The Case for Investing in Climate-Change Resilience: Insights from Science, Engineering, and Economics

John P. Holdren

Teresa & John Heinz Professor of Environmental Policy
Harvard Kennedy School
Professor of Environmental Science and Policy
Harvard Department of Earth & Planetary Sciences

and former
Assistant to President Obama for Science & Technology
and Director, White House Office of Science & Technology Policy
(January 2009 – January 2017)

University of Illinois ISEE Congress 2017

September 18, 2017

Outline of the presentation

SCIENCE

- What we know (true beyond reasonable doubt)
- What we expect (projected impacts for specified emissions)
- What more we fear (plausible but unquantifiable risks)

TECHNOLOGY AND ECONOMICS

- Mitigation
- Adaptation
- The bottom line

Science: What We Know

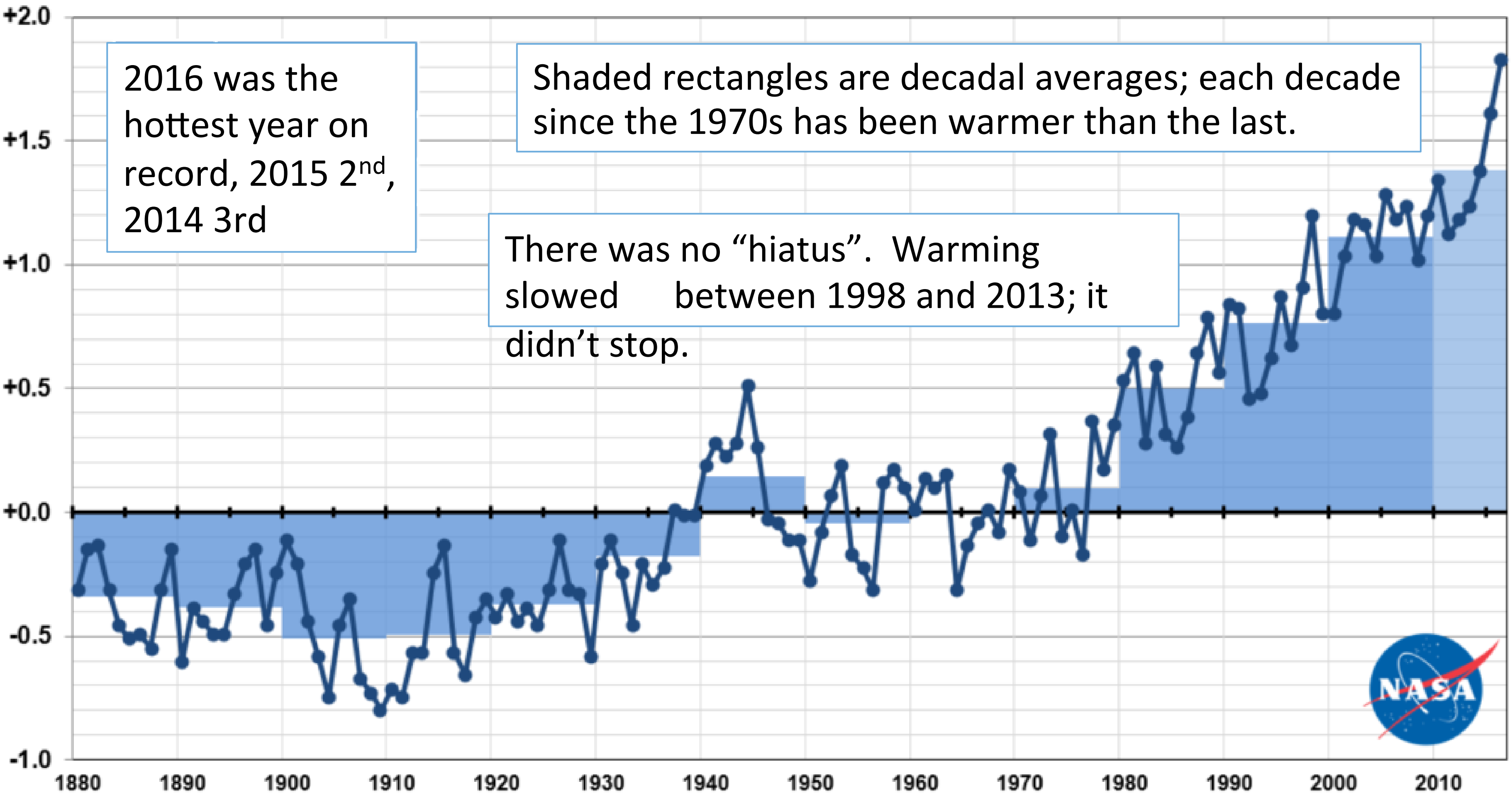
(True Beyond Reasonable Doubt)

"Everyone is entitled to his own opinion, but not his own facts."

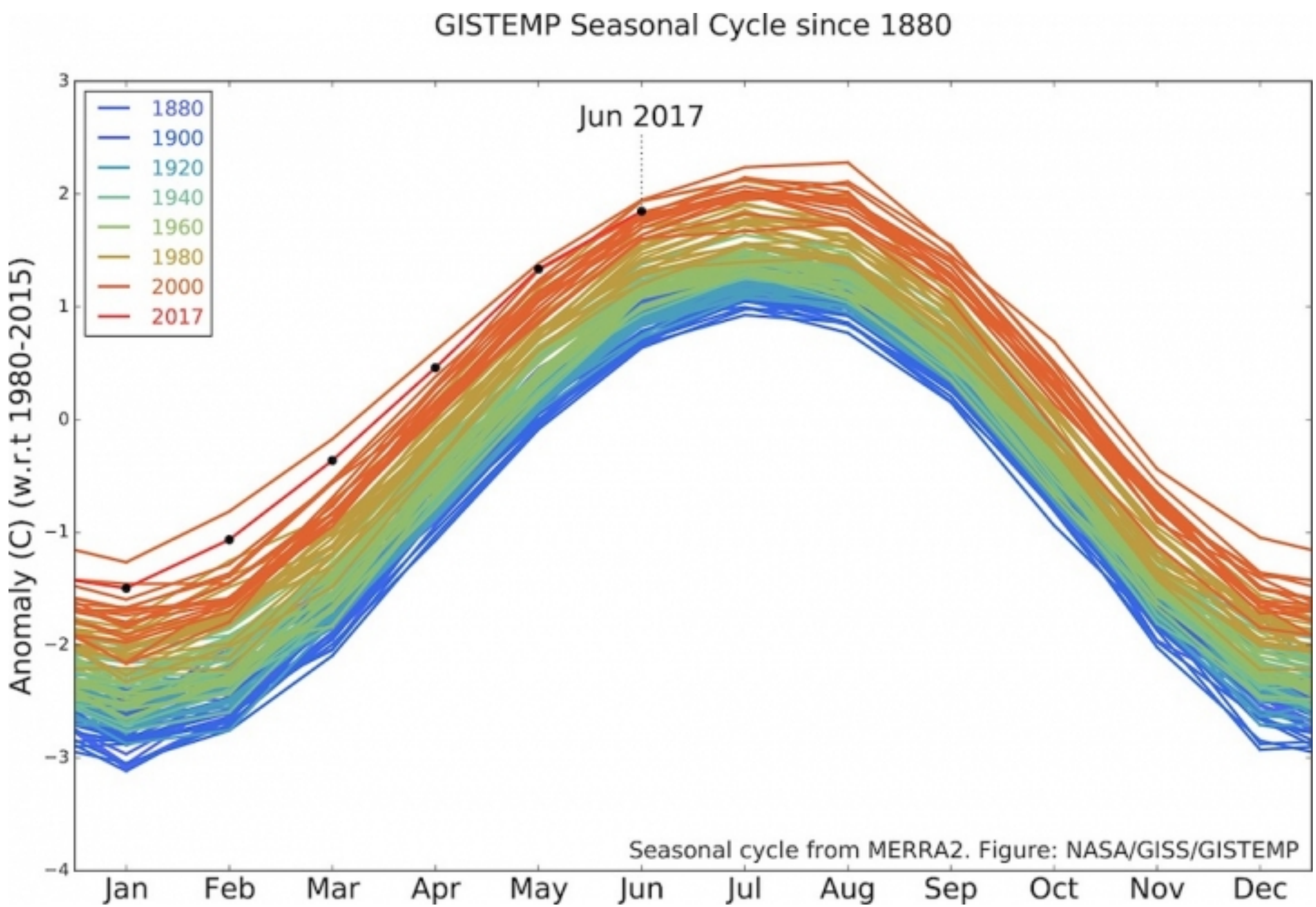
Daniel Patrick Moynihan

Rapid warming of the atmosphere is ongoing

Annual Global Temperature: Difference From 20th Century Average, in °F

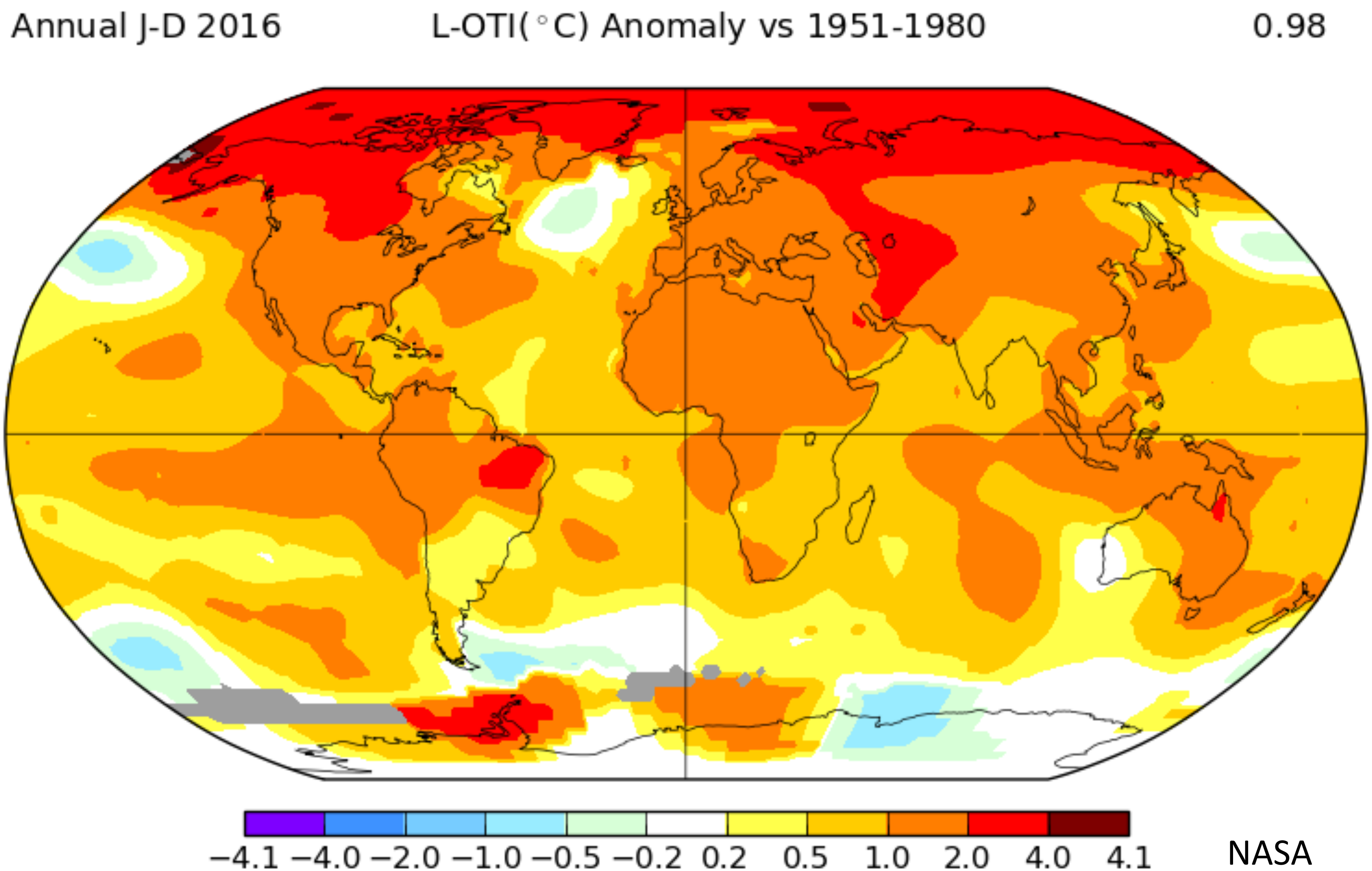


First half of 2017 was the 2nd hottest Jan-Jun on record despite absence of El Niño



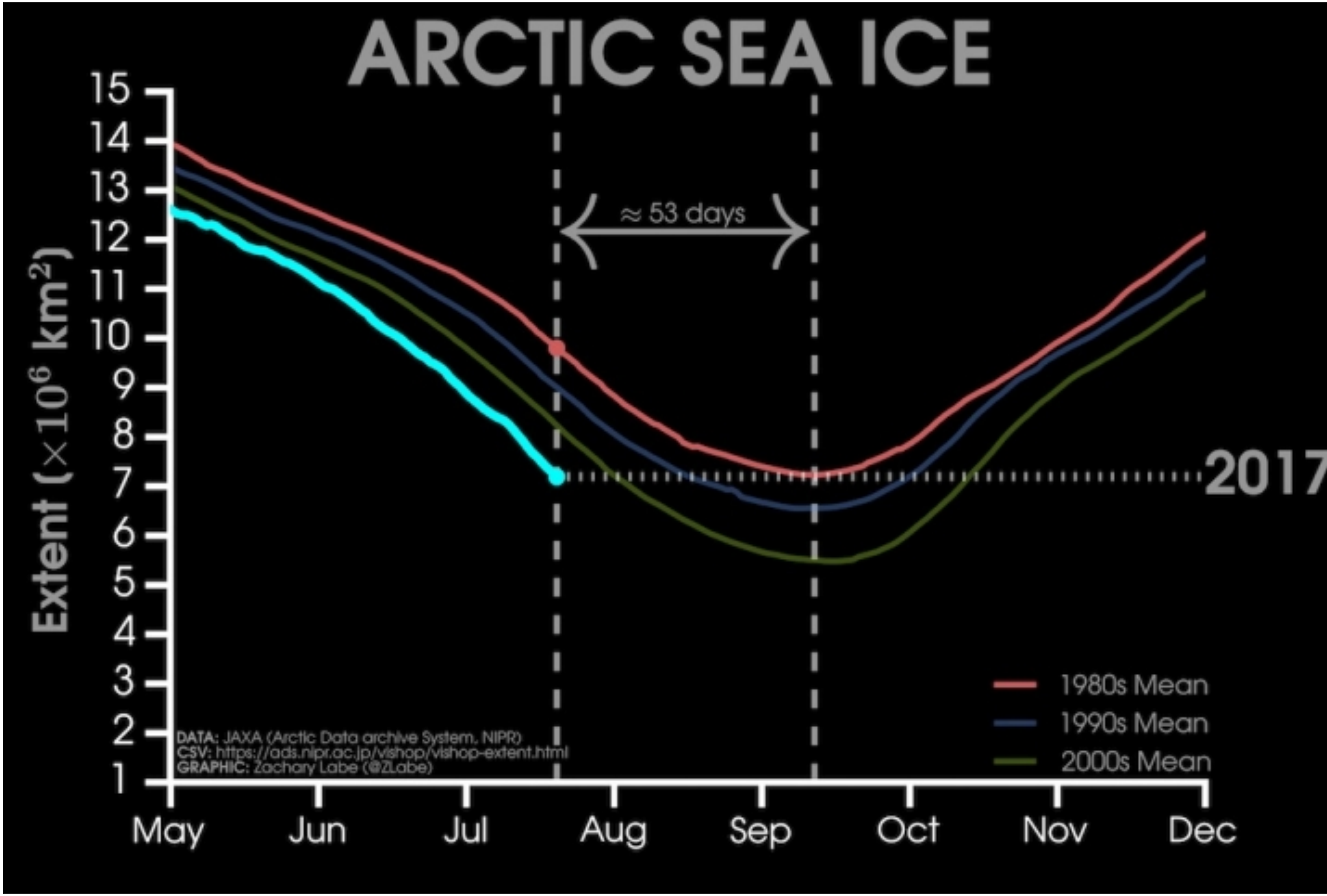
What We Know: The pace, character, and consequences of climate change

The Arctic, West Antarctic Peninsula, and mid-continents are warming 2-4x faster than the global average



NASA

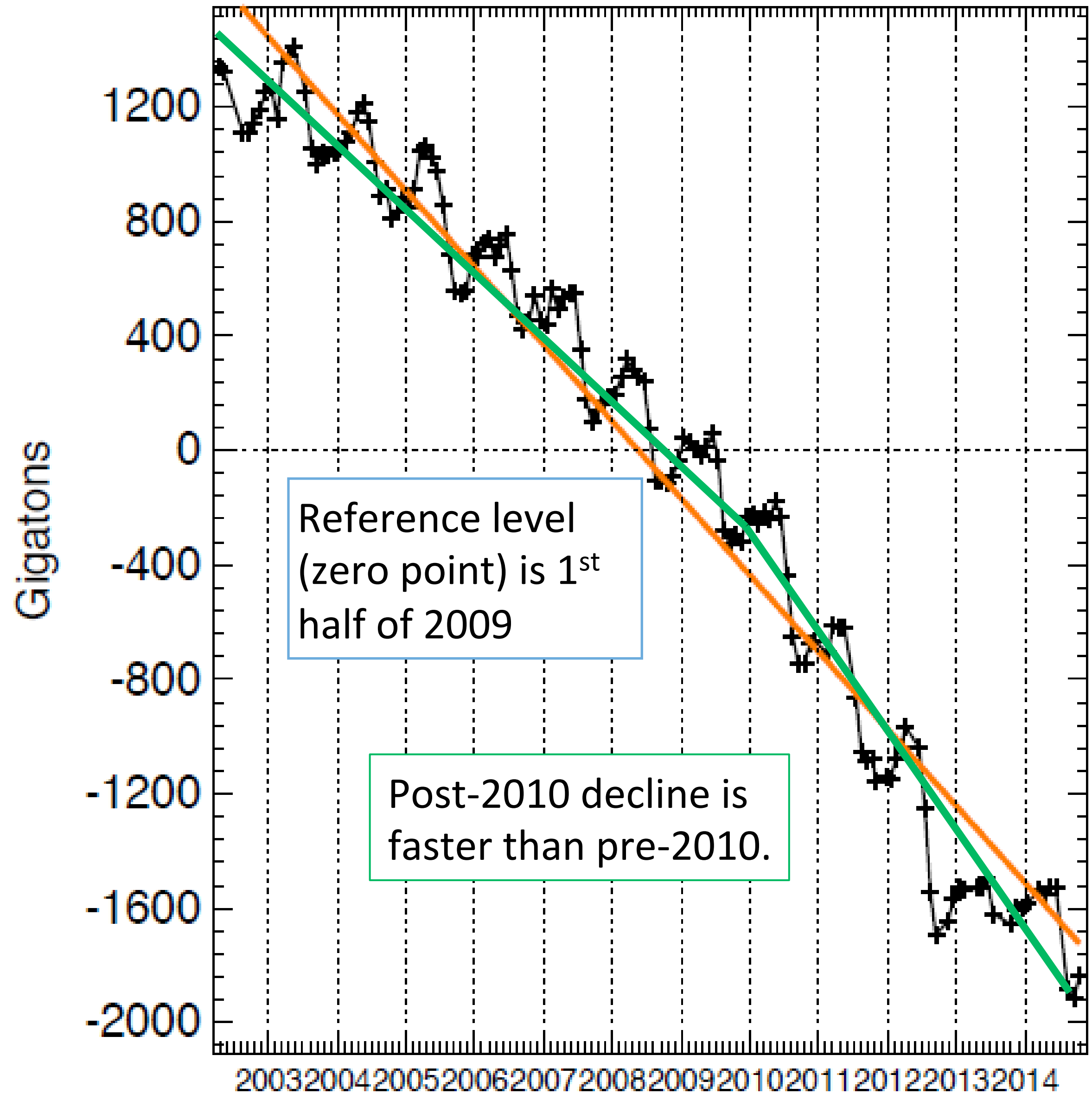
Arctic sea-ice shrinkage is setting new records



Sea-ice loss doesn't raise sea level, but it does accelerate Arctic warming.

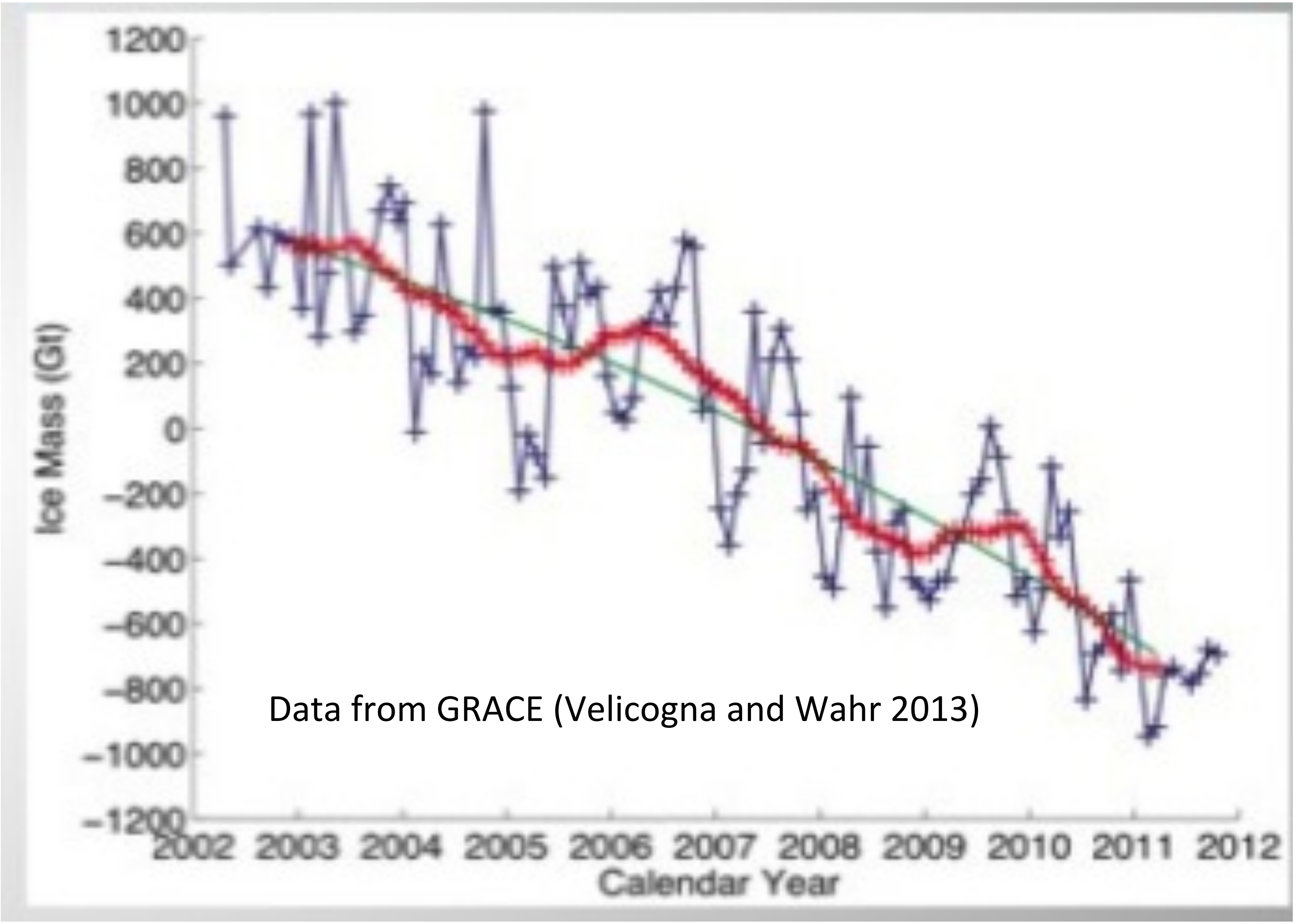
Loss of ice from Greenland is accelerating

Land-ice loss from melting & accelerated calving of icebergs raises sea level.

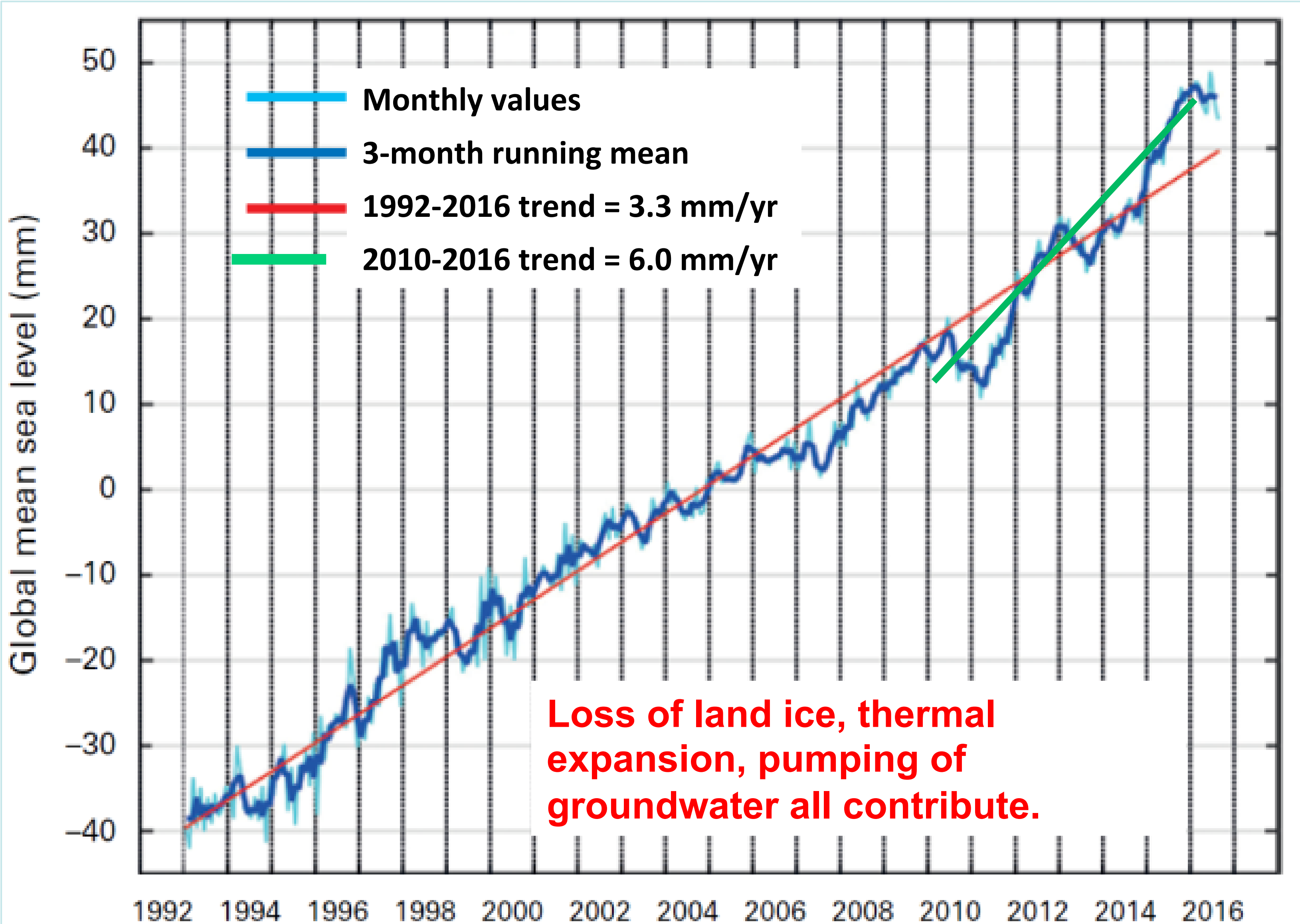


Waleed Abdalati, from GRACE, December 2014

Antarctica as a whole is losing ice, too



Rate of sea-level rise is speeding up



WMO 2017

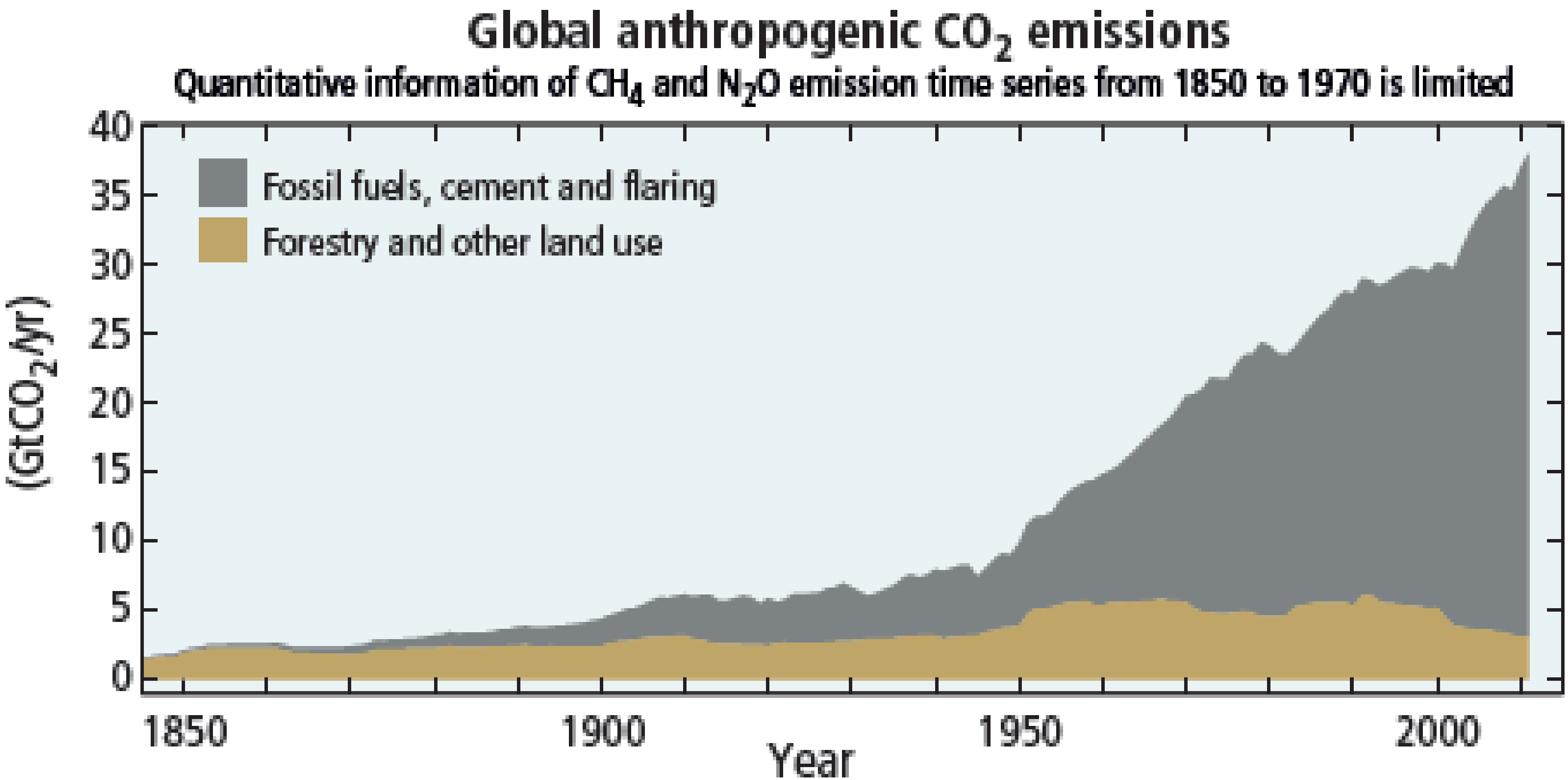
That humans are the cause is irrefutable

- The rapidly rising use of fossil fuels after 1750, augmented by land-use change, produced a pace of increase in atmospheric concentrations of CO_2, CH_4, and N_2O unprecedented in Earth's history. The attribution to humans is scientifically ironclad.

- When the effects of the concurrent buildup of atmospheric particles are accounted for, these human-caused increases in CO_2, CH_4, N_2O, and industrial HFCs explain essentially all of the observed increase in global-average temperature over this period.

- Under the natural influences on Earth's climate, Earth had been cooling for 6500 years up to 1750--and would have continued to cool if human-caused warming had not dominated after that.

The rise of human-caused CO_2 emissions 1840-2011

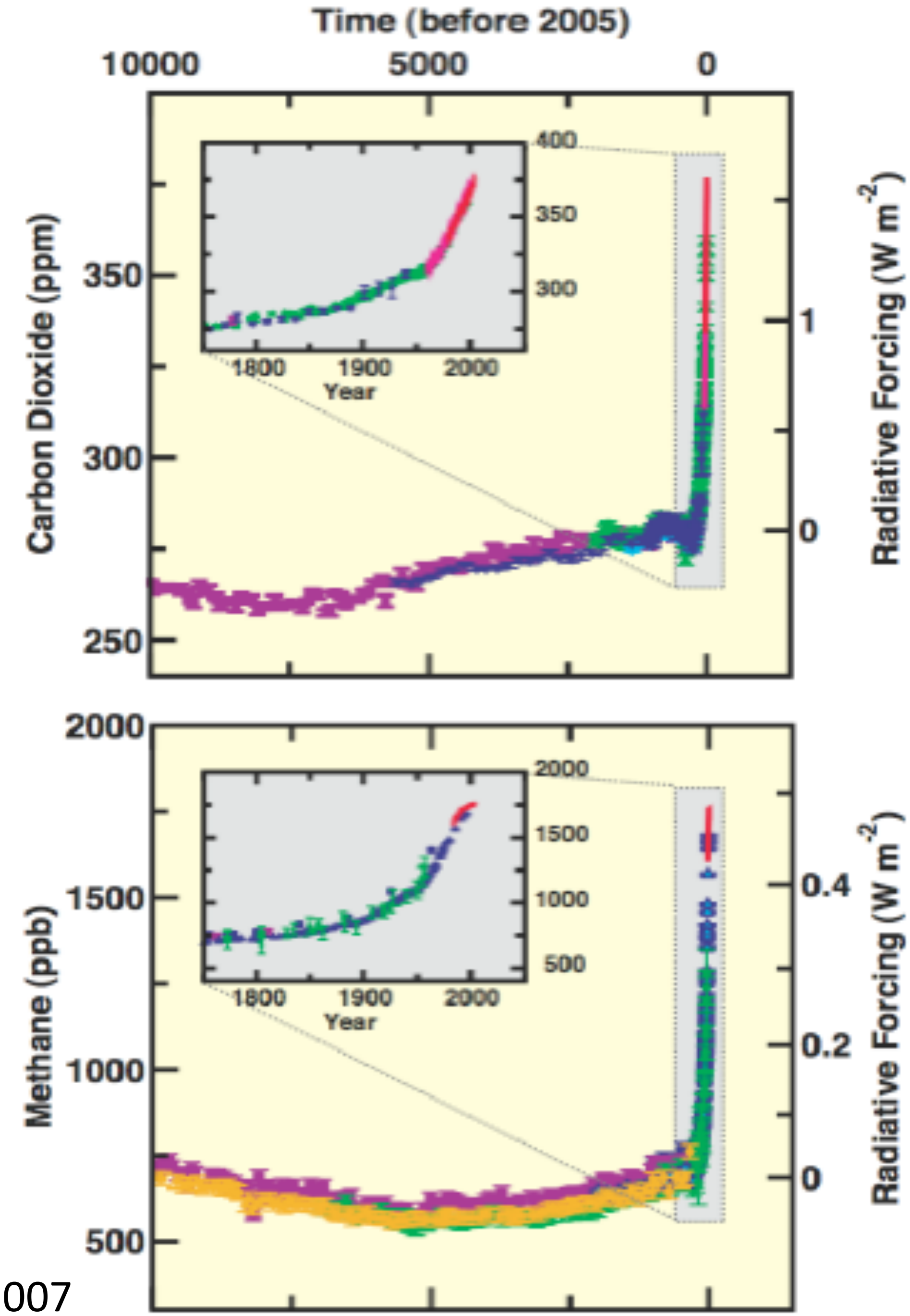


IPCC AR5 SYN Fig SPM-1

What We Know: The causes of the observed changes

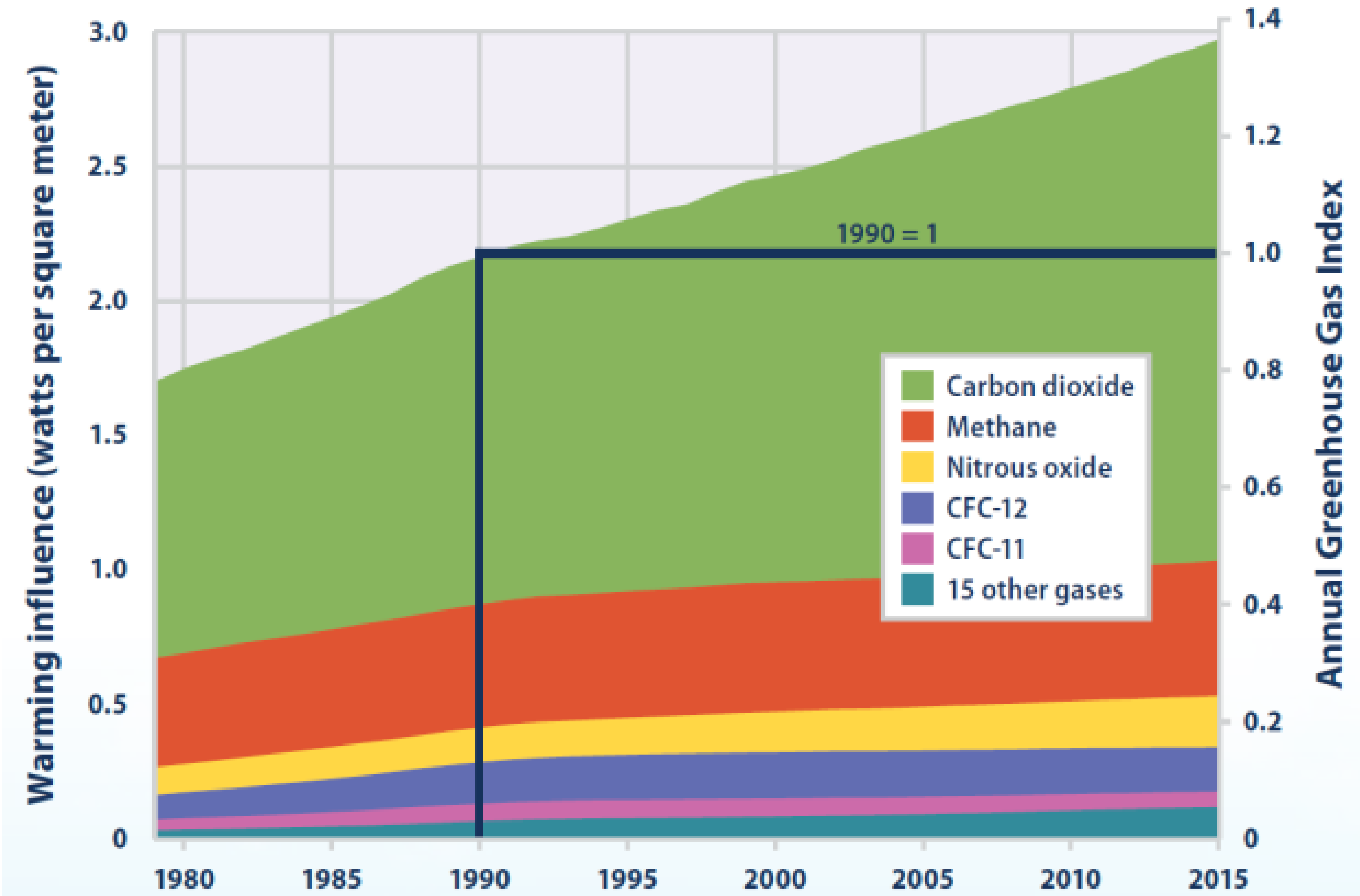
Compared to natural changes over the millennia, the sudden rise of atmospheric concentrations in the industrial era leaps out.

It's clear humans caused the CO_2 spike because fossil CO_2 lacks carbon-14, and the drop in atmospheric C-14 fraction resulting from the fossil-CO_2 additions is measurable.



IPCC AR4, WG1 SPM, 2007

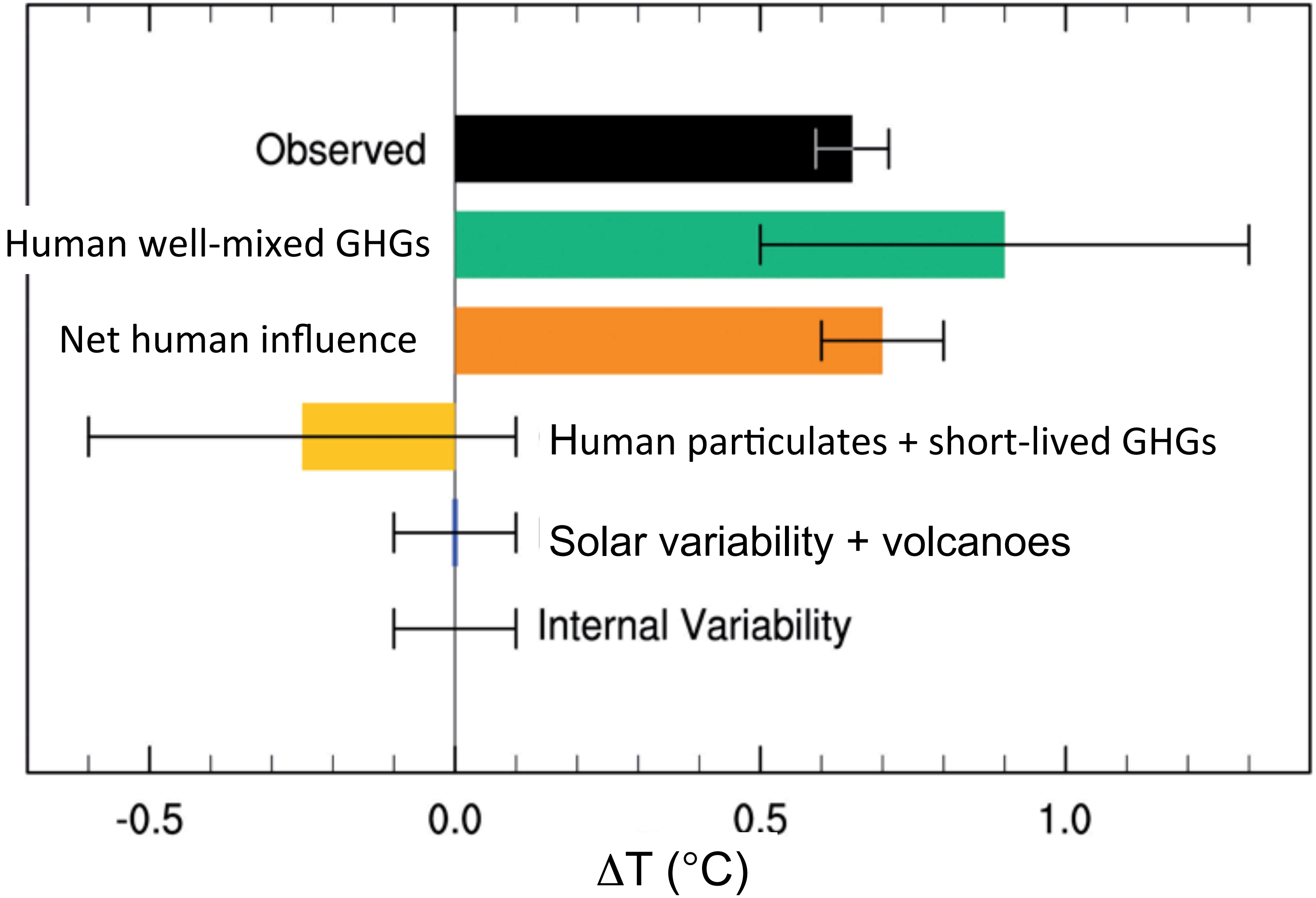
Radiative forcing by long-lived GHGs



What We Know: The causes of the observed changes

Human influences explain all of the recent T increase

Human vs natural influences 1950-2010 (º C)

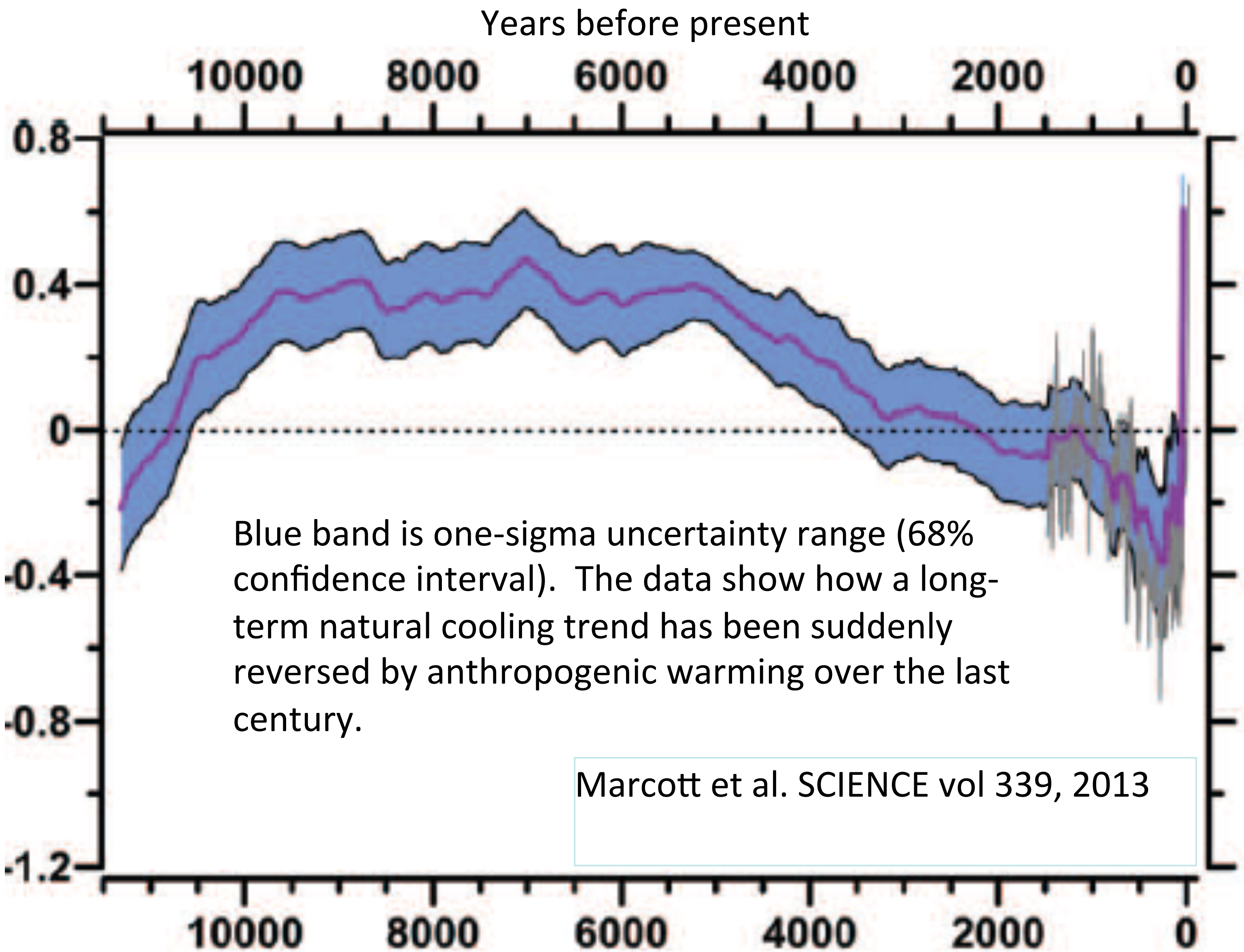


IPCC AR5, WG1 SPM, 2013

What We Know: The causes of the observed changes

Humans reversed 6,500 years of natural cooling

°C departure from 1960-90 average



Blue band is one-sigma uncertainty range (68% confidence interval). The data show how a long-term natural cooling trend has been suddenly reversed by anthropogenic warming over the last century.

Marcott et al. SCIENCE vol 339, 2013

What We Know: The ongoing impacts on people and ecosystems

"Dangerous interference"? Already here.

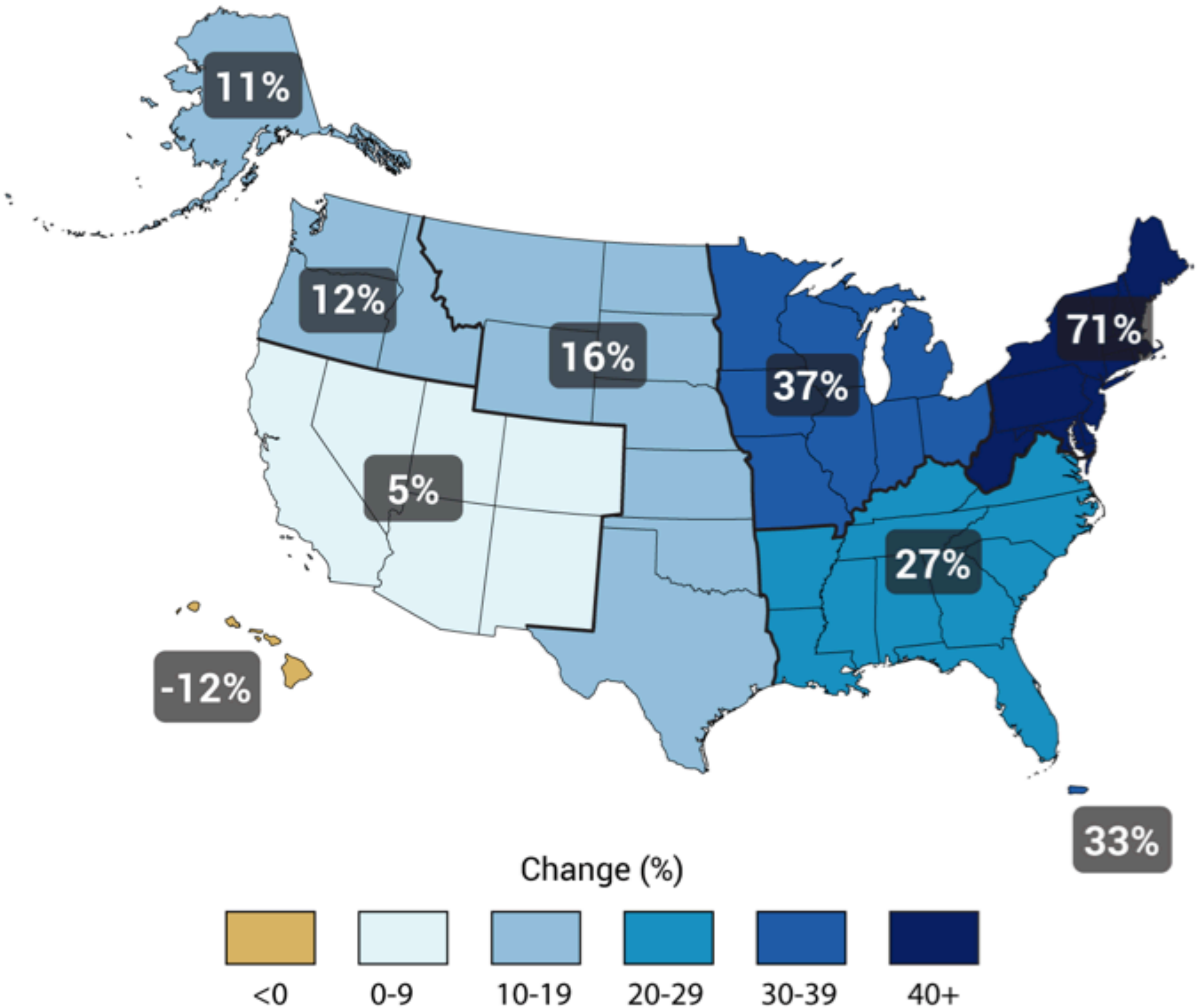
Around the world we're seeing, variously, increases in

- floods
- drought
- wildfires
- heat waves
- coral bleaching
- ocean acidification
- coastal erosion & inundation
- power of the strongest storms
- permafrost thawing & subsidence
- expanding impacts of pests & pathogens
- altered distribution/abundance of valued species

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

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: Heavier downpours → more floods



Percentage increase, between 1958 and 2012, in the amount of precipitation falling in the heaviest 1% of precipitation events in each region.

By far the biggest increase was in the Northeast.

Source: USGCRP, Assessment of Climate Change Impacts in the United States, May 2014

Downpours → Floods (continued)

"Hundred-year" floods now occur once a decade or more in many places.
Three "five-hundred-year" floods occurred in Houston in three years.

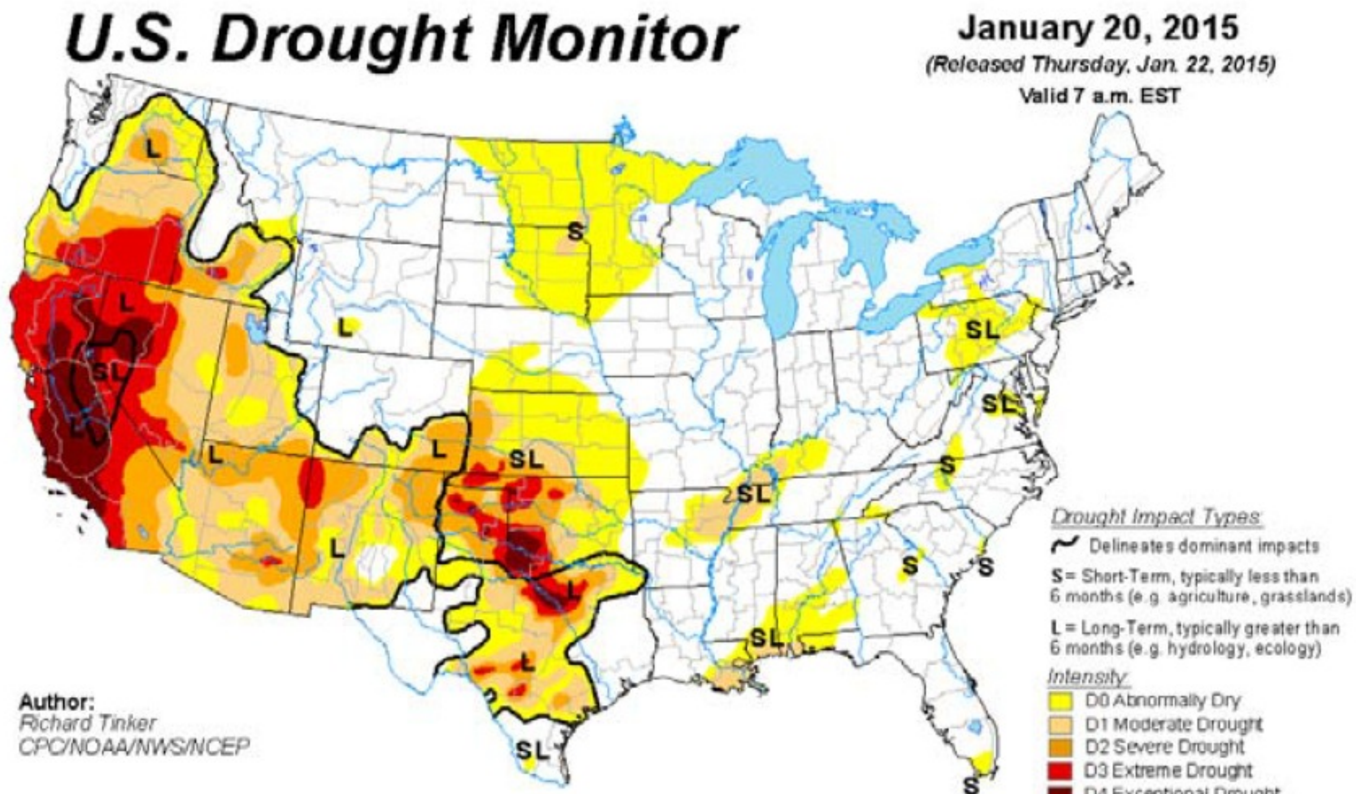
East Baton Rouge, LA, August 2016: Up to 20 inches of rain in 3 days

DigitalGlobe N.O.A.A.

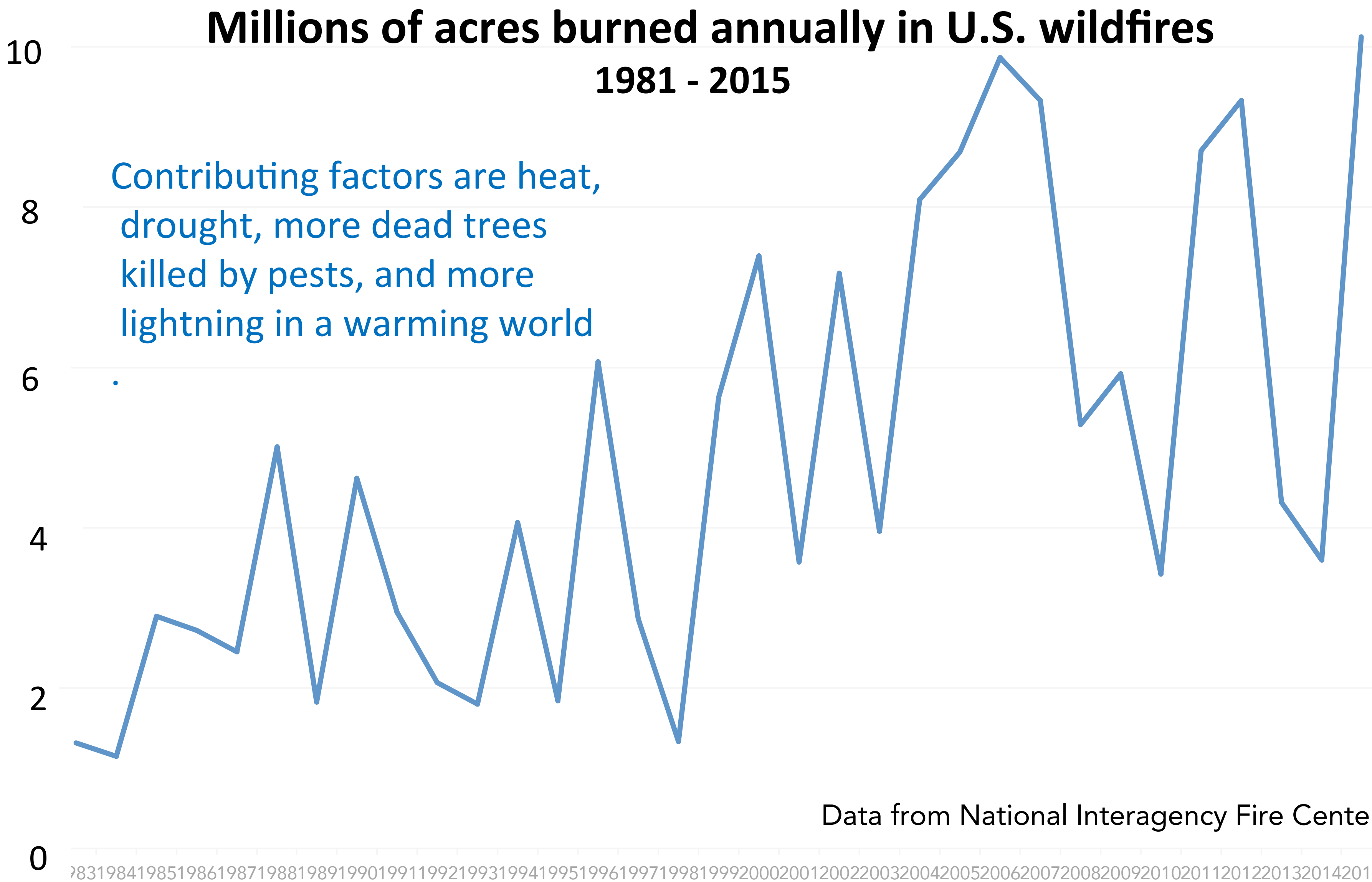
Hurricane Harvey brought >50 inches of rain over 4 days to parts of Texas in August 2017.

Ongoing harm: drought

- Higher temperatures = bigger losses to evaporation.
- More of the rain falling in extreme events = more loss to flood runoff, less moisture soaking into soil.
- Mountains get more rain, less snow, yielding more runoff in winter and leaving less for summer.
- Earlier spring snowmelt also leaves less runoff for summer.
- Altered atmospheric circulation patterns can also play a role.



Ongoing harm: wildfires



What We know: Impacts

Ongoing harm: Wildfires (continued)

- 3.4 million acres had already burned in the USA in 2017 by the beginning of July.
- The fire season in the USA is about 3 months longer than it was 40 years ago.
- The average fire is much bigger & hotter than before. Small wildfires burn at 1300-1400°F; big ones can burn at 2000°F or more, spreading faster, with far greater risks for firefighters.
- In Alaska, even the tundra has experienced wildfires in recent years.

What We Know: The ongoing impacts on people and ecosystems

Wildfires (continued)

Bogus Creek fire, near Aniak, Alaska, June 2015

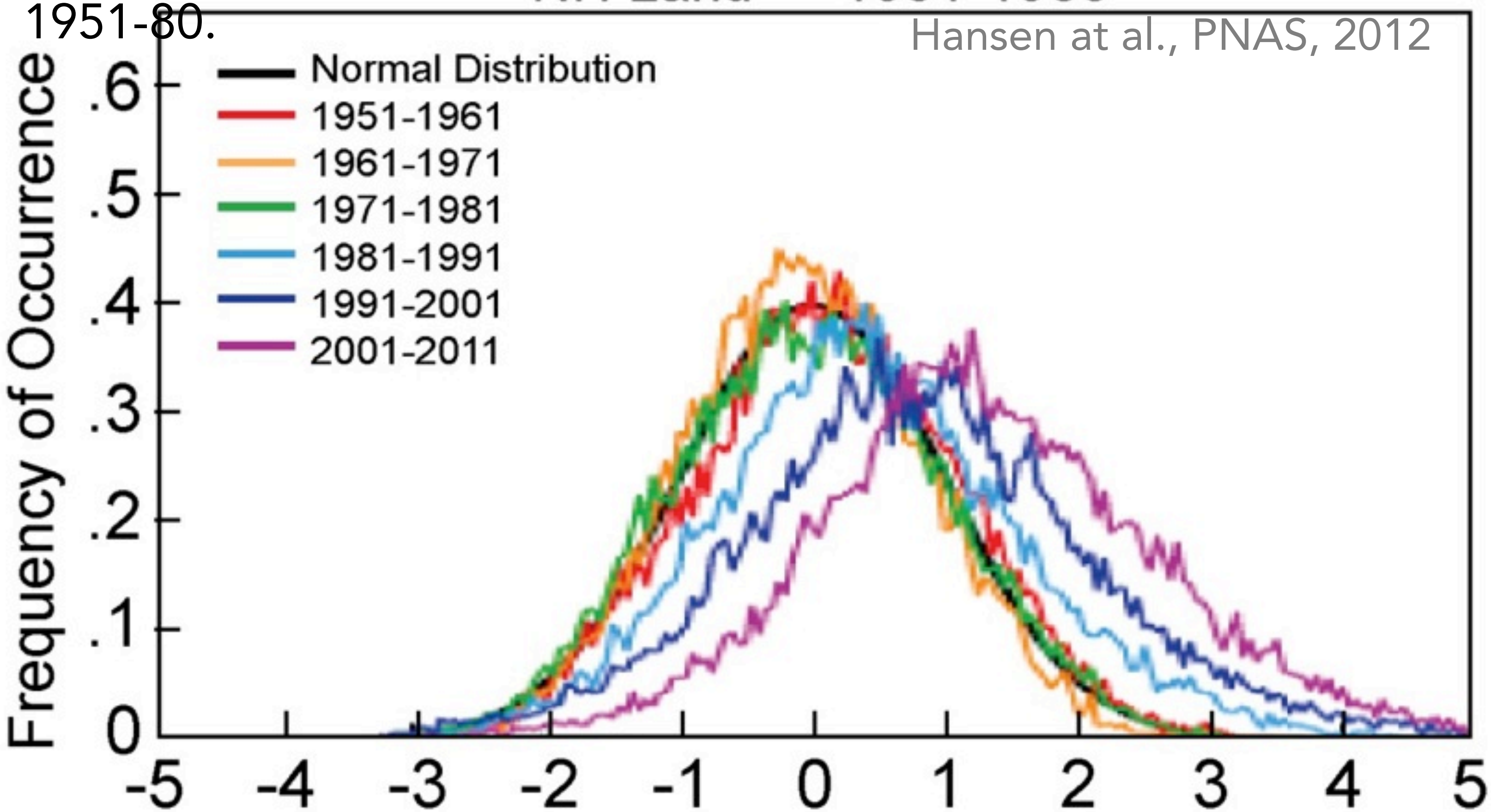
Fires are now occurring in the tundra as well in forested regions.

Courtesy of Nicky Sundt, WWFUS. Photo by Matt Snyder, Alaska Division of Forestry.

Ongoing harm: huge increase in heat waves

Probability distribution for Jun-Jul-Aug temperature anomaly on land in the Northern Hemisphere. Baseline normal distribution is for 1951-80.

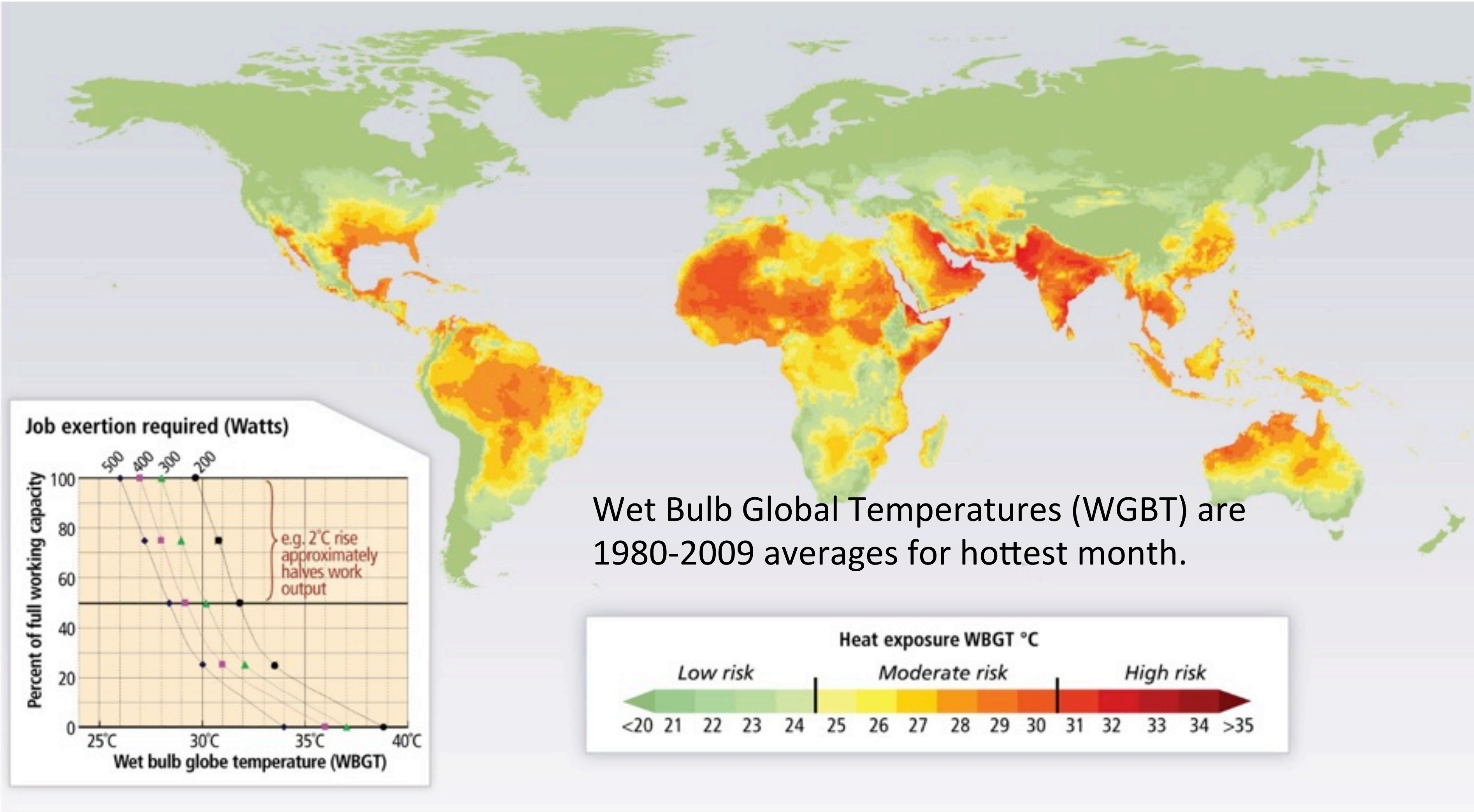
Hansen at al., PNAS, 2012



Portion of Northern Hemisphere land experiencing > 3σ summer heat in a given year increased from 0.1-0.2% in 1951-80 to 10% in 2001-2011—a 50- to 100-fold increase.

What We Know: The ongoing impacts on people and ecosystems

Working outdoors is already difficult & dangerous in the hottest months in many regions



IPCC AR5, WGII, Figure 11-5

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: Coral bleaching

Jarvis Reef, South Pacific (courtesy WHOI)

"As of February 2017, the ongoing global coral bleaching event continues to be the longest and most widespread ever recorded."

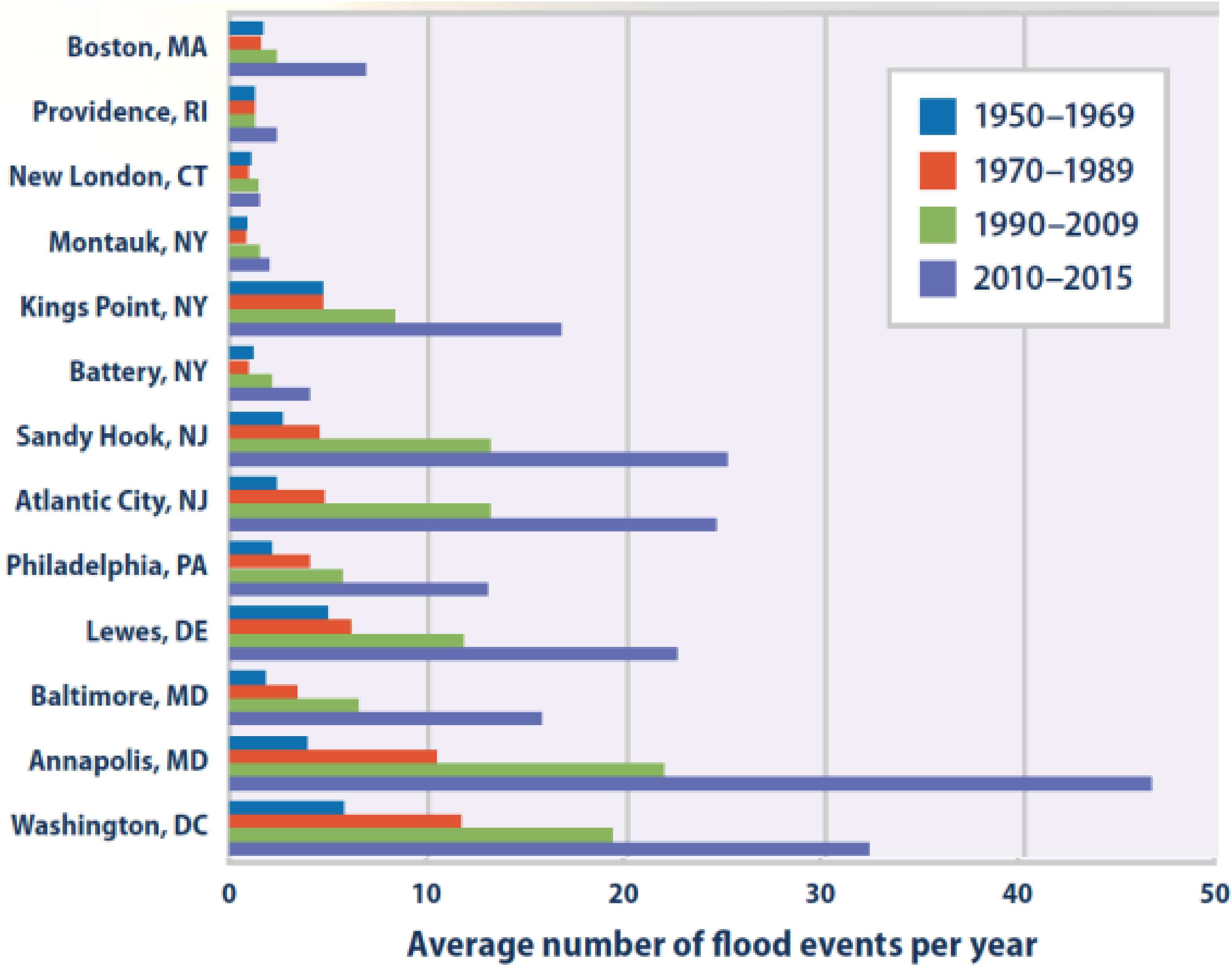
https://coralreefwatch.noaa.gov/satellite/analyses_guidance/global_coral_bleaching_2014-17_status.php

Coral reefs are the 2nd largest reservoir of biodiversity on the planet.

Ongoing harm: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

Ongoing harm: rising sea → coastal inundation



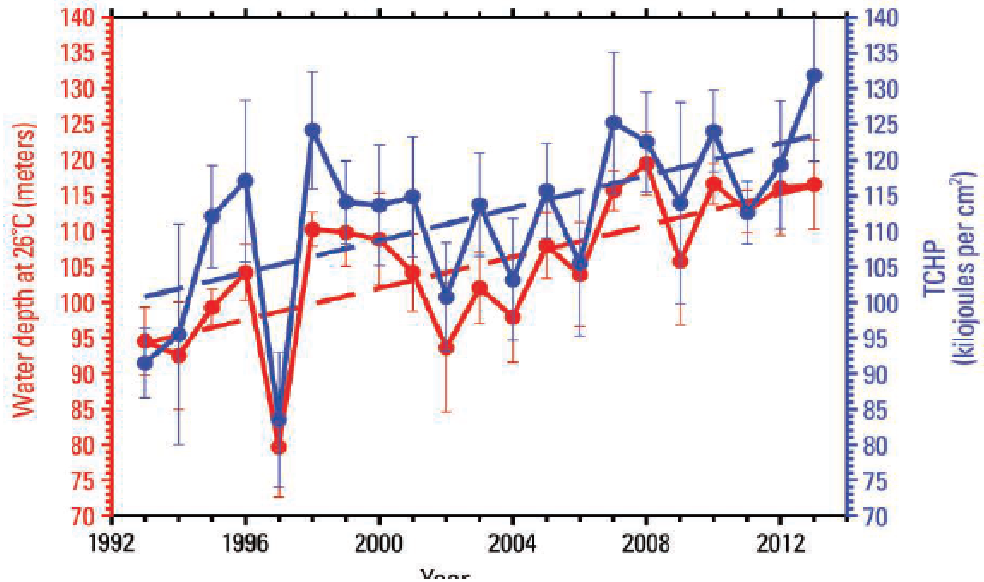
Ongoing harm: bigger, stronger storms

- 10/12: Sandy, largest ever in Atlantic
- 11/13: Haiyan, strongest in N Pacific
- 10/15: Patricia, strongest worldwide
- 10/15: Chapala, strongest to strike Yemen
- 02/16: Winston, strongest in S Pacific
- 04/16: Fantala, strongest in Indian Ocean

Harvey & Irma (09/17) were in the top 2 or 3 ever to make landfall in Texas & Florida.

More-devastating cyclones are not coincidence

- Tropical cyclones get their energy from the warm surface layer of the ocean (which is getting warmer <u>and</u> deeper under climate change). This means more energy is available for evaporating water from the ocean surface. See figure.
- When the water vapor condenses, it heats the atmosphere. The heated air rises, which lowers pressure at the surface.
- That causes air from surrounding areas to flow inward; the spiral pattern results from Coriolis forces.
- More ocean energy → stronger cyclone. And deeper ocean warm layer means waves churn up less cold water to limit storm's power.



In the region that spawned Cyclone Haiyan, the Tropical Cyclone Heat Potential had gone up 20% since 1990.

- Many factors affect the formation and tracks of these storms, but, all else equal, a given cyclone will be more powerful in the presence of a warmer ocean with a deeper warm layer than it would be otherwise. And the hig her local sea level is, the worse the storm surge from any given cyclone w ill be.

Ongoing harm: Pest outbreaks

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

USGCRP 2009

Ongoing harm: impacts on valued species

Sciencexpress / sciencemag.org/content/early/recent / 29 October 2015

Slow adaptation in the face of rapid warming leads to collapse of the Gulf of Maine cod fishery

Andrew J. Pershing,[1*] Michael A. Alexander,[2] Christina M. Hernandez,[1†] Lisa A. Kerr,[1] Arnault Le Bris,[1] Katherine E. Mills,[1] Janet A. Nye,[3] Nicholas R. Record,[4] Hillary A. Scannell,[1,5‡] James D. Scott,[2,6] Graham D. Sherwood,[1] Andrew C. Thomas[5]

PNAS | **September 1, 2015** | vol. 112 | no. 35 | **10823–10824**

Shifting patterns in Pacific climate, West Coast salmon survival rates, and increased volatility in ecosystem services

Nathan J. Mantua[1]

Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Santa Cruz, CA 95060

Science: What We Expect

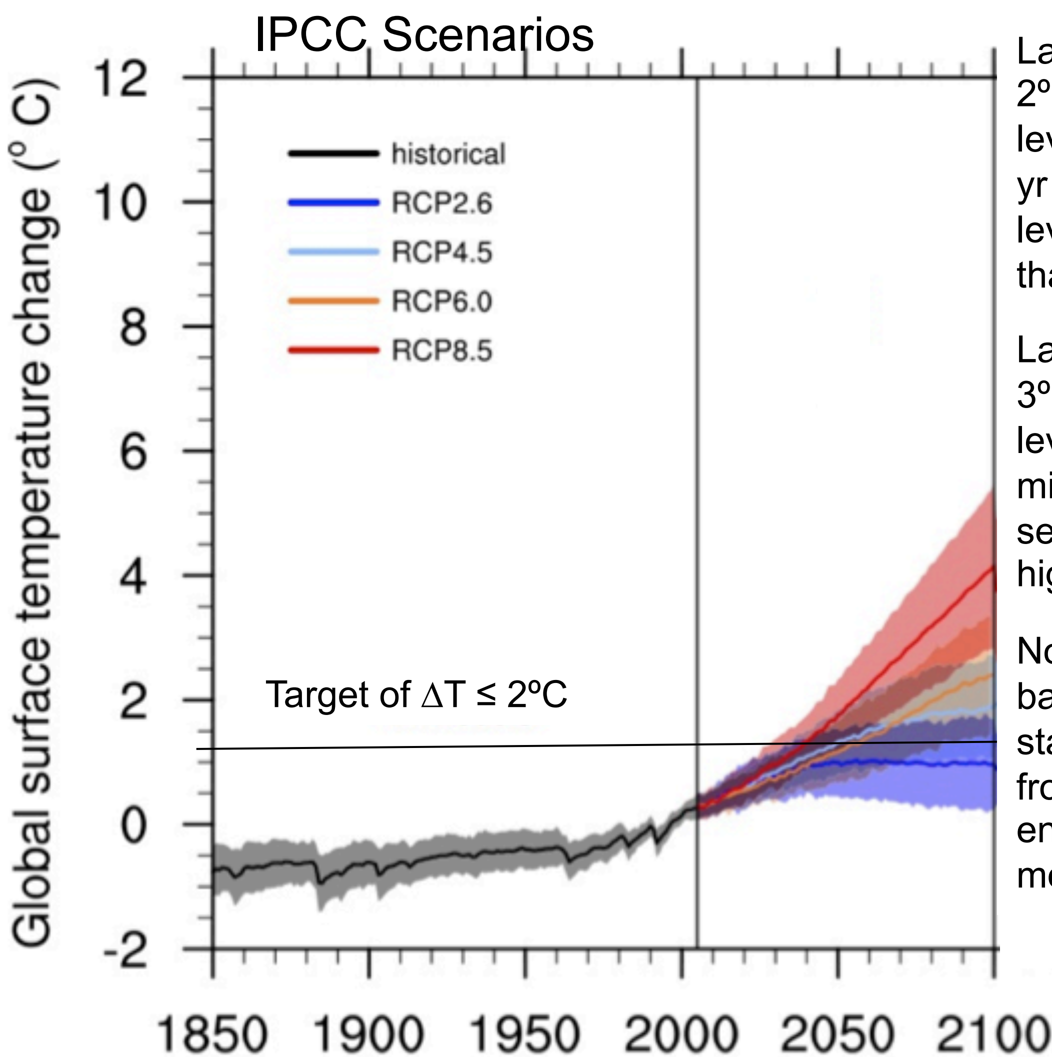
(Projected Impacts for Specified Emissions)

"Prediction is difficult…especially about the future."

attributed to Yogi Berra and Neils Bohr

What We Expect: Projections of future climate change and its impacts

T and impacts grow for decades under all 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 2013

The most worrying recent & emerging insights about future impacts involve…

- Impacts of climate change on human health: heat stress, smog intensity, allergies, pathogens & vectors
- Growing extremes of wet & dry: droughts, wildfires, hailstorms/ downpours/floods
- Impacts of rising temperatures and growing extremes on agriculture.
- Impacts on the coastal zone from the combination of sea-level rise and increasingly powerful storms
- Impacts of ocean heating & acidification on marine food webs and commercial & subsistence fisheries
- Impacts of rapid climate change in the Arctic elsewhere, e.g., Arctic methane release accelerating climate change globally winter extreme weather from weakened polar vortex.

What We Expect: Projections of future climate change and its impacts

Extremes of heat will become much more prevalent

NATURE CLIMATE CHANGE | VOL 5 | JANUARY 2015 | www.nature.com/natureclimatechange

Dramatically increasing chance of extremely hot summers since the 2003 European heatwave

Nikolaos Christidis*, Gareth S. Jones and Peter A. Stott

NATURE CLIMATE CHANGE | VOL 4 | DECEMBER 2014 | www.nature.com/natureclimatechange

Rapid increase in the risk of extreme summer heat in Eastern China

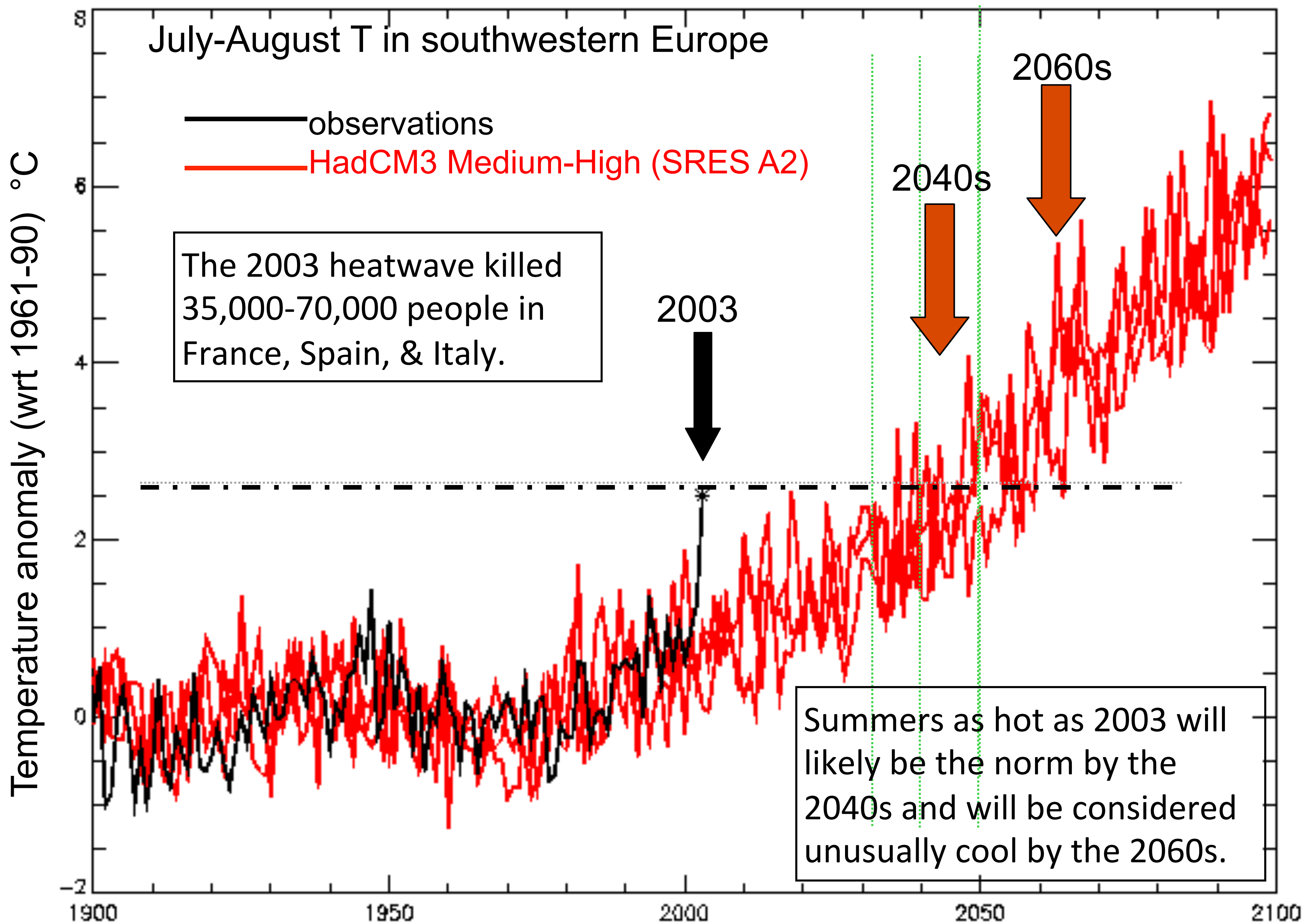
Ying Sun[1], Xuebin Zhang[2*], Francis W. Zwiers[3], Lianchun Song[1], Hui Wan[2], Ting Hu[1], Hong Yin[1] and Guoyu Ren[1]

NATURE CLIMATE CHANGE | VOL 5 | JULY 2015 | www.nature.com/natureclimatechange

Future population exposure to US heat extremes

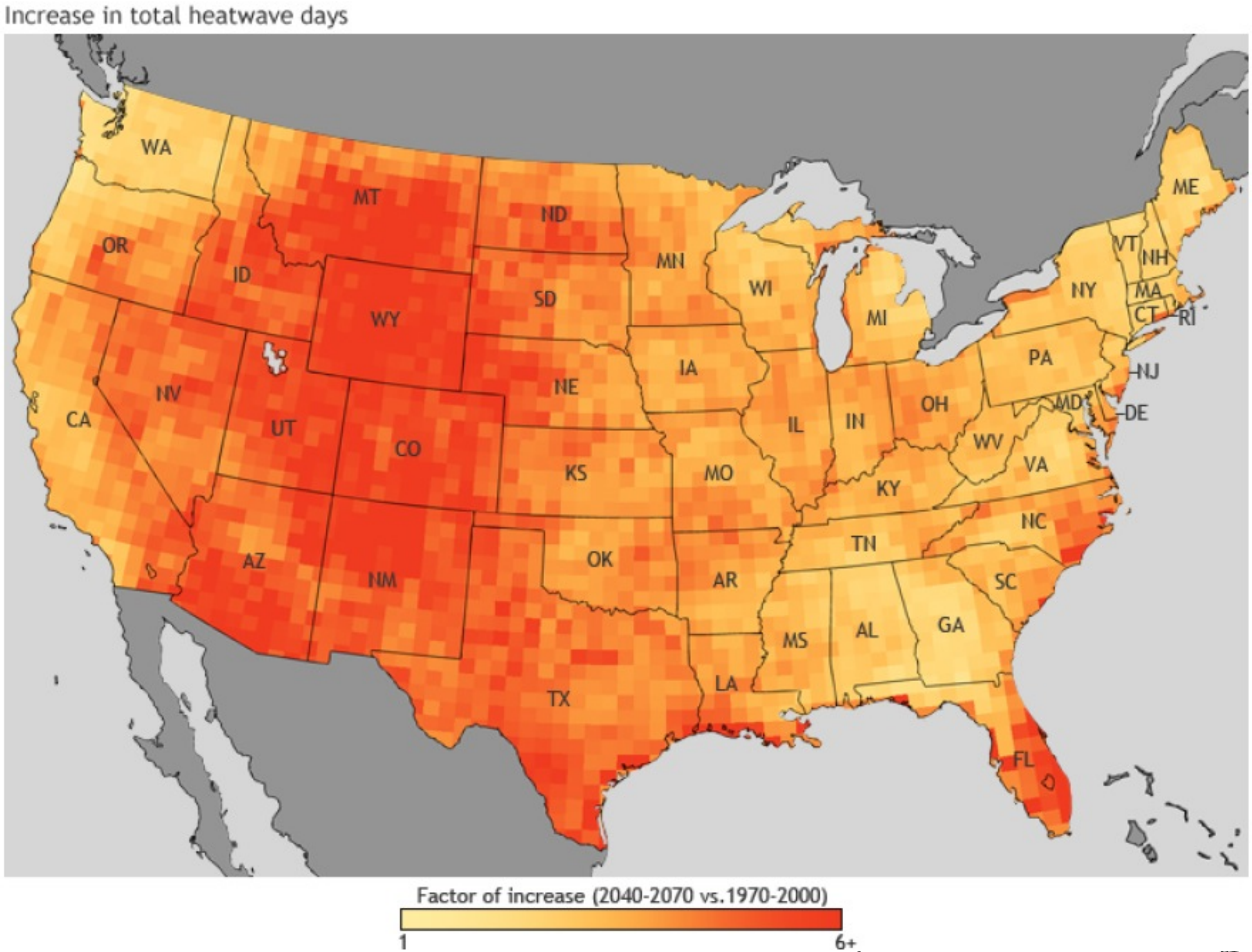
Bryan Jones[1*], Brian C. O'Neill[2], Larry McDaniel[3], Seth McGinnis[3], Linda O. Mearns[3] and Claudia Tebaldi[2]

Summer heat in SW Europe—history & BAU future



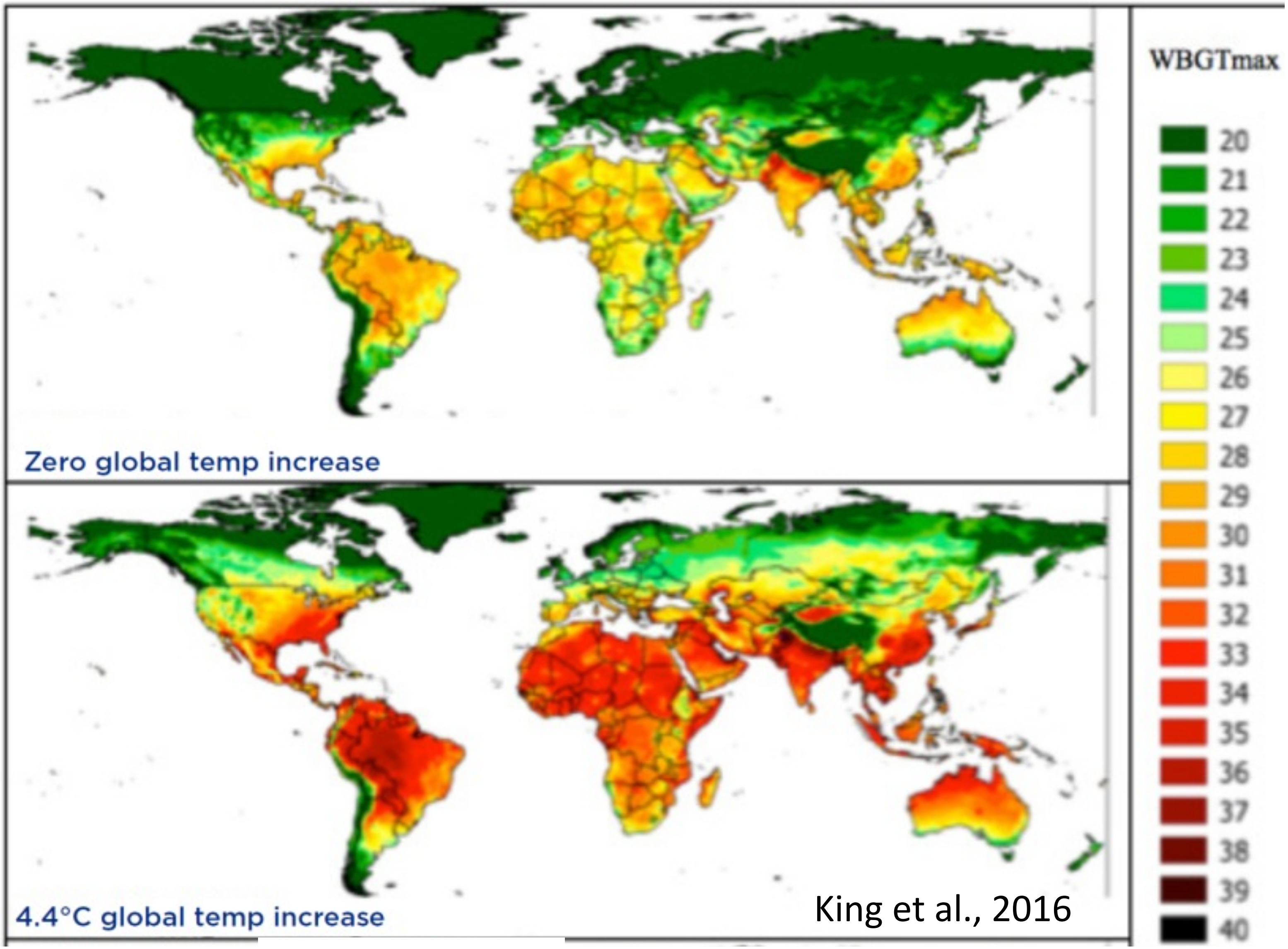
What We Expect: Projections of future climate change and its impacts

US heatwaves at mid-century under BAU



(http://www.climate.gov//sites/default/files/Heatwave_days2040-2070_HR.jpg)

Average daily peak WBGT in hottest month



When WBGT > 34°C, heavy outdoor labor leads to heat stroke and death.

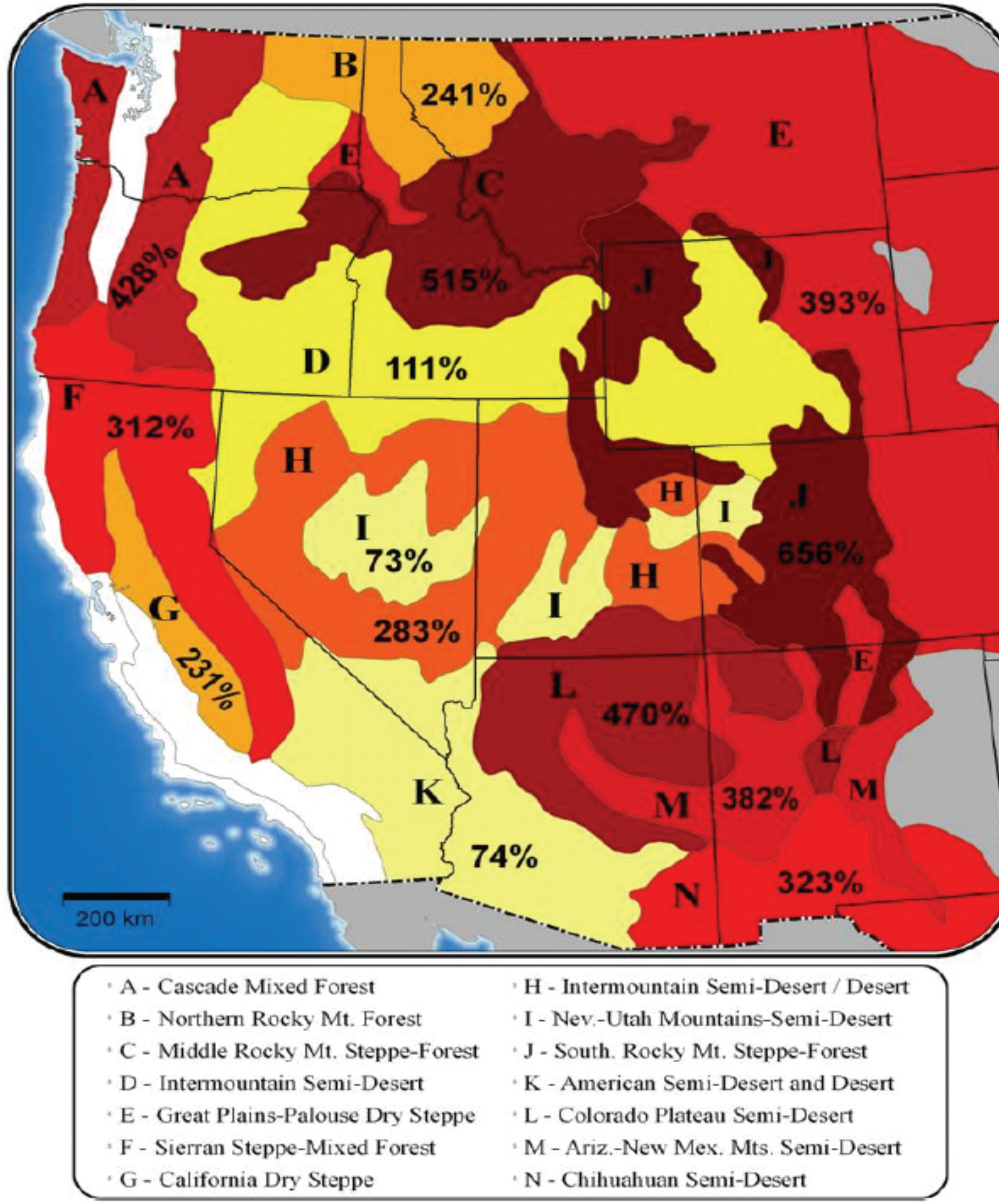
What We Expect

Worse wildfires

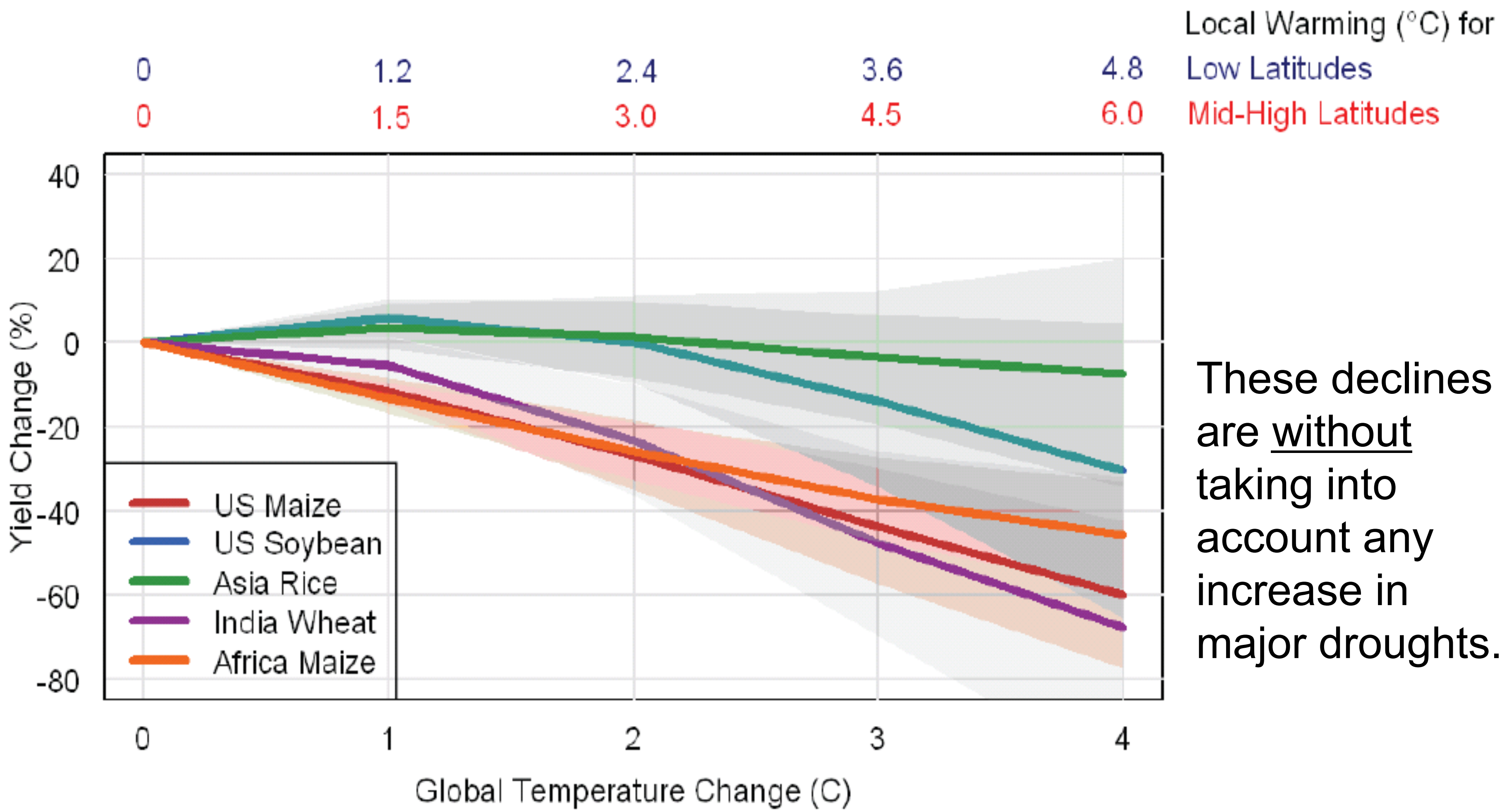
Area burned by wildfires, already up substantially, is destined to go up much more.

Percentages shown are increases in median annual area burned for a 1°C rise in global average temperature, referenced to 1950-2003 averages.

National Academies, Stabilization Targets, 2010



Yields of staple crops decline with warming



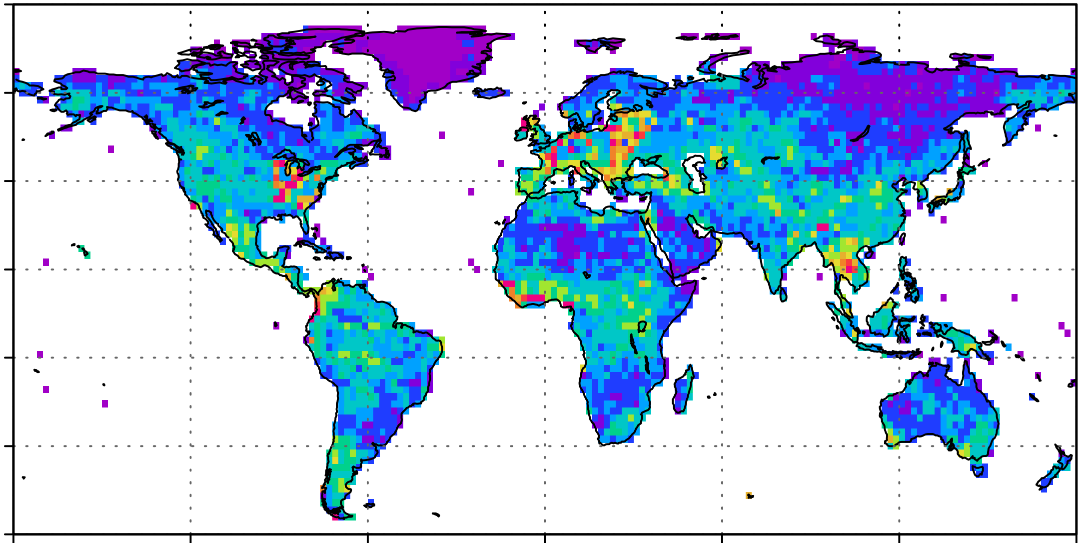
These declines are without taking into account any increase in major droughts.

National Academies, Stabilization Targets, 2010

What We Expect: Projections of future climate change and its impacts

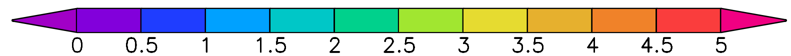
Droughts to increase over much of the globe

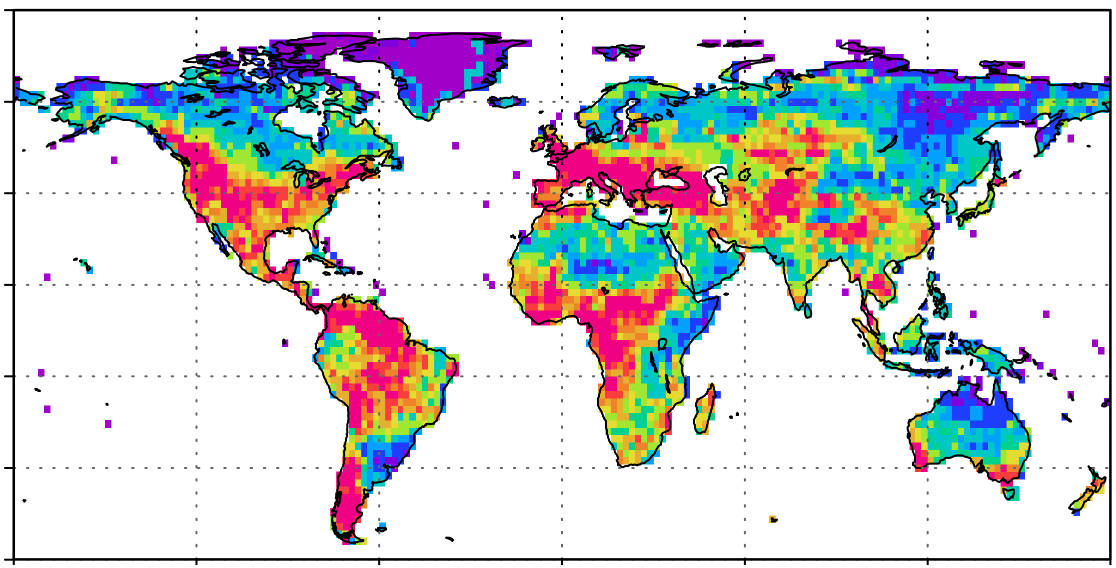
Frequency of 4-6 month duration droughts (events per 30 years)



1961-1990

Drought defined as soil moisture below historical 10th percentile value for that calendar month.





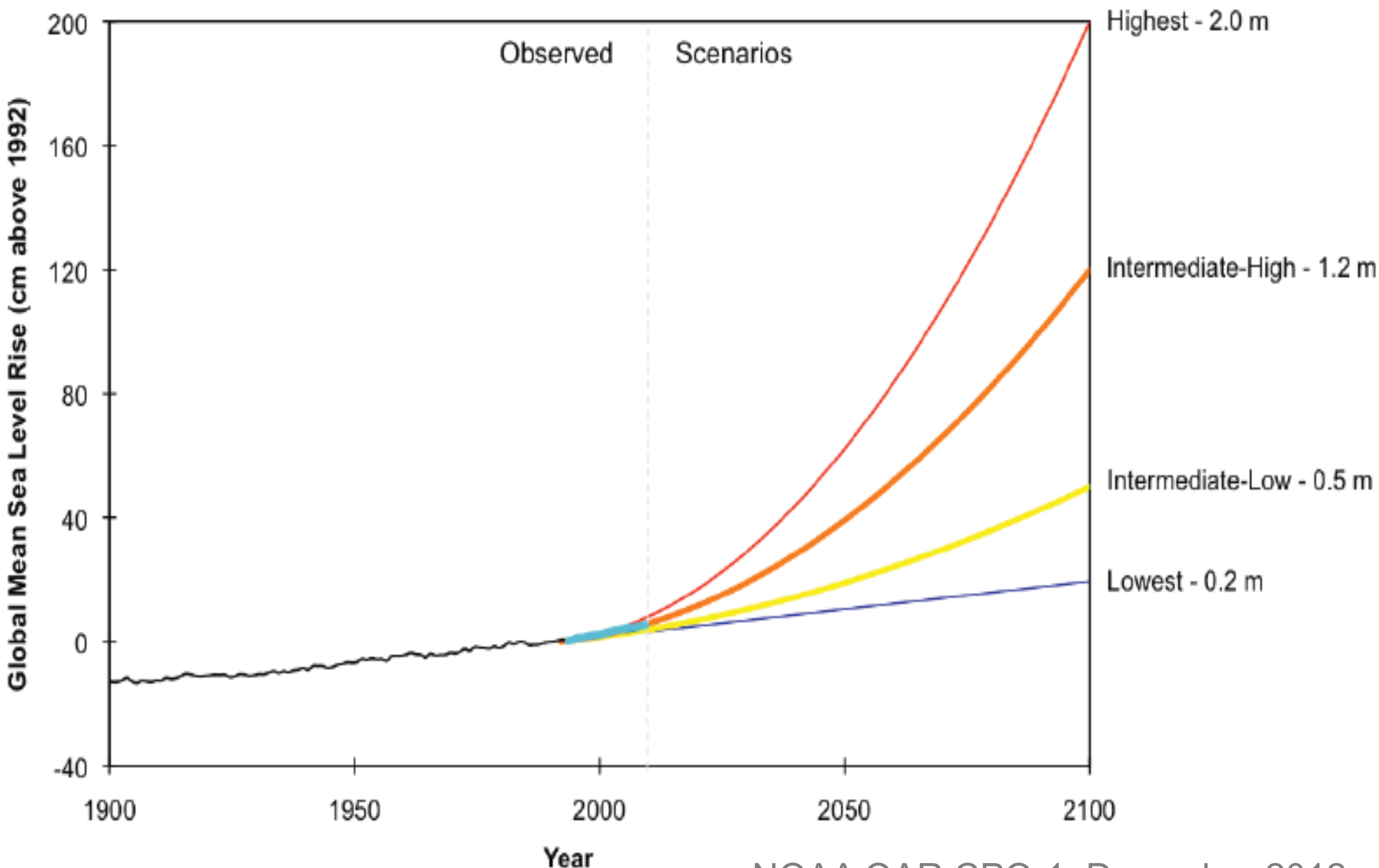
2070-2099, IPCC A2 scenario

Results shown are the mean of 8 global climate models. **Cape Cod drought frequency reaches 5x historical value.**

Source: Sheffield and Wood 2008 Climate Dynamics (2008) 31:79–105
DOI 10.1007/s00382-007-0340-z

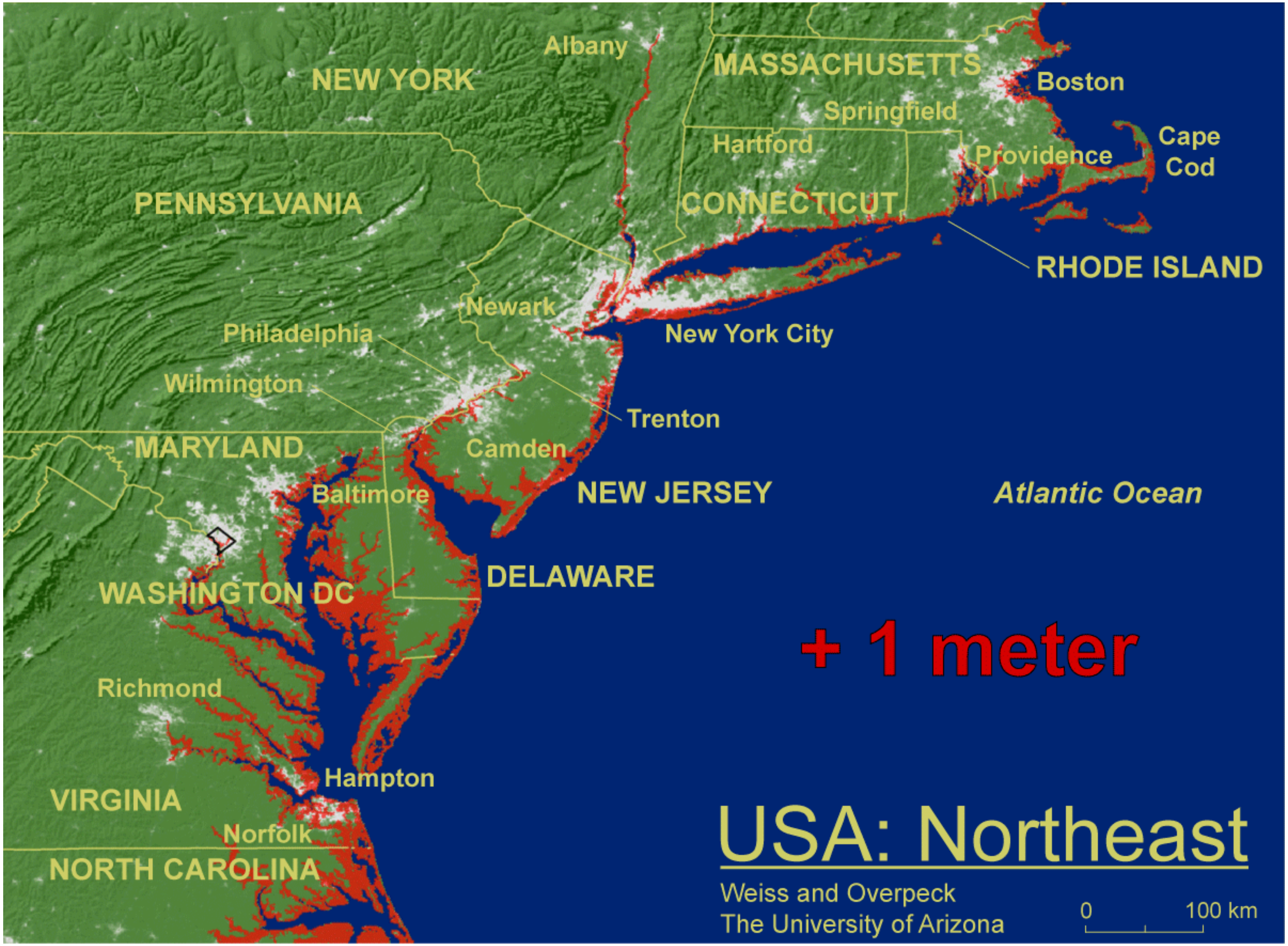
What We Expect: Projections of future climate change and its impacts

Mean sea level could rise 1-2 meters 2000- 2100



NOAA OAR CPO-1, December 2012

Sea level: Flooded area with 1 meter rise



Storminess is expected to continue to increase.

PNAS | October 8, 2013 | vol. 110 | no. 41 | 16361–16366

Robust increases in severe thunderstorm environments in response to greenhouse forcing

Noah S. Diffenbaugh[a,1], Martin Scherer[a], and Robert J. Trapp[b]

SCIENCE 14 NOVEMBER 2014 • VOL 346 ISSUE 6211 851

Projected increase in lightning strikes in the United States due to global warming

David M. Romps,[1*] Jacob T. Seeley,[1] David Vollaro,[2] John Molinari[2]

12610–12615 | PNAS | October 13, 2015 | vol. 112 | no. 41

Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era

Andra J. Reed[a,1], Michael E. Mann[a,b], Kerry A. Emanuel[c], Ning Lin[d], Benjamin P. Horton[e,f], Andrew C. Kemp[g], and Jeffrey P. Donnelly[h]

Princeton hurricane model projects increase in land-falling Cat 3-5 hurricanes in the Northeast

- By the end of the 21st century, HiFLOR projects more frequent TC landfalls for the United States, especially major hurricane landfalls.
- The largest climate change signal is observed along the east coast, with new threats to northern and inland locations.
- The increased frequency of rapidly intensifying storms, coupled with an increase in the number of landfalling storms, will necessitate new mitigation and forecast strategies to overcome more intense hurricanes impacting coastal cities with little lead time (Emanuel 2017).

These findings are for the IPCC's RCP4.5 emissions scenario—a mid-range case, not the worst!

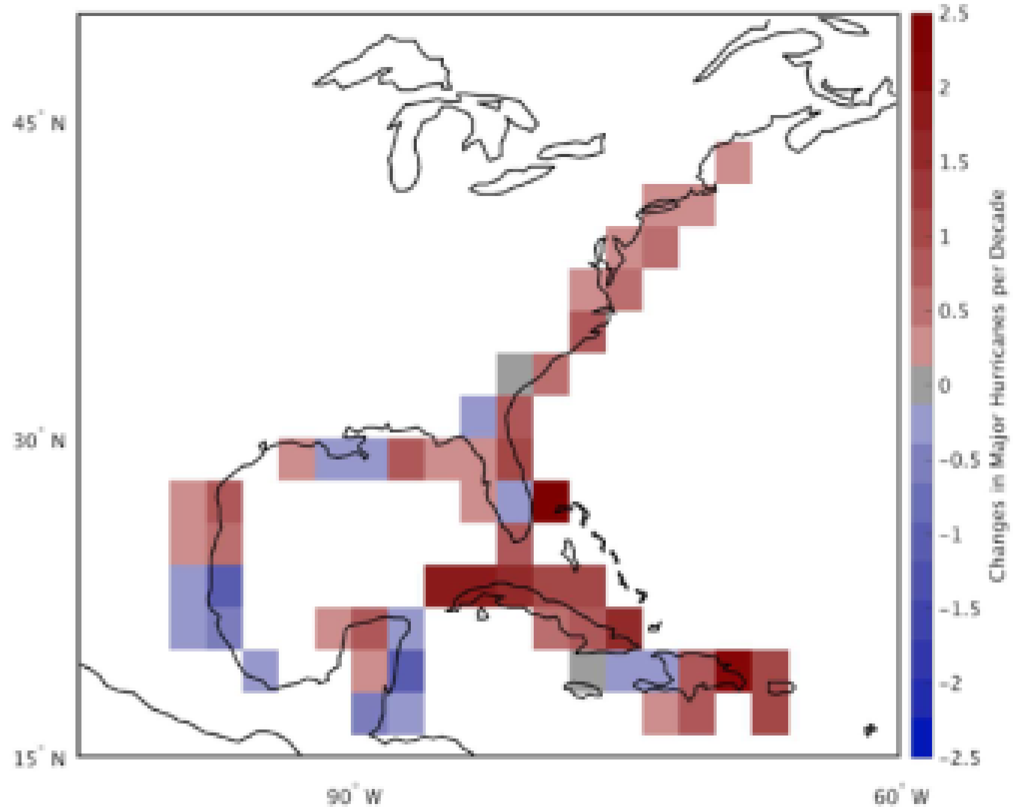


Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

Bhatia and Vechhi, Princeton U, 5 April 2017

What We Expect: Projections of future climate change and its impacts

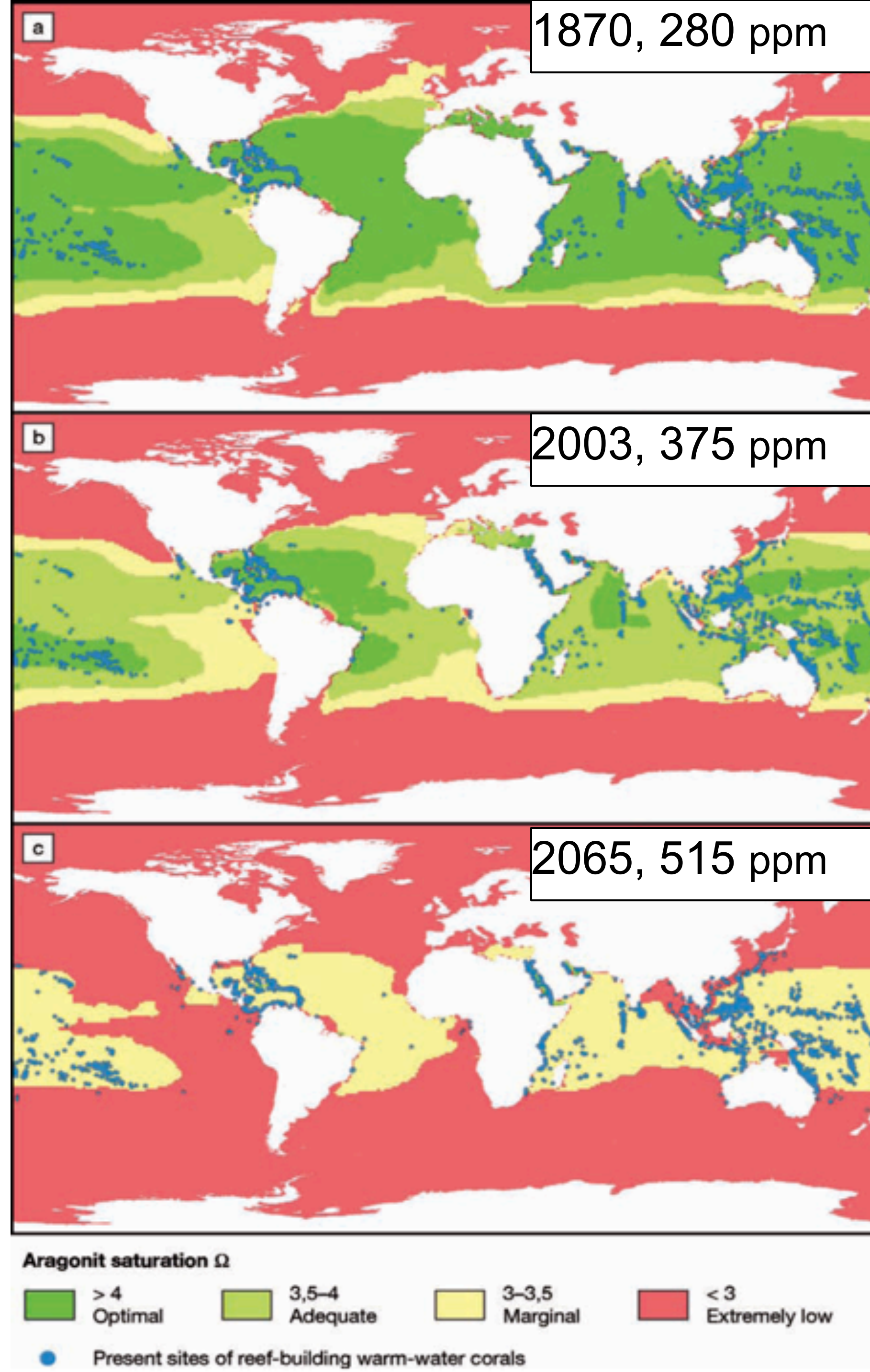
Continued drop in ocean pH, with profound impacts on marine life

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

Adverse effects are already being observed.

Coral reefs could be dead or in peril over most of their range by mid to late 21st century as a result of acidification & warming.

Steffen et al., 2004



Science: What More We Fear
(Plausible But Hard to Quantify Risks)

"What you don't know can hurt you."

Various

The nastiest potential surprises

- Massive CH_4 & CO_2 release from the warming Arctic
- Greatly accelerated sea-level rise from rapid disintegration of Greenland and Antarctic ice sheets
- Ocean food-chain collapse from multiple stresses: ΔT, acidification, O_2 depletion…
- Collapse of Atlantic Meridional Overturning Circulation
- (Add your own favorite)

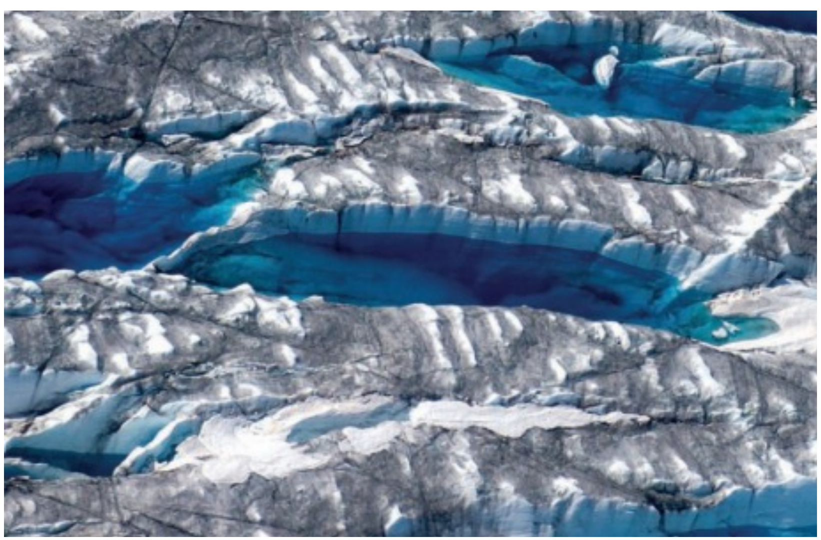
What More We Fear: Could sea-level rise accelerate sharply?

Recent studies have shed new light on mechanisms for rapid ice loss from Greenland & Antarctica

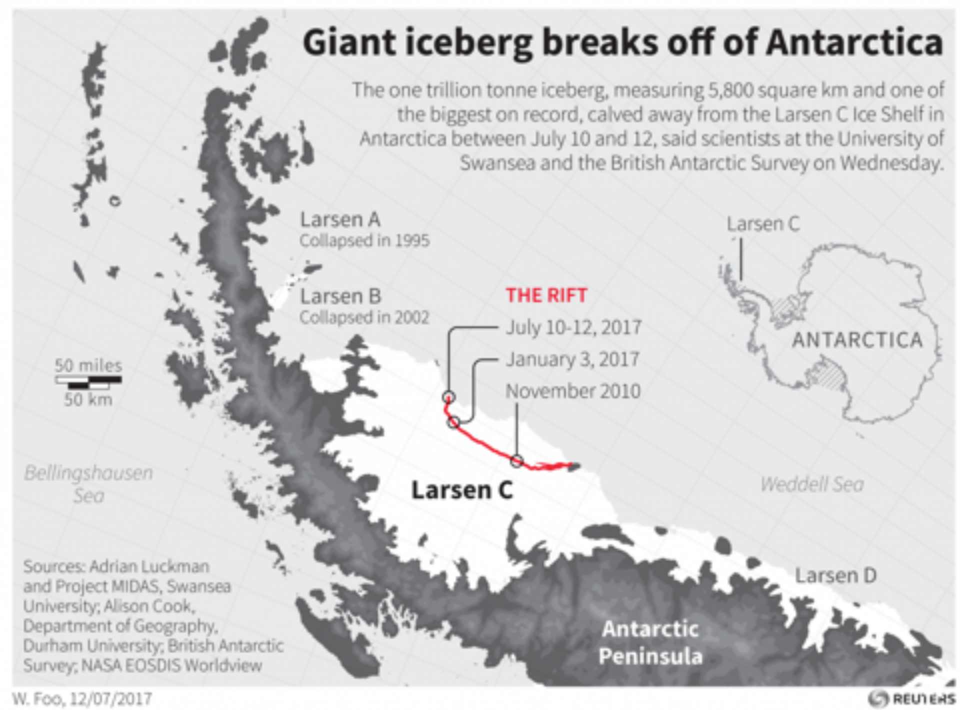
SCIENCE 24 FEBRUARY 2017 • VOL 355 ISSUE 6327

MELTDOWN

As algae, detritus, and meltwater darken Greenland's ice, it is shrinking ever faster

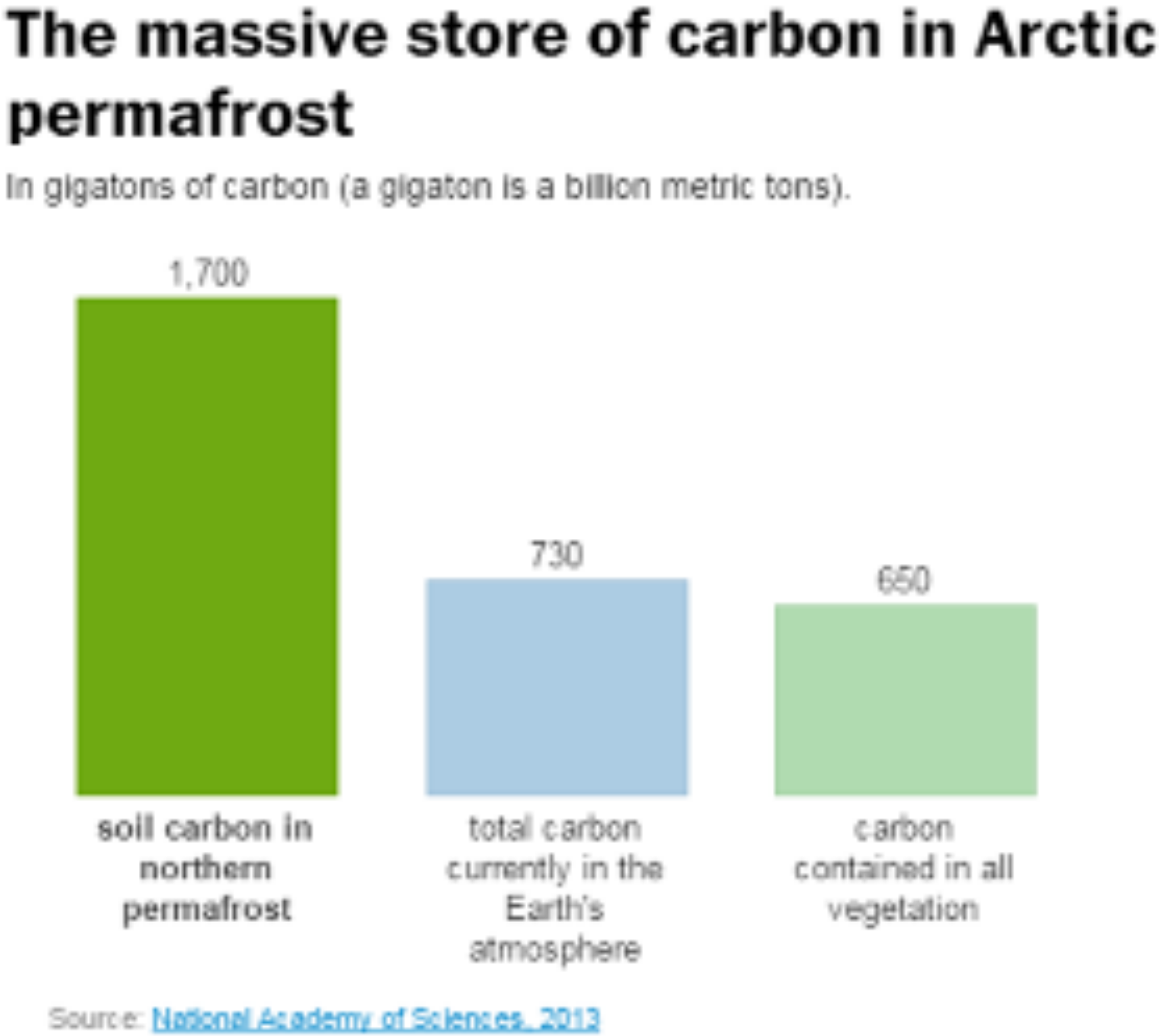


Disintegration of Antarctica's sea ice could greatly accelerate the flow of land ice into the sea



What More We Fear: Could emissions from Arctic soils spike?

CO_2 & CH_4 from Arctic soils > fossil emissions?



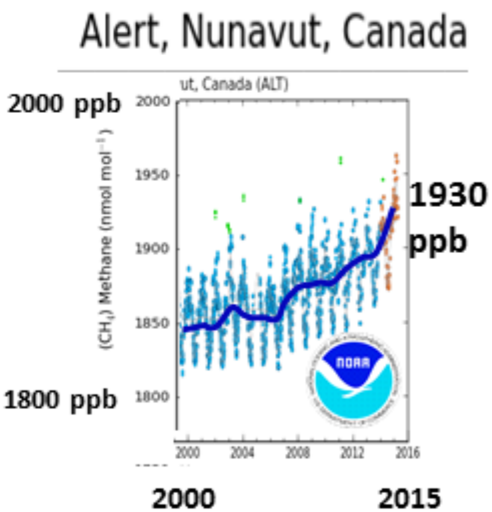
What More We Fear: Spiking methane

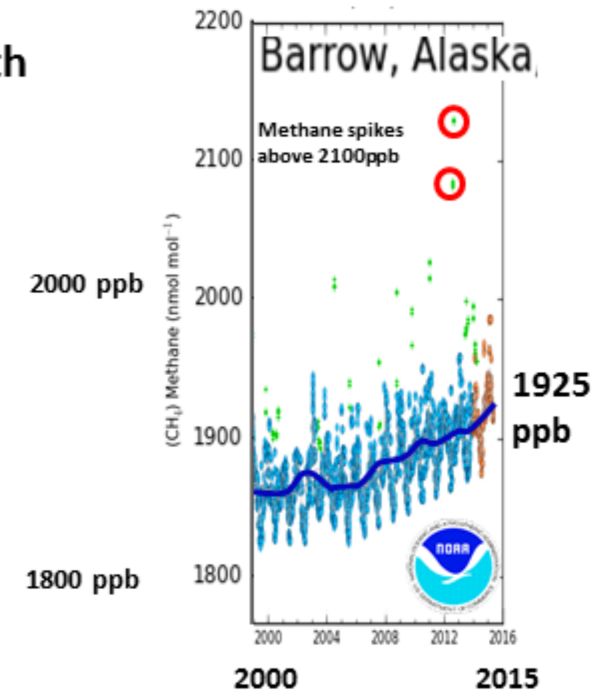
Big boost in methane from the Arctic

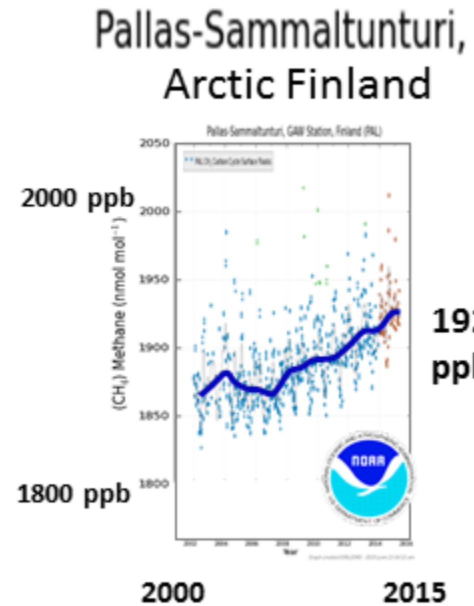
NOAA

Methane above the Arctic 2000-2015

Highest methane on Earth
is the farthest North







NOAA

Peter Carter

The post 2007 renewed sustained atmospheric methane increase is feedback methane emissions from warming wetlands. Wetlands are subarctic and tropical. NOAA methane flux results indicate it is mainly subarctic.

Heating efficiency of CH_4 per molecule in the atmosphere = 26.5x that of CO_2

Methane-burst crater in the Siberian tundra

Technology & Economics: Mitigation Options, Goals, & Costs

"There is no such thing as a free lunch."

Various

Mitigation options

- “Mitigation" means measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.
- The only measures that can do this are those that (a) reduce the atmospheric concentrations of heat trapping substances or (b) offset part of the heating effect of those substances.
  - Concentrations can be reduced by reducing emissions of heat-trapping substances or by increasing the sinks that remove them.
  - The effects of the concentrations that exist can be reduced by managing solar radiation (“geoengineering”)

Mitigation options (continued)

REDUCING EMISSIONS

- Increased end-use efficiency in buildings, transport, industrial processes
- Replace coal-burning electric power plants with wind, solar, or nuclear plants or natural-gas plants with carbon capture
- Replace fossil-based transport fuels with electricity or cleanly produced hydrogen for light-duty vehicles and with biofuels or hydrogen for heavy-duty vehicles and aircraft
- Reduce deforestation & forest degradation with incentives plus stricter regulation & enforcement

Mitigation options (continued)

INCREASING SINKS

- Increase reforestation and afforestation
- Alter agricultural practices to store more soil carbon
- Burn sustainably grown biofuels in power plants with carbon capture & sequestration
- Develop affordable technological means to capture CO_2 from air for sequestration.

MANAGING SOLAR RADIATION

- Increase reflectivity of Earth's surface
- Inject reflecting particles into the stratosphere

Key mitigation realities

- CO_2 emissions are the biggest piece of the problem (65% of GHG forcing and growing)
  - About 85% of the CO_2 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 CO_2 emissions (but not per capita).
- Global energy system can't be changed quickly: ~$25T 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.

Key mitigation realities

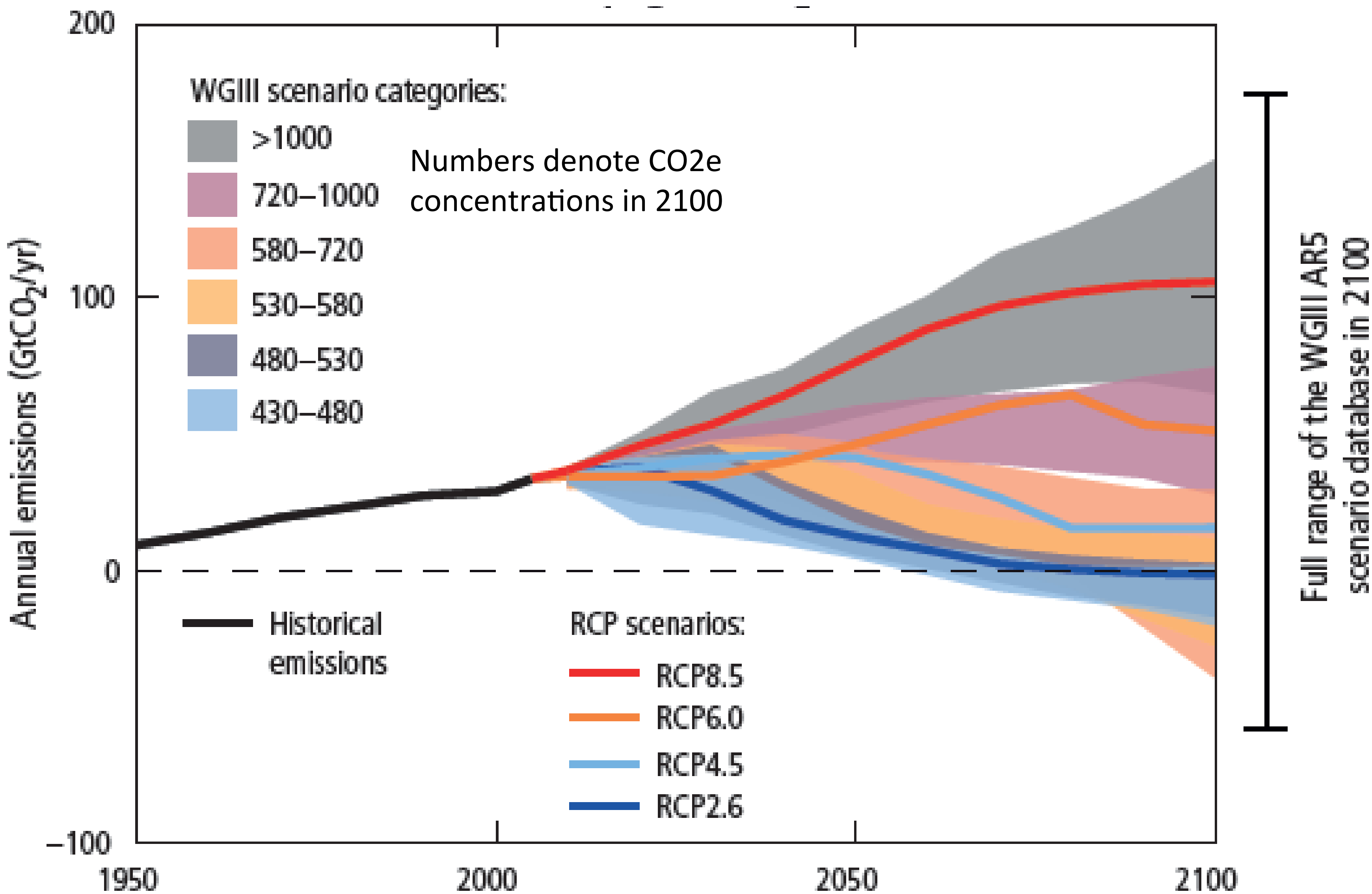
- CO_2 emissions are the biggest piece of the problem (50% and growing)
  - About 85% of the CO_2 comes from burning coal, oil, & natural gas (which provide >80% of world energy)
  - Most of the rest comes from deforestation & burning in the tropics
- Developing countries now exceed industrialized ones in total CO_2 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.

Mitigation goals: How much, how soon?

- Limiting ΔT_{avg} to ≤2ºC is now considered by many the most prudent target that still may be attainable.
  - EU embraced this target in 2002, G-8 & G-20 in 2009
- To have a >50% chance of staying below 2ºC:
  - atmospheric concentration of heat-trapping substances must stabilize at around 450 ppm CO_2 equivalent (CO_2e);
  - to get there, developed-country emissions need to peak by about now and decline rapidly going forward, and
  - developing-country emissions must peak no later than 2025 and decline rapidly thereafter.
- CO_2 emissions may need to go negative before 2100 to stay below 2ºC; must do so sooner for 1.5°C.

Technology & Economics: Mitigation

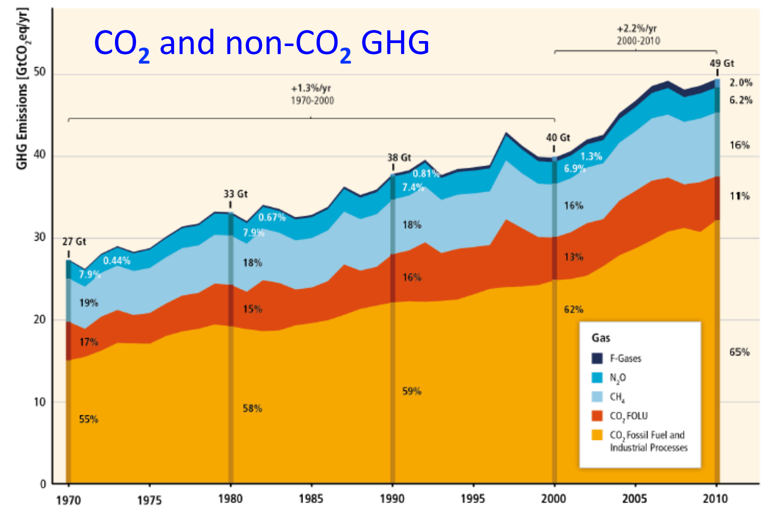
IPCC CO_2 emission scenarios to 2100



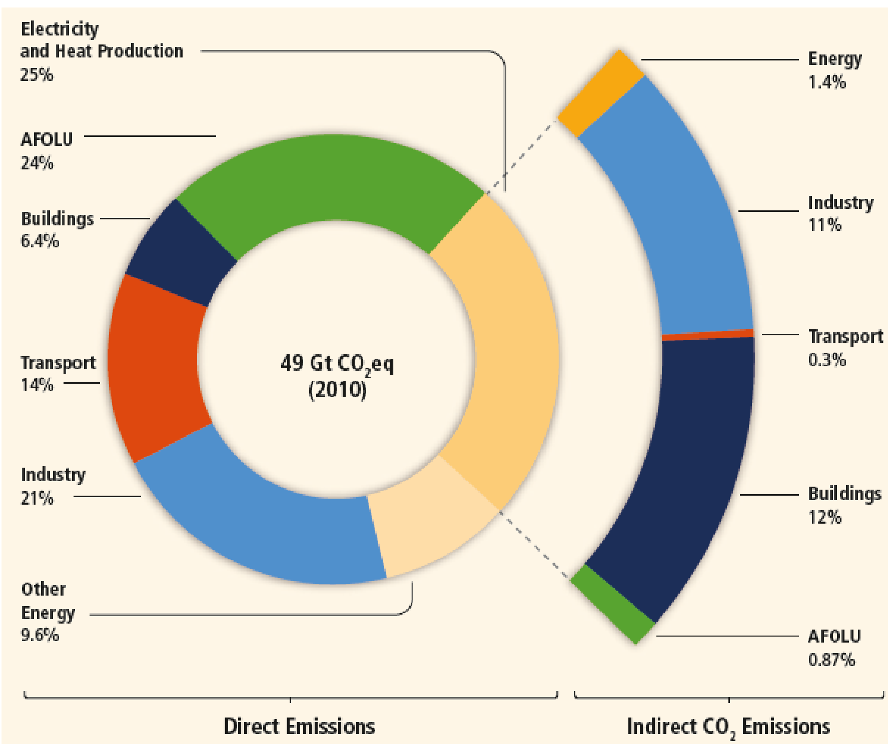
IPCC AR5 SYN Fig SPM-5

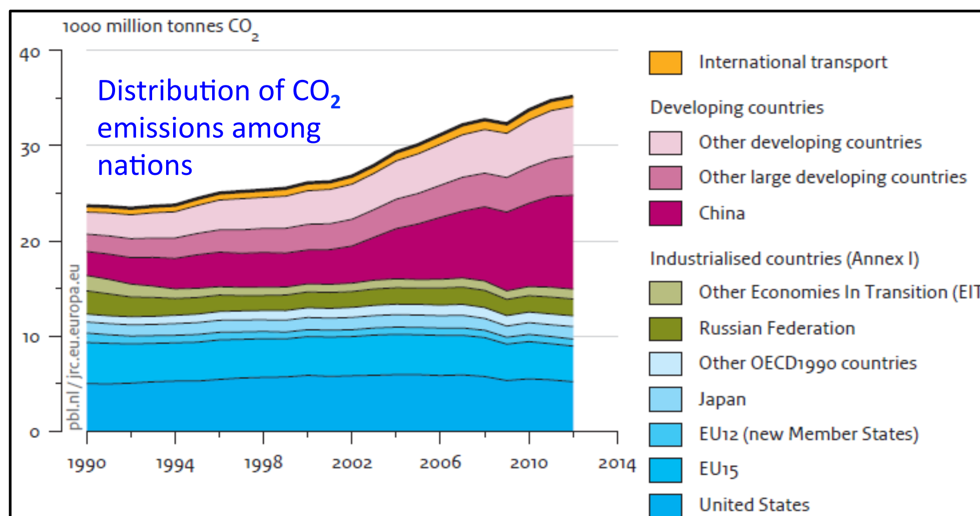
Emissions cuts need to be across the board

Adequate mitigation will require addressing <u>most heat-trapping substances</u> across <u>most emitting sectors</u> in <u>most countries</u>.



Sectoral sources of global GHG emissions

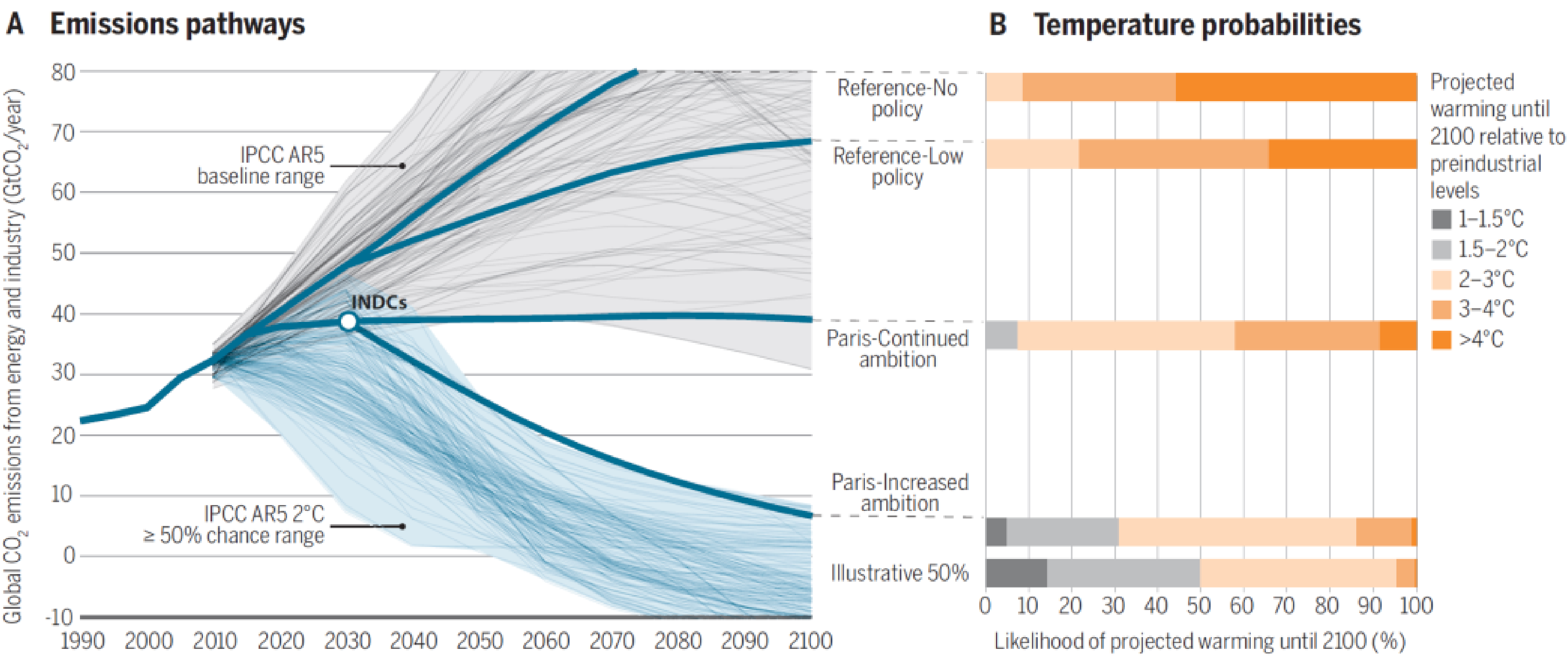




Technology & Economics: Mitigation

How much reduction , how soon? (continued)

Emissions pathways & ΔT probabilities



Fawcett et al., SCIENCE, December 4, 2015

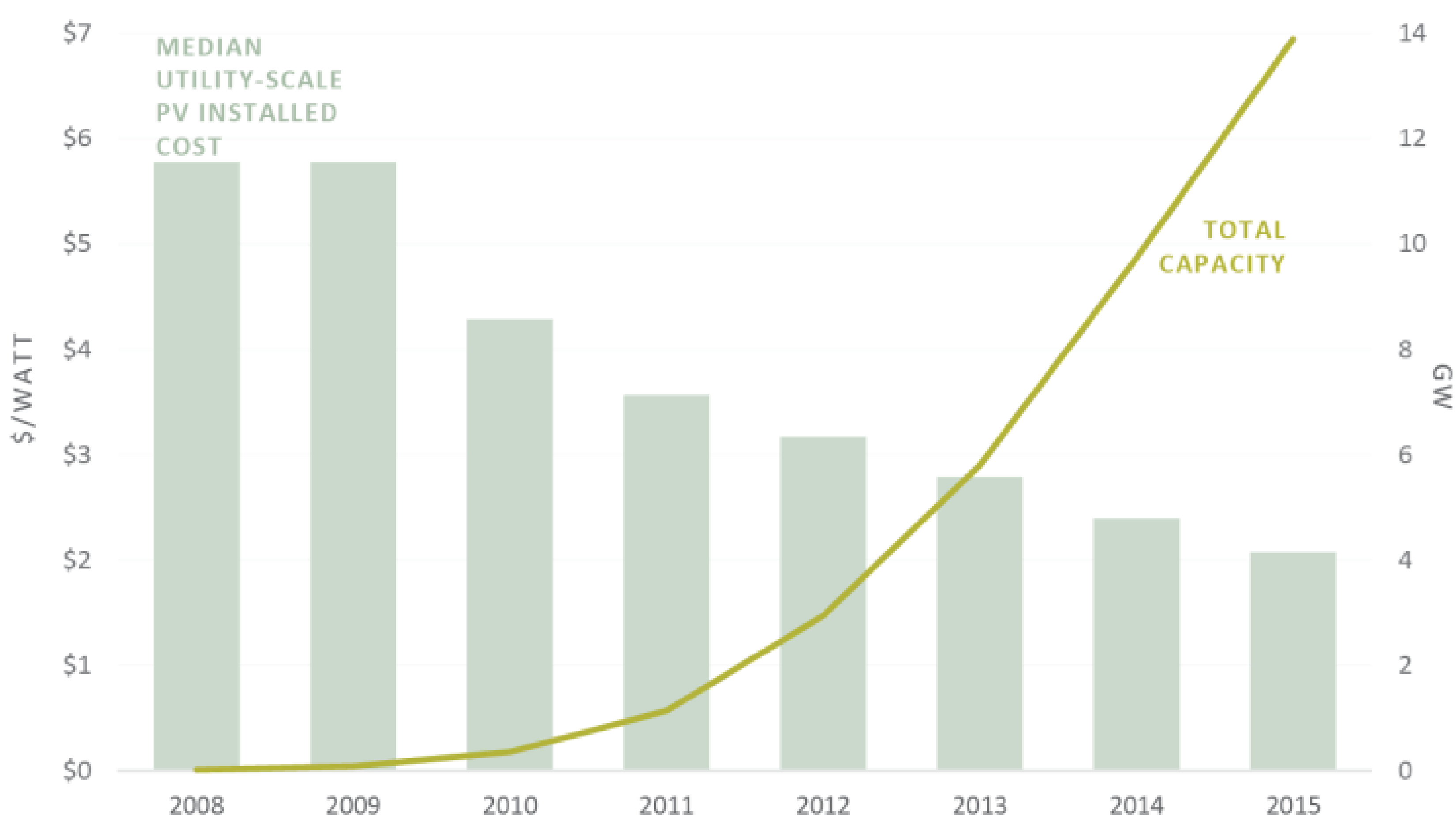
What do such deep cuts require?

- The trajectory for a 50% chance of $\Delta T \leq 2^{\circ}C$ calls for 2050 global CO_2 emissions to be ~7-9 GtC/yr below BAU
- Each of the following avoids 1 GtC/yr (3.64 $GtCO_2$/yr):
  - 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

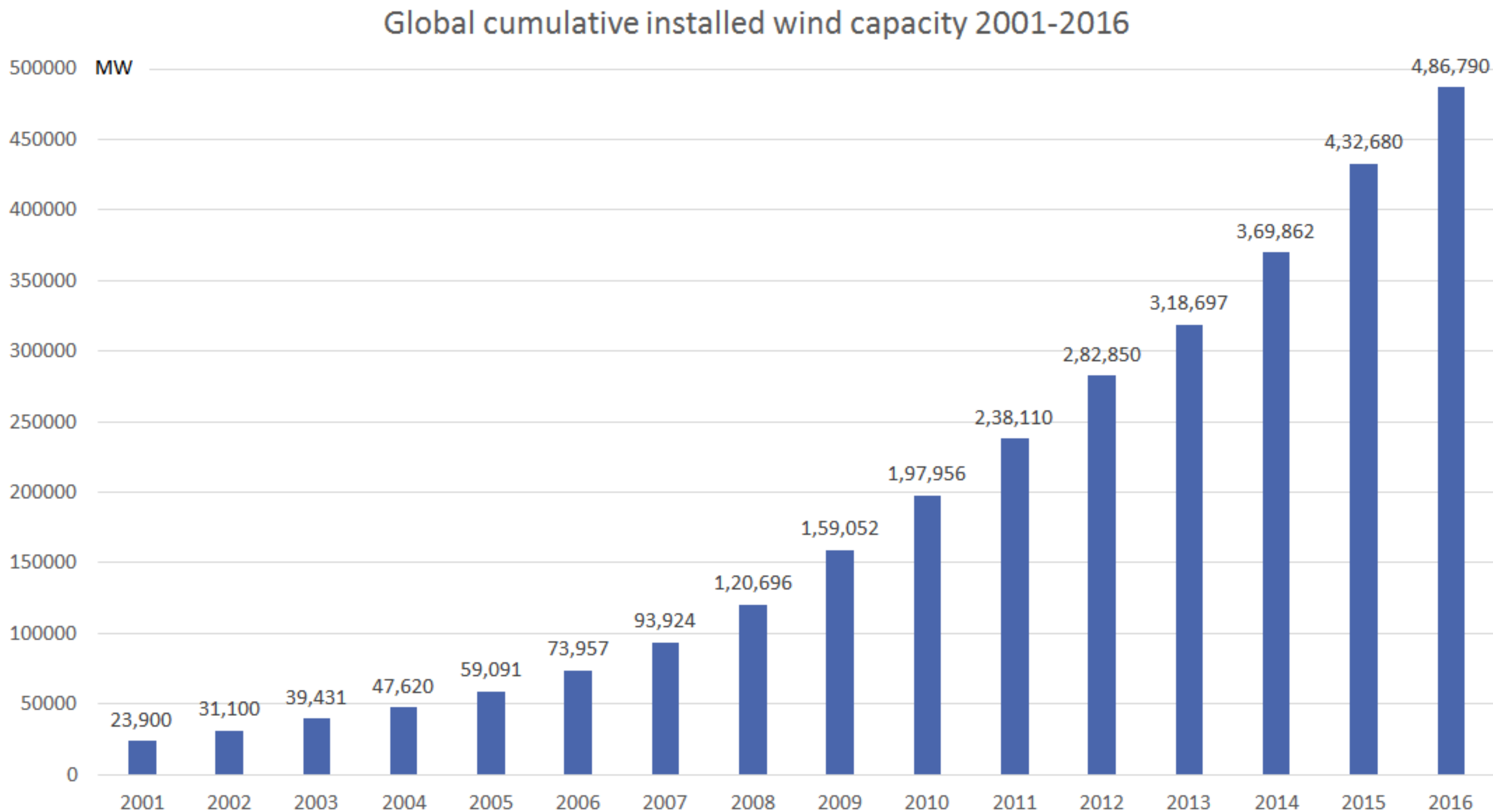
The economics of mitigation: Some good news

FIGURE E9: SOLAR ENERGY COSTS AND DEPLOYMENT IN THE UNITED STATES



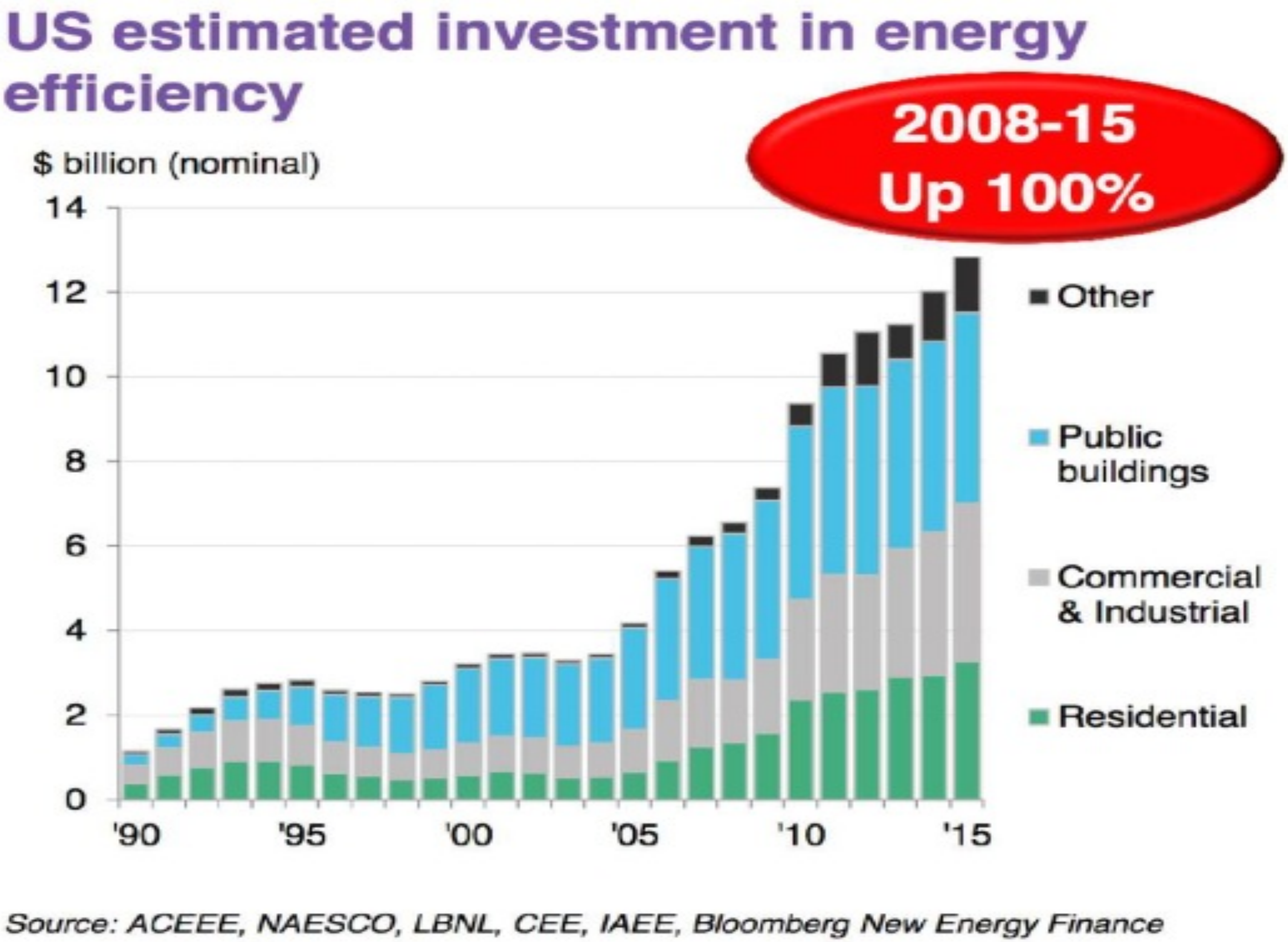
U.S. Mid-Century Strategy for Deep Decarbonization, 11-16

Economics: Wind-power has also gotten much cheaper, and wind capacity is growing



https://en.wikipedia.org/wiki/Wind_power_by_country#/media/File:GWEC2016.png

Economics: energy efficiency is booming



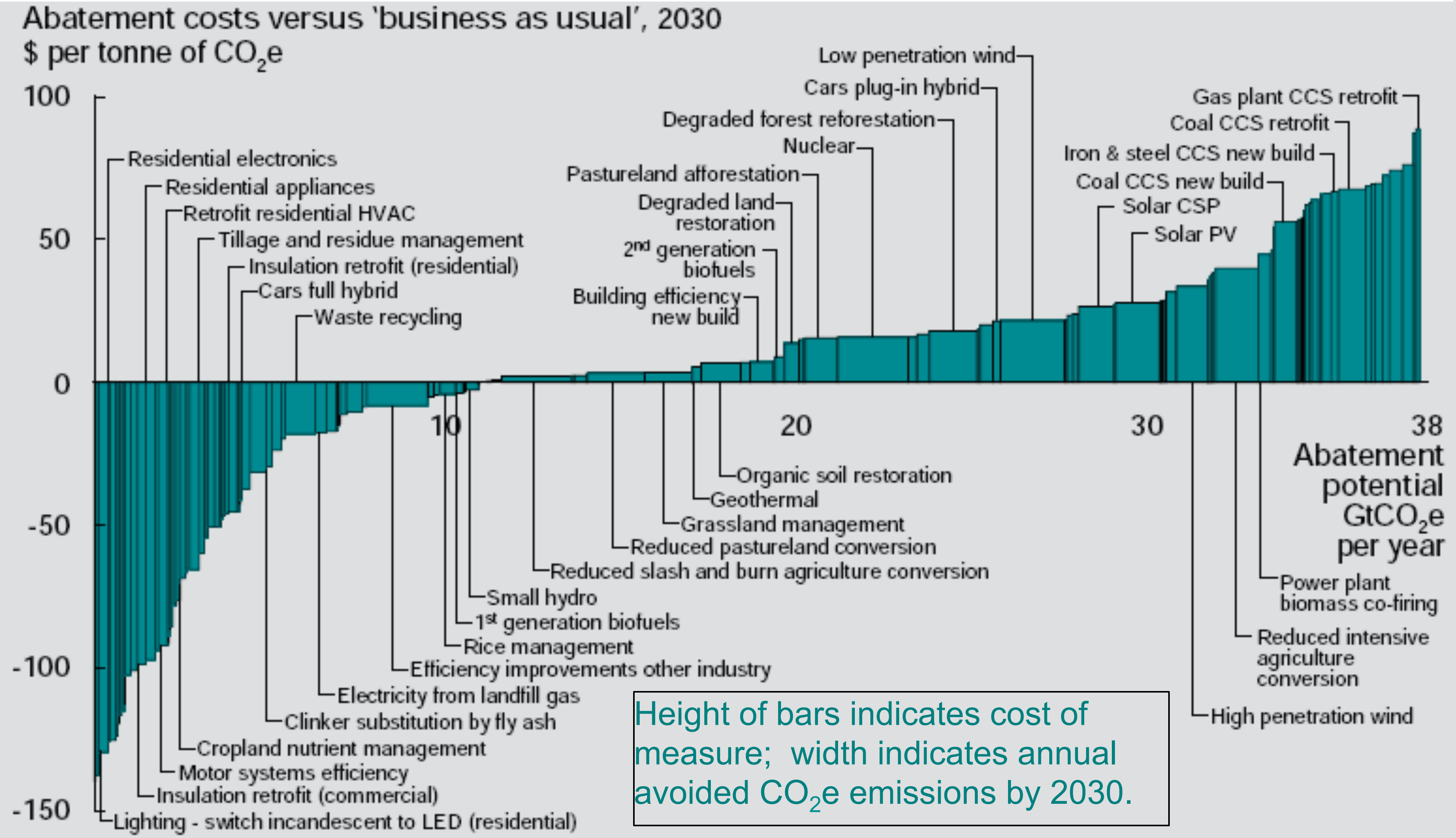
https://thinkprogress.org/watch-almost-everything-you-know-about-clean-energy-is-outdated-594cd2bfccdd

Mitigation options with farther to go

- CO_2 capture & storage from fossil-fuel- and biofuel processing and power plants and from air
- Sustainably grown & processed biofuels that don't compete with food & forests
- Advanced fission reactors with low cost, high safety, and proliferation-resistant fuel cycles
- Improved batteries & fuel cells
- Improved hydrogen production, storage, & distribution
- Determination whether <u>any</u> solar-radiation management options are scalable with acceptable costs & risks
- Practical fusion reactors

Is aggressive mitigation affordable?

Mitigation supply curve for 2030: aiming for 450 ppm CO2e



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.

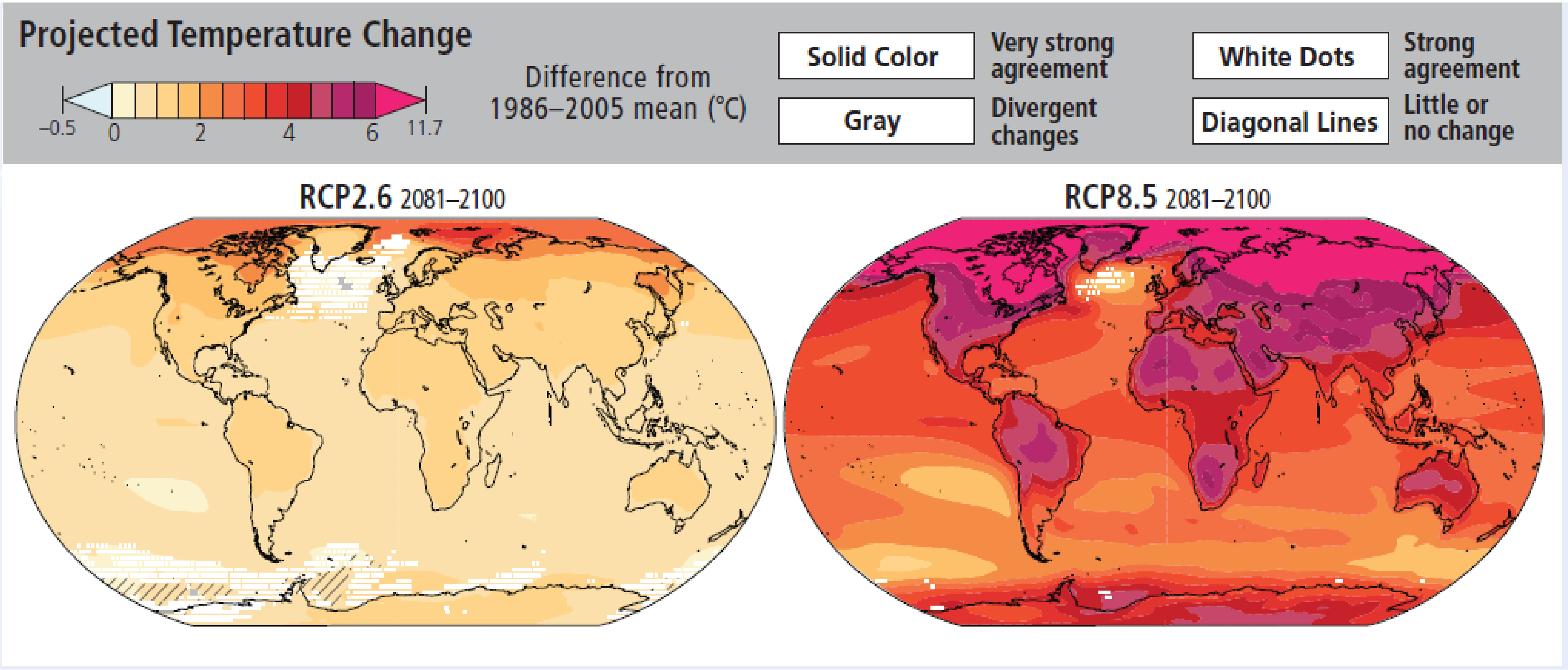
Source: McKinsey Global GHG Abatement Cost Curve v2.0

Is this much mitigation affordable?

- Achieving all the reductions on the McKinsey cost curve would require a carbon price of $70 per ton of CO_2e by 2030 (in 2015 dollars).
  - The total tax bill of $2 trillion per year would not represent the cost, because the average cost of reduction would be much less than $70 per ton. Society could spend the difference in other ways.
  - GWP in 2030 at 2.5%/yr growth between now and then would be $170 trillion, so even the $2 trillion figure would be ~1%.
- World now spends 2.5% of GWP on defense; USA spends 5% on defense, 2% on env protection
- Most economic models find costs of 2-3% of GWP by 2100, but they underestimate innovation.

Technology & Economics: Mitigation

Is it worth it? There is a huge difference between high- and low-emission futures



IPCC WGII, 2014

Most uncertainty about the future extent of climate change resides in society's choices, not in the science.

Is it enough?

NO

- Remember, this amount of mitigation gives us about a 50% chance of keeping the T increase at or below 2°C.
- But the world is already experience serious damage at about 1°C.
- 2°C is NOT "safe".

IF MORE MITIGATION IS NOT PRACTICALLY ATTAINABLE, WHAT ELSE CAN WE DO?

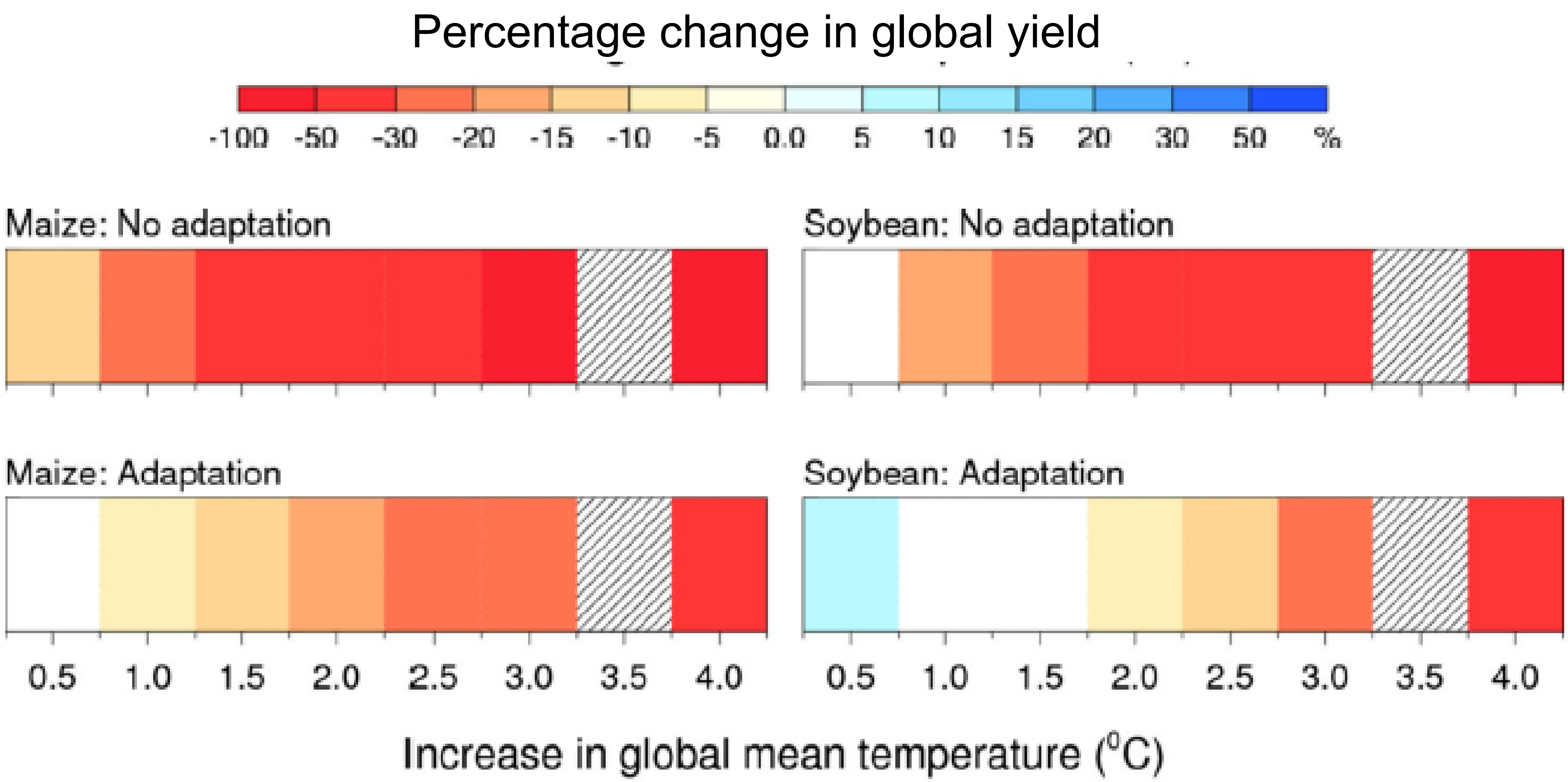
- Adaptation (including preparedness & resilience): Measures we take to reduce to damage to society and ecosystems resulting from the changes in climate we cannot avoid.

Adaptation possibilities include…

- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Preserving & enhancing "green infrastructure" (ecosystem features that protect against extremes)
- Preparing hospitals & transportation systems for heat waves, power outages, and high water.
- 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.

The limits of adaptation: Crop yield reduction vs global T change with & without adaptation



Rose *et al*., CLIMATIC CHANGE, online 10 Feb 2016

Limits of adaptation: Low-lying island nations

David Gray (Reuters)

WMO State of the Global Climate in 2016

What society can 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 and societal disruption 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.