

Coping With Climate Change: Issues in Science, Policy, and Education

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Overarching questions

In climate-change science:

- What do we know (or think we know)?
- How (and with what confidence) do we know it?
- What more do we most need to know?
- How (and when) can we know it?

In climate-change policy:

- What should we do and when should we do it?

At the intersection of science and policy:

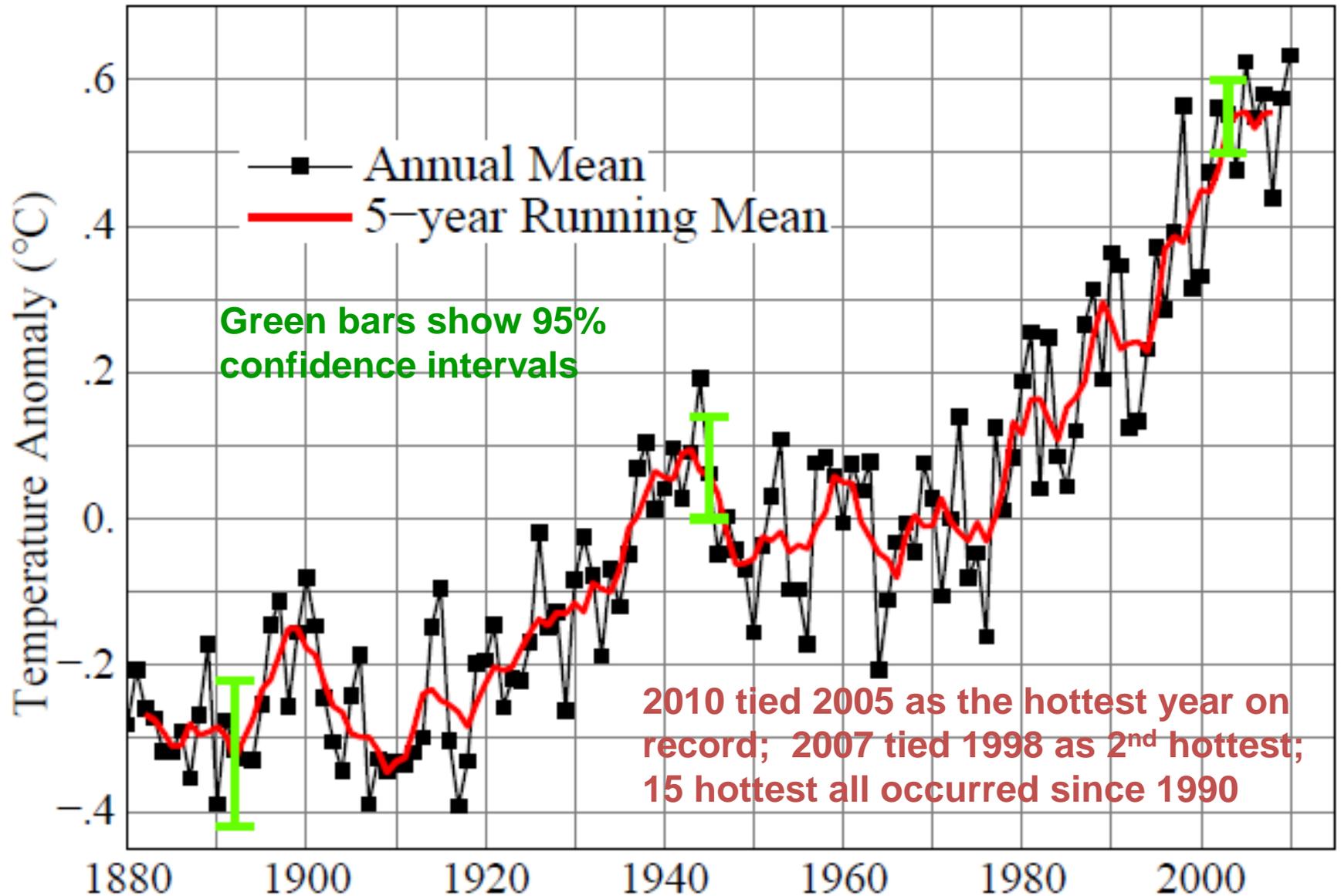
- How can the answers about the science better inform the answers that publics and policy-makers embrace about what to do and when to do it?

The science questions

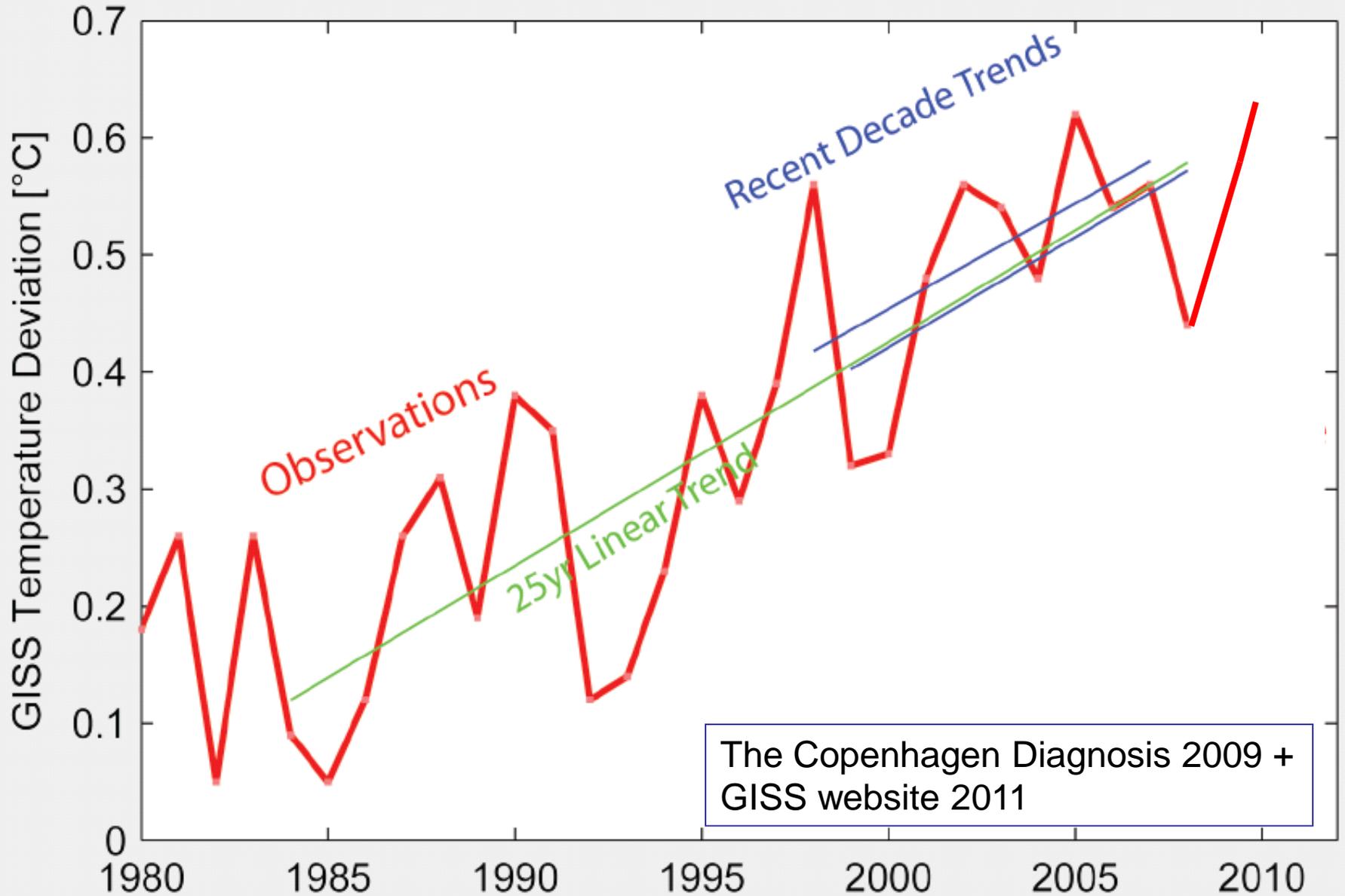
Five myths about the science

1. The Earth stopped warming in the last decade.
2. If it is warming, humans aren't the main cause.
3. A little warming isn't harmful anyway.
4. If there is any danger, it's far in the future.
5. The CRU e-mails & IPCC mistakes show that mainstream climate science is deeply flawed.

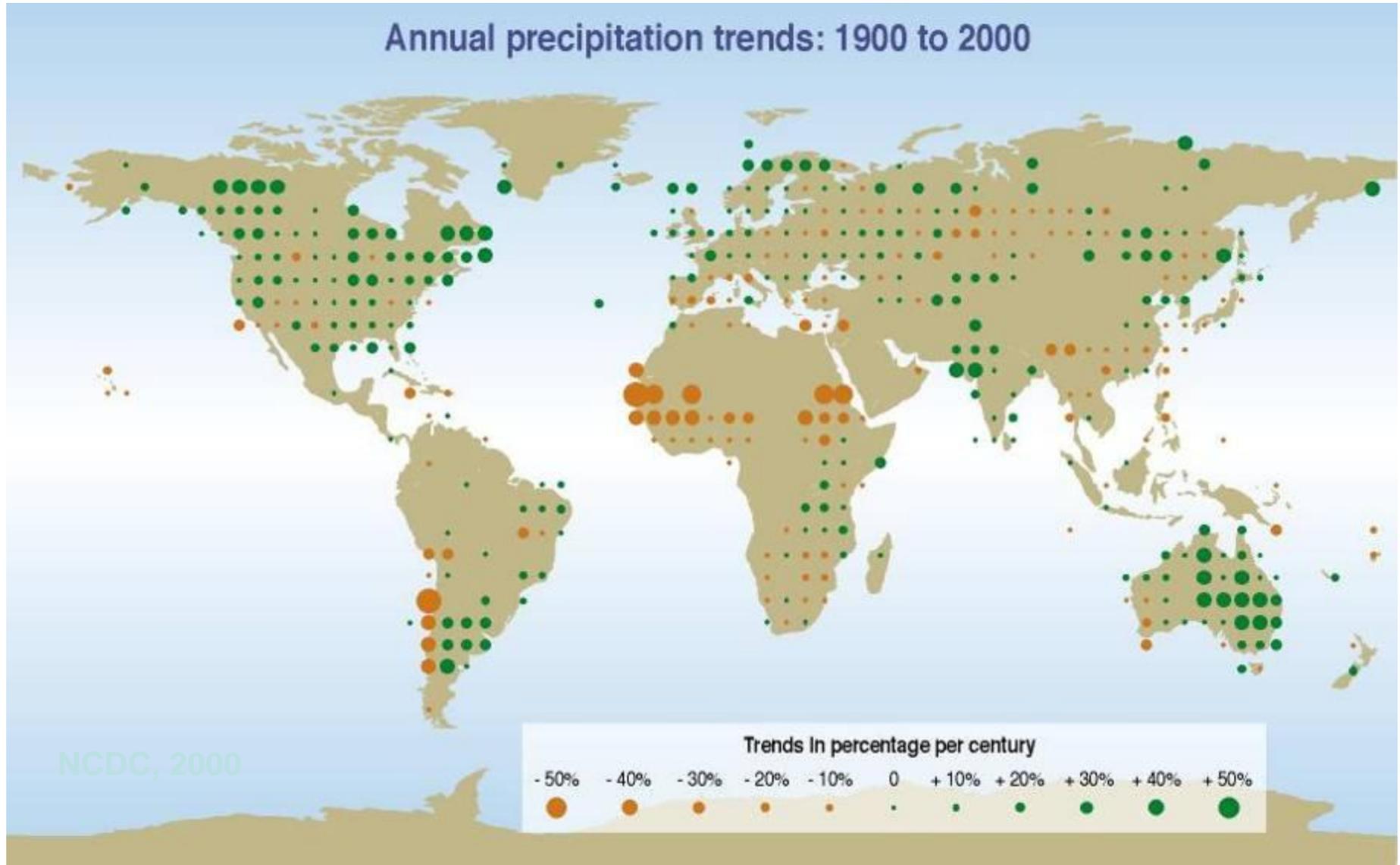
No longer warming? Here's what thermometers say



No longer warming? 1998 was just a bump

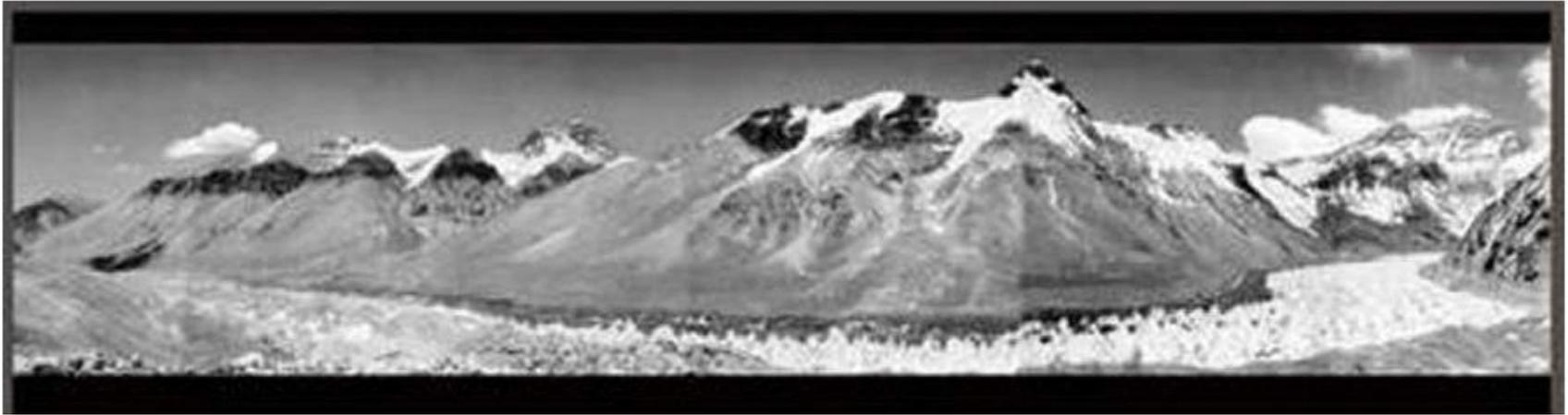


Other climate indicators are changing apace



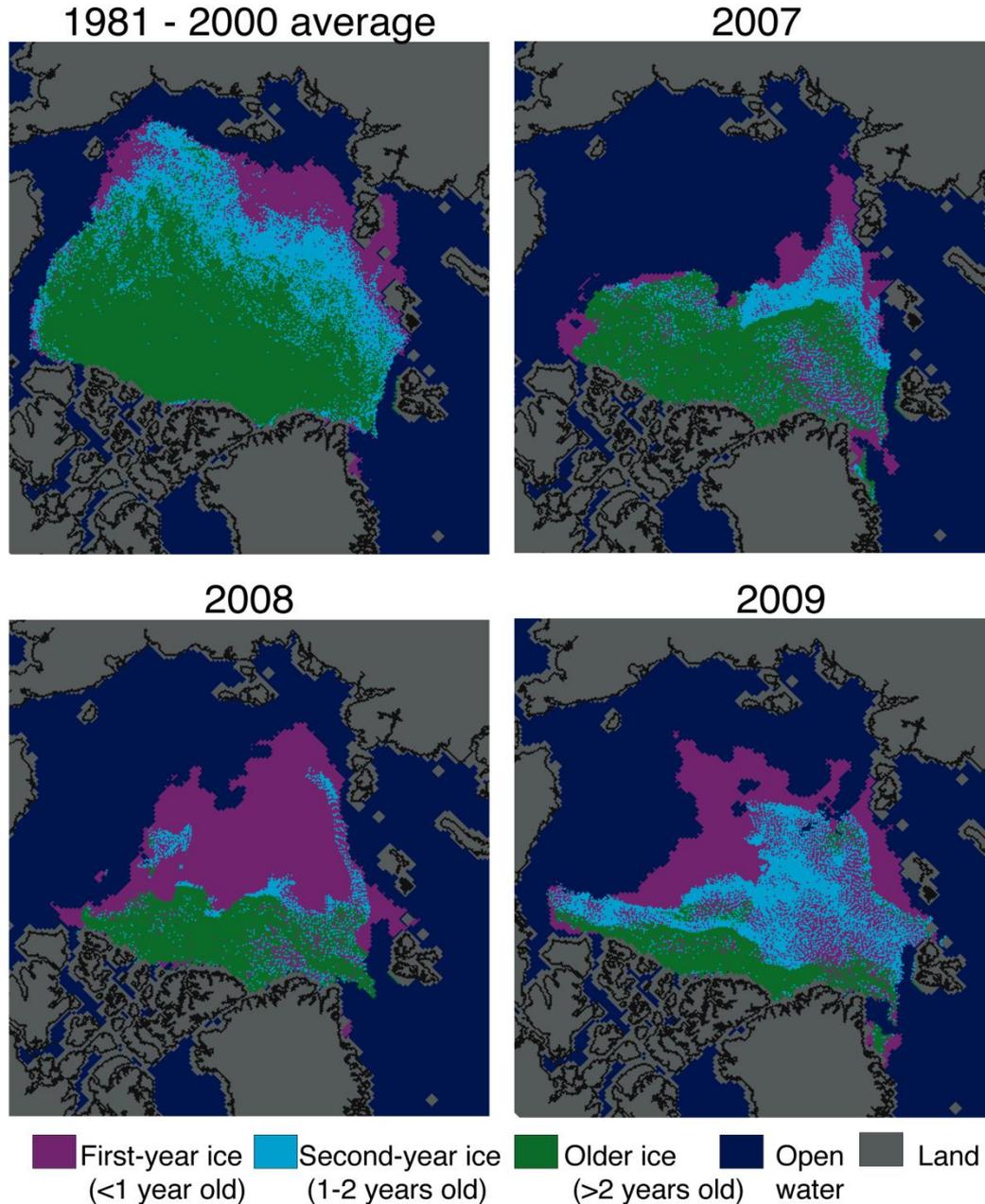
Most places getting wetter, some drier; Earth wetter overall.

Indicators: glaciers retreating



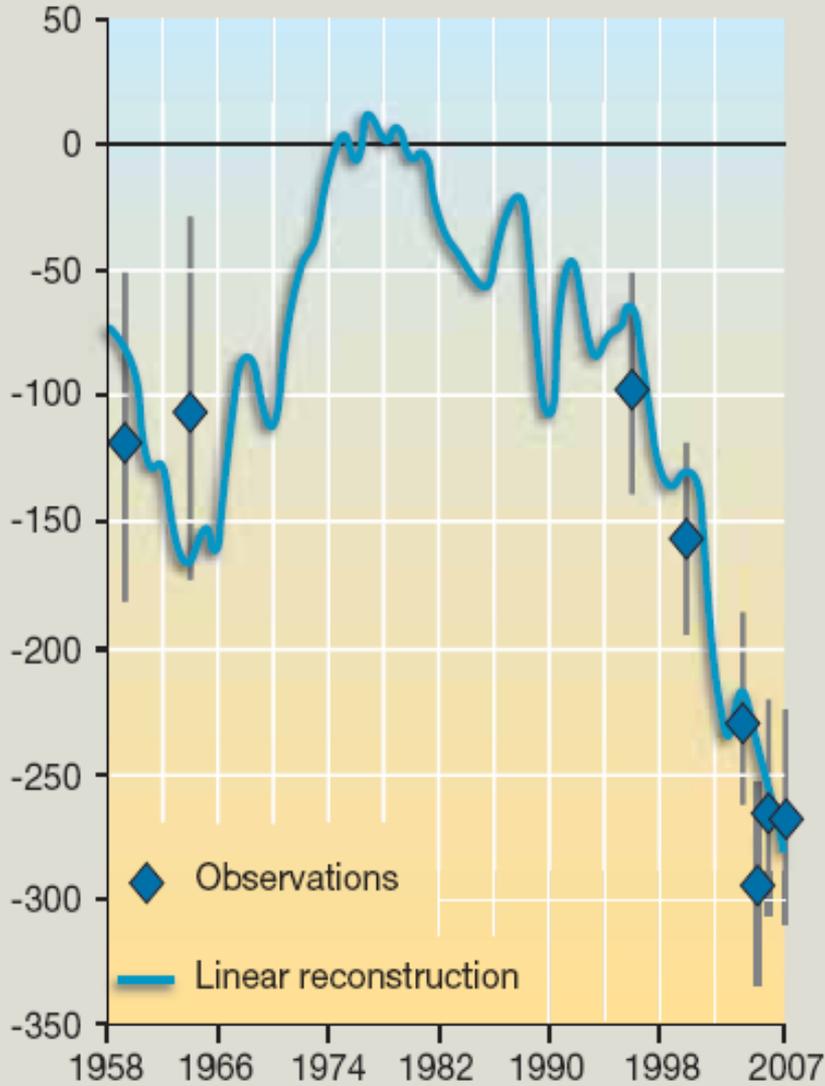
Rongbuk glacier in 1968 (top) and 2007. The largest glacier on Mount Everest's northern slopes feeds Rongbuk River.

Indicators: Arctic sea ice shrinking & thinning

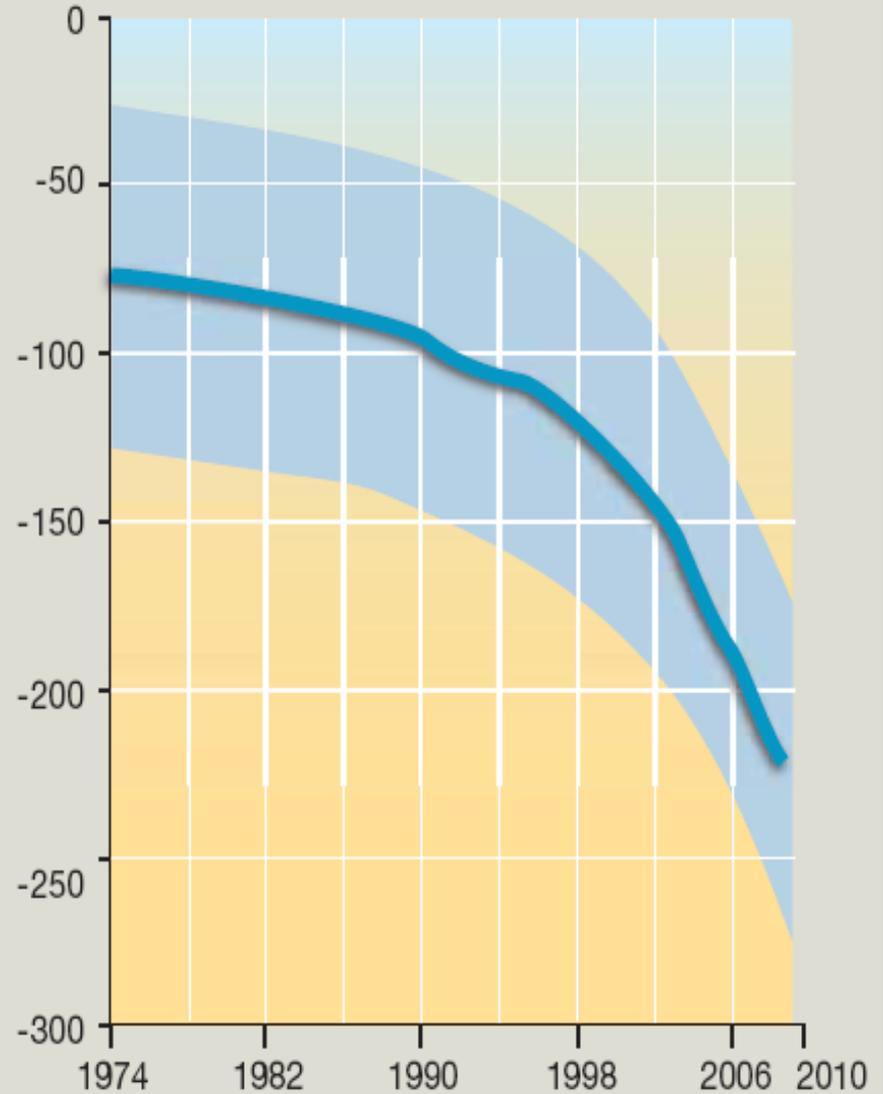


Indicators: Greenland & Antarctic ice losing mass

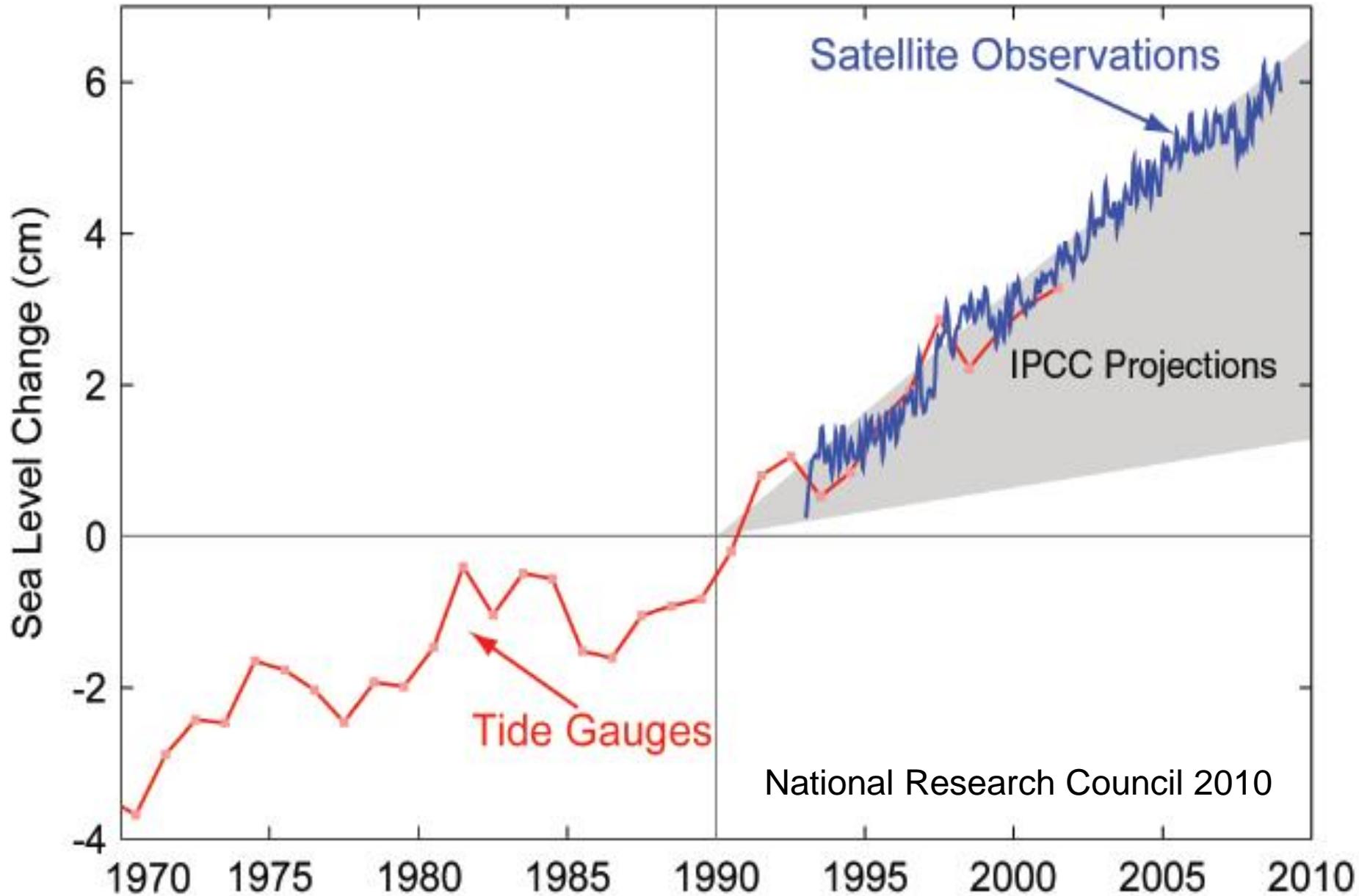
Mass balance of the Greenland Ice Sheet
Gigatonnes per year



Mass balance of the West Antarctic Ice Sheet
Gigatonnes per year



Indicators: sea level rising



What do we know about the causes?

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

Human emissions leading to increases in...

atmospheric carbon dioxide + 1.7

methane, nitrous oxide, CFCs + 1.0

net ozone (troposphere[↑], stratosphere[↓]) + 0.3

absorptive particles (soot) + 0.3

reflective particles (sulfates, etc.) - 0.7

indirect (cloud forming) effect of particles - 0.7

Human land-use change increasing reflectivity - 0.2

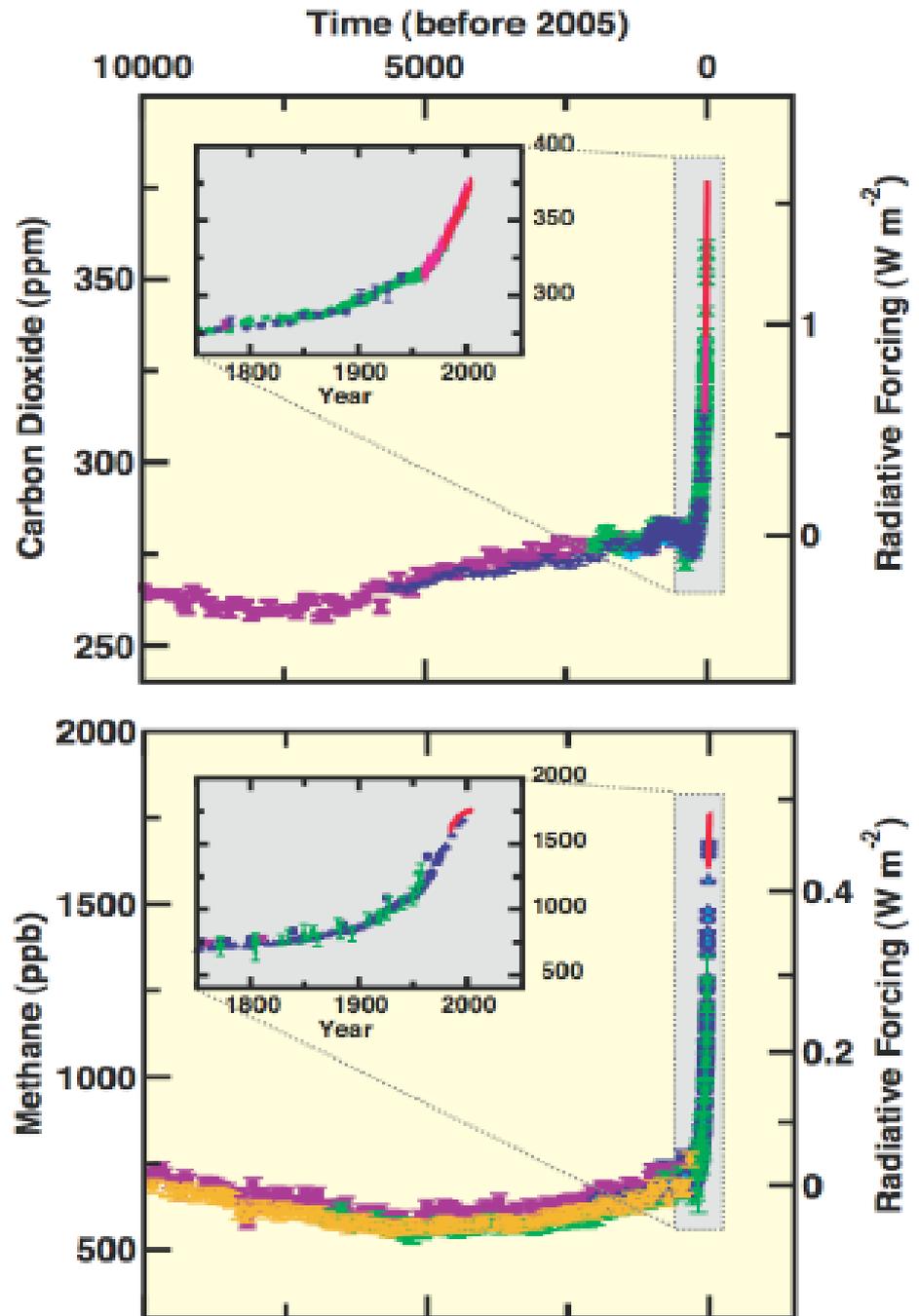
Natural changes in sunlight reaching Earth + 0.1

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

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

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

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

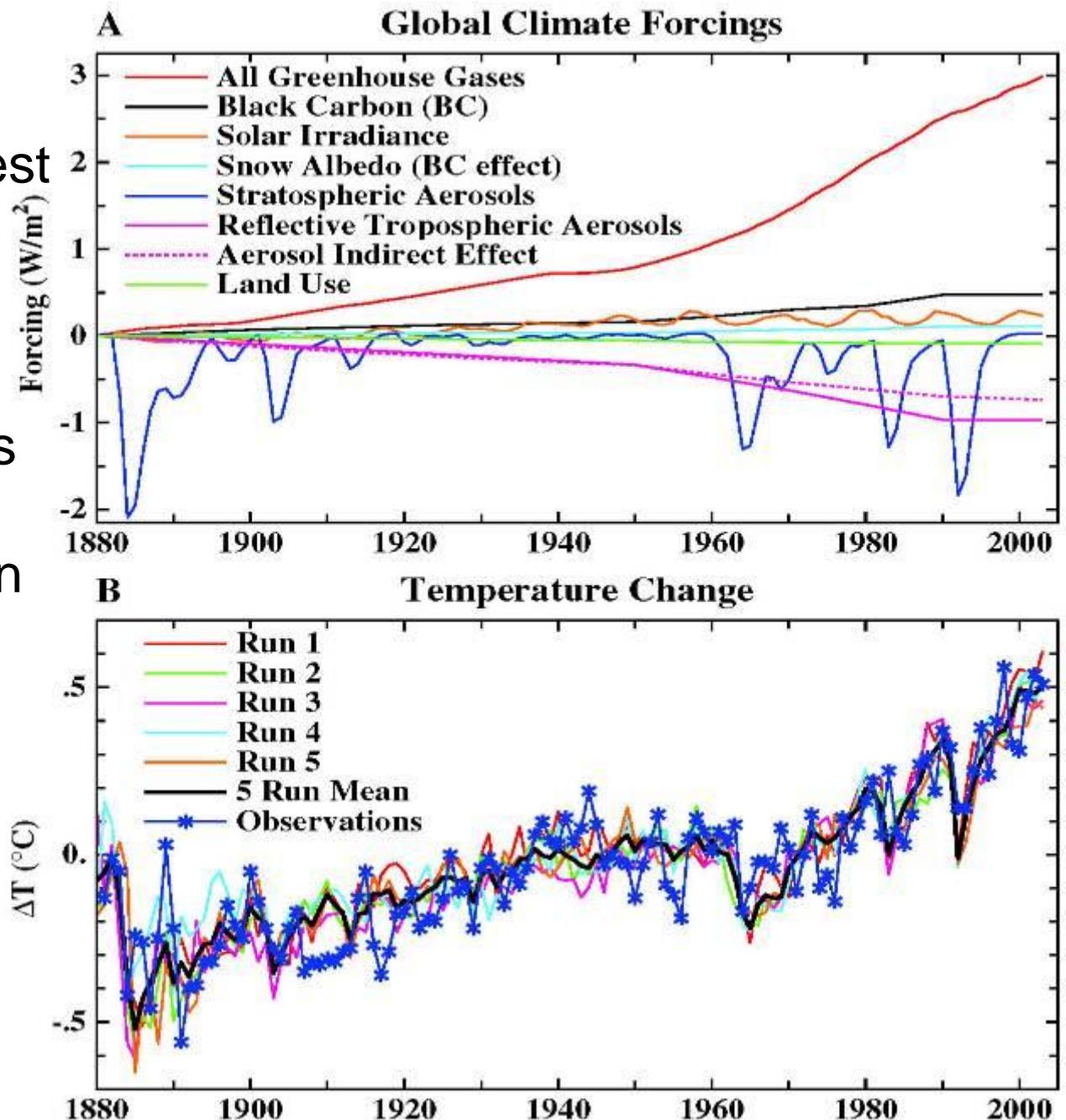


Human influence: the “fingerprint”

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.



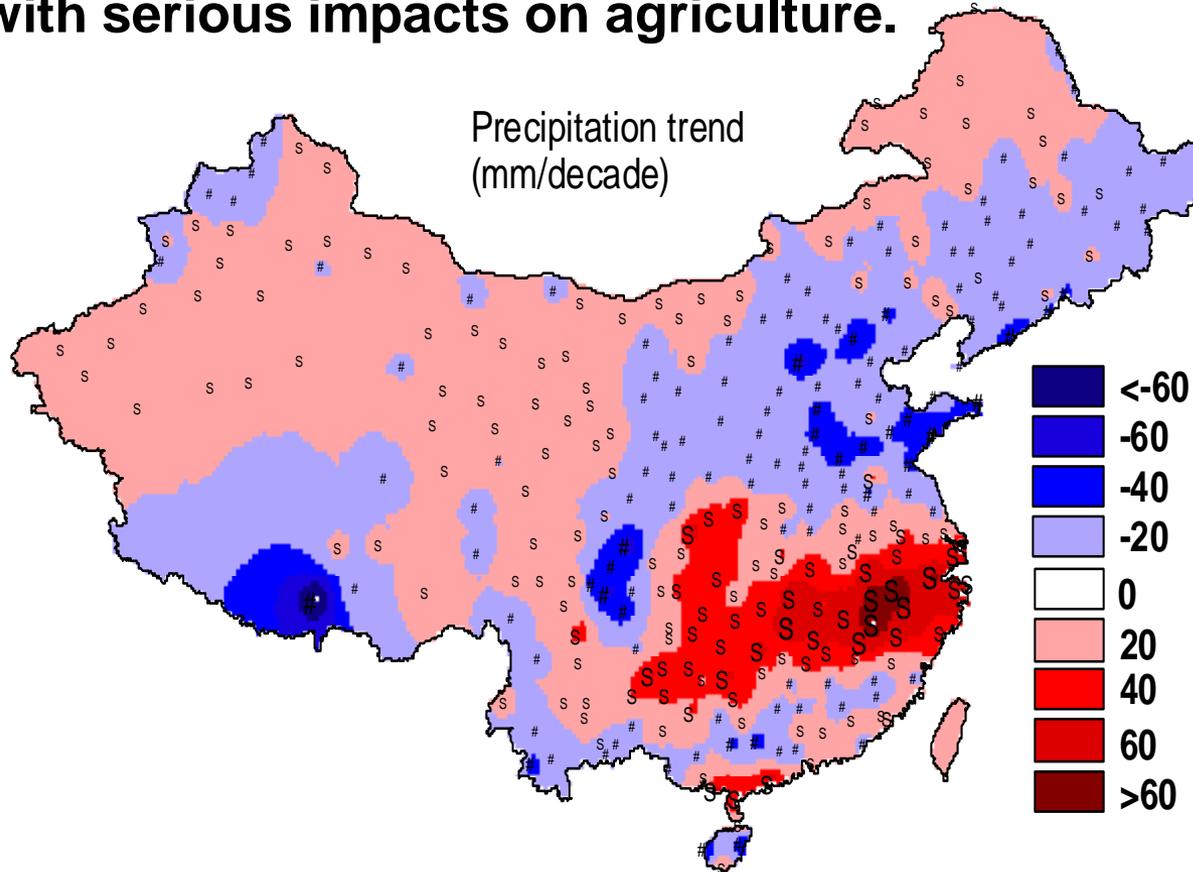
Why worry? What harm can it do?

Climate governs (so altering climate will affect)

- 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

Are we seeing harm? Floods & droughts

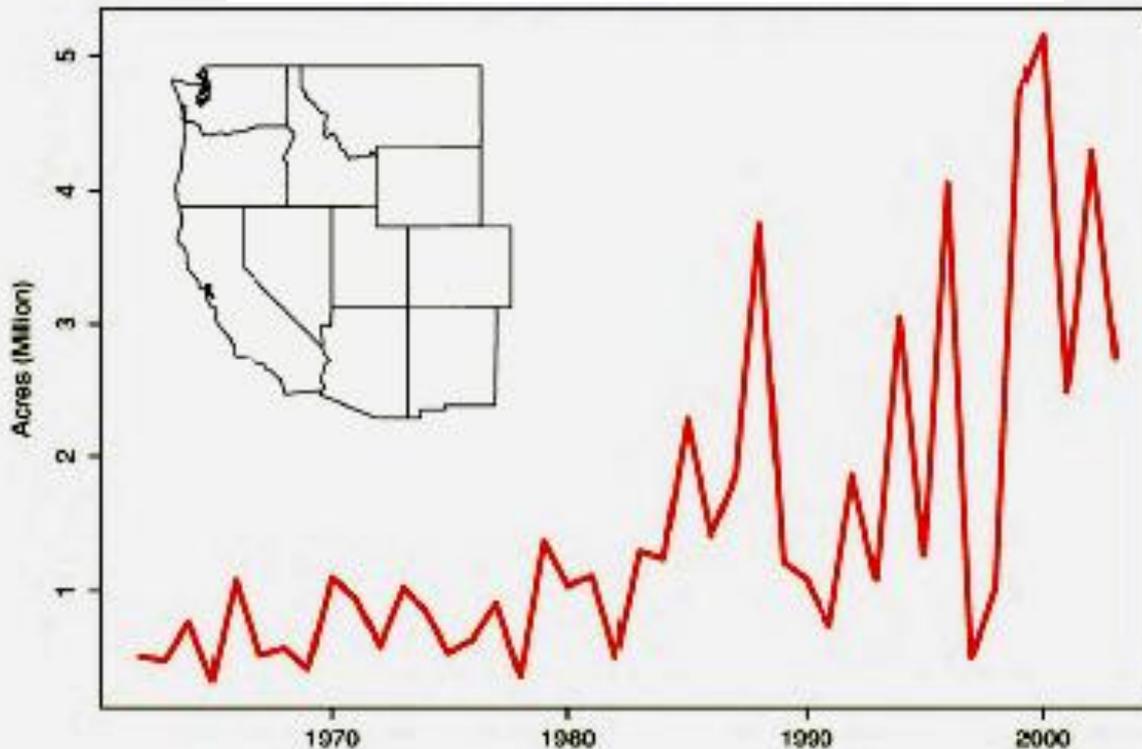
30-year weakening of East-Asia monsoon – attributed to global climate change -- has meant less moisture flow South to North over China, producing increased flooding in South, drought in North, with serious impacts on agriculture.



Are we seeing harm? 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

Are we seeing harm? Pest outbreaks

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



Are we seeing harm? Melting permafrost



Are we seeing harm? Coastal erosion



Courtesy Gary Braasch

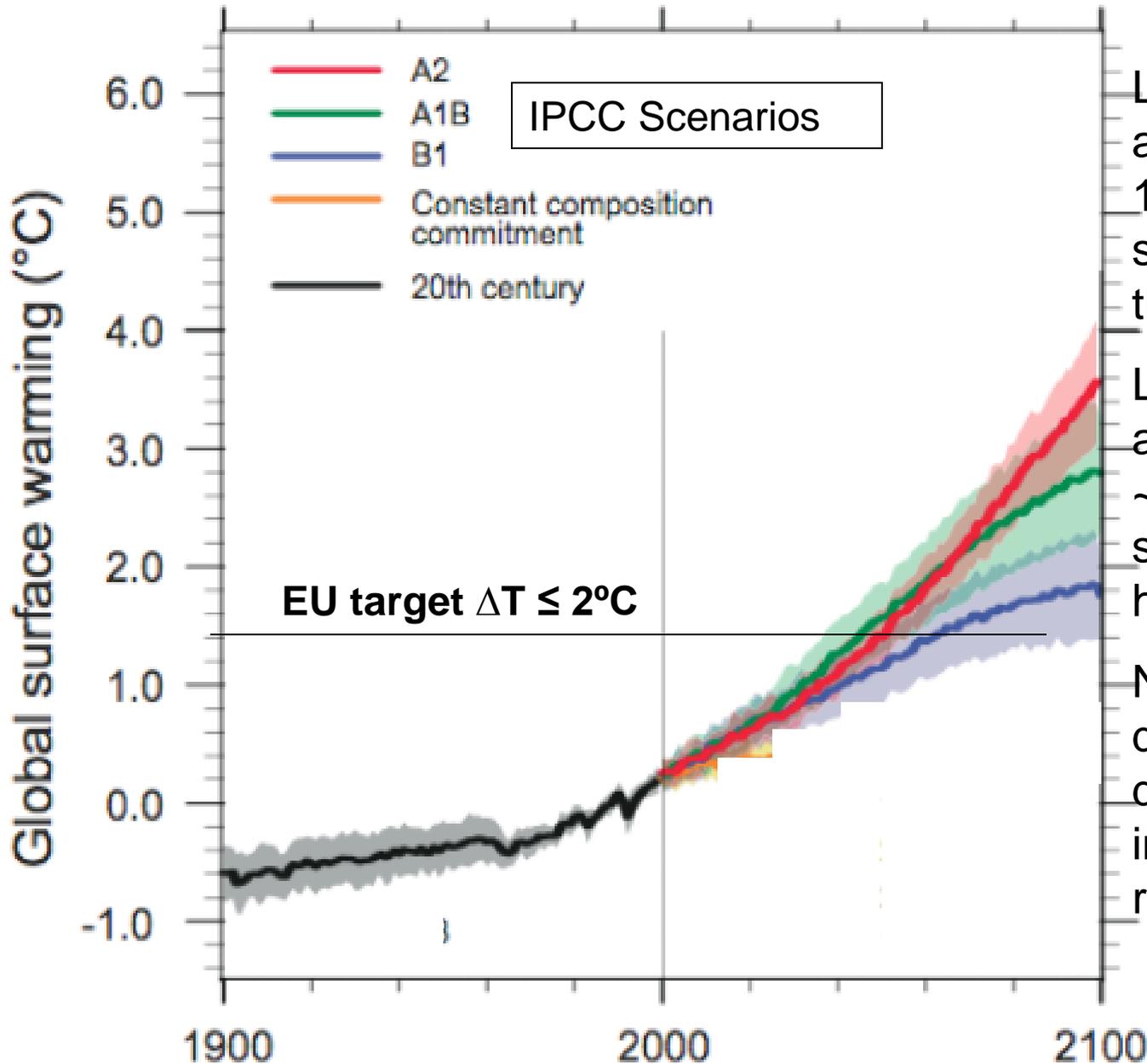
Current harm is widespread

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”

Much worse lies ahead if “business as usual” persists



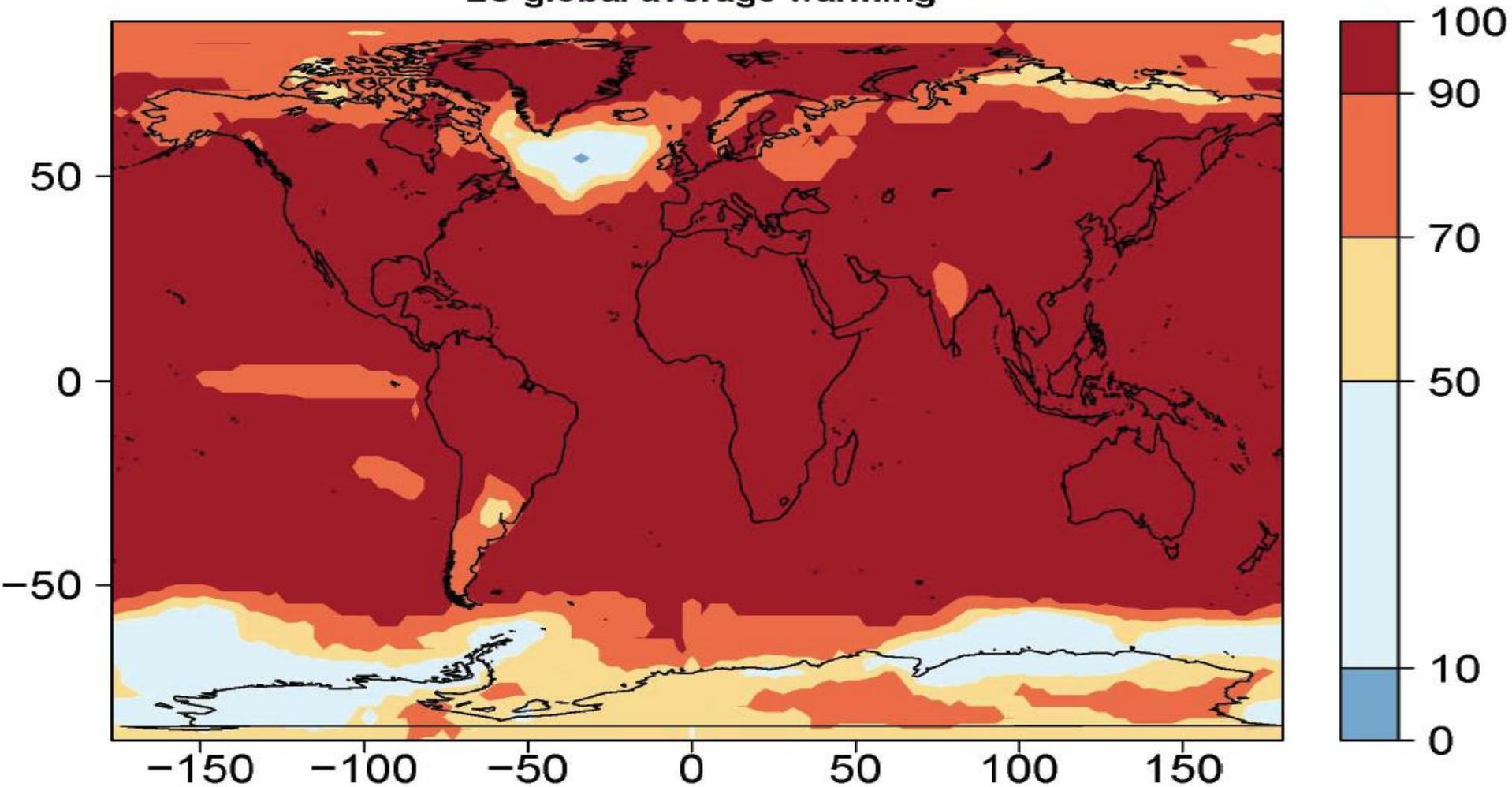
Last time T was 2°C above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

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

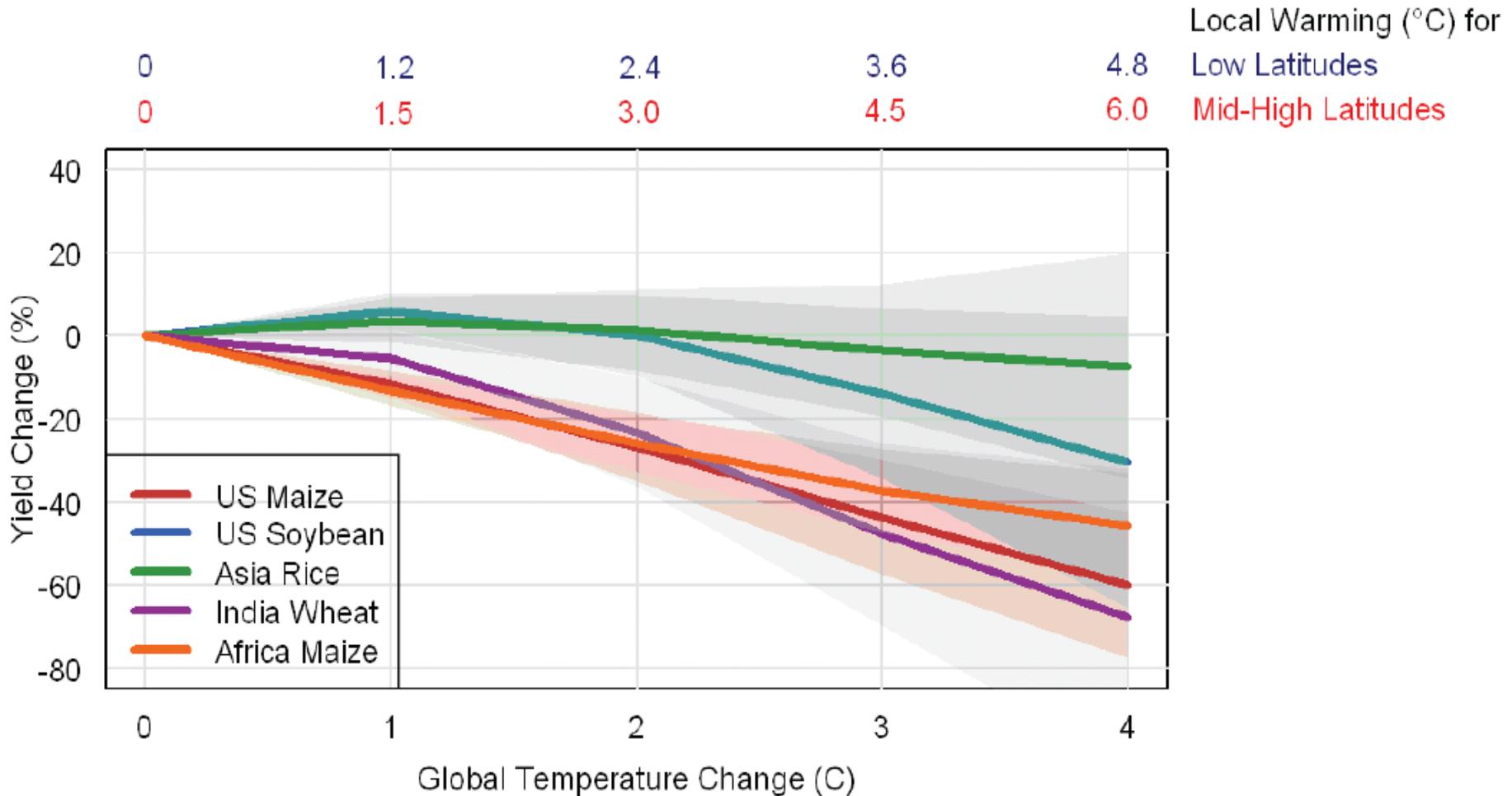
Note: Shaded bands denote 1 standard deviation from mean in ensembles of model runs

What's expected: Hotter summers

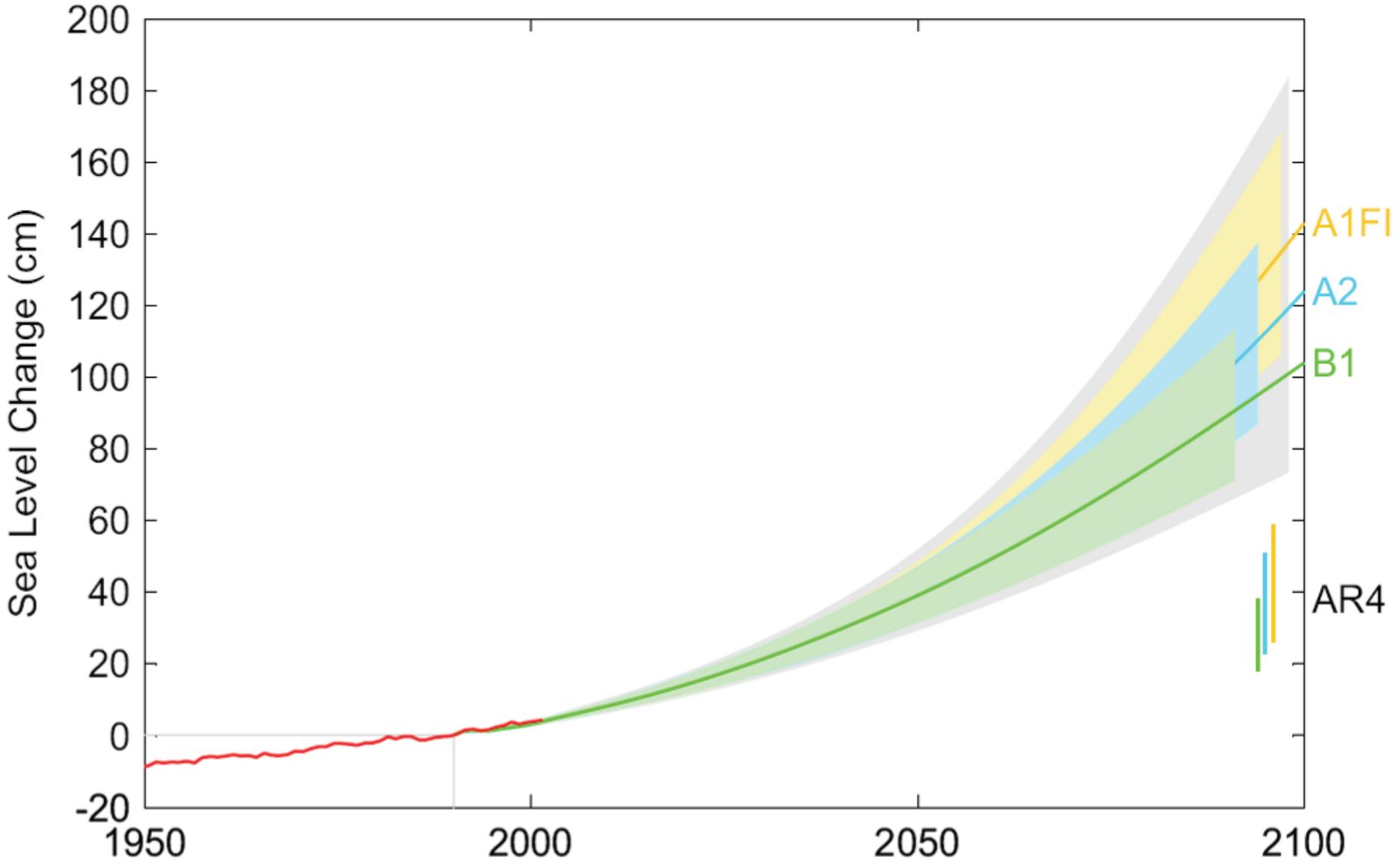
**% summers warmer than current 95th percentile
2C global average warming**



What's expected: declining crop yields



What's expected: sea-level rise to 2100

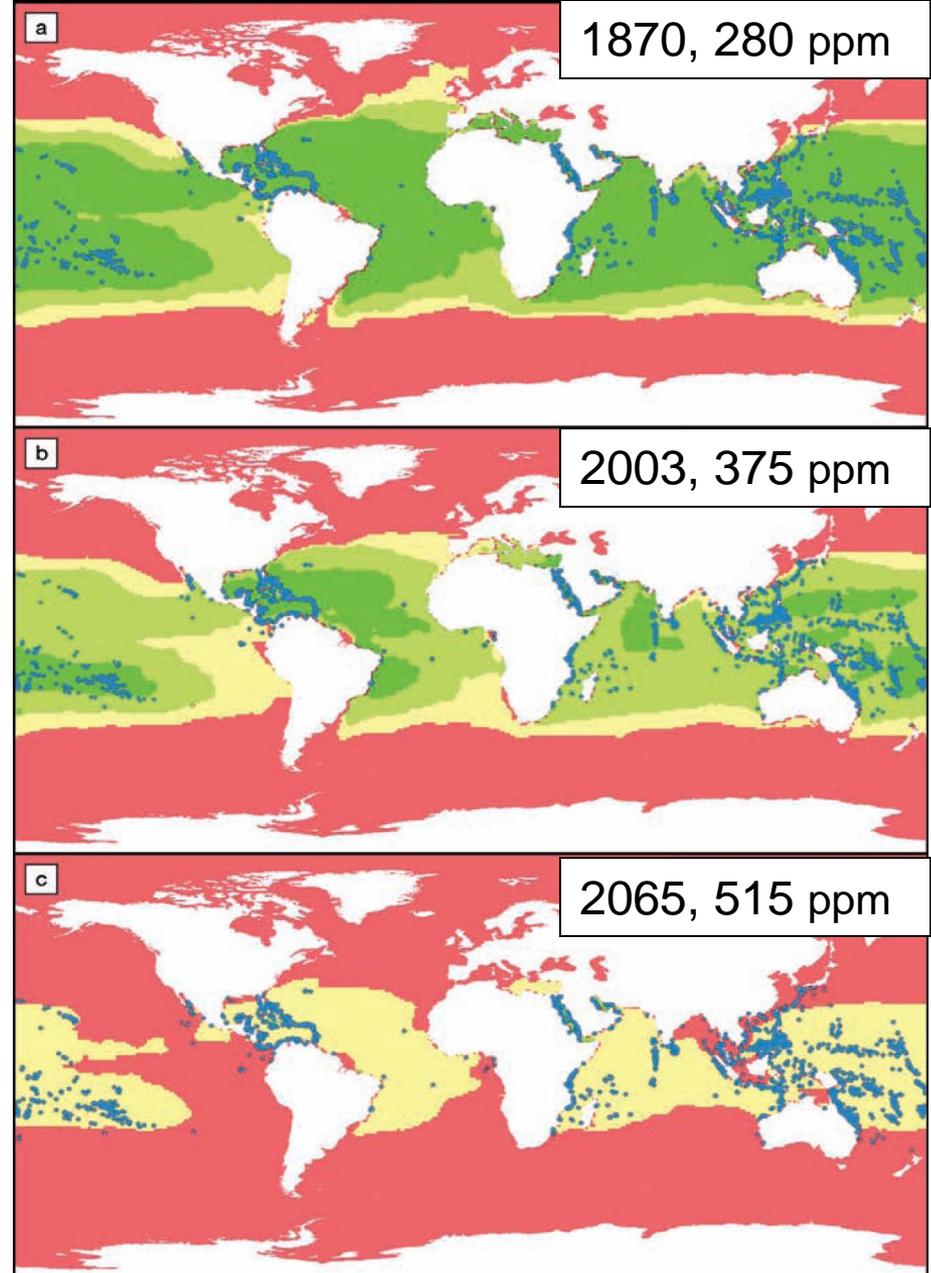


What's expected: falling ocean pH

About 1/3 of CO₂ added to atmosphere is quickly taken up by the surface layer of the oceans (top 80 meters).

This lowers pH as dissolution of CO₂ forms weak carbonic acid (H₂O + CO₂ → H₂CO₃).

Increased acidity lowers the availability of CaCO₃ to organisms that use it for forming their shells & skeletons, including corals.



Aragonit saturation Ω



 Present sites of reef-building warm-water corals

Did the U of East Anglia e-mails and IPCC missteps cast doubt on these conclusions?

- E-mails show climate scientists are human, too; more efforts at openness & transparency are warranted
- IPCC missteps show need for increased rigor in adhering to organization's strict review procedures; but errors discovered so far are few & unimportant.
- IPCC isn't the source of scientific understanding of climate, just one of the messengers. Sources are the global community of climate scientists & mountain of peer-reviewed research they've produced over decades.

What more do we most need to know?

- Improved understanding of climate “sensitivity” to human & natural forcings (including effects of particles, clouds)
 - Sensitivity means, in essence, how much average T increase for a doubling of atmospheric CO₂ or its equivalent.
 - Improvements in this understanding will improve predictions.
 - Getting there will require continuing investments in paleo-climatology, basic climate physics, maintaining & improving our constellation of Earth-observation satellites, and running better climate models on faster computers.
- Better regional disaggregation of predicted changes in temperatures, precipitation, storm tracks, ice sheets
 - Requirements for getting there similar to those above

What more we need to know? (continued)

- Better understanding of ecological effects of regional climate changes
 - Including impacts on oceans, crops, domestic animals, wildlife, pests, pathogens
 - This is needed to shape adaptation strategies
 - Requires continuing investments in ecological sciences, major improvements in diversity & density of monitoring networks
- Better integrated assessments combining predictions, mitigation and adaptation options (character, capabilities, costs), social dimensions
 - Requires additional effort in integrated-assessment methods and practice as well as in specifics of mitigation & adaptation options

The policy questions

What should we do?

There are only three options:

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

Concerning the three options...

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

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 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

Key mitigation realities

- Human CO₂ emissions are the biggest piece of the problem (50% and growing)
 - About 85% comes from burning coal, oil, & natural gas (which provide >80% of world energy)
 - Most of the rest comes from deforestation & burning in the tropics
- Developing countries now exceed industrialized ones in total CO₂ emissions (but not per capita).
- Global energy system can't be changed quickly: ~\$20T 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.

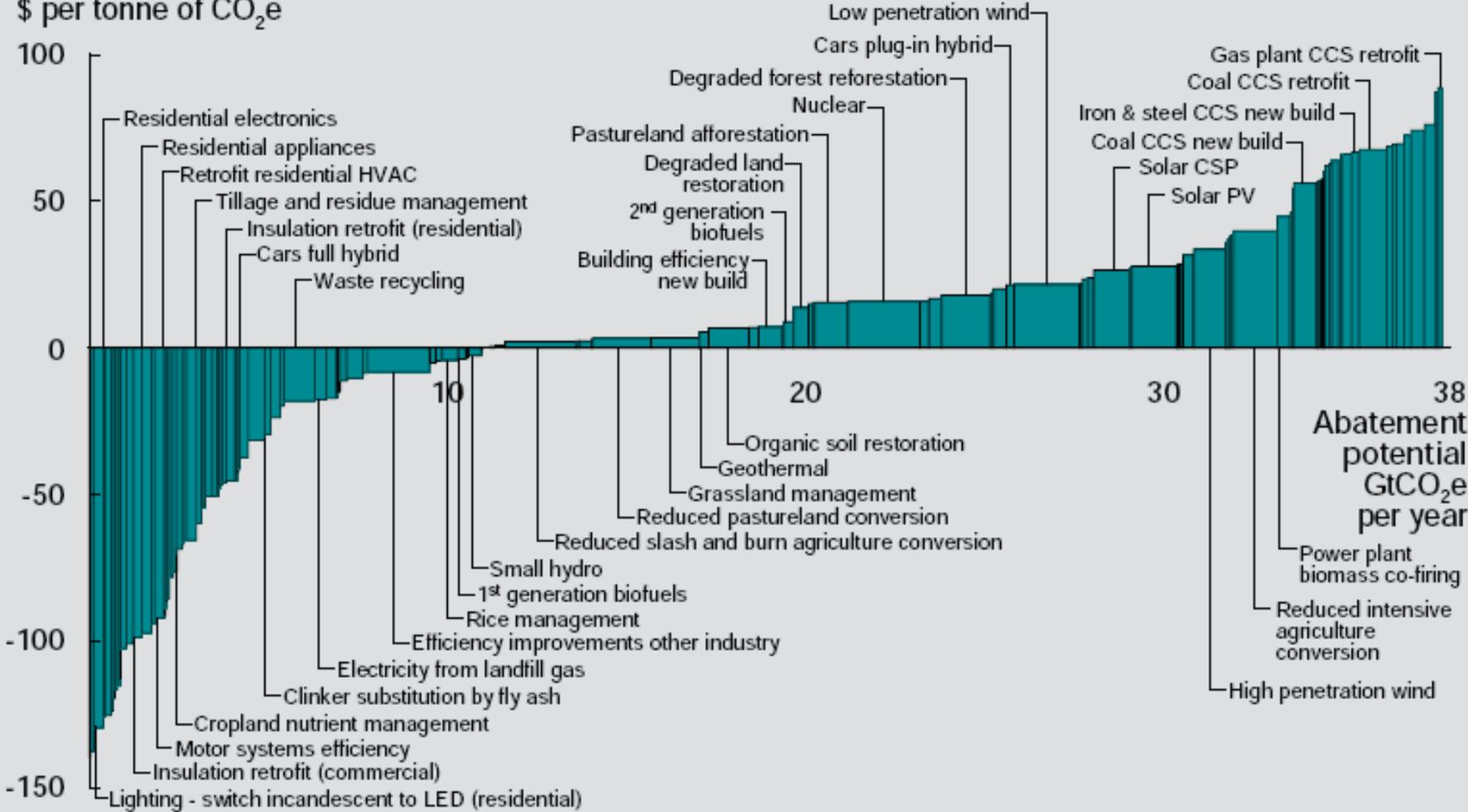
How much mitigation, how soon?

- Limiting ΔT_{avg} to $\leq 2^{\circ}\text{C}$ is now considered by many the most prudent target that's still attainable.
 - EU embraced this target in 2002, G-8 & G-20 in 2009
- Just to have a 50% chance of staying below 2°C
 - developed-country emissions must peak no later than 2015 and decline rapidly thereafter
 - developing-country emissions must peak no later than 2025 and decline rapidly thereafter.

Mitigation supply curve for 2030: aiming for 450 ppm CO₂e

Global GHG abatement cost curve

Abatement costs versus 'business as usual', 2030
\$ per tonne of CO₂e

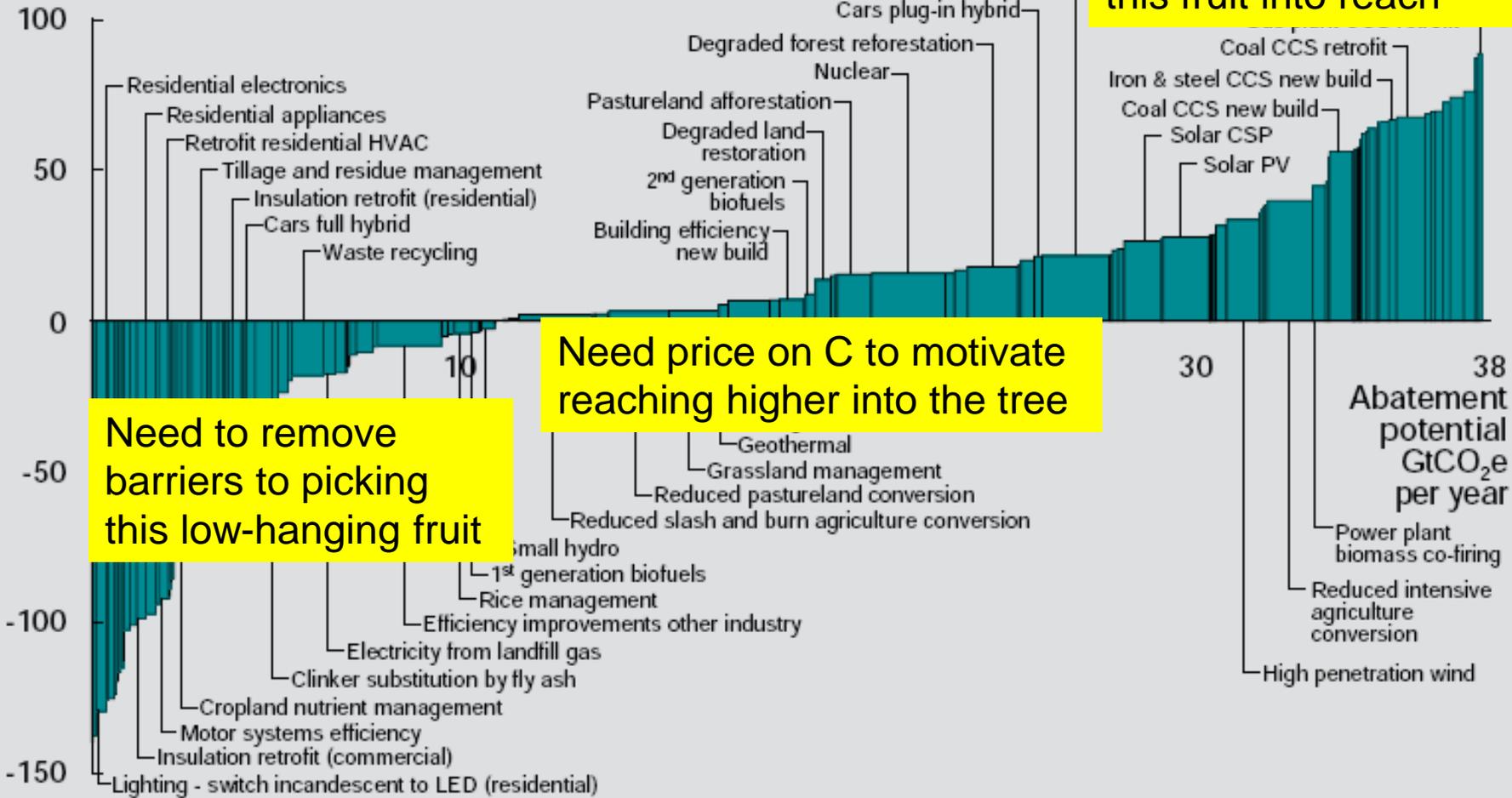


Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below \$90 per tCO₂e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.
Source: McKinsey Global GHG Abatement Cost Curve v2.0

Policy needs for the 450 ppm CO₂e supply curve

Global GHG abatement cost curve

Abatement costs versus 'business as usual', 2030
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Source: McKinsey Global GHG Abatement Cost Curve v2.0

Is the needed mitigation affordable?

- Rough calculations
 - Paying an average of \$100/tC to avoid half of current world CO₂ emissions would cost \$0.5 trillion/yr, under 1% of current GWP (much of it a transfer, not a “loss”).
 - Using McKinsey cost curve for what we’d need to be doing in 2030 to be on 450 ppmv stabilization trajectory shows net cost of only about \$0.1 trillion/yr.
- Current econ models say mitigation to stabilize at 450 ppmv CO₂e probably means 2-3% GWP loss in 2030, 2100 (range 1-5%).
- World now spends 2.5% of GWP on defense; USA spends 5% on defense, 2% on env protection

The education questions

Q: How can the answers about the science better inform the answers that publics and policy-makers embrace about what to do and when to do it?

A: Through more effective education and communication.

What are the ingredients of more effective communication & education?

Communication

- Start with the basics
- Be clear about terminology
- Explain how we know what we know
- Link it to what can be observed
- Link it to regions and communities

Education

- Focus on how science works, sources of authority & credibility in scientific findings
- Lift the level of STEM literacy

Starting with the basics

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

The problem is that the world is getting most of the energy its economies need in ways that are imperiling the climate its environment needs.

Terminology: “global warming” is a misnomer

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

A more descriptive term is “global climate disruption”.

Terminology (cont): Weather, climate, disruption

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.

Observables: Powerful storms (USA, Oct 2010)



This super-storm – the strongest US non-coastal storm on record -- spawned 67 tornadoes over a 4-day period.

Observables: Heat waves (Russia, summer 2010)

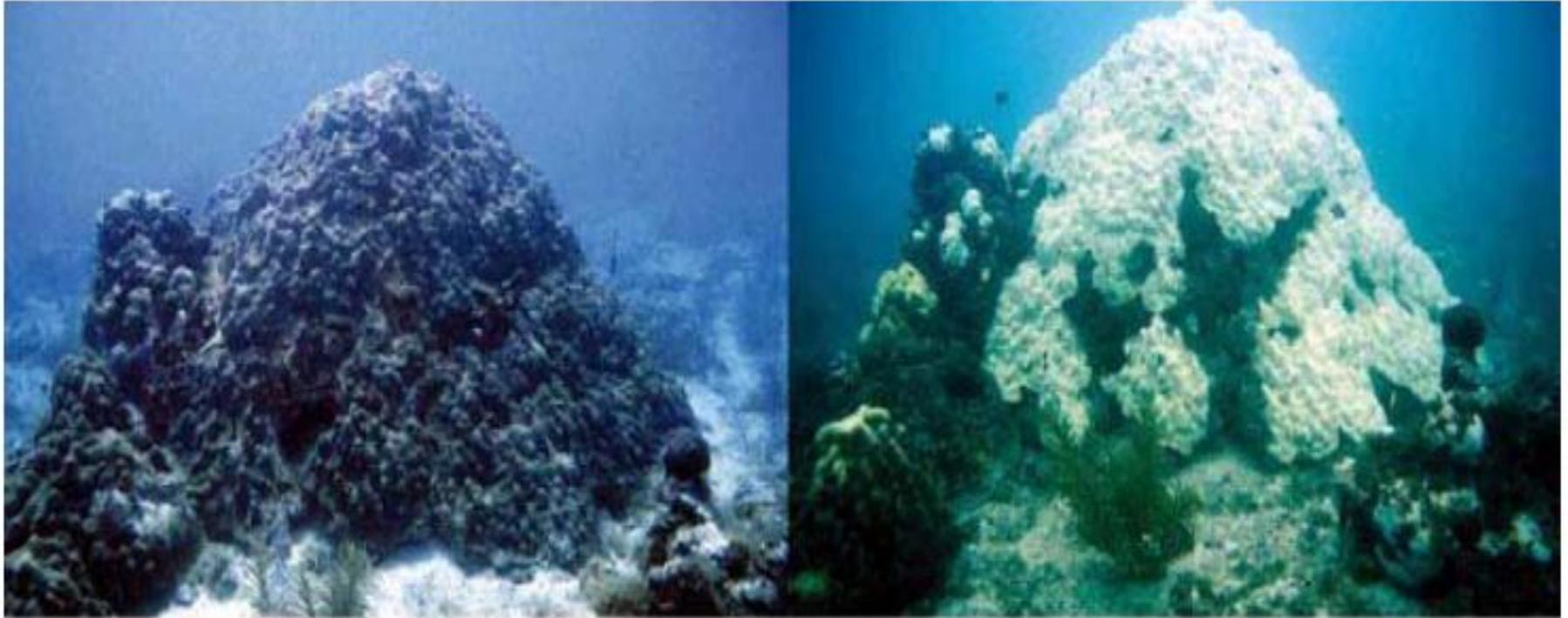


Observables: Floods (Australia, 2010-2011)



Record warm sea temperatures contributed to the wettest spring ever in Australia and flooding in Queensland that was the costliest natural disaster in Australia's history.

Observables: Coral bleaching (Carribean, 2010)



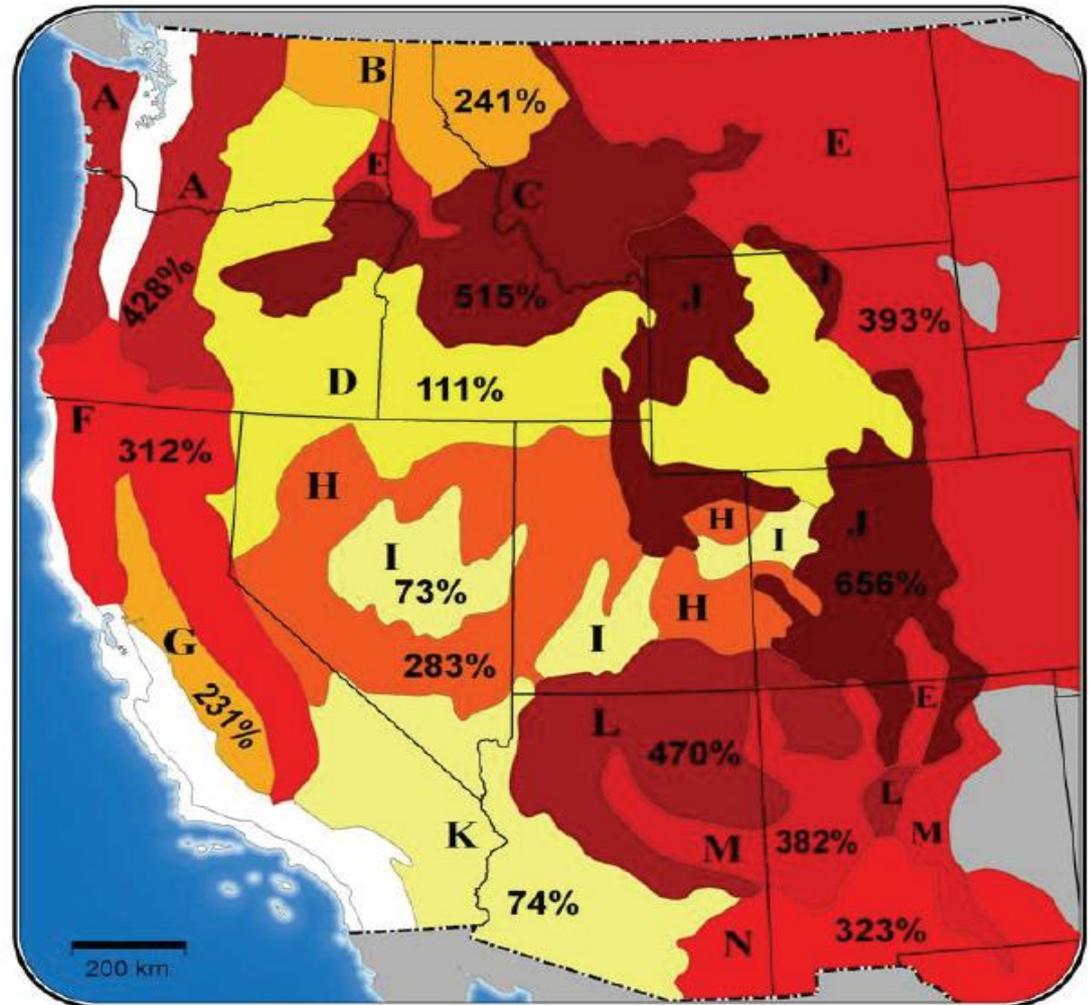
1996 - Healthy

1997 - Bleached

2010 brought the worst coral bleaching since 1998.

Link to the local: wildfire predictions

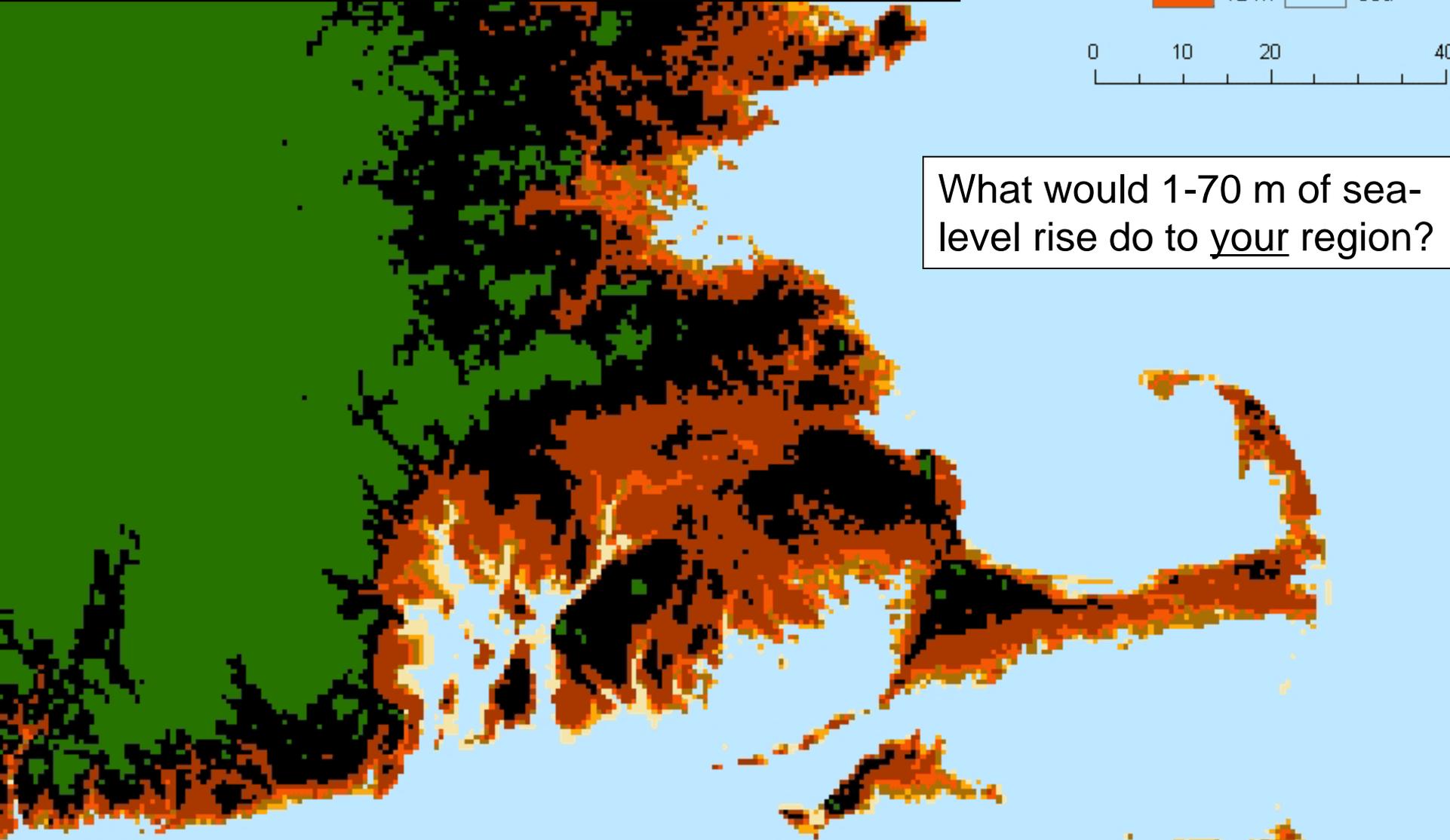
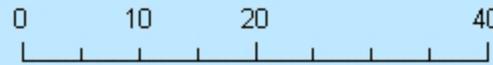
Percentage increases in median annual area burned for a 1°C increase in global average temperature



National Academies,
Stabilization Targets,
2010

- A - Cascade Mixed Forest
- B - Northern Rocky Mt. Forest
- C - Middle Rocky Mt. Steppe-Forest
- D - Intermountain Semi-Desert
- E - Great Plains-Palouse Dry Steppe
- F - Sierran Steppe-Mixed Forest
- G - California Dry Steppe
- H - Intermountain Semi-Desert / Desert
- I - Nev.-Utah Mountains-Semi-Desert
- J - South. Rocky Mt. Steppe-Forest
- K - American Semi-Desert and Desert
- L - Colorado Plateau Semi-Desert
- M - Ariz.-New Mex. Mts. Semi-Desert
- N - Chihuahuan Semi-Desert

Link to the local: 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 your region?

Courtesy Jeffrey Bielicki, Kennedy School of Government

How science works

UNCERTAINTIES ARE TWO-SIDED

- Yes, it could be that the climate changes occurring under a continuation of BAU would be less disruptive, and the adverse impacts on human well-being less severe, than the scientific-mainstream best estimates contained in the reports of the Intergovernmental Panel on Climate Change (IPCC) and the US National Academy of Sciences.
- But it could also turn out that the climate changes under business as usual would be more disruptive, and the impacts on human well-being more severe, than the “consensus” estimates suggest. (Recent results suggest this is more likely than the reverse.)

How science works (continued)

BURDEN OF PROOF

- The “skeptics” routinely brandish some single contrary piece of evidence or analysis -- often a newly reported one that has not yet been subjected to the scrutiny of the scientific community -- and declare that this new result invalidates the mainstream view.
- That’s not how science works. Contrary results appear regularly in all scientific fields. But when a strong preponderance of evidence points the other way (as in the case of climate-change science), isolated apparent contradictions are given due scrutiny but not, initially, very much weight.
- That’s because it’s far more likely that the “contradiction” will turn out to be explainable as a mistake, or otherwise consistent with the preponderance of evidence, than that the preponderance of evidence will turn out to have been wrong.

How science works (concluded)

PRUDENCE

- All science is contingent. It is always possible that persuasive new evidence and analysis will come to light that will change the mainstream view.
- But the greater the consistency and coherence of the existing body of evidence and analysis, the lower the likelihood that the principal conclusions derived from it will be overturned.
- The consistency and coherence of the evidence and analysis supporting the mainstream view of climate-change risks embodied in the reports of the NAS & IPCC are immense.
- Policymakers, on whose decisions the preservation and expansion of the public's well-being depends, are gambling against very long odds if they bet that the mainstream position is wrong. This is not prudent.

The much longer-term project of raising the overall level of STEM literacy across our society would need to be the topic of another lecture!