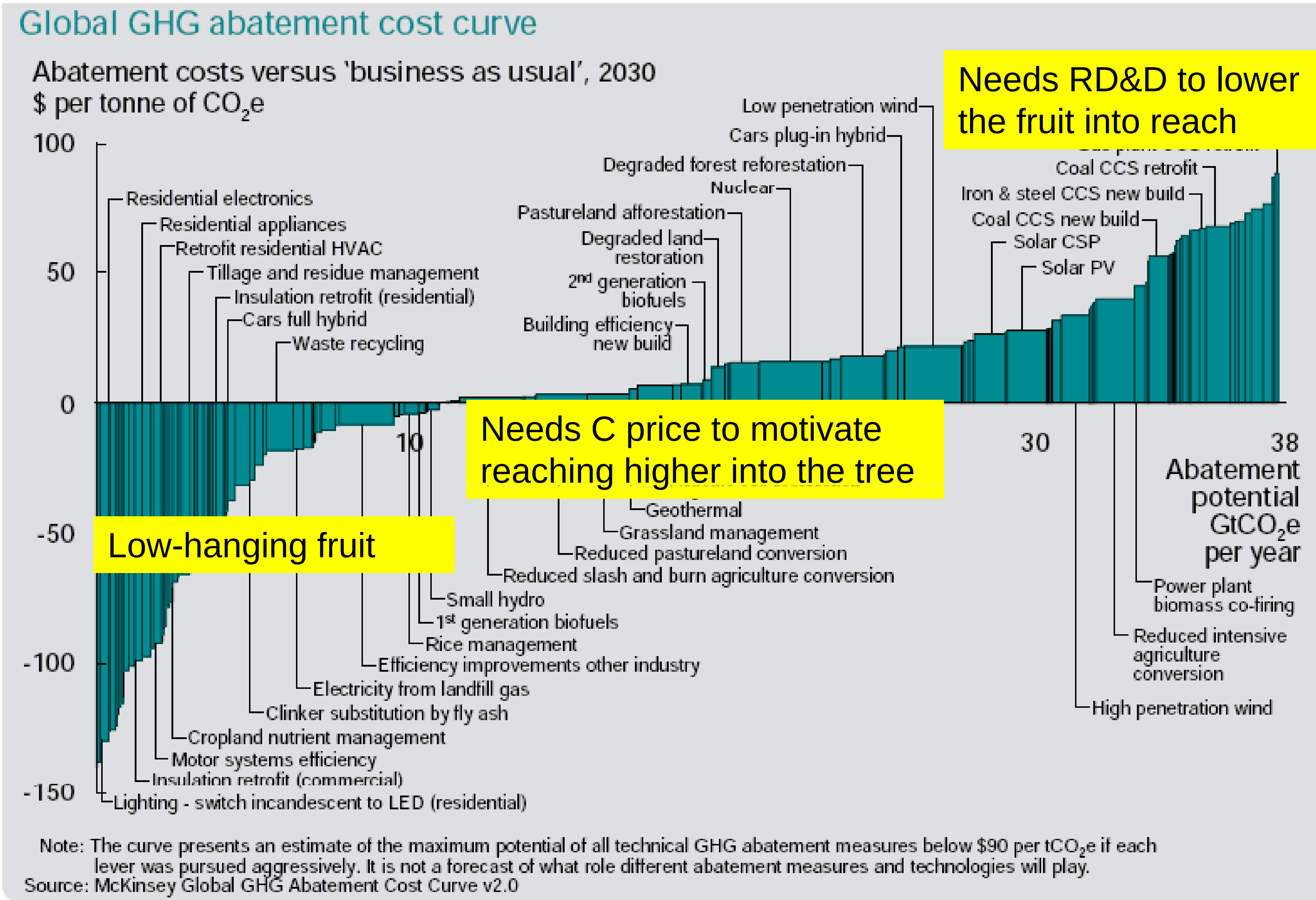
- The "win-win" approaches will not be enough. Adequate mitigation will require putting a price on emissions of GHG to make the costlier reduction options profitable.

GHG-abatement costs and quantities



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

Costs and quantities: the fruit-tree metaphor



The Obama administration's strategy

- Promote recognition that this isn't "climate change policy <u>versus</u> the economy" but "climate change policy <u>for</u> 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, and global competitiveness.

Obama administration strategy (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 & maximum co-benefits.

- Work with other major emitting countries – industrialized & developing – to build technology cooperation and individual & joint climate policies consistent with “avoiding the unmanageable”.

Energy-environment actions to date

- $80 billion for clean & efficient energy in ARRA
- creation of ARPA-E ($400M in 2009-10, $300M proposed for 2011), Energy-Innovation Hubs, Energy Frontier Research Centers
- first-ever fuel-economy/CO2 tailpipe standards
- US Global Change Research Program increased to $2.56 billion for FY2011 (19.4% real increase).
- FY11 budget also restructures NPOESS for success, funds Orbiting Carbon Observatory replacement
- strengthened bilateral partnerships on energy & climate change w China, India, Brazil, Russia…

Energy-environment actions to date (continued)

- Restructuring of NOAA to consolidate "climate services" germane to climate-change adaptation
- Inter-agency task force led by OSTP, CEQ, NOAA on coordination of government's adaptation activities
- PCAST review of the effectiveness of the US energy-innovation system (Moniz-Savitz)

A closing observation

- On this and all the other national and global challenges where science & technology matter both for understanding the problem and for supplying major elements of the solution., e.g.,
  - other issues in resources & environment
  - biomedicine and health
  - technological innovation for productivity & growth
  - science, technology, engineering, and math education
  - national & international security

  it’s a huge asset and a huge opportunity to have a President who gets it!

A President with vision.

"Astronomy for Kids on the White House Lawn", October 7, 2009