Global Climatic Disruption: Risks and Opportunities

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Outline of the presentation

- Climate science: What do we know?
- Climate technology: What can we do?
- Climate economics:
  - Can we afford to do it? Can we afford not to?
  - Climate risks & opportunities for firms & investors
- Climate policy: How do we get it done?

Climate science: What do we know?

- "Global warming" is a misnomer because it implies uniform, gradual, quite possibly benign.
  - But what's happening is nonuniform, rapid, harmful.
  - "Global climatic disruption" is a more accurate description.
- The disruption is…
  - real without doubt;
  - mainly human-caused;
  - already producing significant harm; and
  - growing more rapidly than expected.

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.

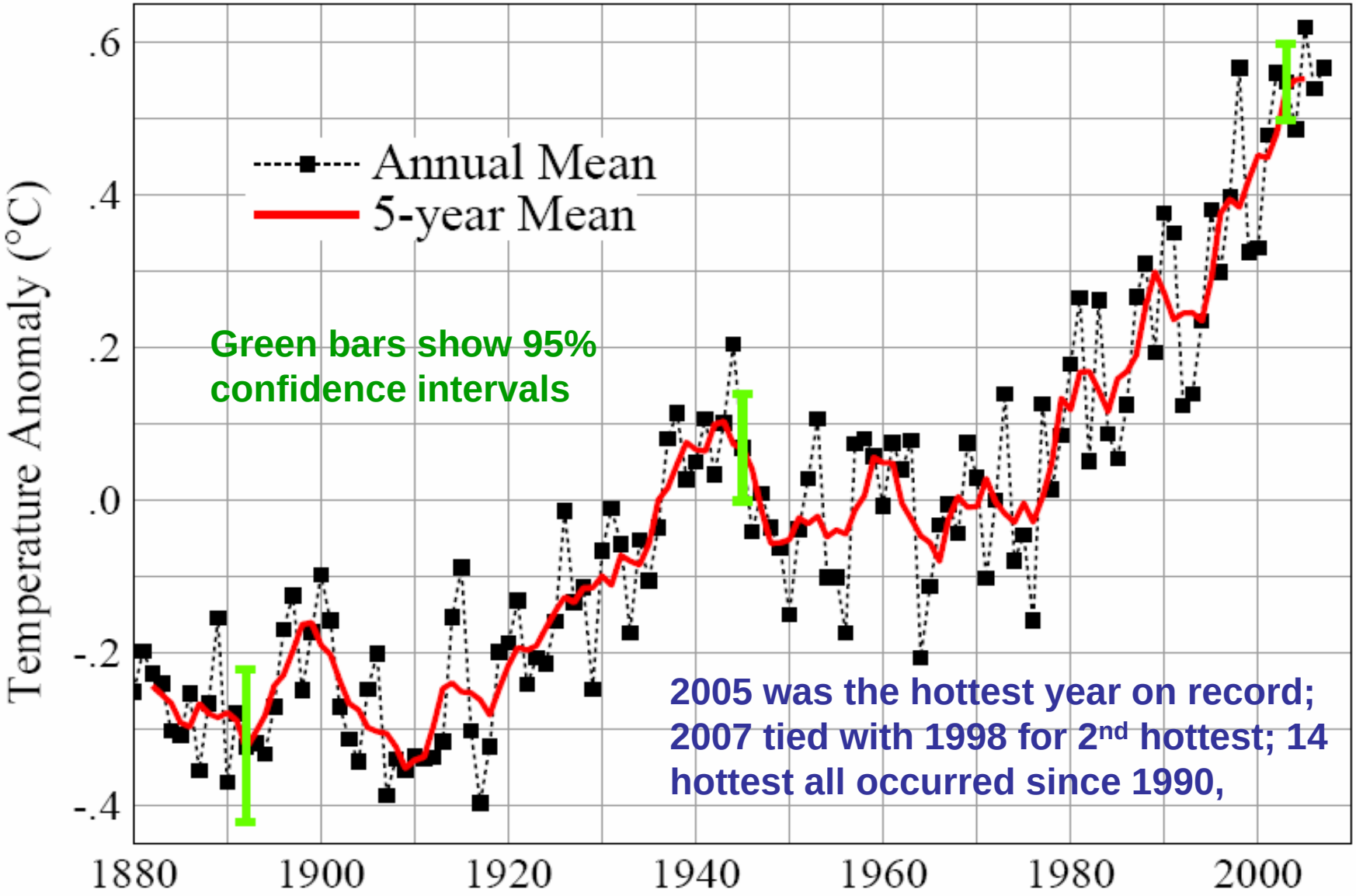
Global average temperature is just an index of the state of the global climate as expressed in these patterns. Small changes in the index → big changes in the patterns.

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 <u>is</u> getting hotter.



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

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

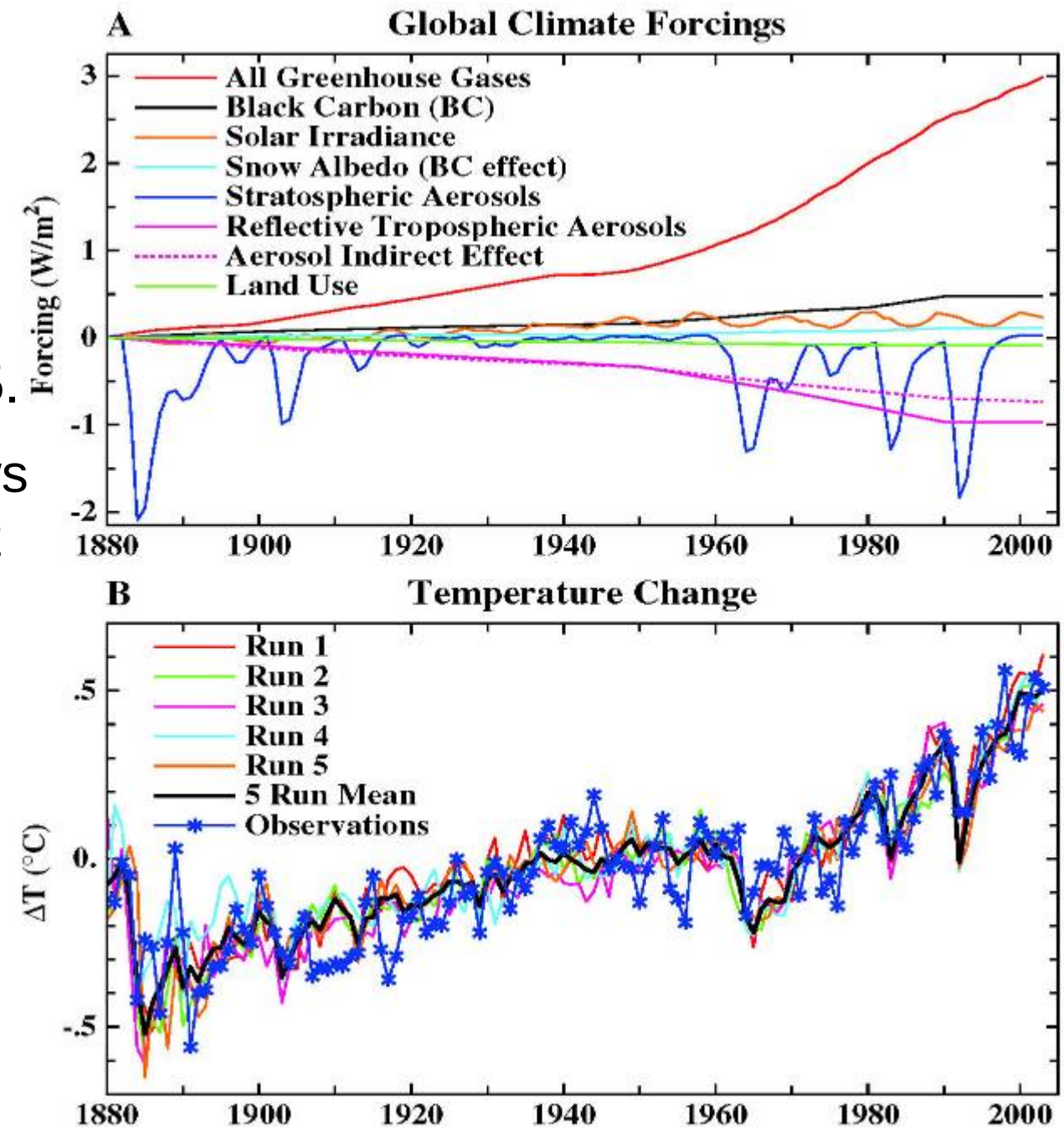
The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

IPCC AR4, WG1 SPM, 2007

Human influence: the smoking gun

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

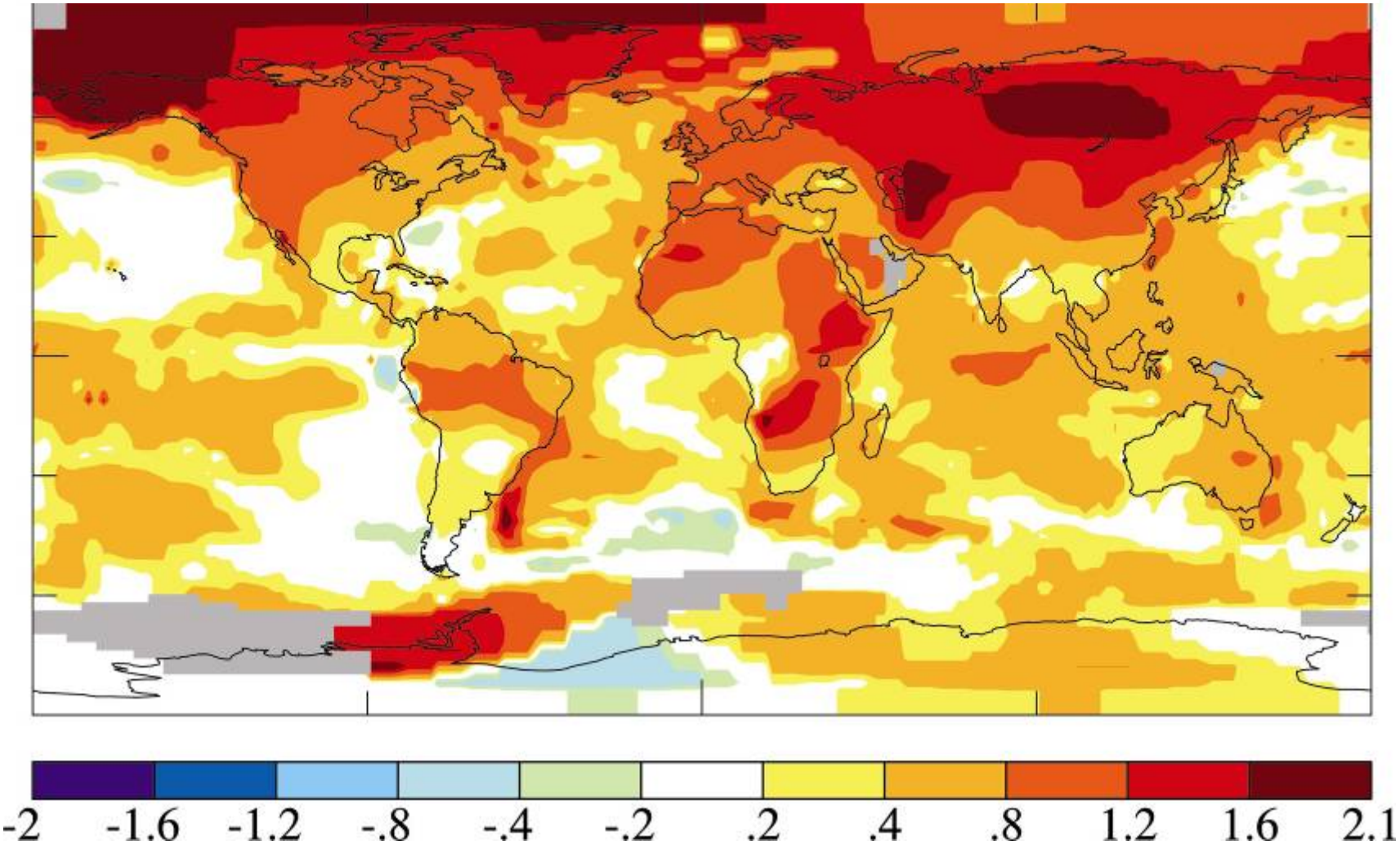
Bottom panel shows that state-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.



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

The current heating is not uniform geographically

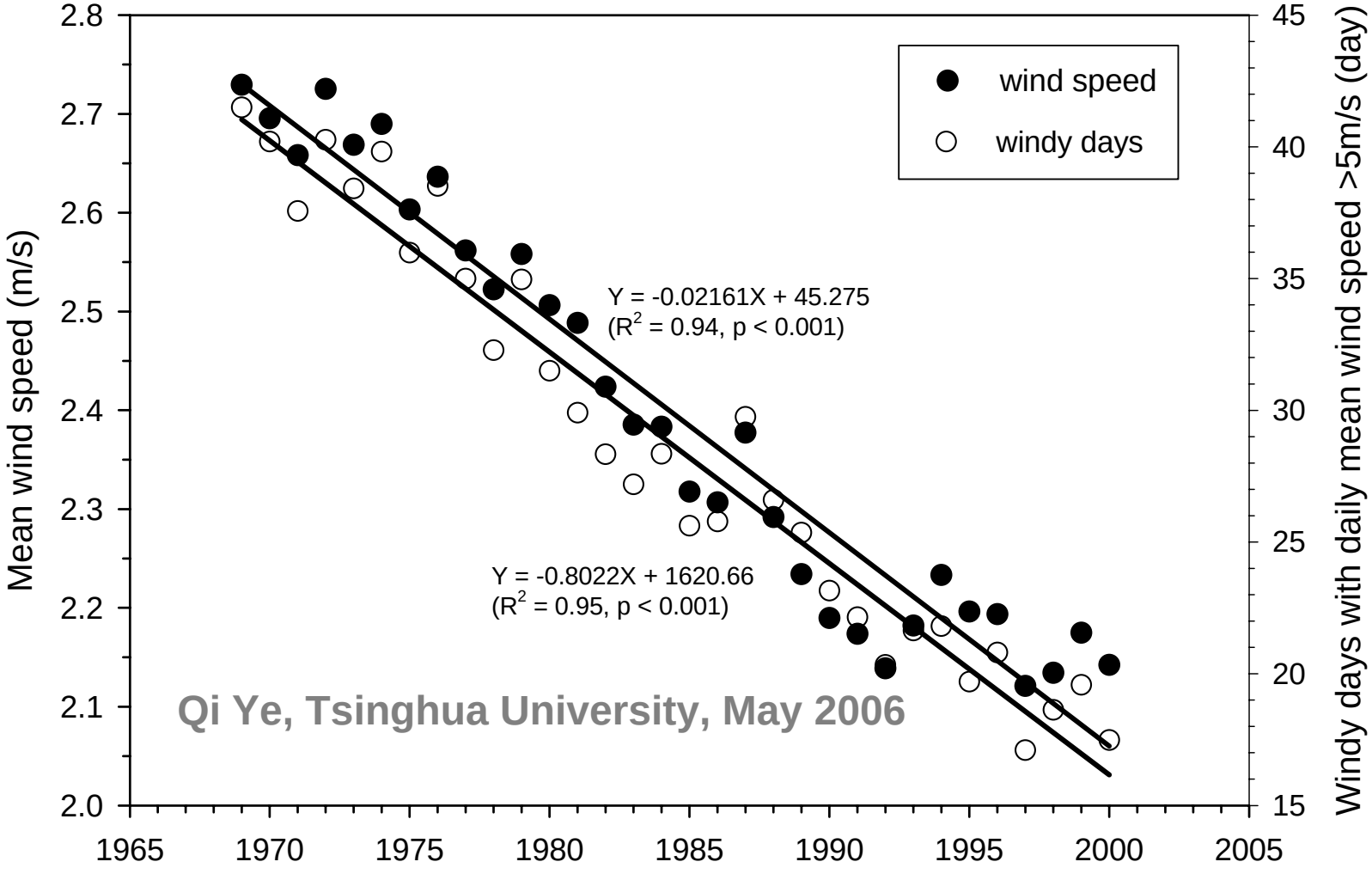
Surface T in 2001-2005 *vs* 1951-80, averaging 0.53ºC increase



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

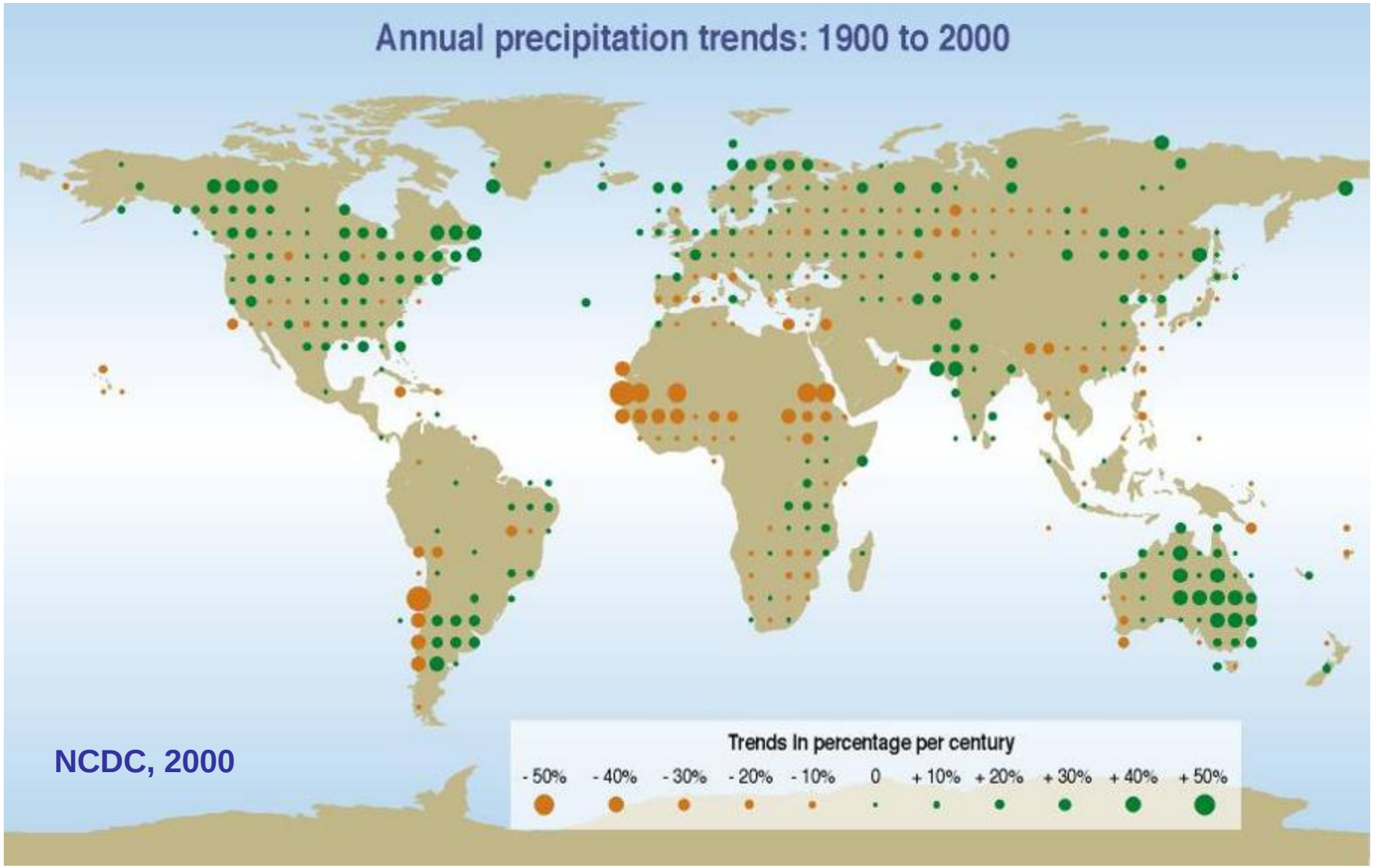
Circulation patterns are changing

Weakening of the East Asia Monsoon is an example



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

Evaporation & precipitation are increasing

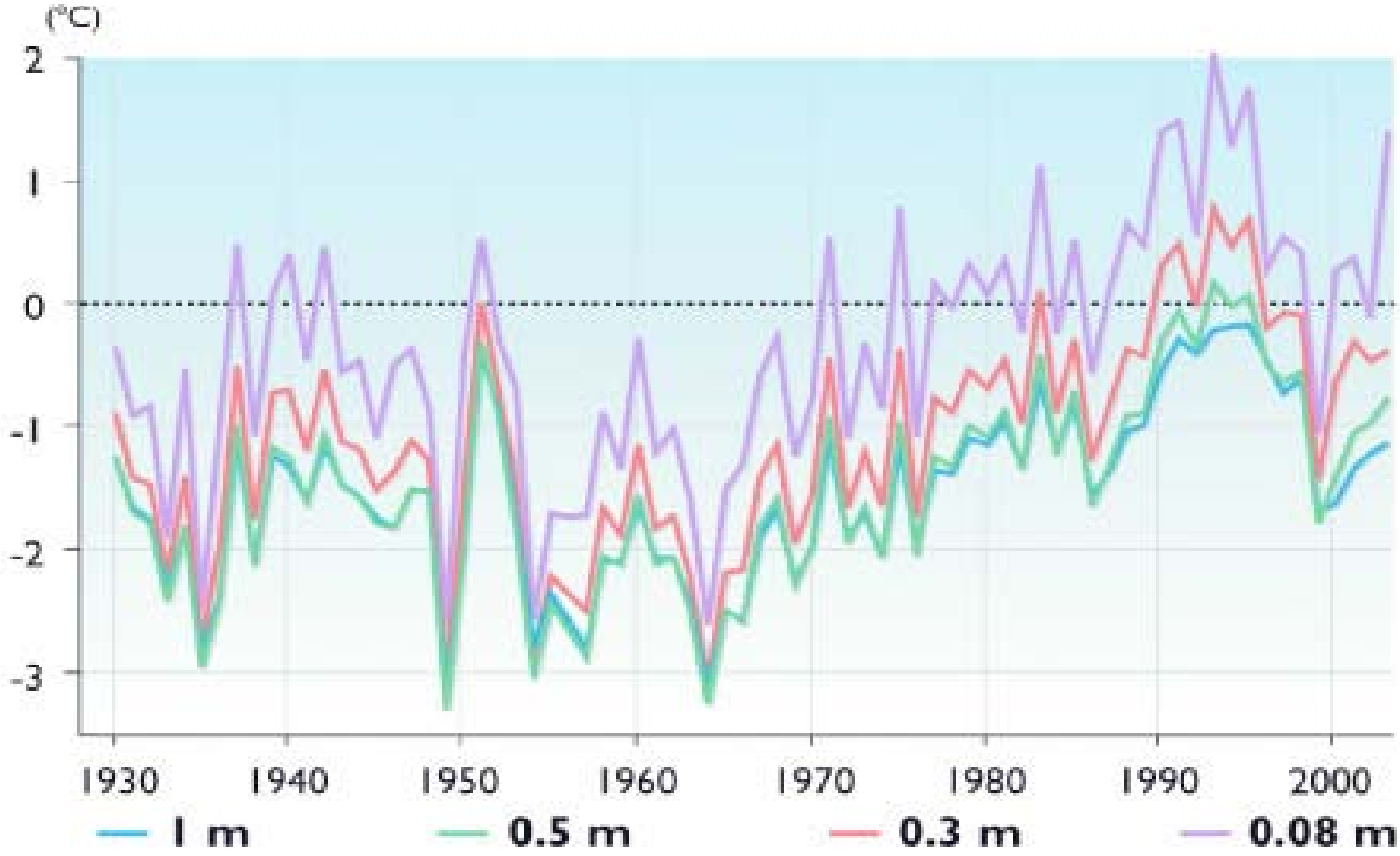


NCDC, 2000

But this is <u>also</u> not uniform; most places getting wetter, some drier.

Permafrost is thawing

Average ground temperature near Fairbanks, Alaska, degrees C



Permafrost thaws when T ≥ 0°C

ACIA 2004

Glaciers are shrinking

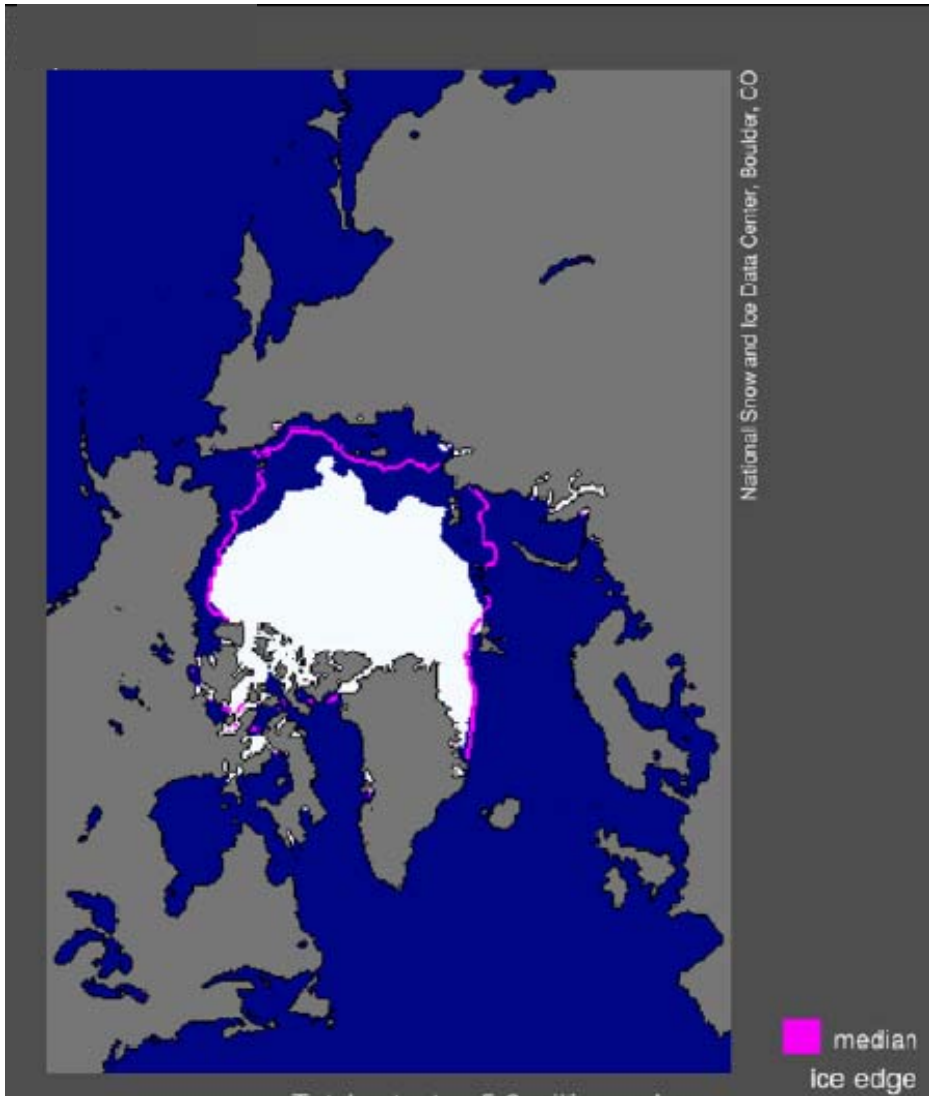
Muir Glacier, Alaska

August 1941

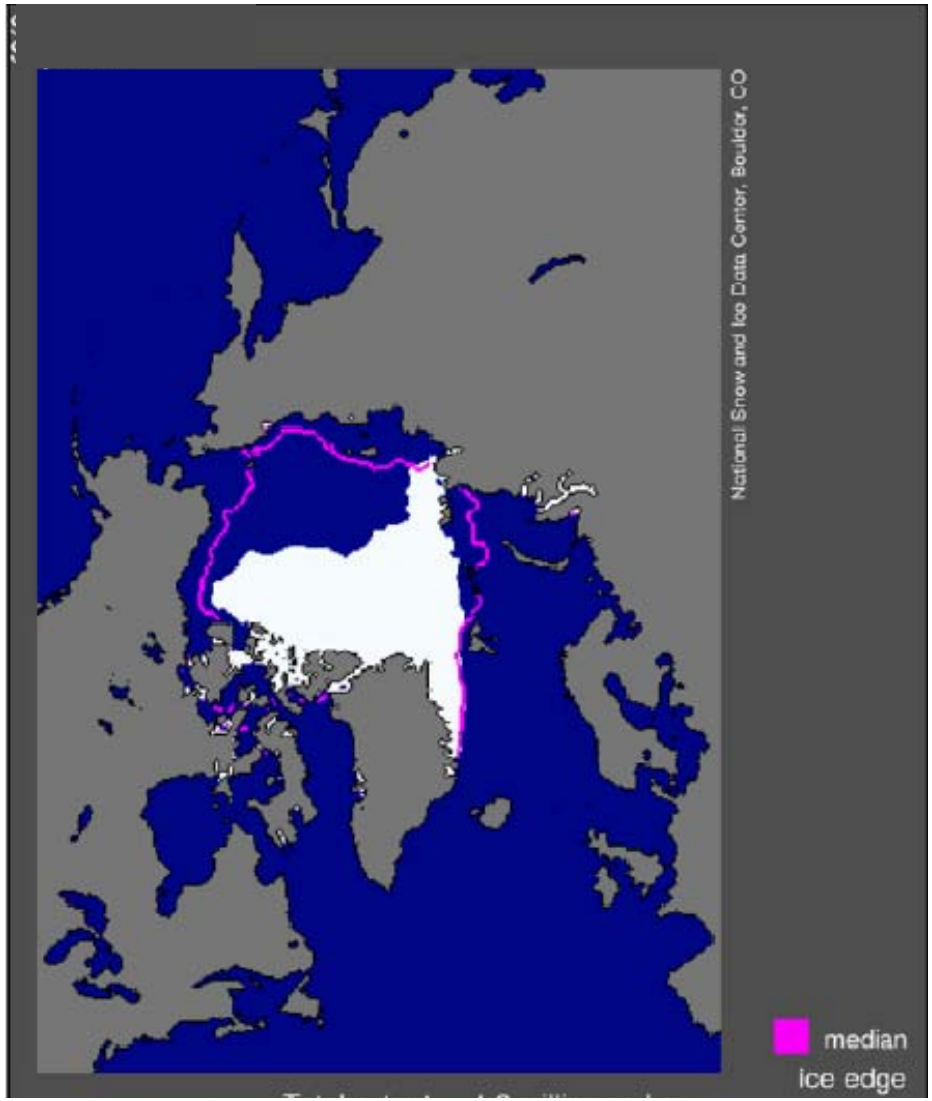
August 2004

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

Arctic summer sea ice is disappearing



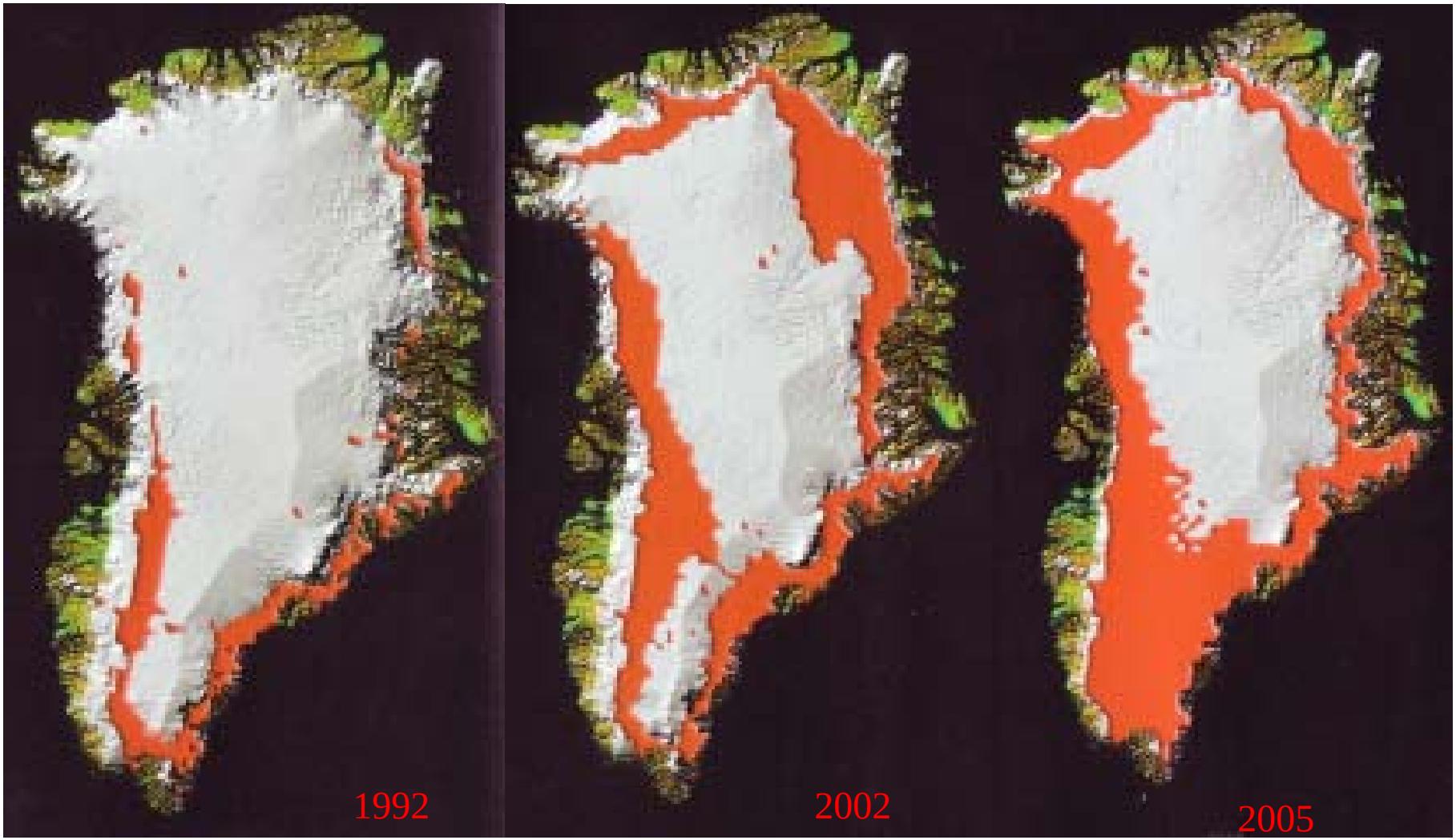
September 2005



September 2007

US National Snow & Ice Data Center, 2007

Surface melting on Greenland is expanding



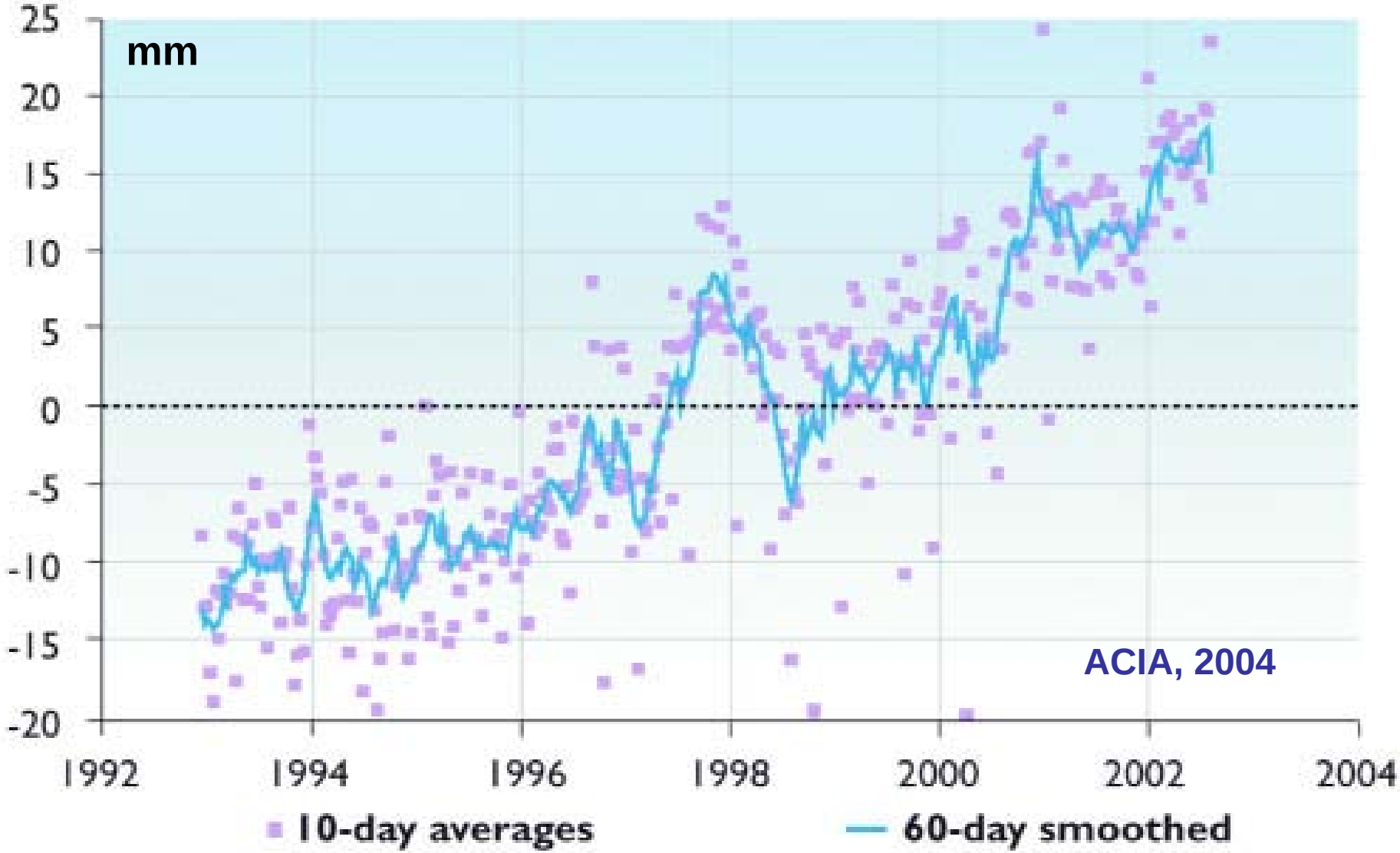
In 1992 scientists measured this amount of melting in Greenland as indicated by red areas on the map

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

And in 2005, it accelerated dramatically yet again

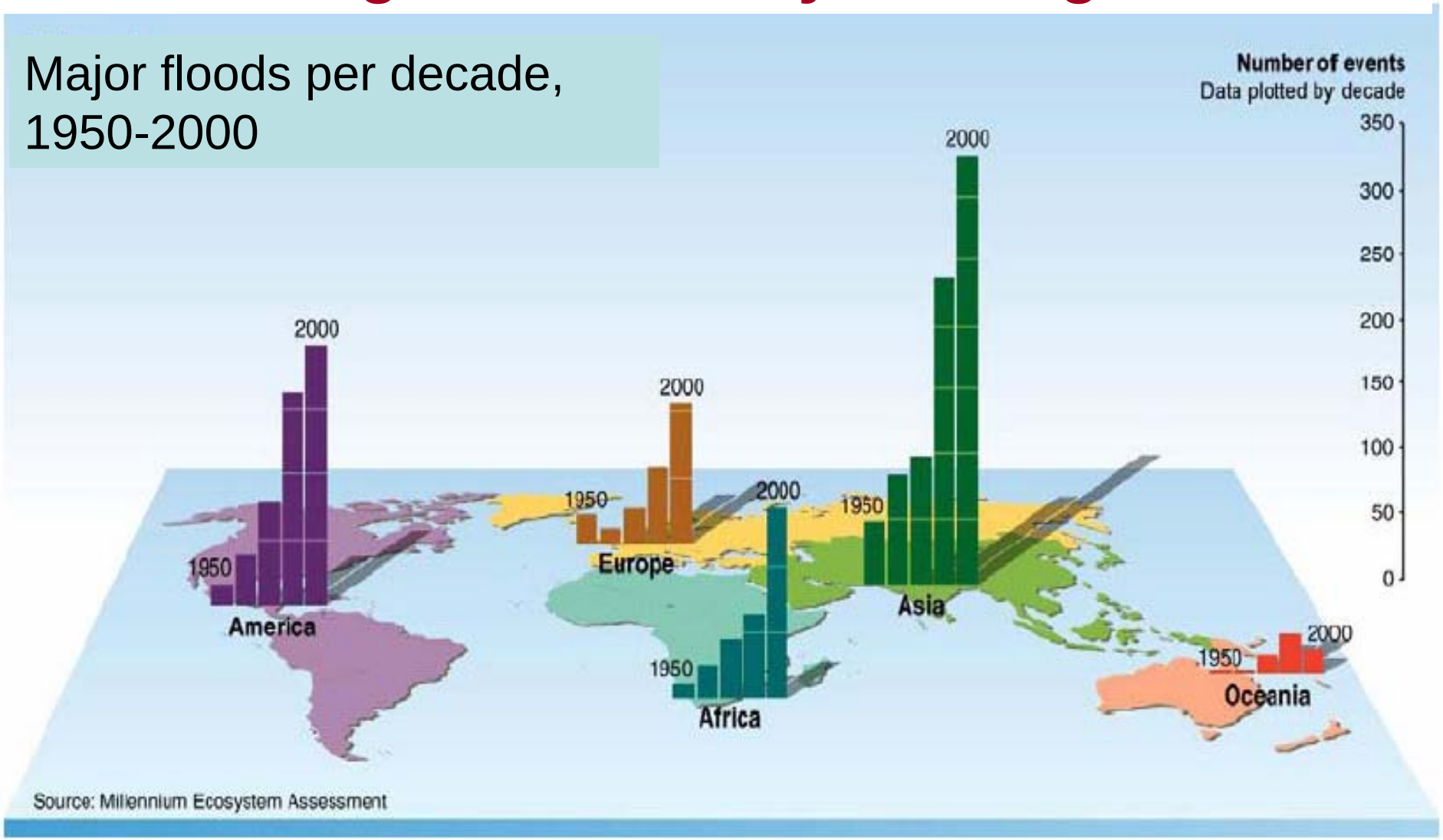
Source: ACIA, 2004 and CIRES, 2005

Sea-level is rising



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

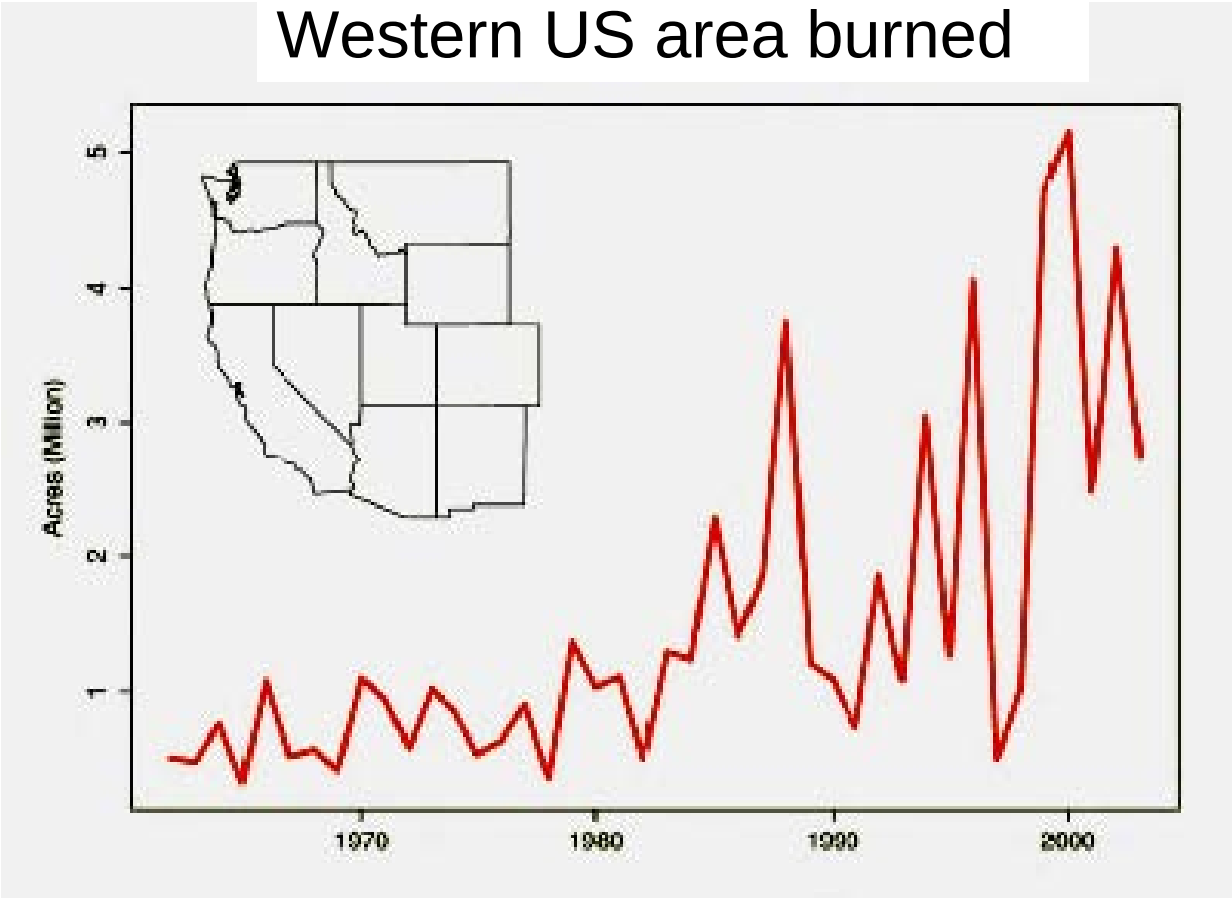
These changes are already causing harm



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

Harm is already occurring (continued)

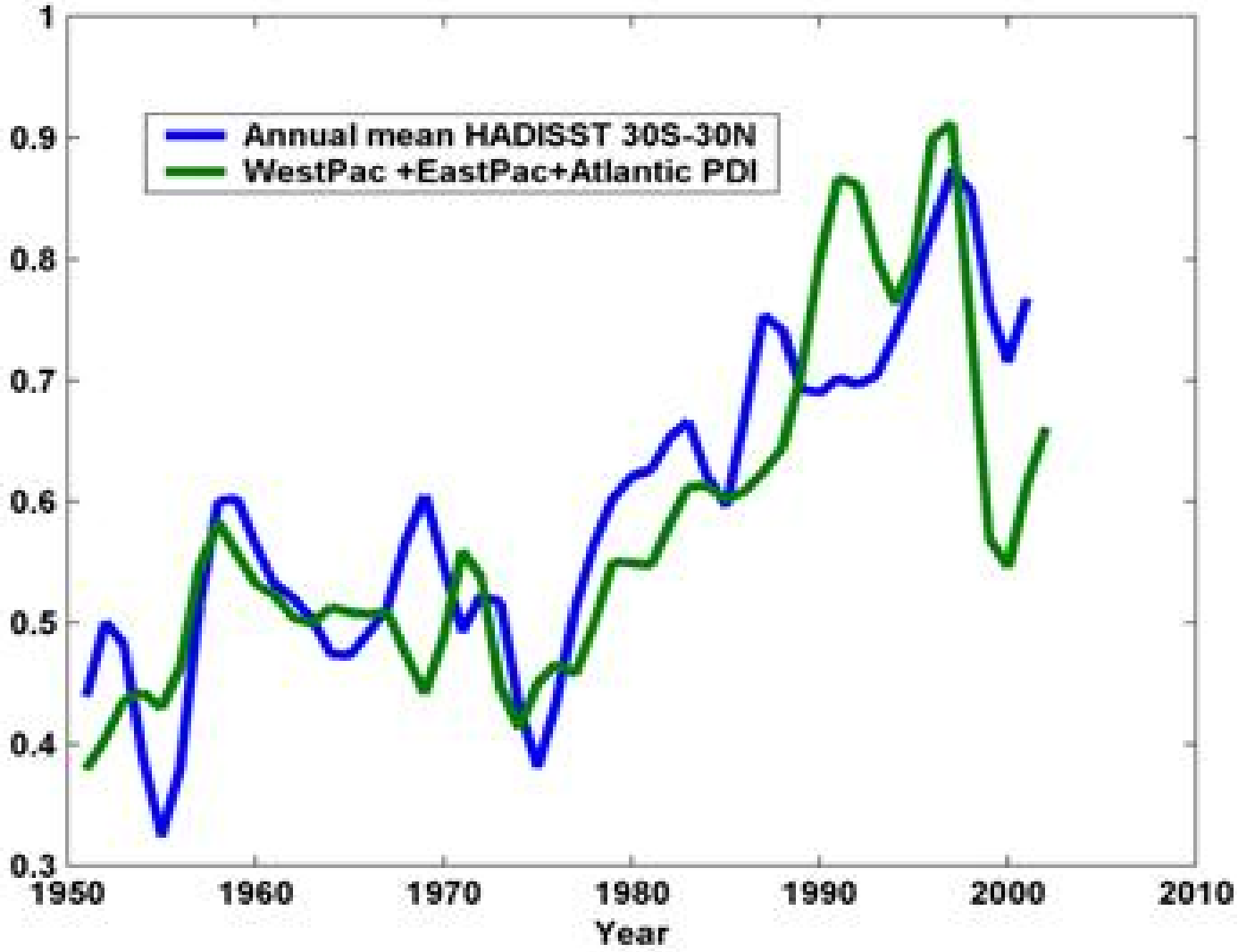
Wildfires in the Western USA have increased 4-fold in the last 30 years.



Source: Westerling et al. 2006

Harm is already occurring (continued)

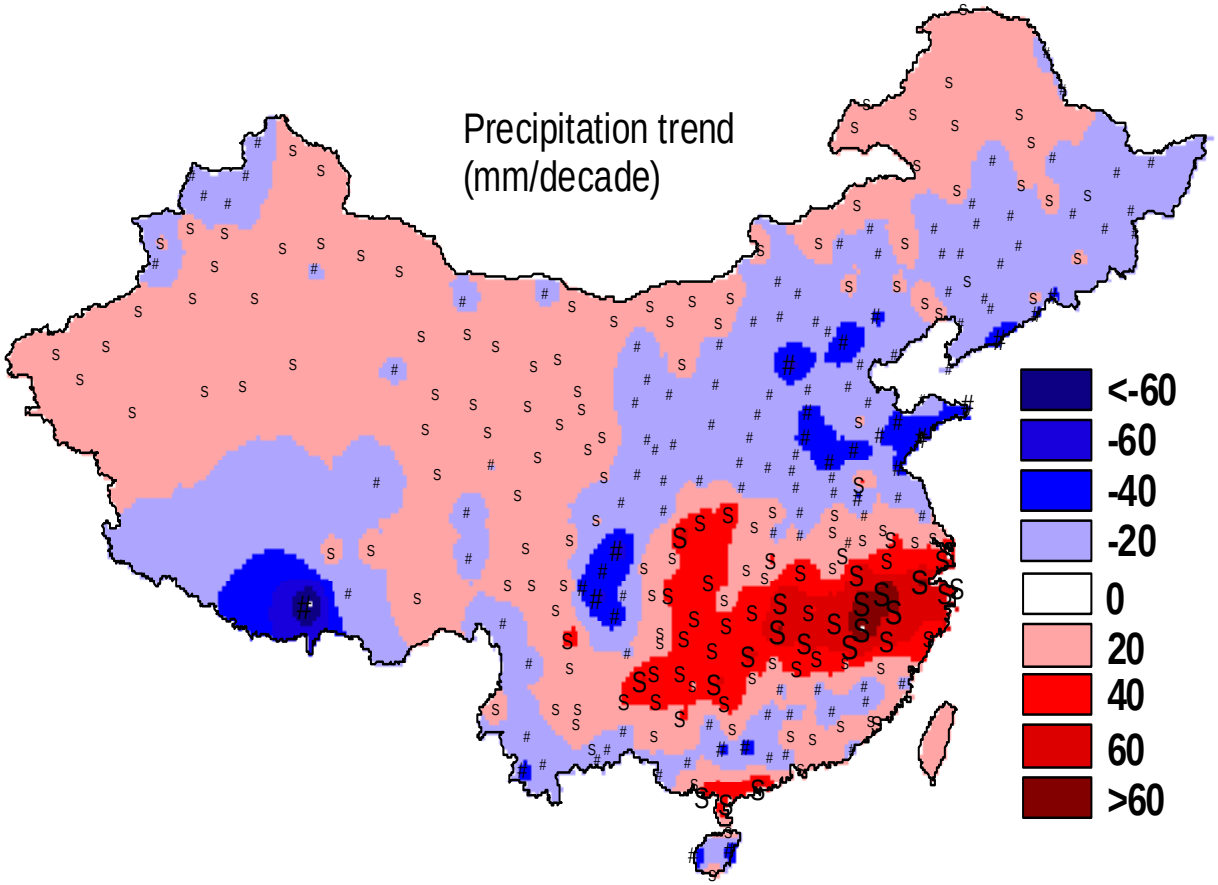
Total power released by tropical cyclones (green) has increased along with sea surface temperatures (blue).



Kerry Emanuel, MIT, 2006

Harm is already occurring (continued)

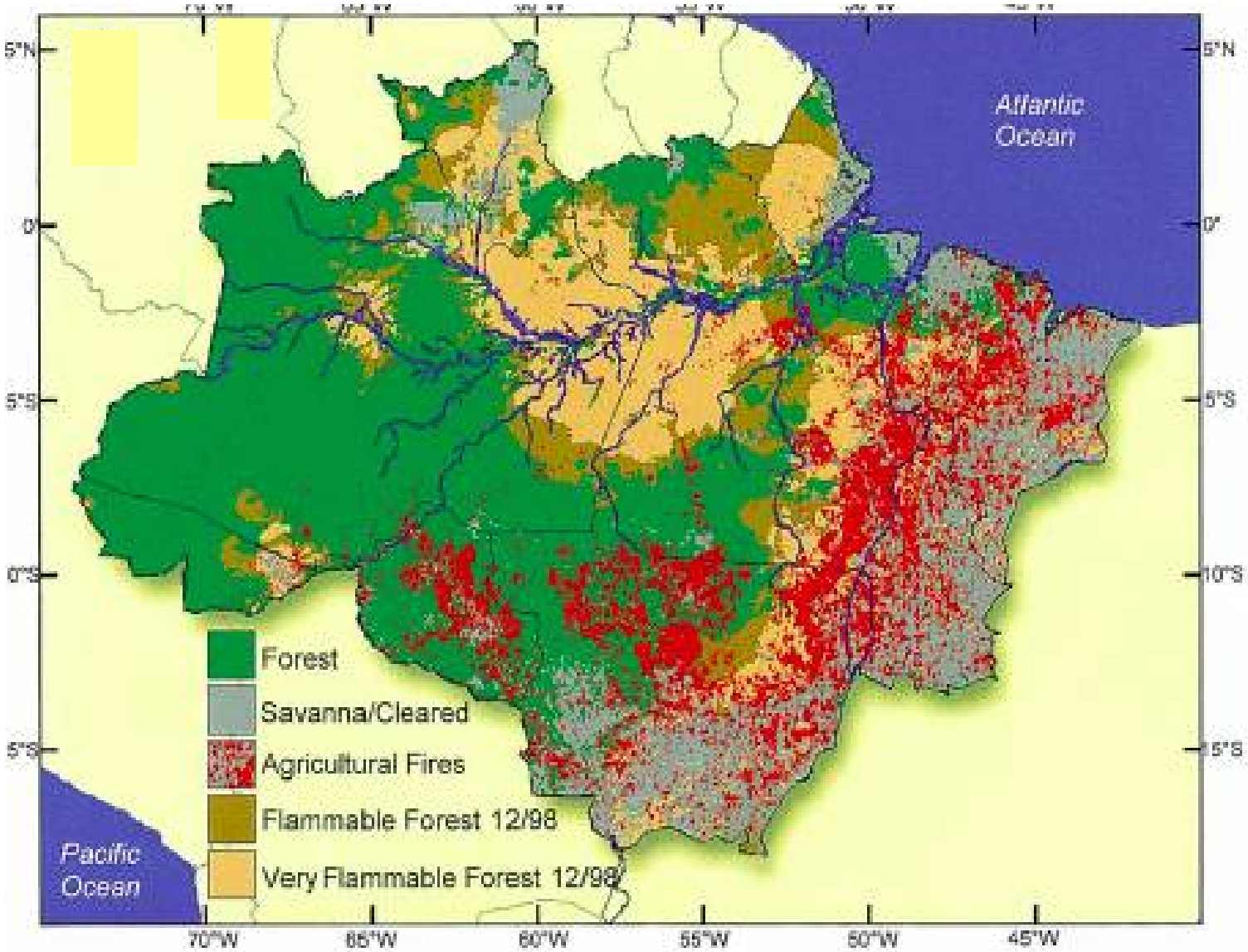
Weakening East-Asia monsoon has meant less moisture flow South to North, producing increased flooding in South, drought in North



Qi Ye, Tsinghua University, May 2006

Harm is already occurring (continued)

The Amazon is drying; parts are burning that didn't before.



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

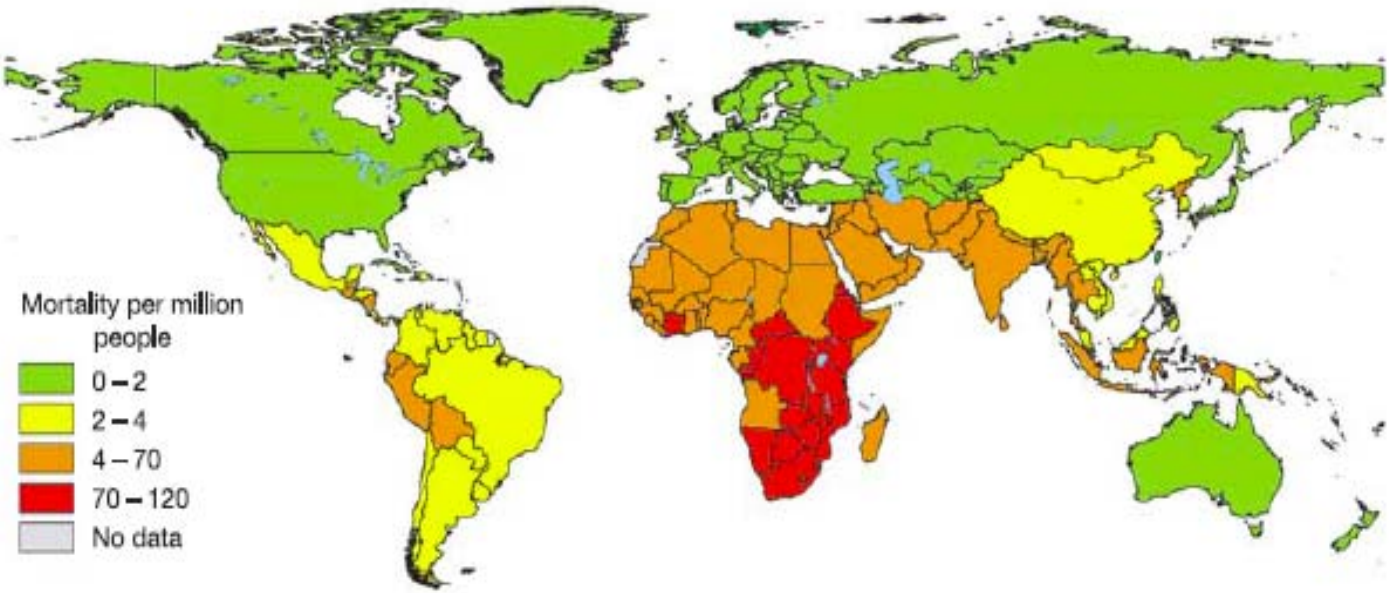
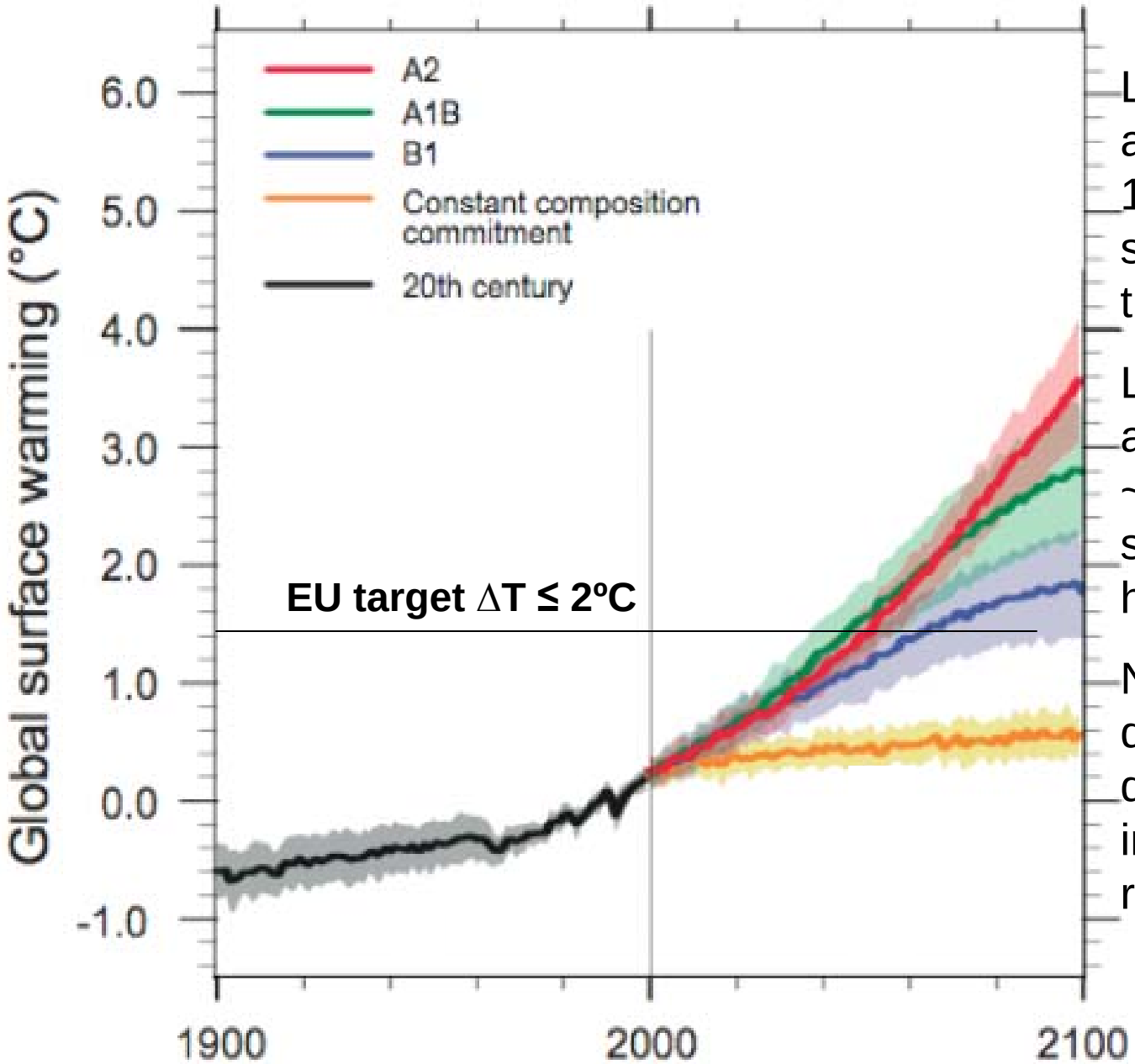


Figure 2 | WHO estimated mortality (per million people) attributable to climate change by the year 2000. The IPCC 'business as usual' greenhouse gas emissions scenario, 'IS92a' and the HadCM2 GCM of the UK Hadley Centre were used to estimate climate changes relative to 'baseline' 1961–1990 levels of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



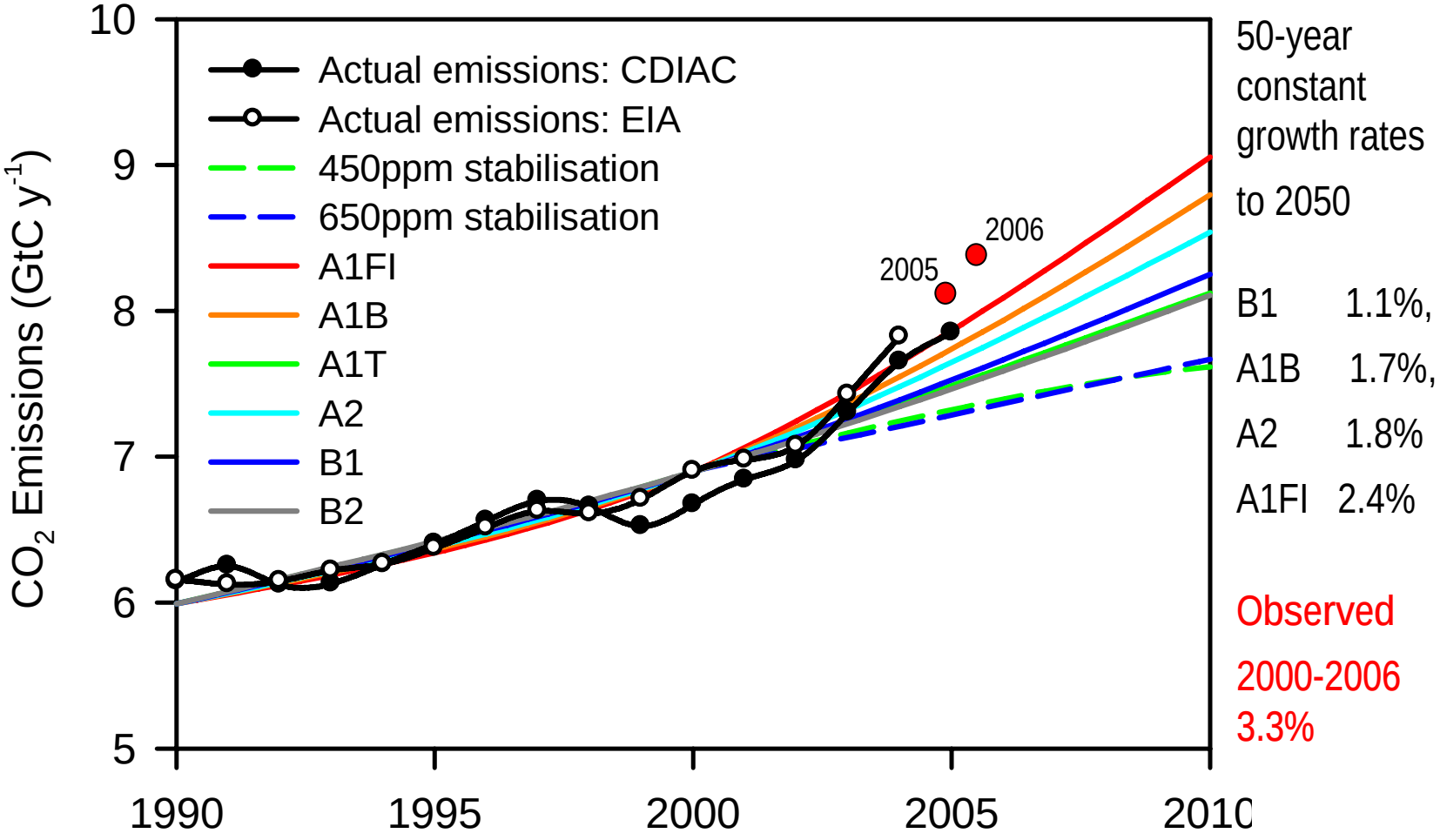
Last time T was 2ºC above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

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

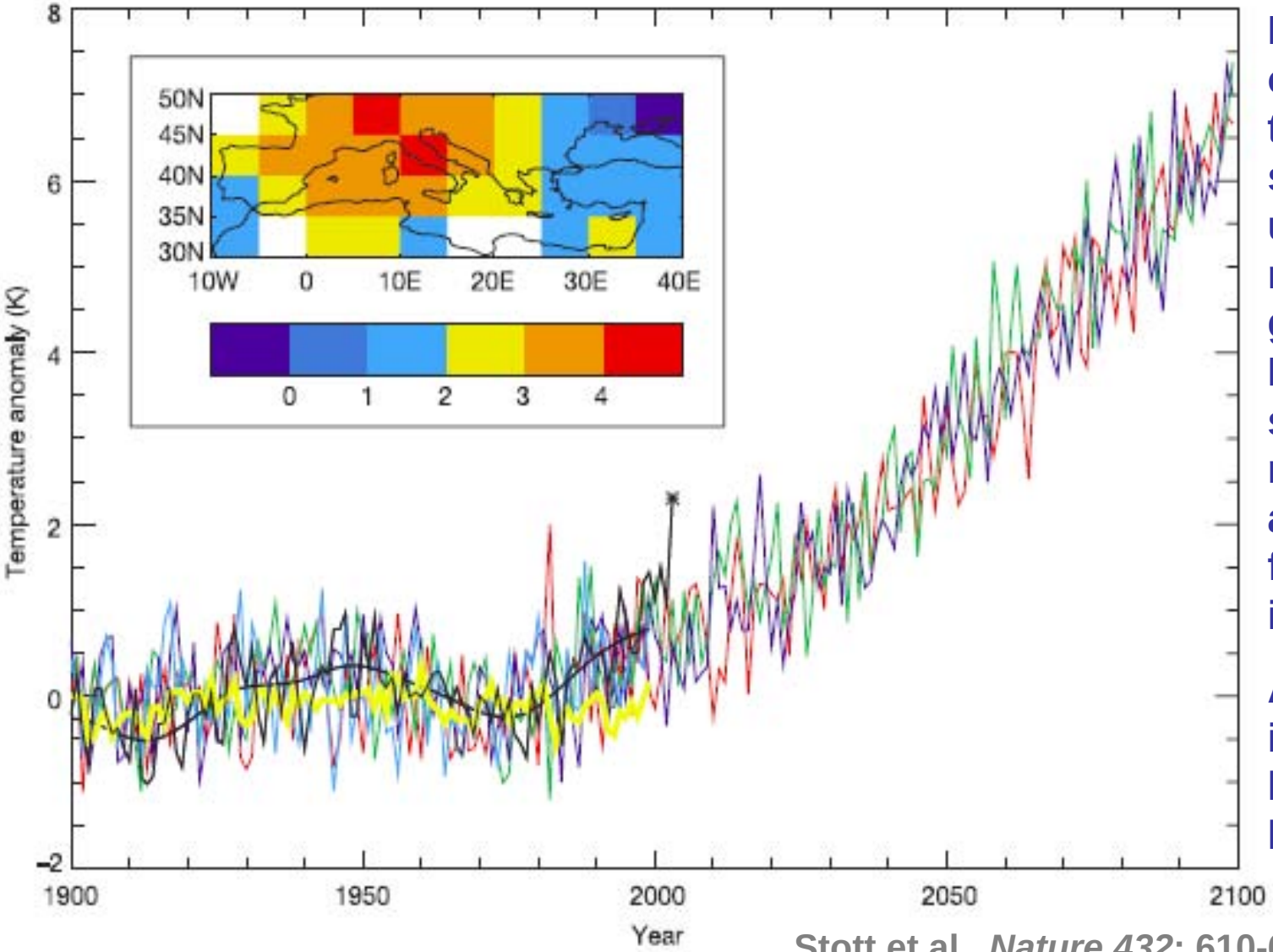
Past IPCC assessments have underestimated the pace of change



Raupach et al. 2007, PNAS

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 2040

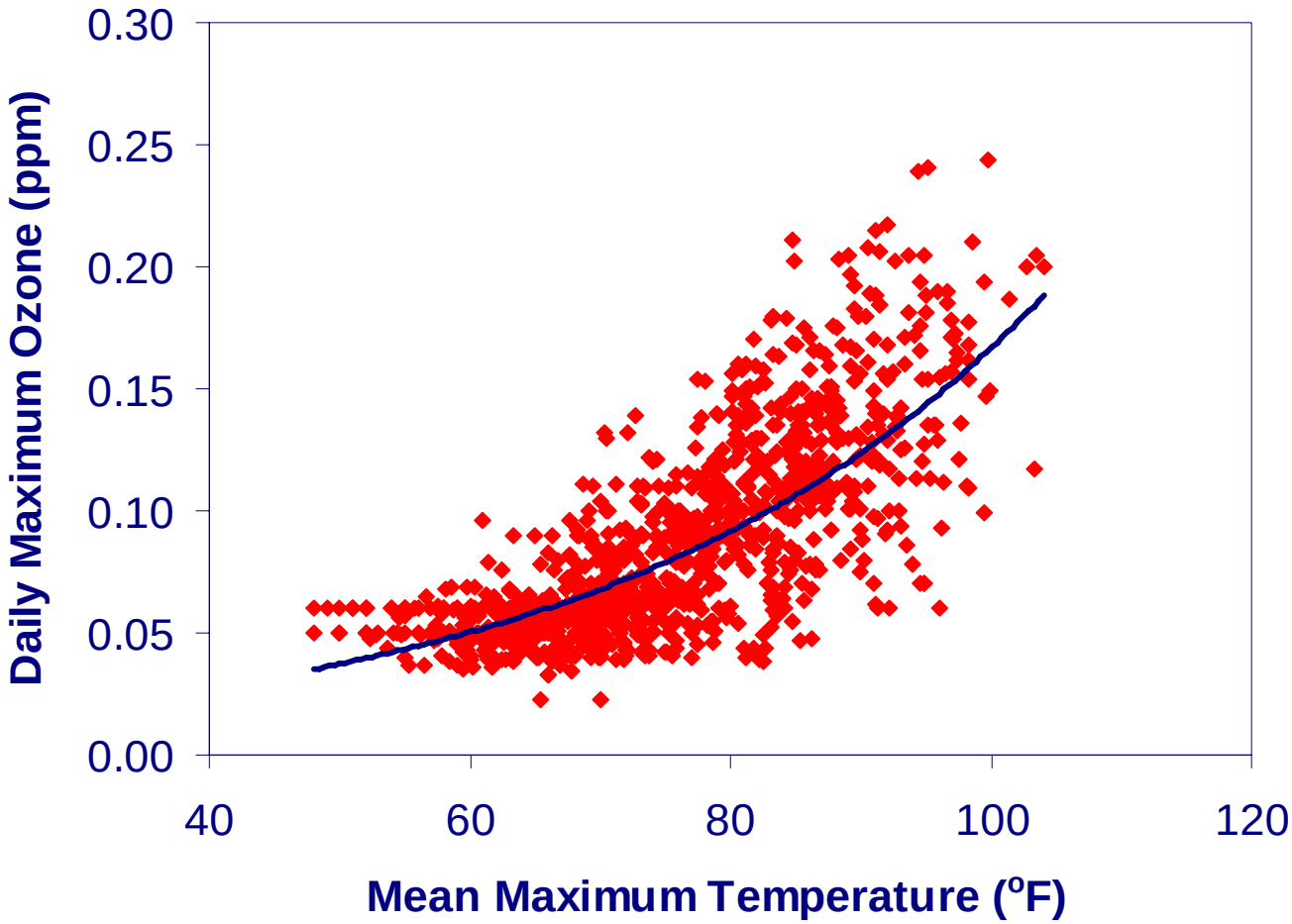


Black lines are observed temps, smoothed & unsmoothed; red, blue, & green lines are Hadley Centre simulations w natural & anthropogenic forcing; yellow is natural only.

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

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

Where we're headed: 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*.

Where we're headed: Agriculture

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

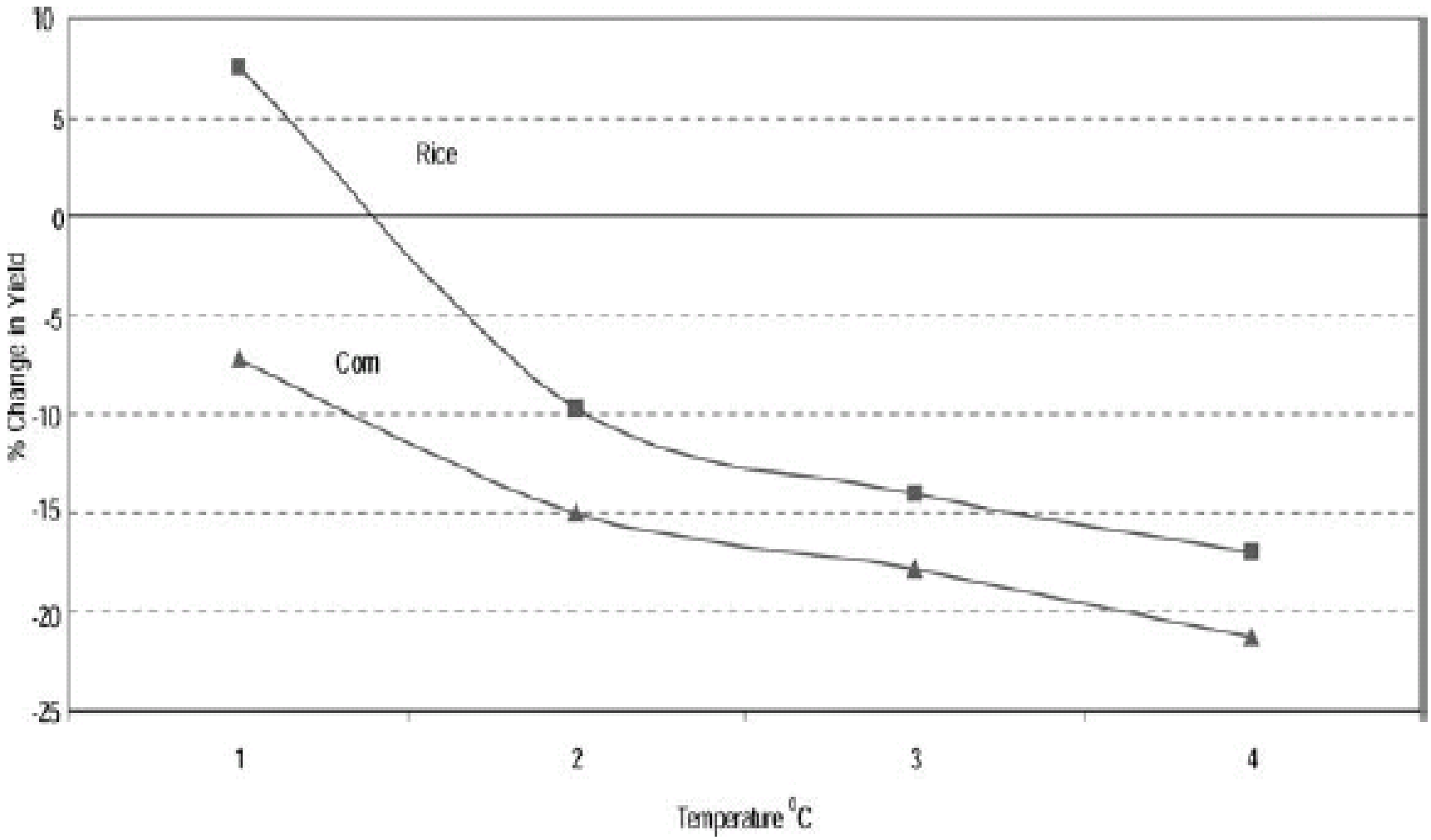
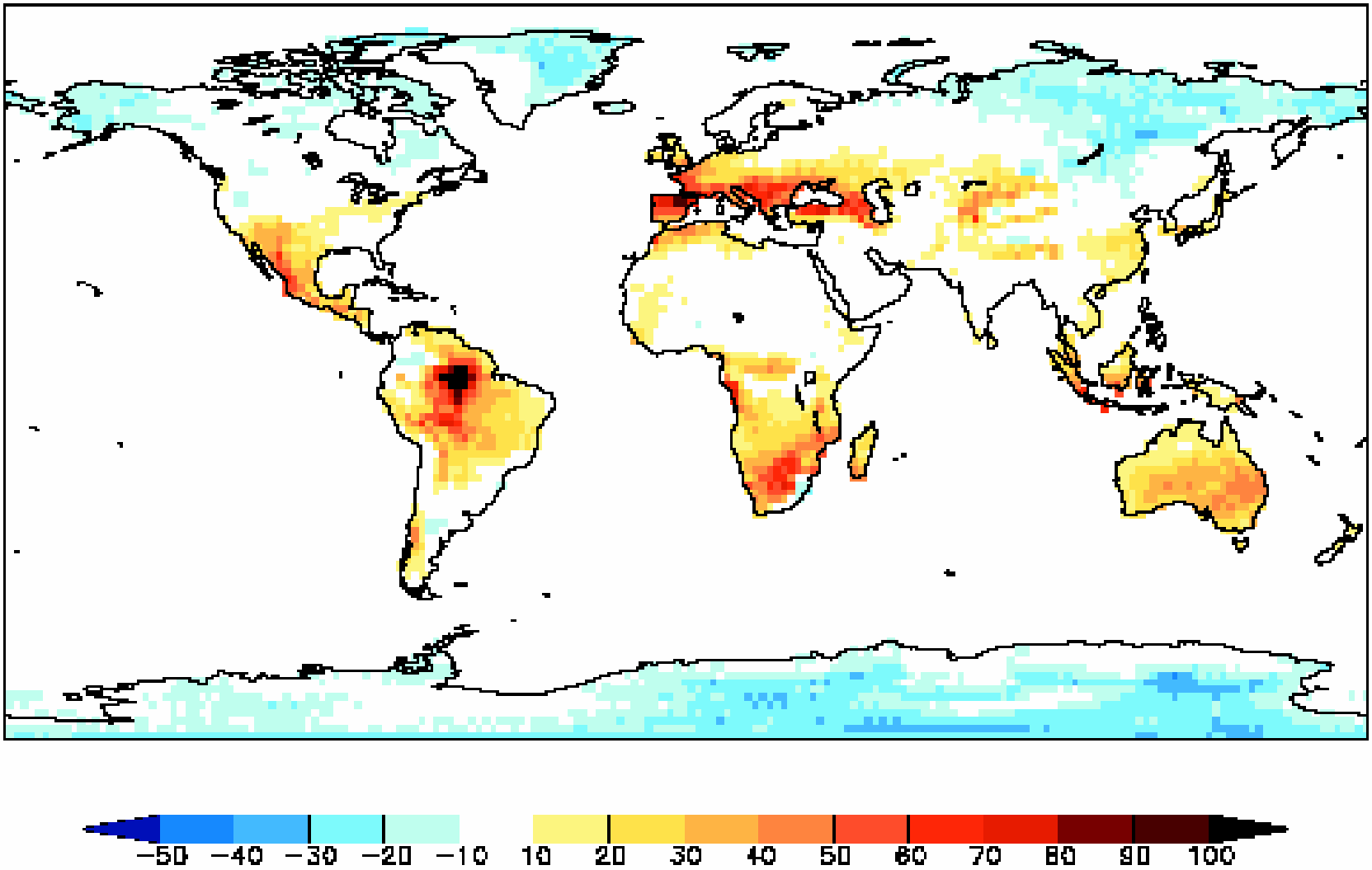


Figure 1. Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. CO_2 direct effects were included in all studies.

Easterling and Apps, 2005

Where we're headed: droughts

Drought projections for IPCC's A1B scenario



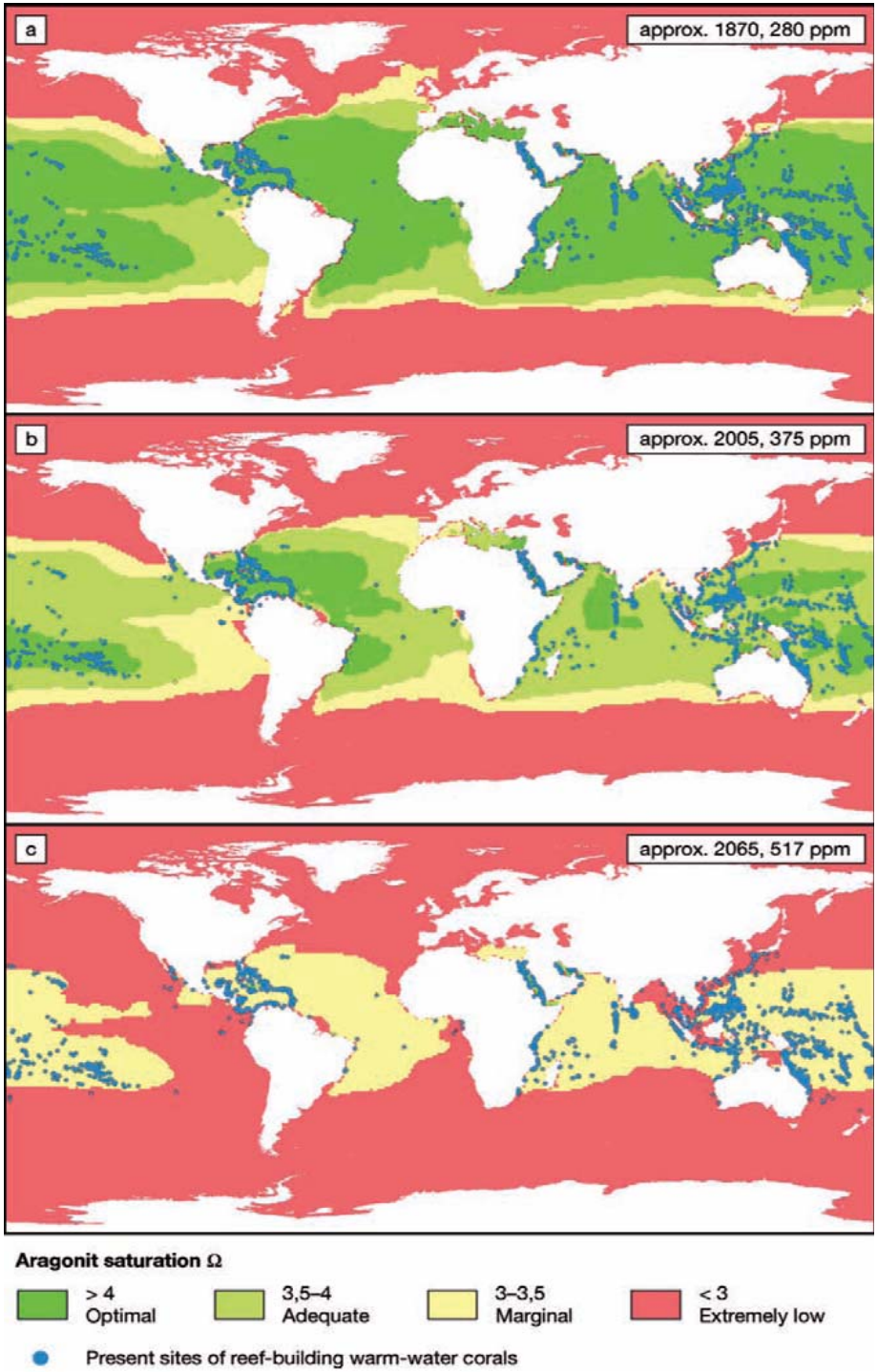
Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.

Where we're headed: Pickling 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.

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



Steffen et al., 2004

Where we're headed: sea level

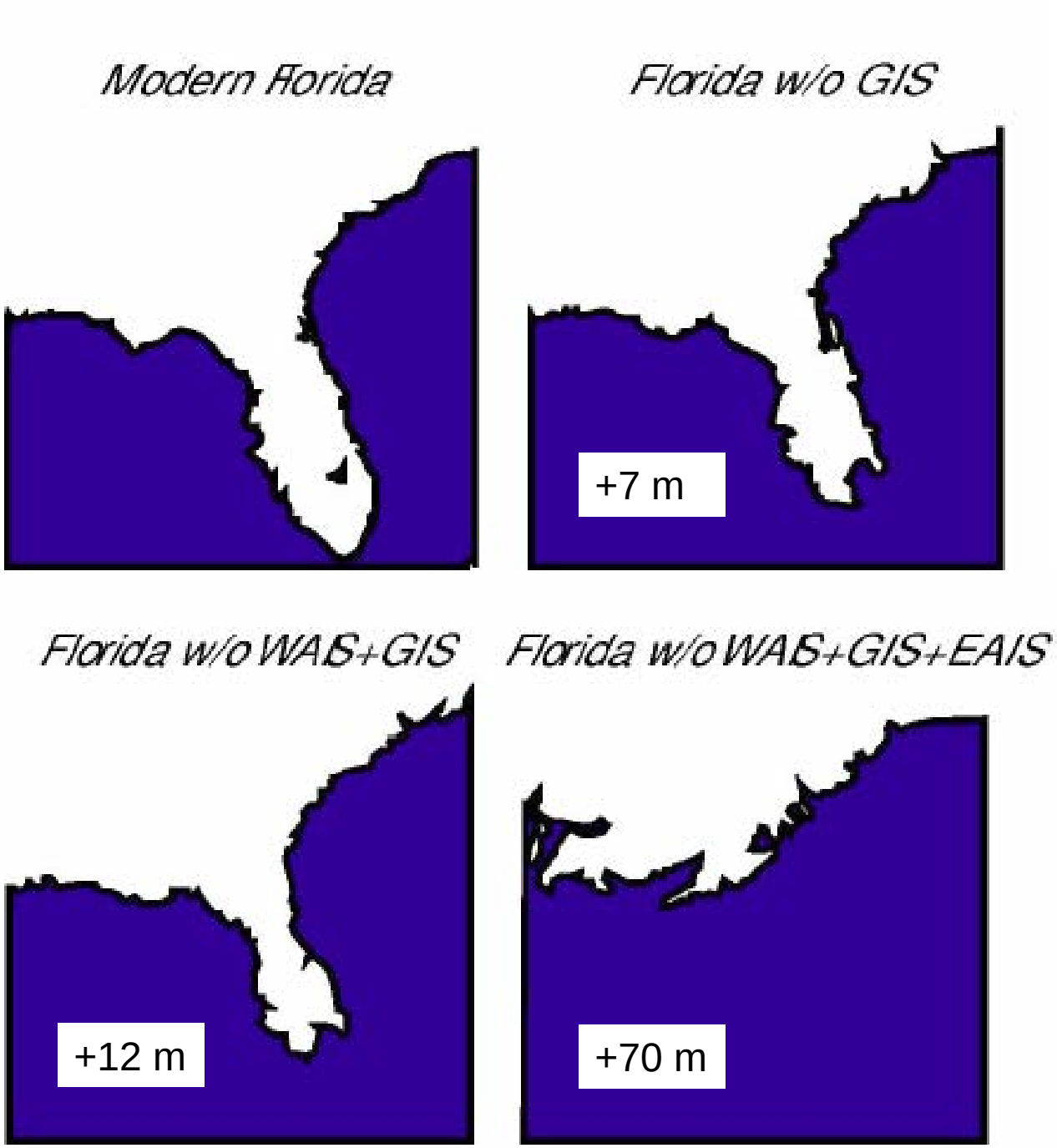
Melting the Greenland and Antarctic Ice Sheets would raise sea level up to 70 meters.

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

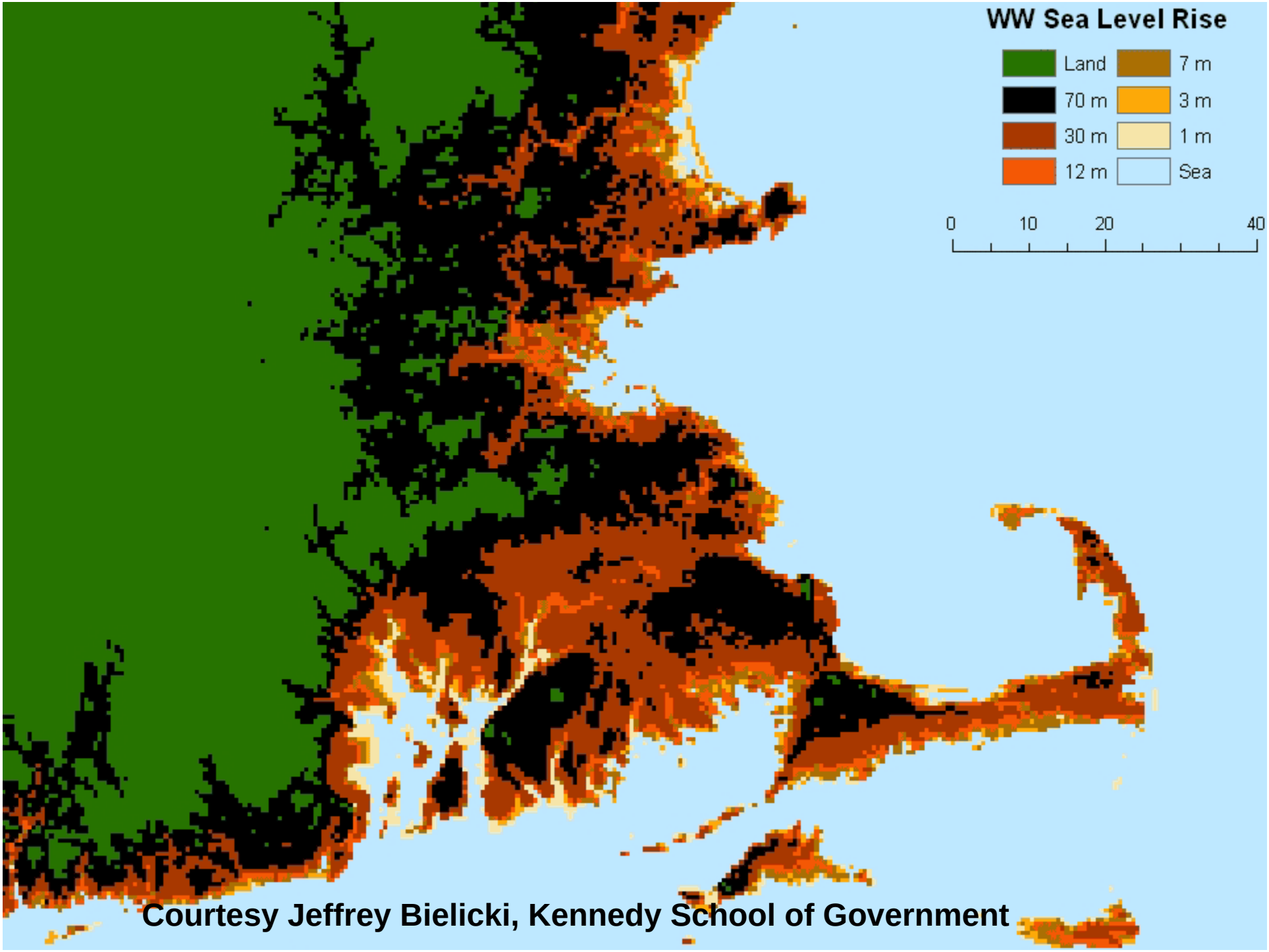
GIS = Greenland Ice Sheet

WAIS = West Antarctic Ice Sheet

EAIS = East Antarctic Ice Sheet



Dr. Richard Alley, 2005



Courtesy Jeffrey Bielicki, Kennedy School of Government

Climate technology:
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…

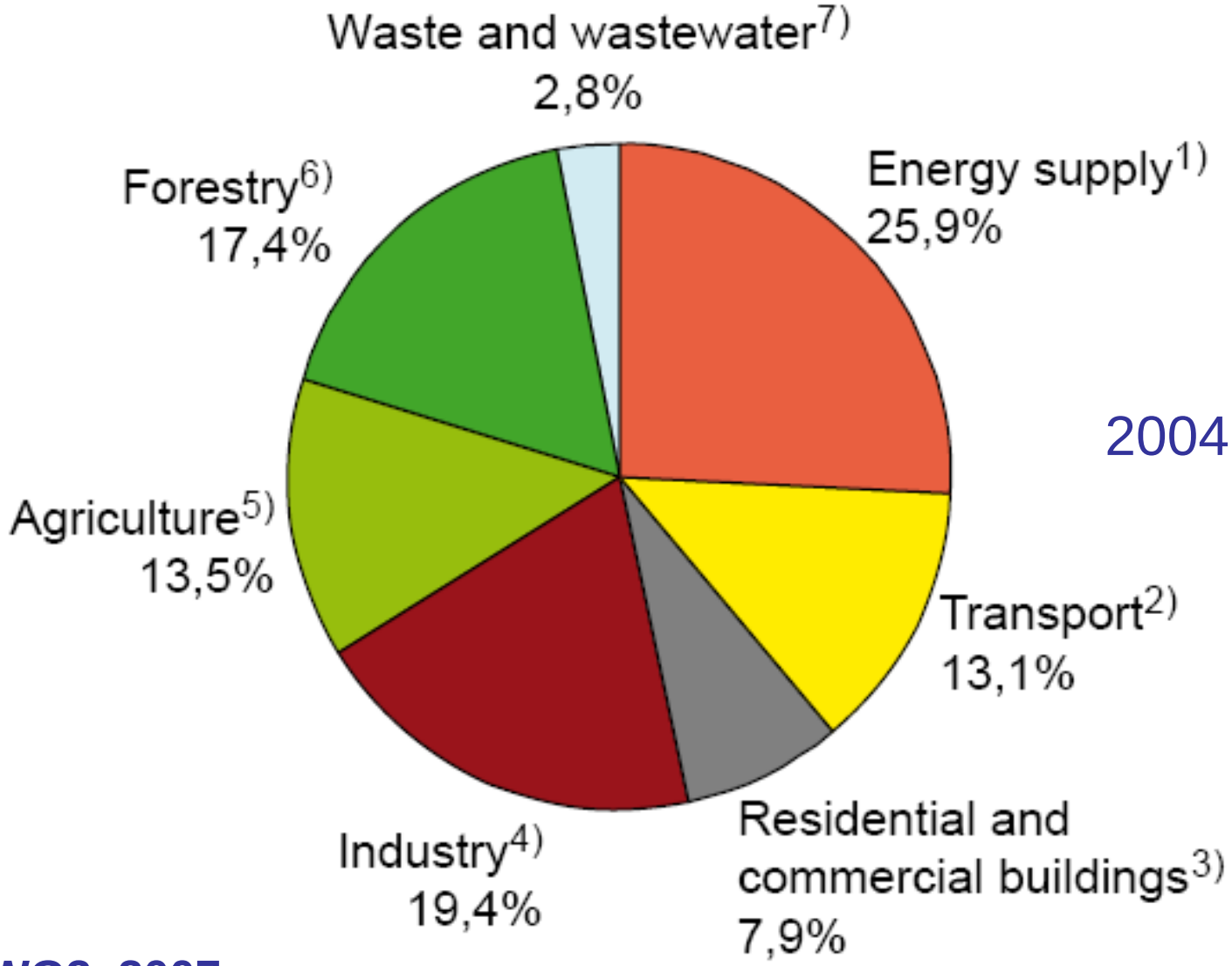
- We're already doing <u>some of each</u>.
- What's up for grabs is the future <u>mix.</u>
- Minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation <u>and</u> a lot of adaptation.
  - Mitigation alone won't work because climate change is already occurring & can't 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.

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.

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.

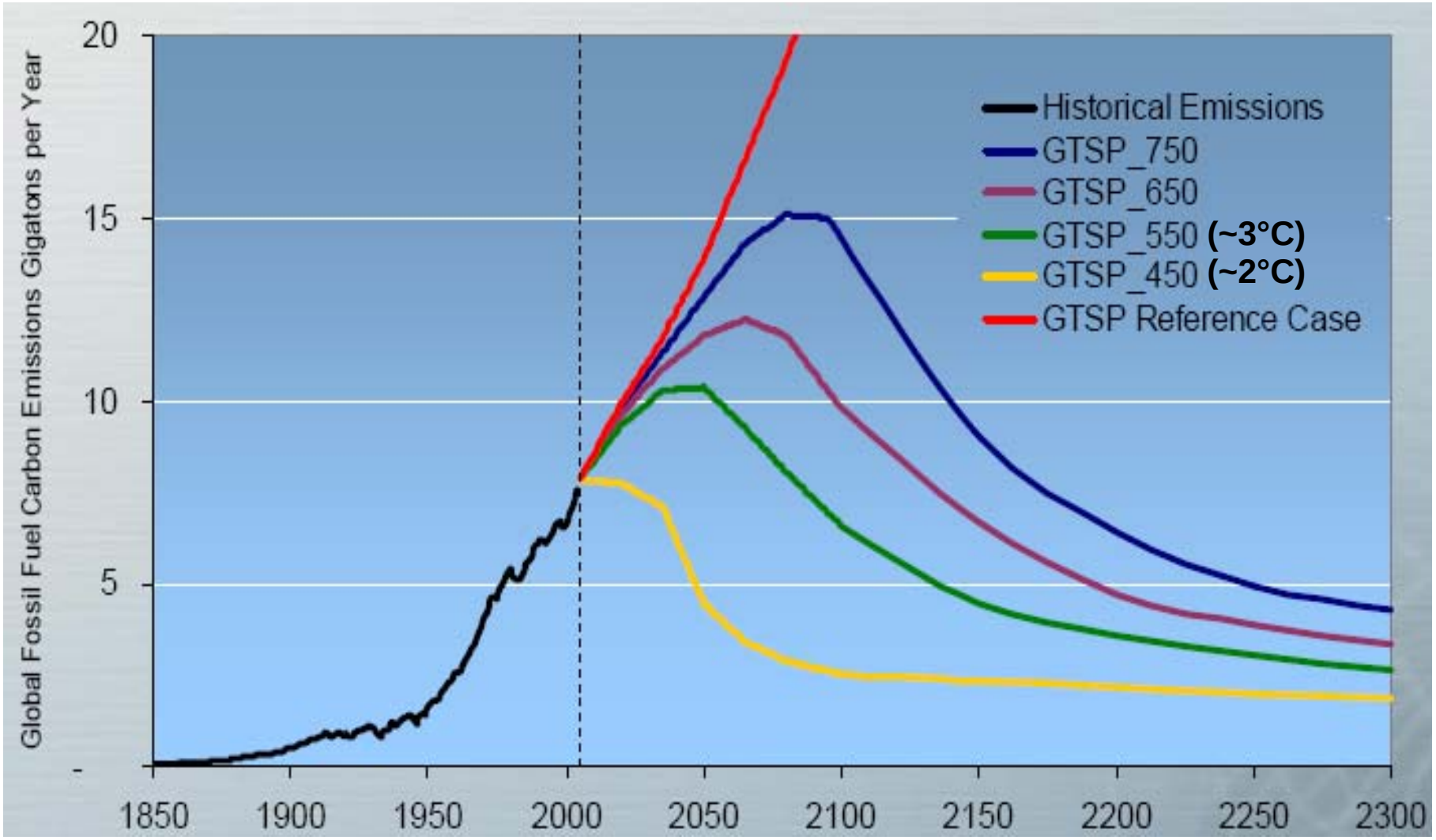
How much, how soon? (continued)

- 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
- 60% of fossil CO_2 came from industrialized countries in 2006, but developing countries will pass us around 2015. Mitigation must happen everywhere.
- Global energy system can't be changed quickly: $15T is invested in it & normal turnover is ~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…

$$6.4 \times 10^9 \text{ pers} \times \$6500/\text{pers} \times 0.012 \text{ GJ}/\$ \times 15 \text{ kgC/GJ}$$

$$= 7.5 \times 10^{12} \text{ kgC} = 7.5 \text{ billion tonnes C}$$

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
- hydrogen: energy to make it, infrastructure to store & transport it
- end-use efficiency: education, other barriers

Big problem & lack of panacea mean…

- We need a portfolio of approaches
  - Not just one or two, but many.
  - But not necessarily everything on the menu: developing the better options to their full potential may allow foregoing costlier and riskier ones.
- We need increased research & development on all of the options to try to
  - understand their potential & limitations
  - improve their performance,
  - lower their costs, and
  - reduce their adverse side effects,

so future menu can be better than today's.

Deployment must be on a large 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, <u>or</u>
- fuel economy of 2 billion cars ~60 mpg instead of 30, <u>or</u>
- carbon capture & storage for 800 1-GWe coal-burning power plants, <u>or</u>
- 700 1-GWe nuclear plants replacing coal plants, <u>or</u>
- 1 million 2-MWe(peak) wind turbines replacing coal power plants <u>or</u>
- 2,000 1-GWe(peak) photovoltaic power plants replacing coal power plants

We can't just think big. We have to think huge.

Climate economics

Some good and bad news

- Good: The cheapest, fastest, cleanest emissions reductions come from <u>increasing the efficiency of energy use</u> in buildings, industry, and transport.

- Good: <u>Efficiency increases are often “win-win”</u>: co-benefits in saved energy, increased domestic jobs & energy security, reduced pollution are more than worth their costs.

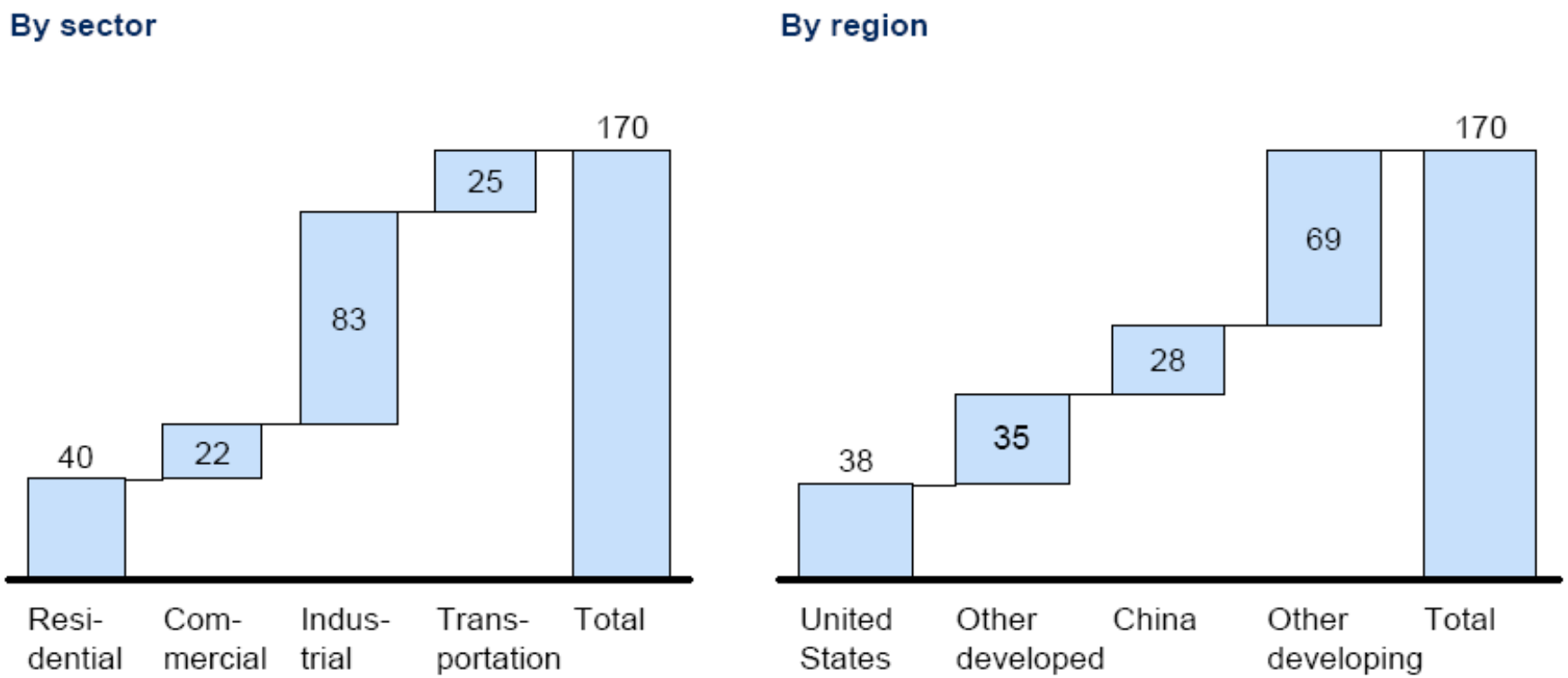
- Good: <u>Supply-side mitigation is also sometimes “win-win”</u>, e.g., wind, some biofuels.

- Bad: <u>The “win-win” approaches will not be enough</u>. Adequate mitigation requires putting a price on emissions of GHG (via emissions tax or tradable emissions permits).

McKinsey estimate of global energy-efficiency opportunity

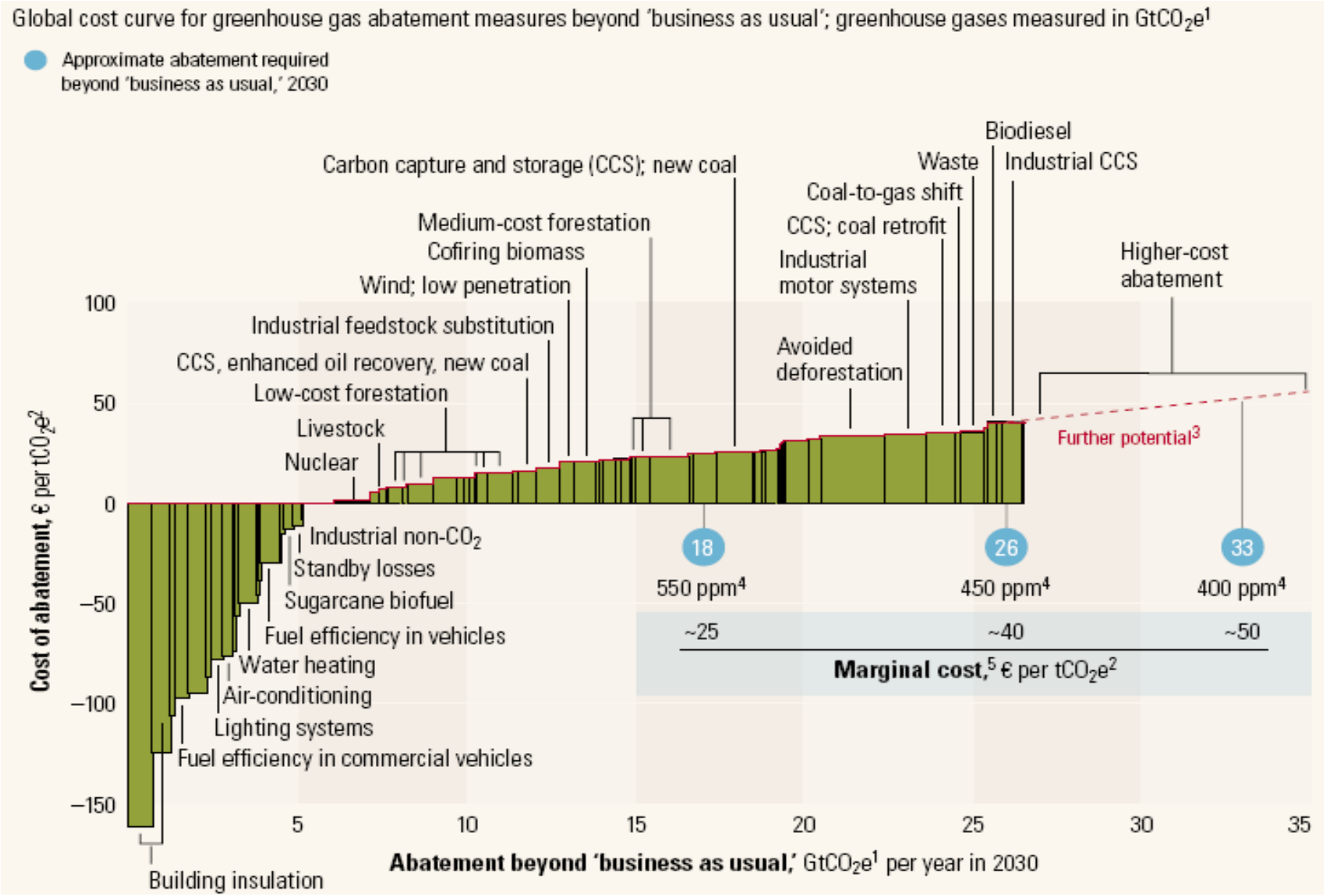
Investment of $170B/yr for 13 years can <u>halve</u> projected global energy demand growth to 2020 at average IRR = 17% and energy savings of $900B/yr in 2020

$ billion per annum



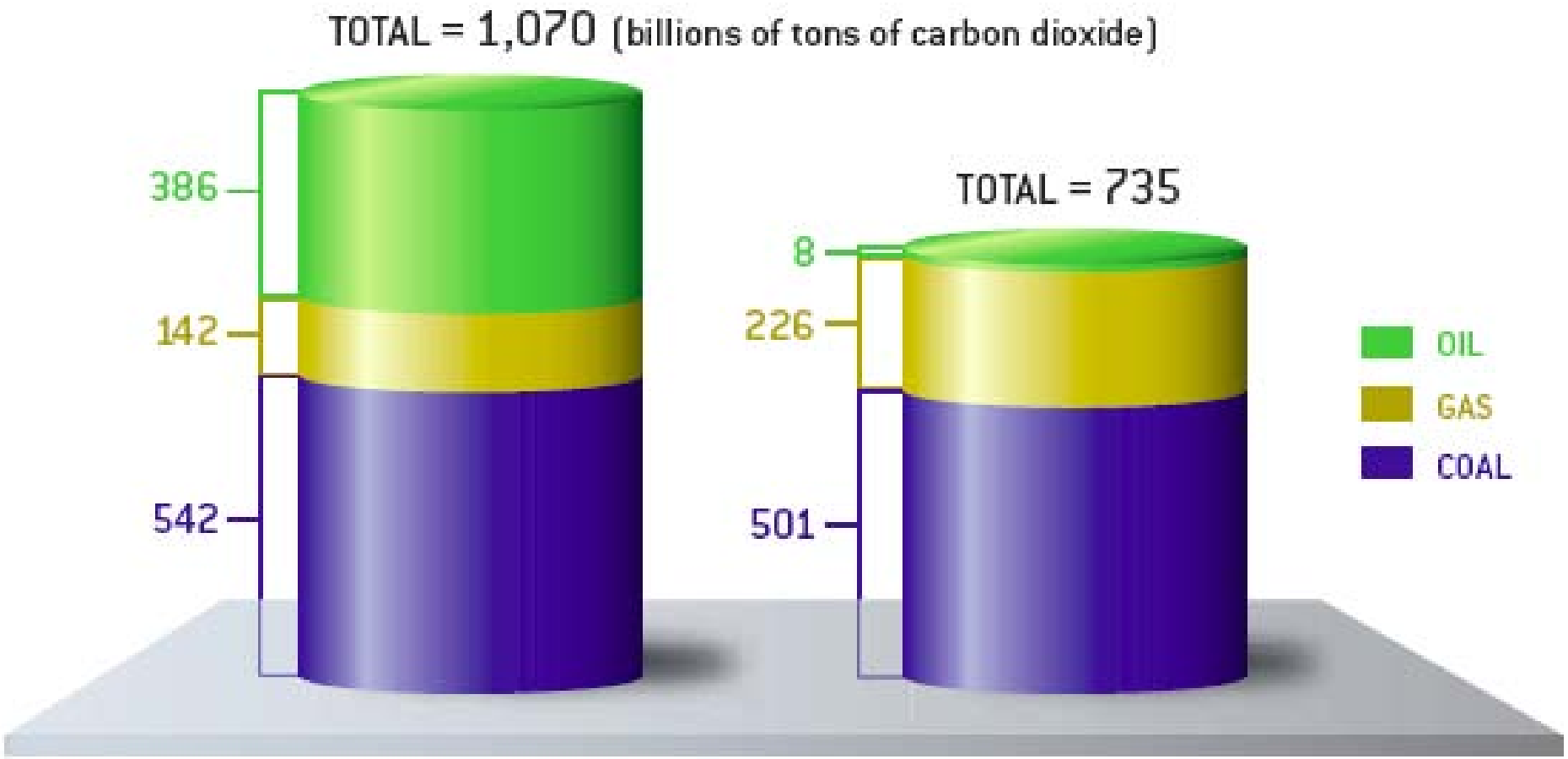
McKinsey Global Institute, Feb 2008

Supply curve for GHG abatement in 2030



McKinsey, 2007

Capturing CO_2 from power plants will be costly, but un-manageable climate change can't be avoided without 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

Can we afford to do it?

- Current global CO_2 emission rate from fossil fuels + deforestation ≈ 10 billion tonnes of C per year.

  Paying $100/tC to avoid half of it would be $0.5 trillion/year, under 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.

- Mainstream models say 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.

Can we afford not to?

- More imaginative view says transformation to climatic sustainability could create an economic boom.
- Economic damages of <u>not</u> stabilizing climate are incalculable (literally) but likely >> mitigation costs.

Risks & opportunities for firms & investors

Global climatic disruption entails both…

- big dangers for firms and investors who make bad choices (or no choices) about how to respond to the risks posed by climate change; and
- big opportunities for firms and investors who act creatively and aggressively to help society reduce the risks it faces from climate change…and make money doing so.

Business risks from climate change

- climate-change damage to firm's assets & operations
- climate-change damage to firm's customers & markets
- liability for firm's contribution (by commission or omission) to climate-change risks
  - financial
  - reputational
- competitive disadvantage as a result of
  - differential effects of government climate policies
  - failure to exploit the opportunities presented by climate change

Business opportunities from climate change

- new/improved products & services for a climate-challenged world
  - identification, characterization, communication, and management of climate-change risks & opportunities
  - mitigation products & services
  - adaptation products & services
- trading emissions permits & offsets
- “green” portfolio development & management

Climate policy:
How do we get it done?

U.S. domestic policy: some thoughts

- It needs to be <u>national</u>

  Separate climate policies for 30 state & 300 cities add up to a nightmare for business.

- It needs to be <u>mandatory</u>

  Measures that are immediately profitable will be done voluntarily, but relying on voluntarism for more is like relying on voluntary speed limits.

- It needs to be <u>stiff</u>

  …meaning both stiff emission charges (to bring big reductions) & difficult to soften (because companies need predictability & the problem isn't going away).

- It needs to be <u>soon</u>

  …if the <u>world</u> is to avoid catastrophe.

Some international policy realities

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

  A matter of historical responsibility, capacity, equity, and existing international agreements.

- Compensation for developing countries for not cutting down their forests will be essential.

  Otherwise current patterns & trends in market forces will lead to near-total destruction, with huge additional CO_2 emissions.

- A formal & binding global agreement on allocation of emissions in the post-2012 period is indispensable.

  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.

The most important next steps

- Accelerate “win-win” mitigation and adaptation measures starting immediately.
- Put a price on GHG emissions now so marketplace can start working to find cheapest reductions
- Complete by 2009 a new global framework for mitigation and adaptation in the post-2012 period
- Ramp up investments in energy-technology RD&D by 4-10X starting now.
- Expand international cooperation on deploying advanced energy technologies starting now.

The USA must switch from laggard to leader if this is to happen worldwide, as needed both to control the risk and maximize the opportunity.

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