Why the Wafflers are Wrong:

Addressing Climate Change is Urgent (and a Bargain)

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Keynote Address

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Outline of these remarks

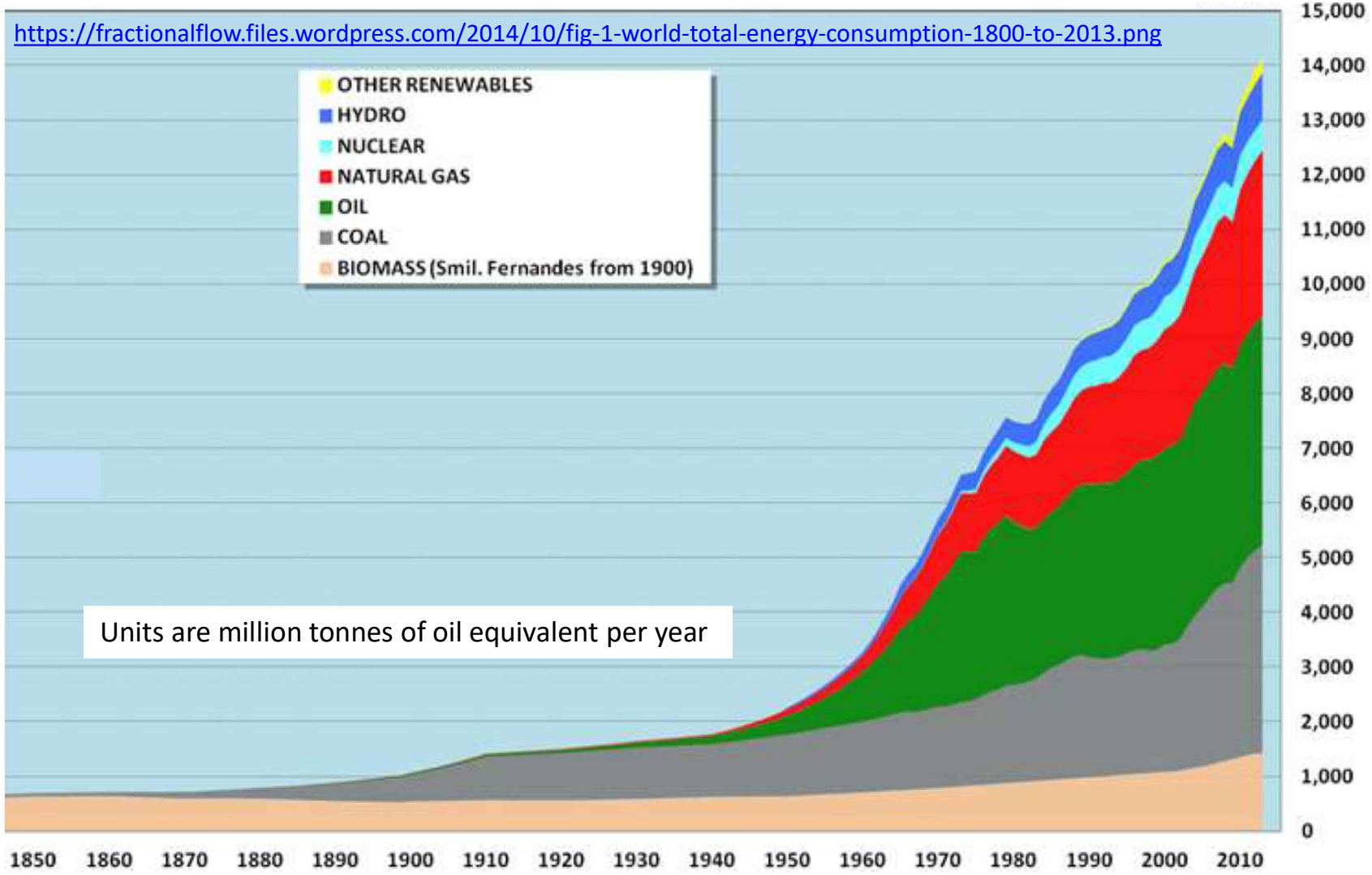
- Fundamentals of global climate change (CC)
- Categorizing contrarian confusions
  - Denial
  - Waffling
  - Surrender
- Rebutting denial: How we know CC is real
- Rebutting waffling: How we know CC urgent
- Rejecting surrender: How we know fixing CC will be a bargain

Fundamentals

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

Daniel Patrick Moynihan

Growth of world population & prosperity from 1850 to 2015 led to a 22-fold increase in energy use.

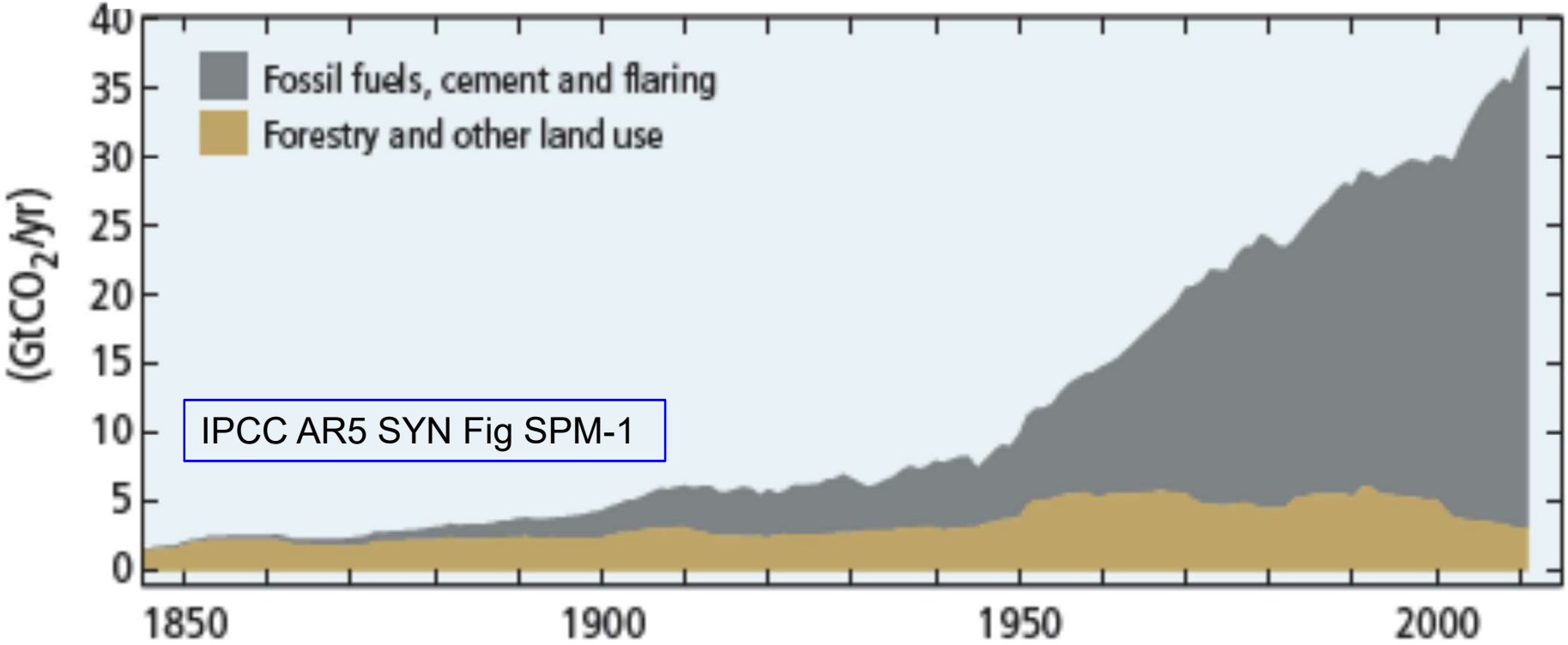


In 2015 the world still depended on coal, oil, & natural gas for about 80% of its total energy supply and two-thirds of its electricity.

Civilization's CO_2 emissions tracked the rise of fossil-fuel use & deforestation

Roughly, coal is CH, oil is CH_2, natural gas is CH_4, and wood is CH_2O. In each case, their combustion produces CO_2 and H_2O, all going into the atmosphere.

Global anthropogenic CO_2 emissions



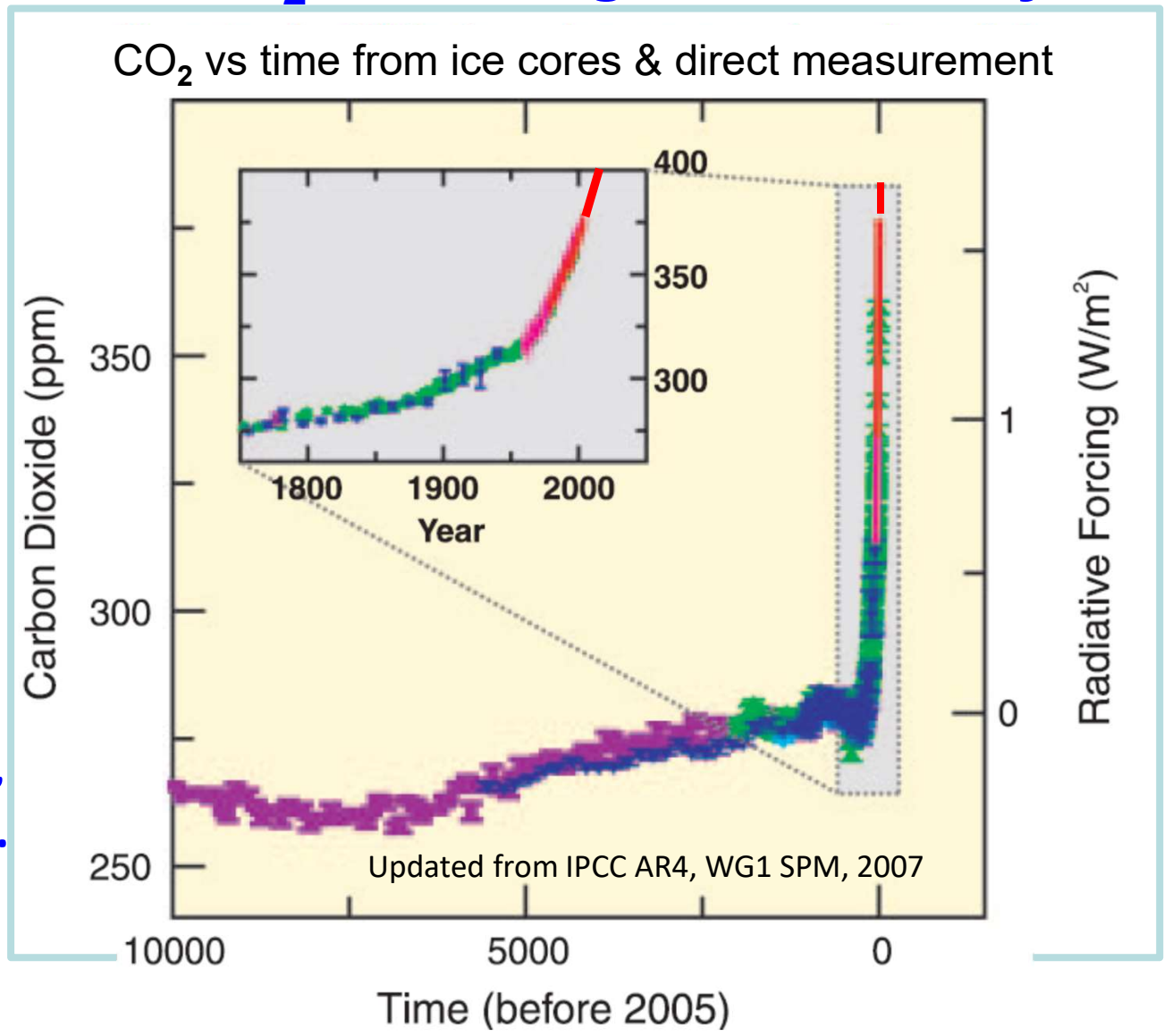
The H_2O stays in the atmosphere only briefly, so the additions do not accumulate there. But some of the CO_2 stays long and accumulates.

So the atmosphere's CO_2 content grew markedly

The record of CO_2 content over the millennia (from ice cores, large curve) shows the gradual rise from the Agri-cultural Revolution and the steep one from the Industrial Revolution.

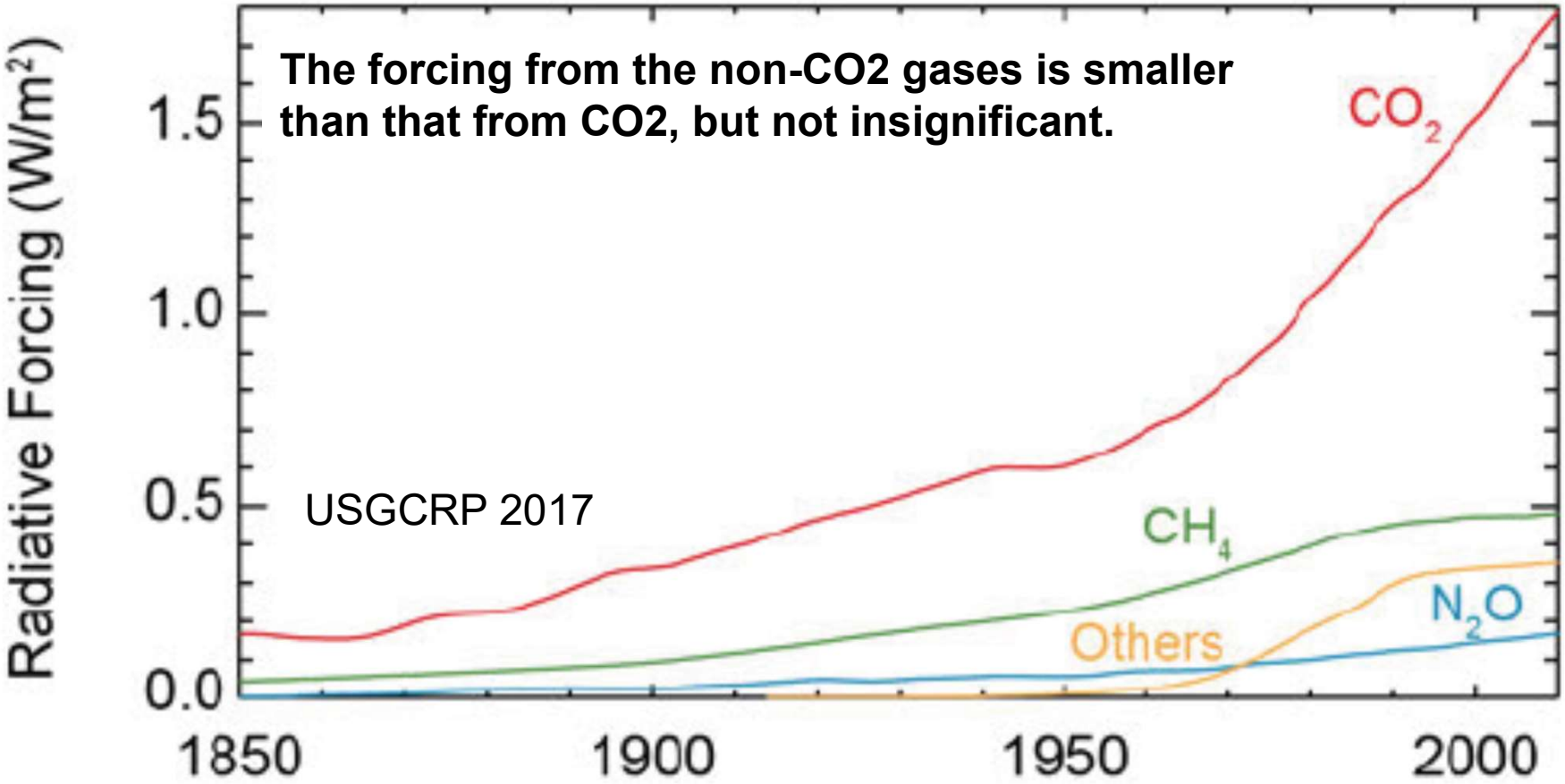
The 2016 CO_2 concen-tration was 403 ppmv, 45% higher than 1750.

The "forcing" (scale on the right) is the resulting change in the energy balance of the atmosphere since 1750.

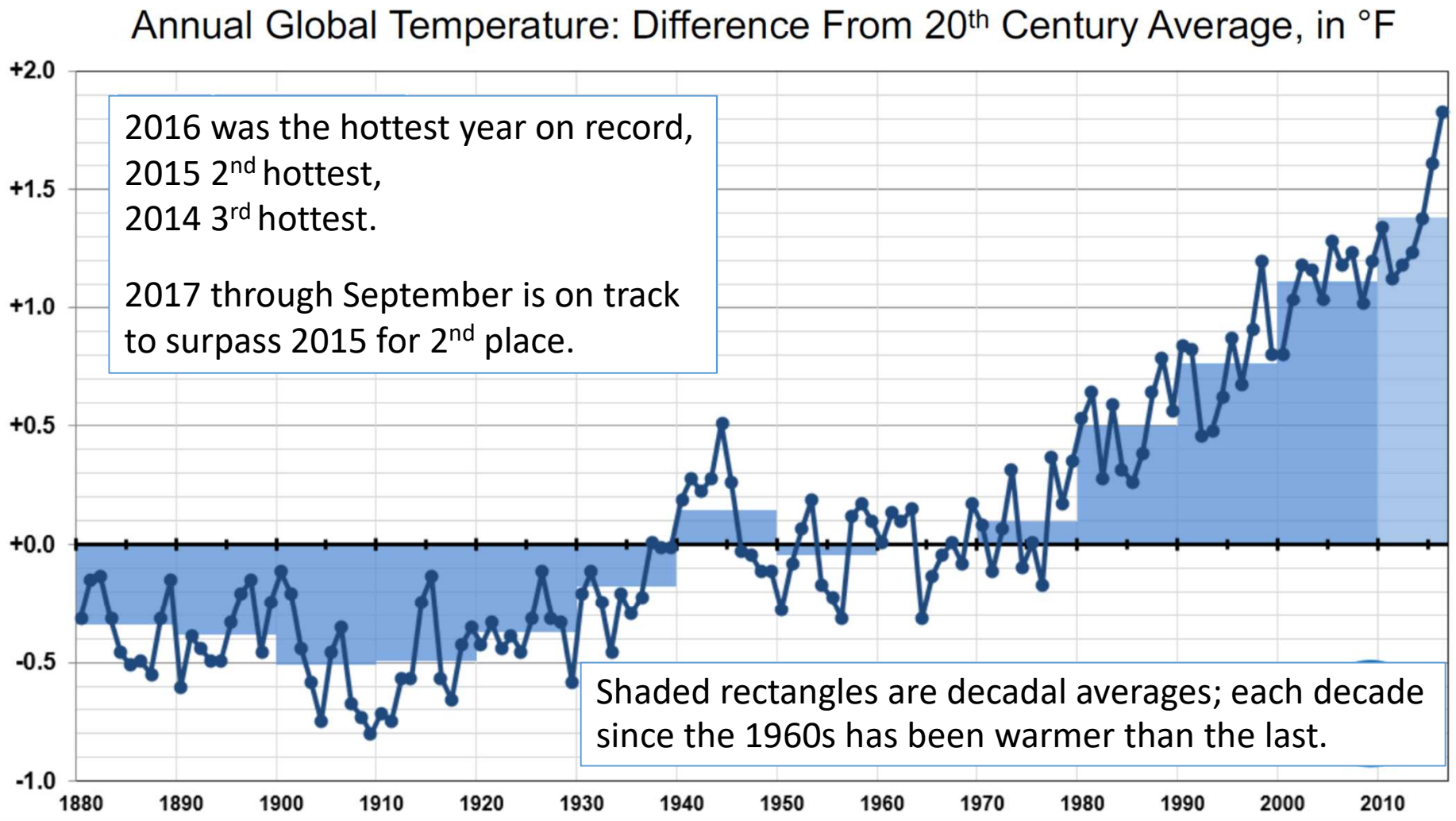


Humans have added other heat-trapping gases too

Most important are methane (CH_4) & nitrous oxide (N_2O) from energy systems & agriculture and CFCs and (most recently) CFCs & HFCs from consumer products & industry



Global-average surface air temperature from 1880



Earth has been warming more or less steadily for the last 100+ years, as the increasing forcing from the human-caused GHG buildup came to dominate natural variability.

But "global warming" is something of a misnomer

That term implies something…

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

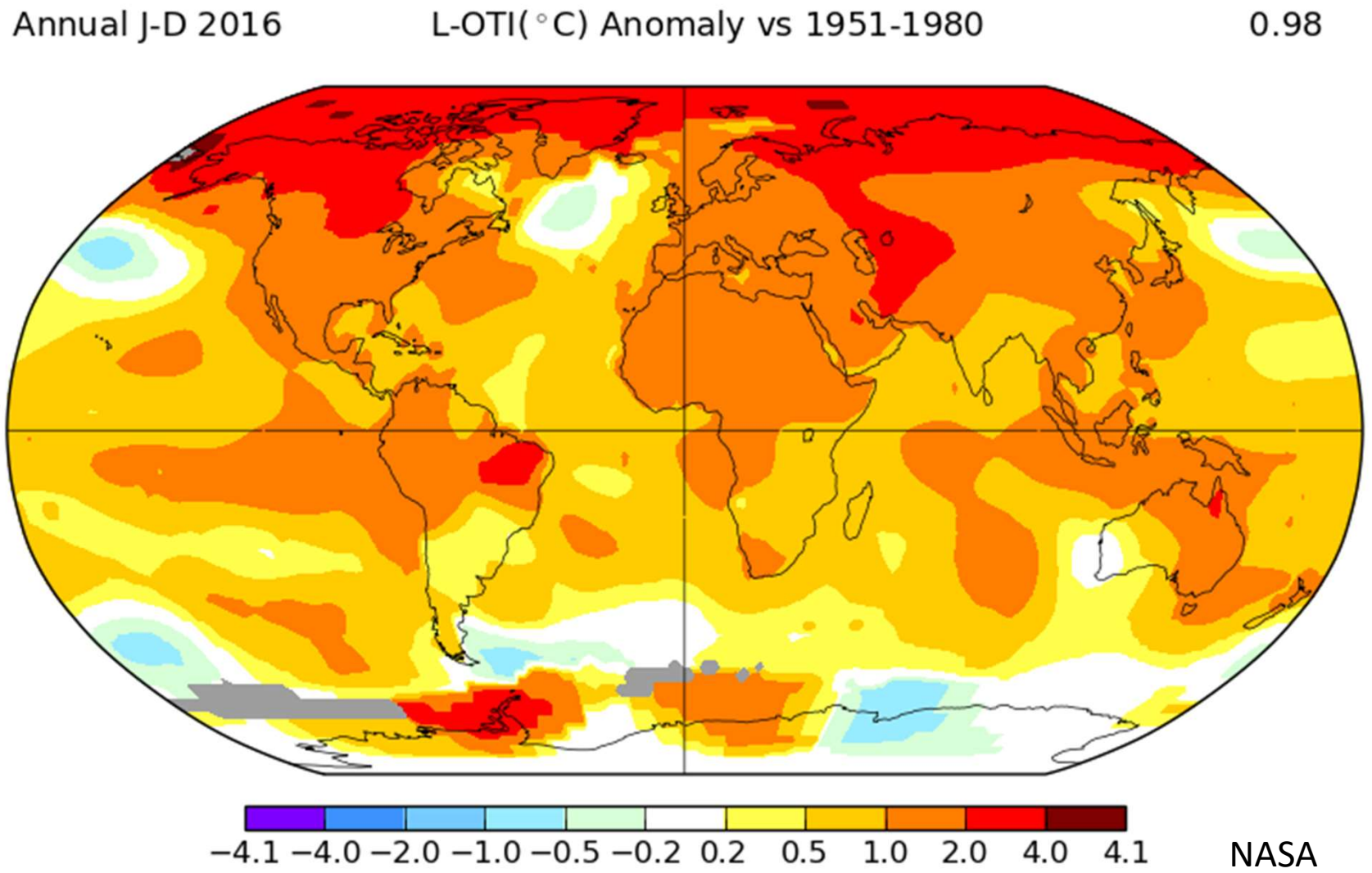
This seems to have confused people.

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".

The T change is highly non-uniform



Uneven T change → changes in atmospheric & ocean circulation.

The changes are not just about temperature.

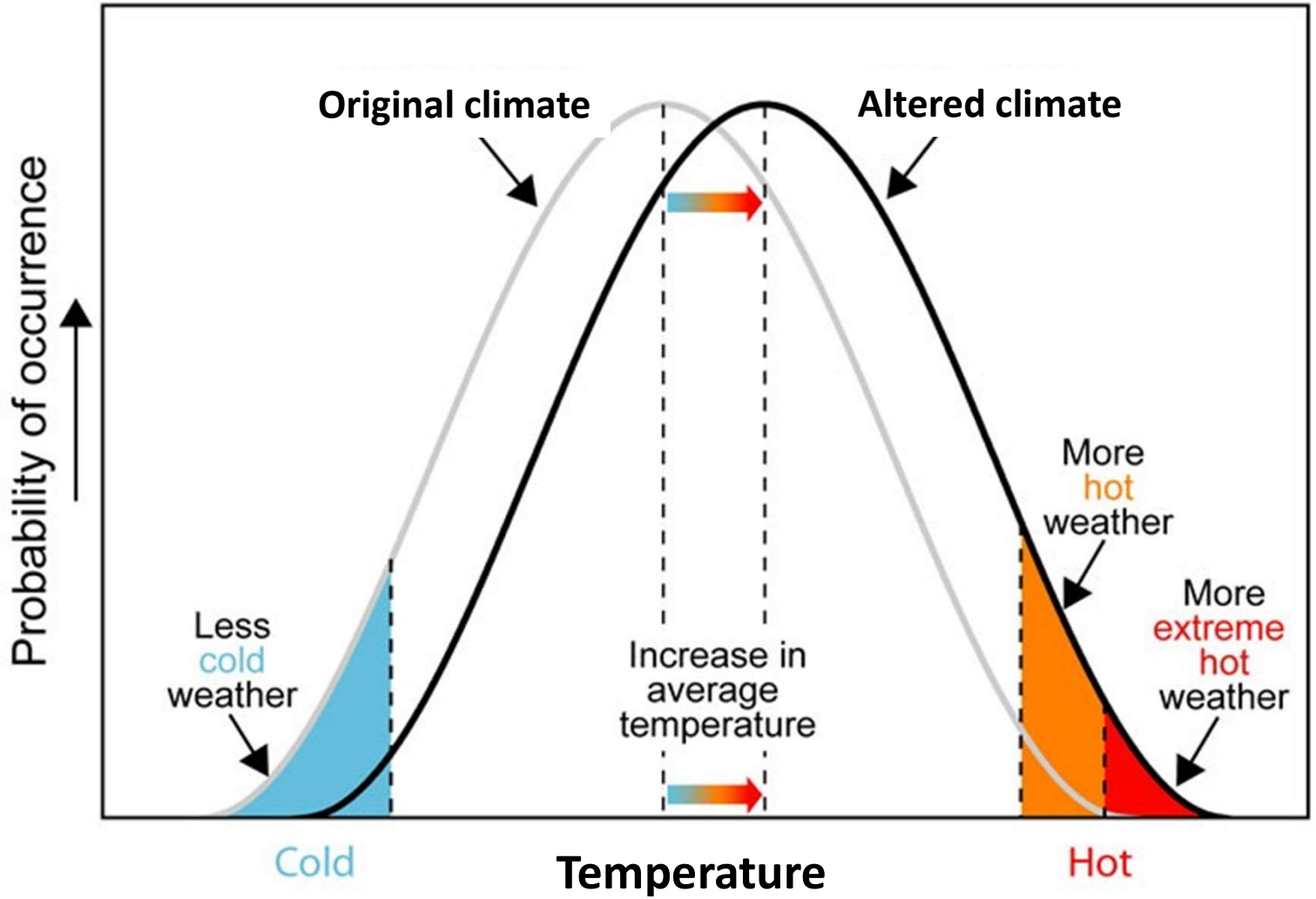
Climate = weather patterns, meaning averages, extremes, timing, and spatial distribution of…

- yes, hot & cold, but also…
- cloudy & clear
- humid & dry
- drizzles, downpours, & hail
- snowfall, snowpack, & snowmelt
- breezes, blizzards, tornadoes, & typhoons

Climate change entails disruption of the patterns.

Global average T is just an index of the state of the global climate system as expressed in these patterns. Small changes in the index correspond to big changes in the system (much like your body temperature).

When the average of any of these weather variables changes, the extremes change much more.



The principle holds for any "normally distributed" climate variable:
A modest change in the average → big changes at the "tails".

These changes matter because…

Climate governs (so altering climate 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

Categorizing Contrarian Confusions

"A lie gets halfway around the world before the truth can get its boots on."

Mark Twain

Categorizing contrarian confusions

Classes of contrarian arguments

Type 1: "The Earth isn't really warming."

Type 2: "It's warming, but humans have nothing to do with it."

Type 3: "Humans may have something to do with it, but…

3.a …"we don't know how much," or

3.b …"it doesn't matter because it's a good thing," or

3.c … "it's slow so we have plenty of time to adapt," or

3.d … "we're better off investing in economic development than addressing climate change directly."

Type 4: "Yes, the human role is large and dangerous, and development alone is inadequate protection, but it's too late (or too costly) to fix it…so let's just hunker down."

Categorizing contrarian confusions

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Type 1: "The Earth isn't really warming."

DENIAL

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WAFFLING

3.c … "it's slow so we have plenty of time to adapt," or

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SURRENDER

Categorizing contrarian confusions

Among contemporary contrarians, the wafflers are the ones being taken most seriously

- The numbers of deniers are dwindling in the face of ever more obvious climate change that everyone can see and for which no one has offered a plausible alternative to human influence.
- The wafflers are more numerous and seem less unreasonable. They are not denying the obvious, and their arguments are more nuanced than those of the deniers.
- Those suggesting surrender, while slowly increasing in number, are offering an argument of despair that is unpalatable to most who agree that the problem is real.

I'll offer rebuttals to the arguments of all 3 categories of contrarians but spend the most time on the most dangerous—the wafflers.

Rebutting the Deniers

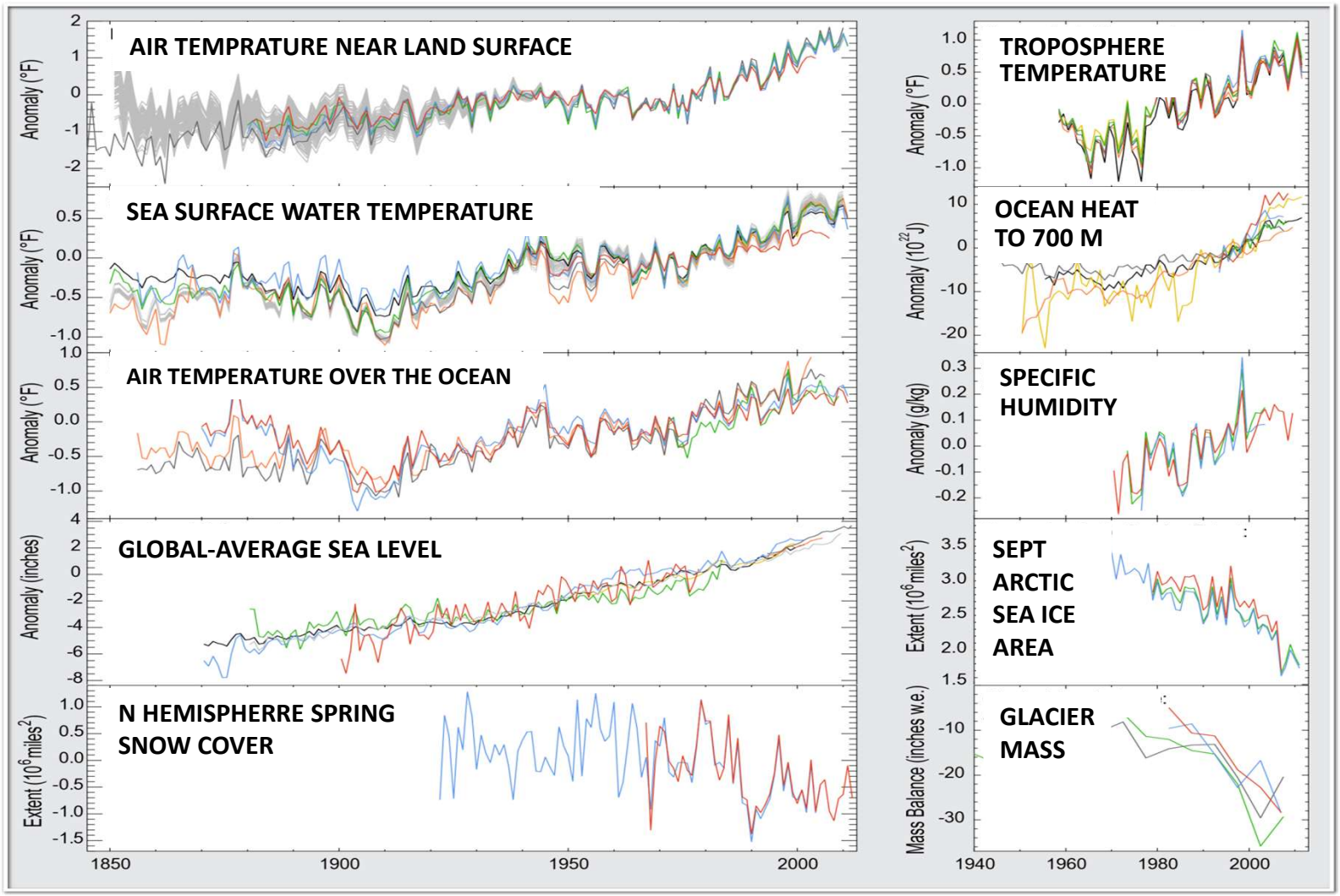
"Science is true whether or not you believe in it."

Neil deGrasse Tyson

Rebutting the deniers

There is no scientific doubt the world is warming.

Trends in every relevant indicator are consistent.



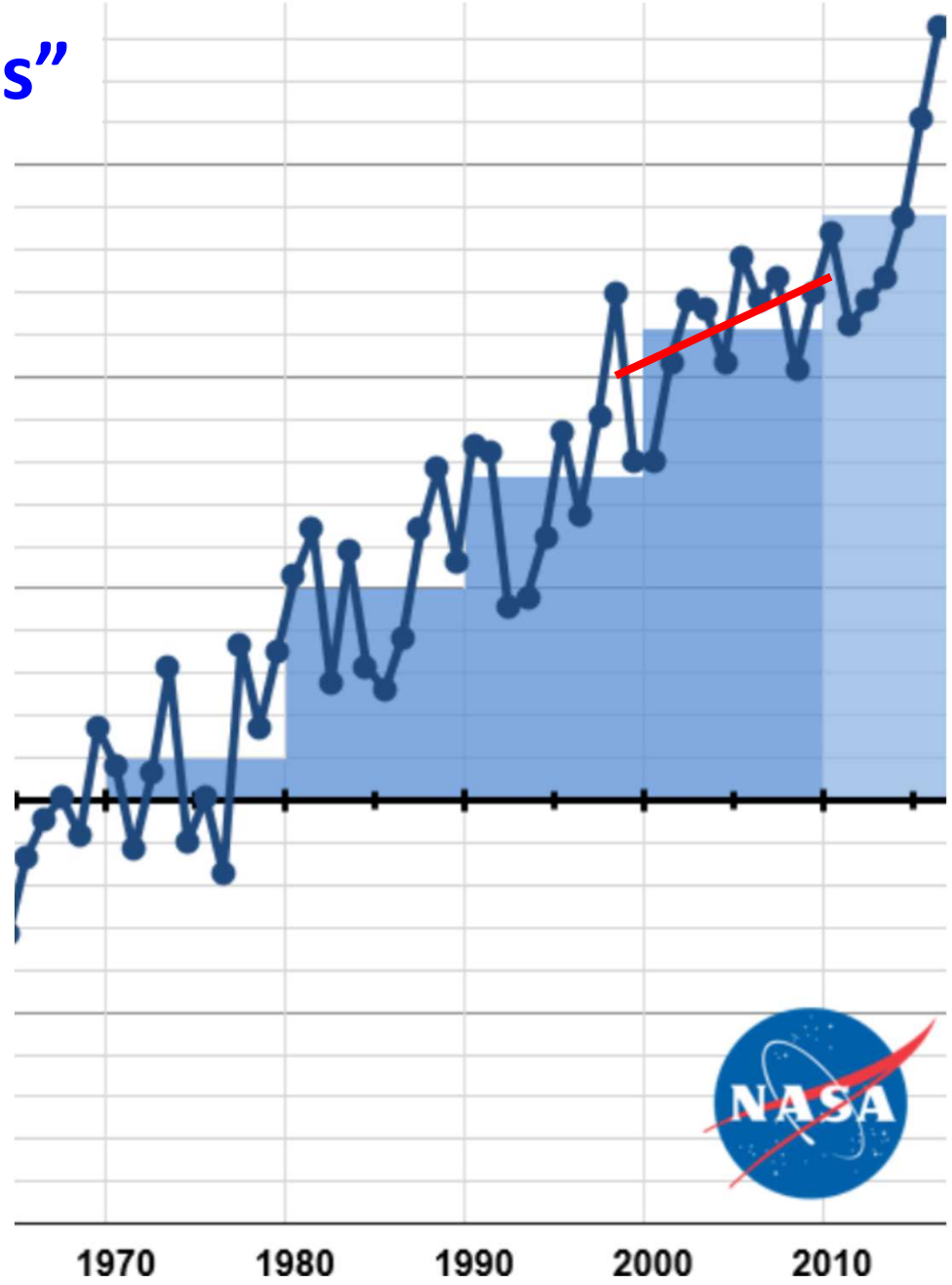
IPCC WGI 2013

Rebutting the deniers

There was no “hiatus”

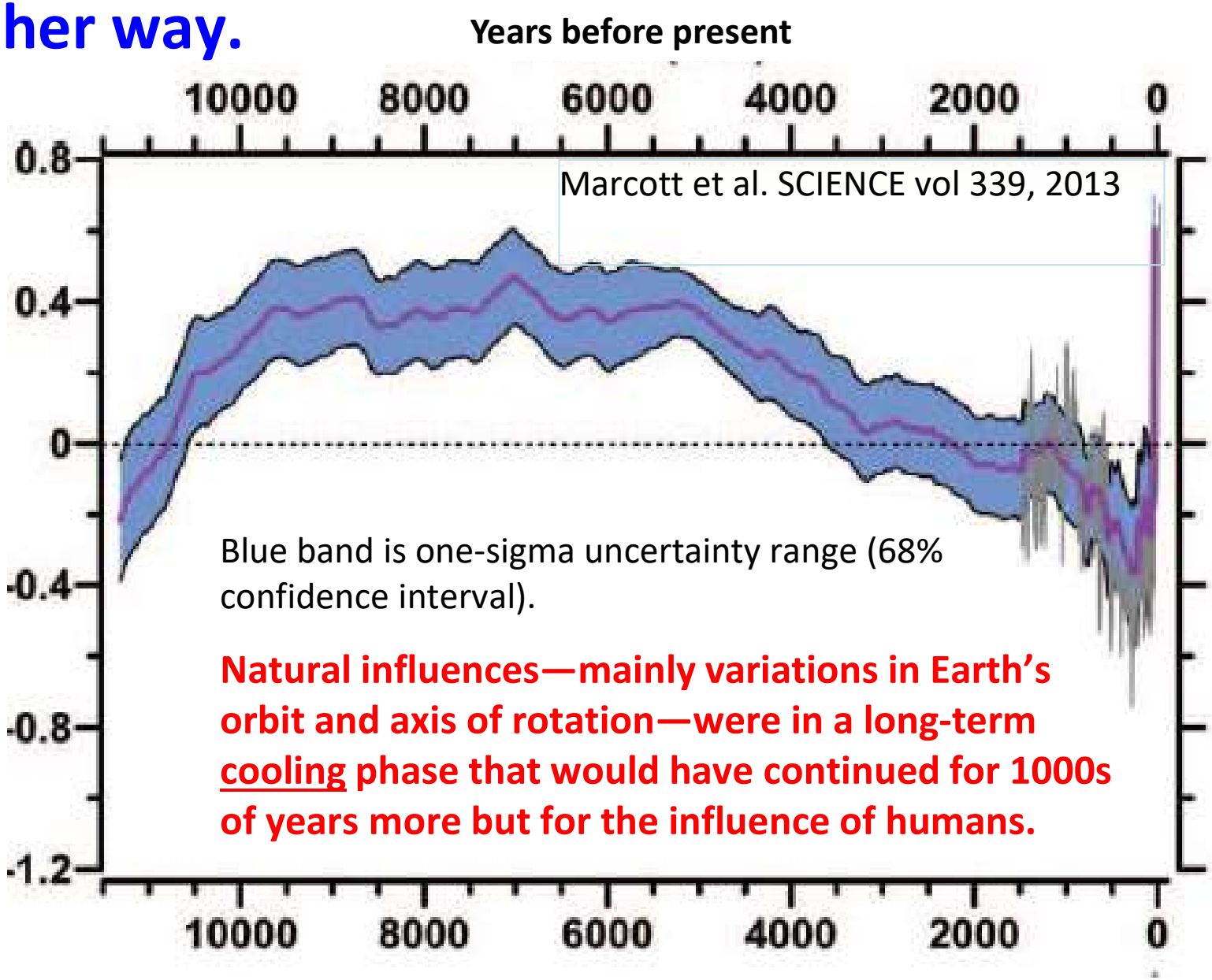
“Hiatus means “pause”. The claim that there was a pause in warming for 10-15 years after 1998 rests on the fact that the anomalously high 1998 T (boosted by a strong El Niño) was not exceeded until 2005 and was about the same as the 2009 and 2013 values.

This claim “cherry picks” specific dates to compare, in contrast to the scientific procedure of finding the best-fit straight line through all the years in the period of interest. By that standard, warming was slower between 1998 and 2013 than in the preceding 15 years, but it didn’t pause (red line is best fit).



Rebutting the deniers

Humans are clearly the cause; nature was heading the other way.



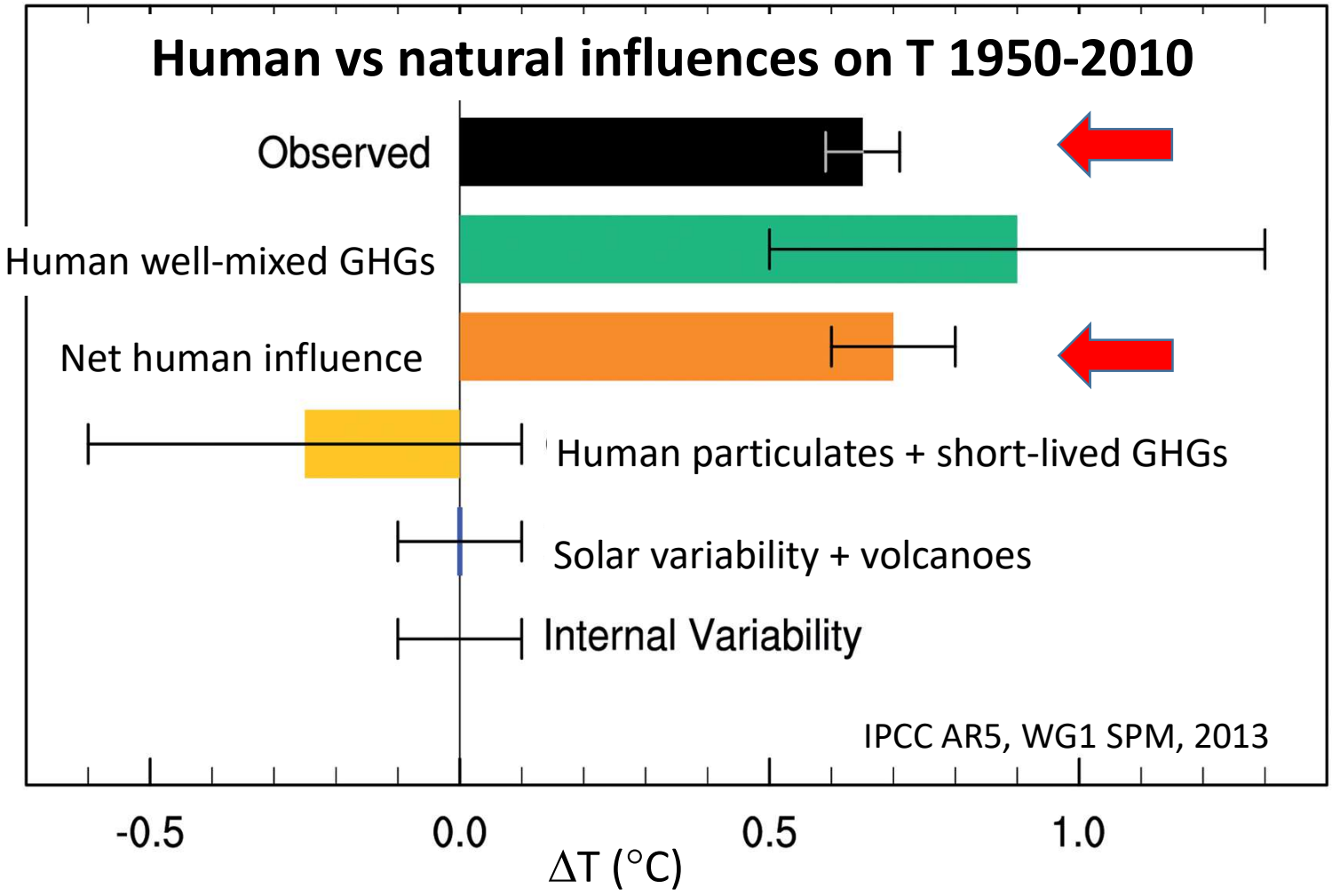
Rebutting the Wafflers

"You may be able to fool the voters, but not the atmosphere."

Donella Meadows, co-author of Limits to Growth (1971)

Rebutting the Wafflers

We know how much of the warming trend is human-caused: Over the past 60 years, essentially all of it.



The wafflers' claim there's a lot of uncertainty about the human role is wrong.

Rebutting the wafflers

Climate change is already causing serious harm

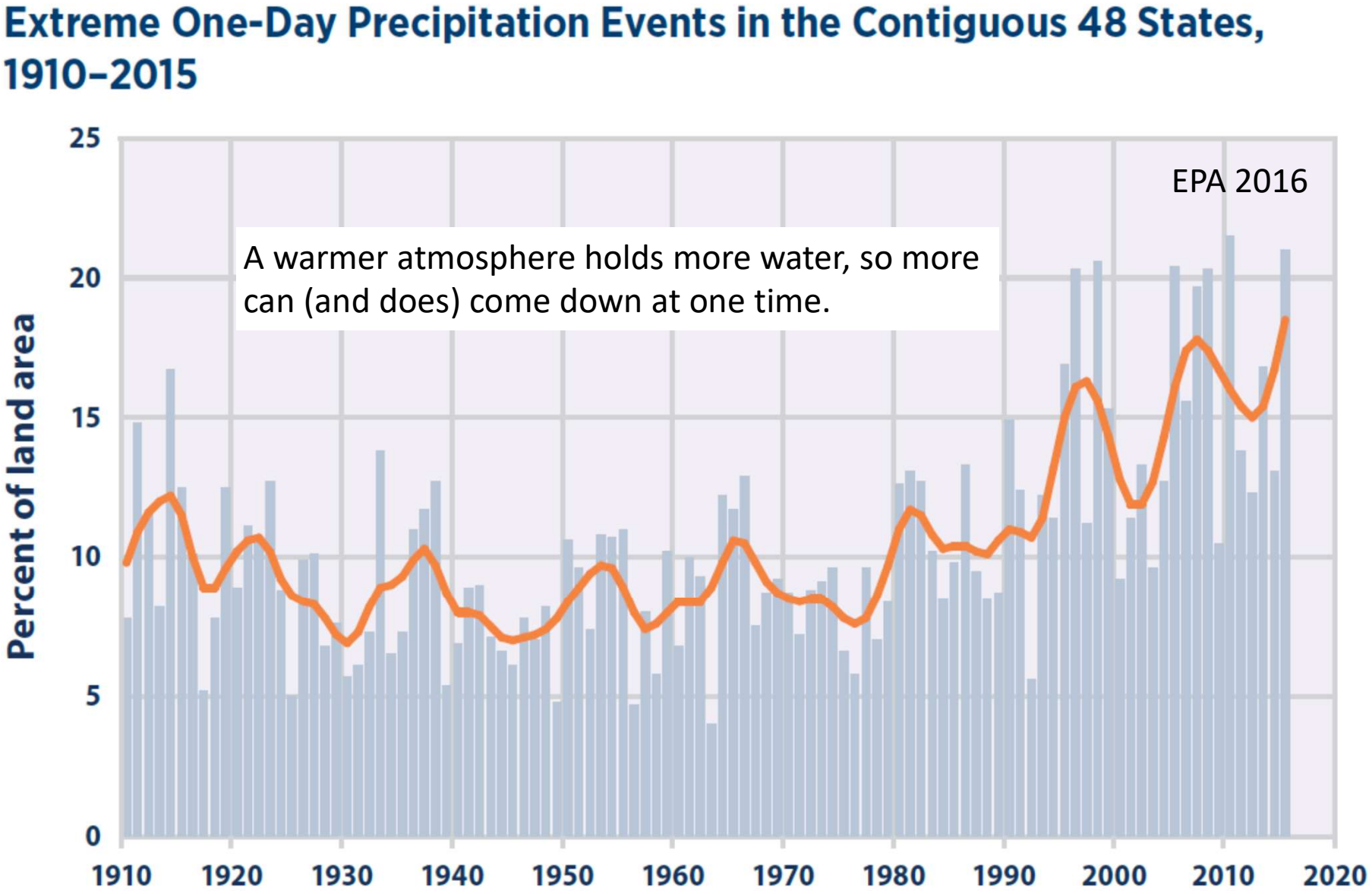
Around the world we're seeing, variously, increases in

- 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 are plausibly linked to climate change by theory, models, and observed "fingerprints"; most growing faster than projected.

Rebutting the wafflers

Growing harm: Torrential downpours → floods



Rebutting the wafflers

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

Hurricane Harvey brought >50 inches of rain over 5 days to parts of Texas in August 2017.

Downpours → Floods (continued)

Rebutting the wafflers

Growing harm: In a wetter world overall, many drought-prone regions are getting more so!

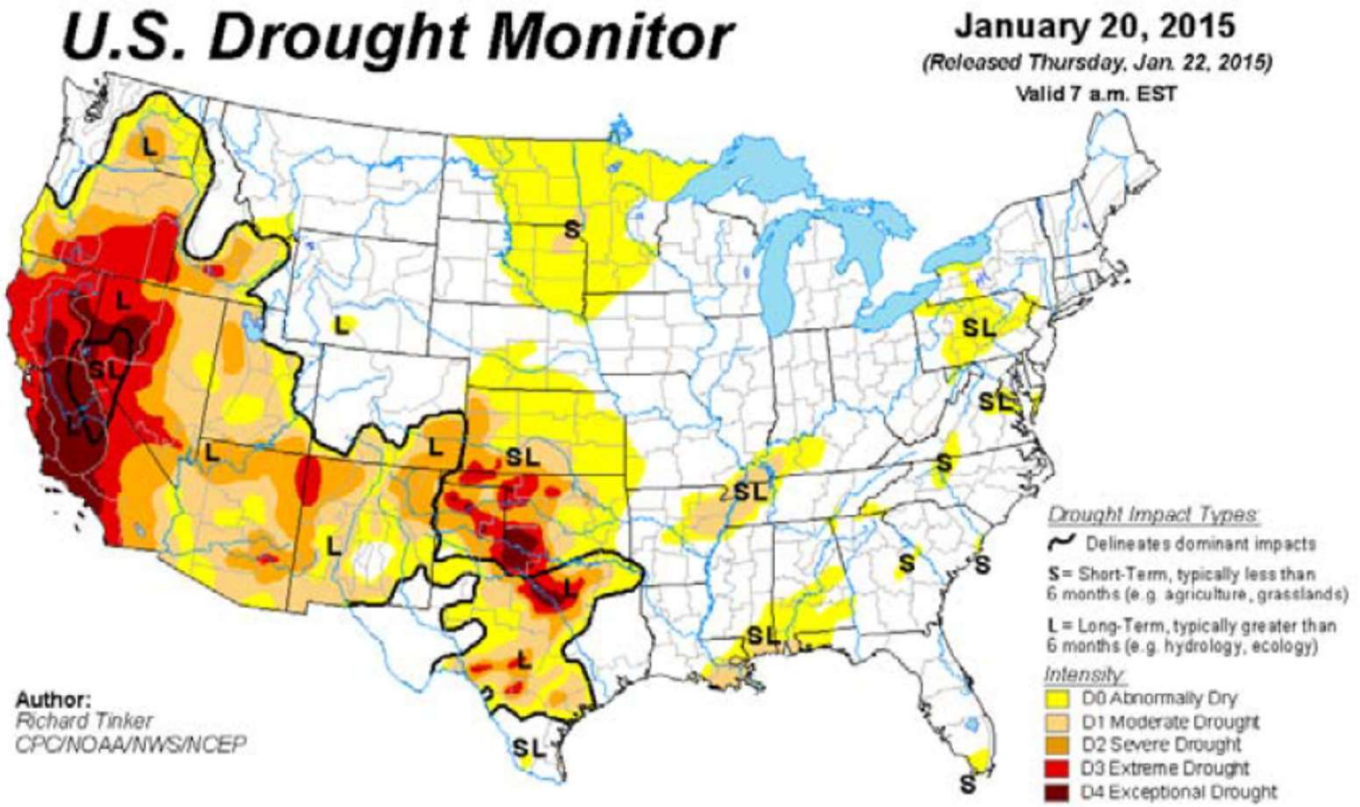
California's Folsom Lake at 17% capacity, 02-02-14

Credit: Ken James / Bloomberg

Rebutting the wafflers

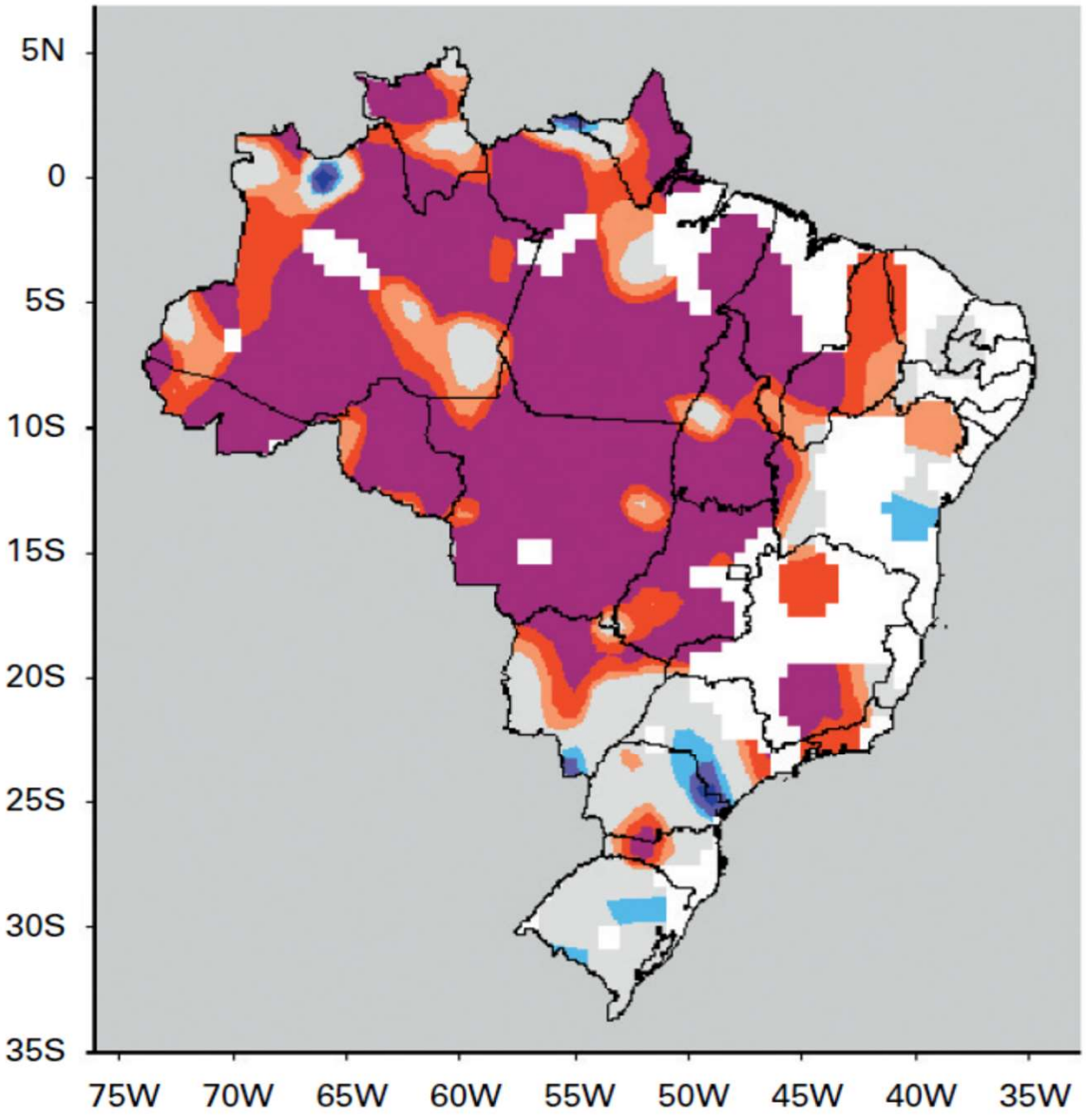
Growing harm: drought (continued)

- 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.

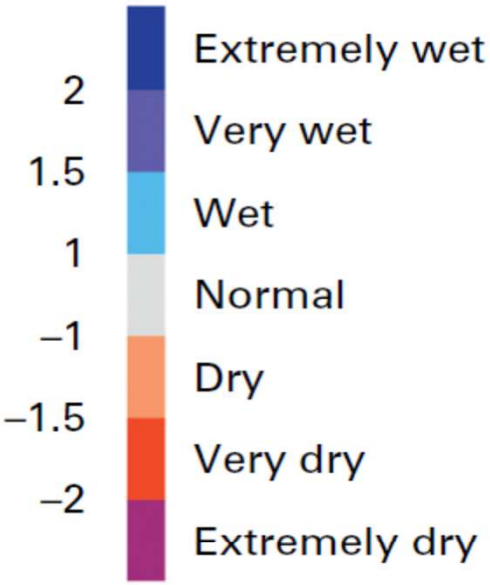


Rebutting the wafflers

Growing harm: Drought in the Amazon



Precipitation index for Brazil, 1/15 – 12/16

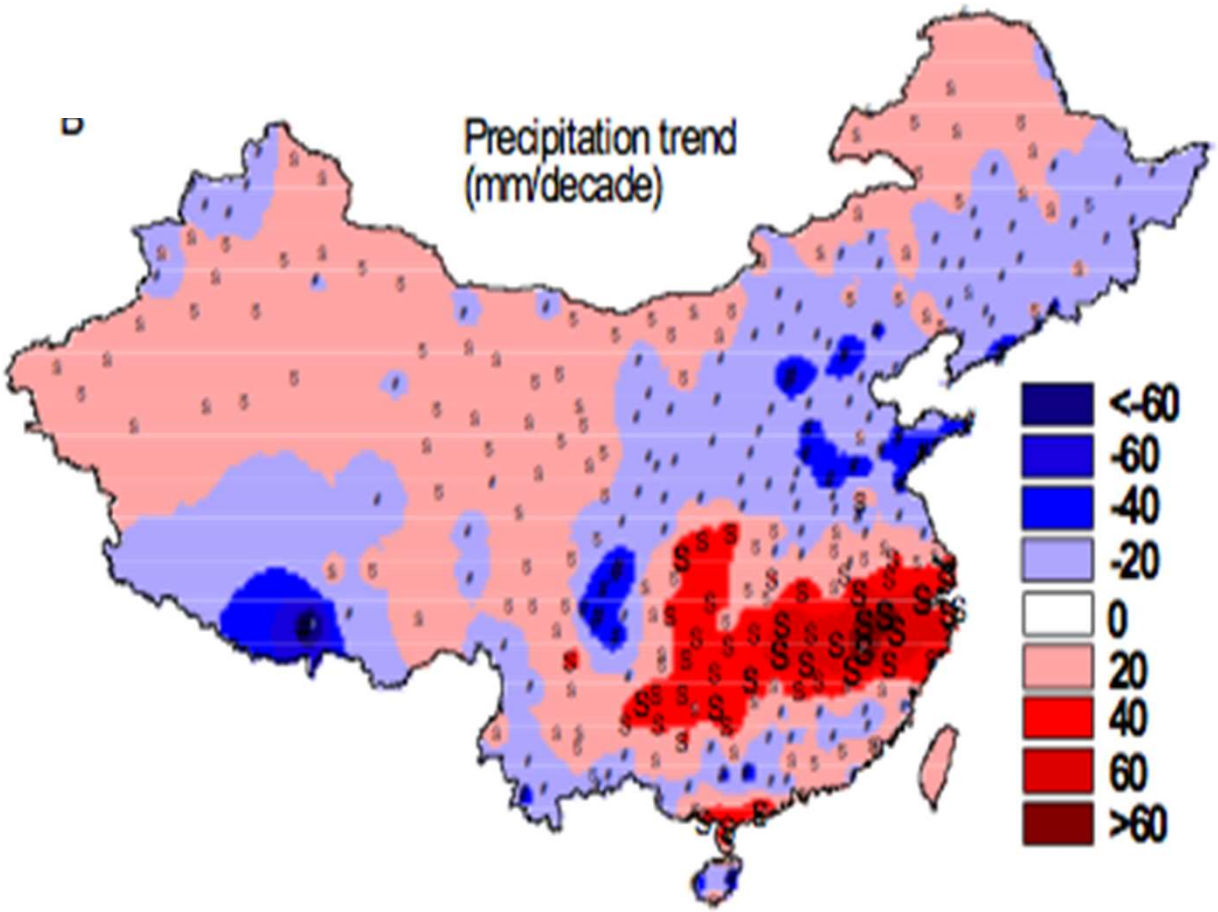


WMO 2017

Rebutting the wafflers

Growing harm: Floods and droughts in China

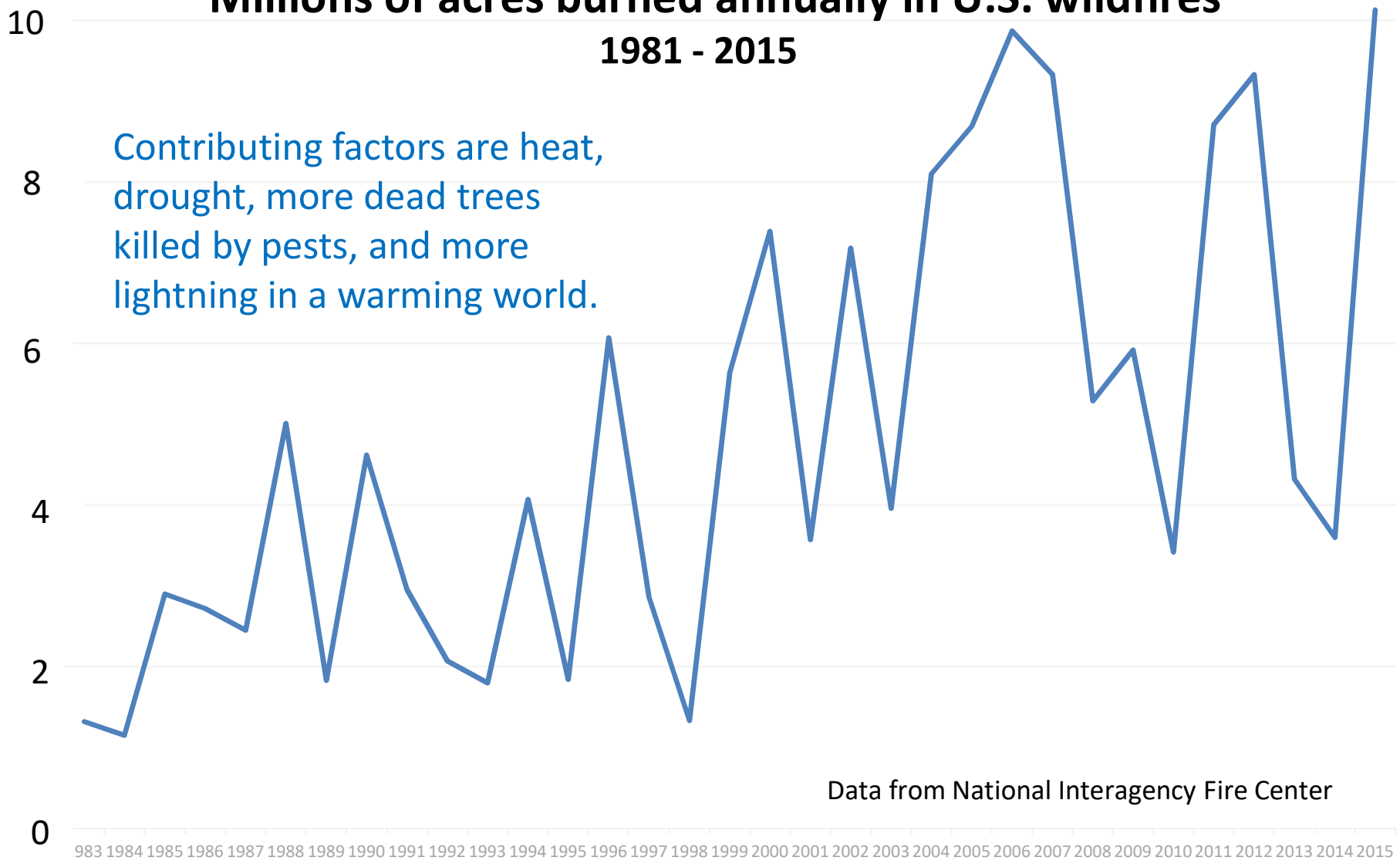
30-year weakening of East-Asia monsoon – attributed to global climate change -- has meant less moisture flow South to North over China, producing increased flooding in South, drought in North, with serious impacts on agriculture.



Qi Ye, Tsinghua University, May 2006

Rebutting the wafflers

Growing harm: Wildfires



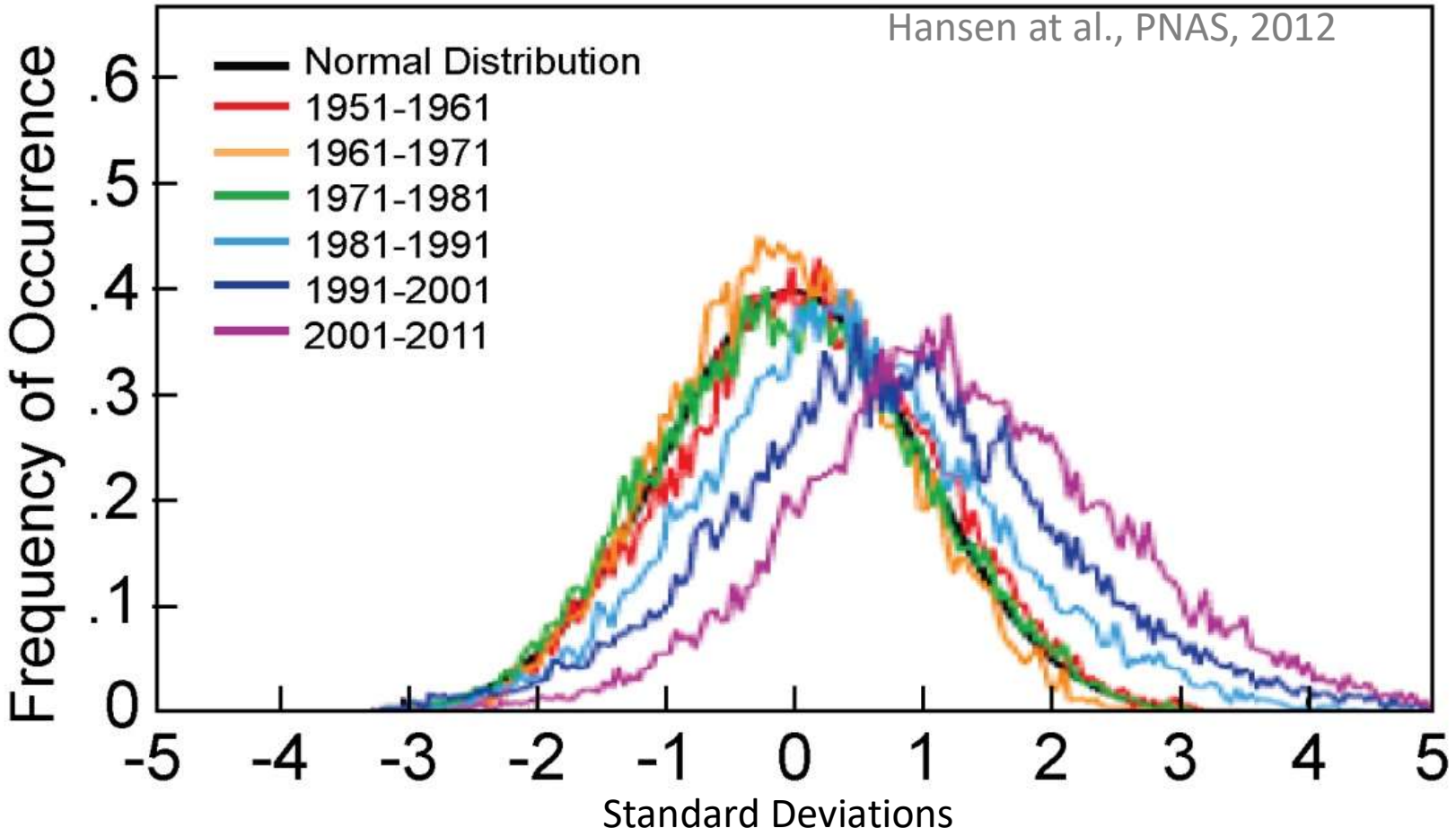
Rebutting the wafflers

Wildfires

- 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.

Growing harm: huge increase in heat waves

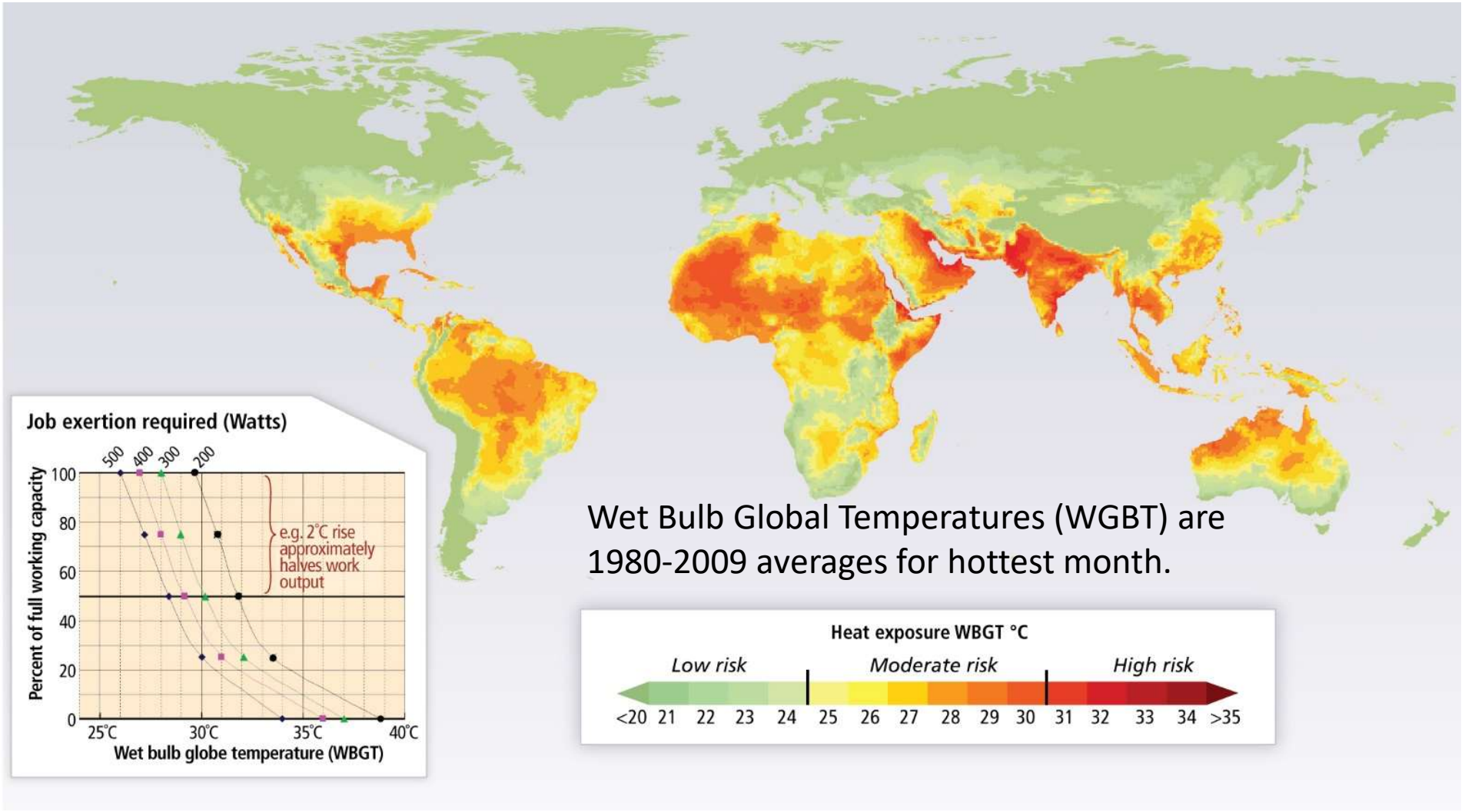
Probability distribution for Jun-Jul-Aug temperature anomaly on land in the Northern Hemisphere. Baseline normal distribution is for 1951-80.



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.

Rebutting the wafflers

Growing harm: Heat already makes working out-doors dangerous in summer in many regions



IPCC AR5, WGII, Figure 11-5

Rebutting the wafflers

Growing harm: Coral bleaching

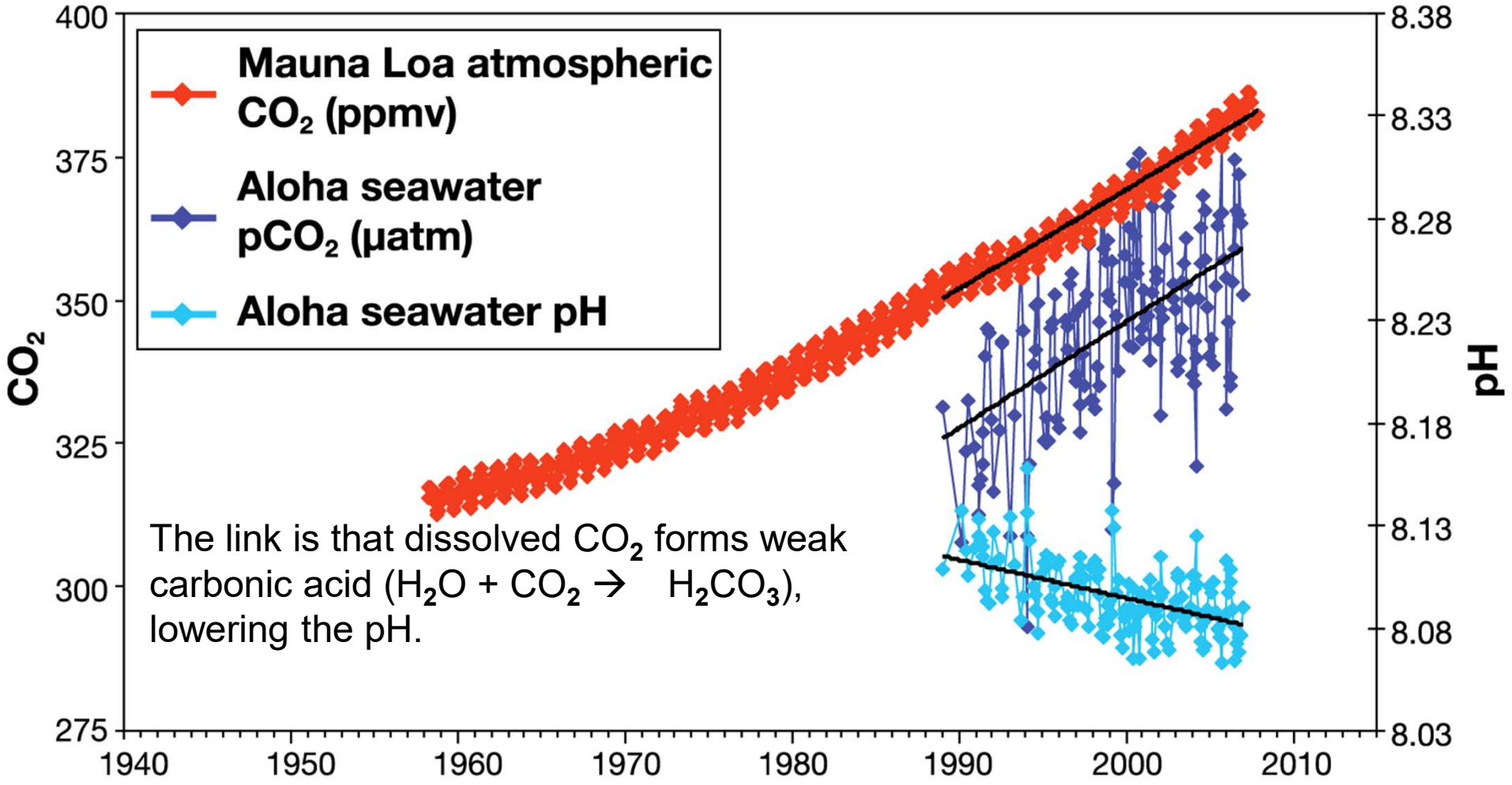
Jarvis Reef, South Pacific (courtesy WHOI)

"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

Growing harm: Ocean acidification

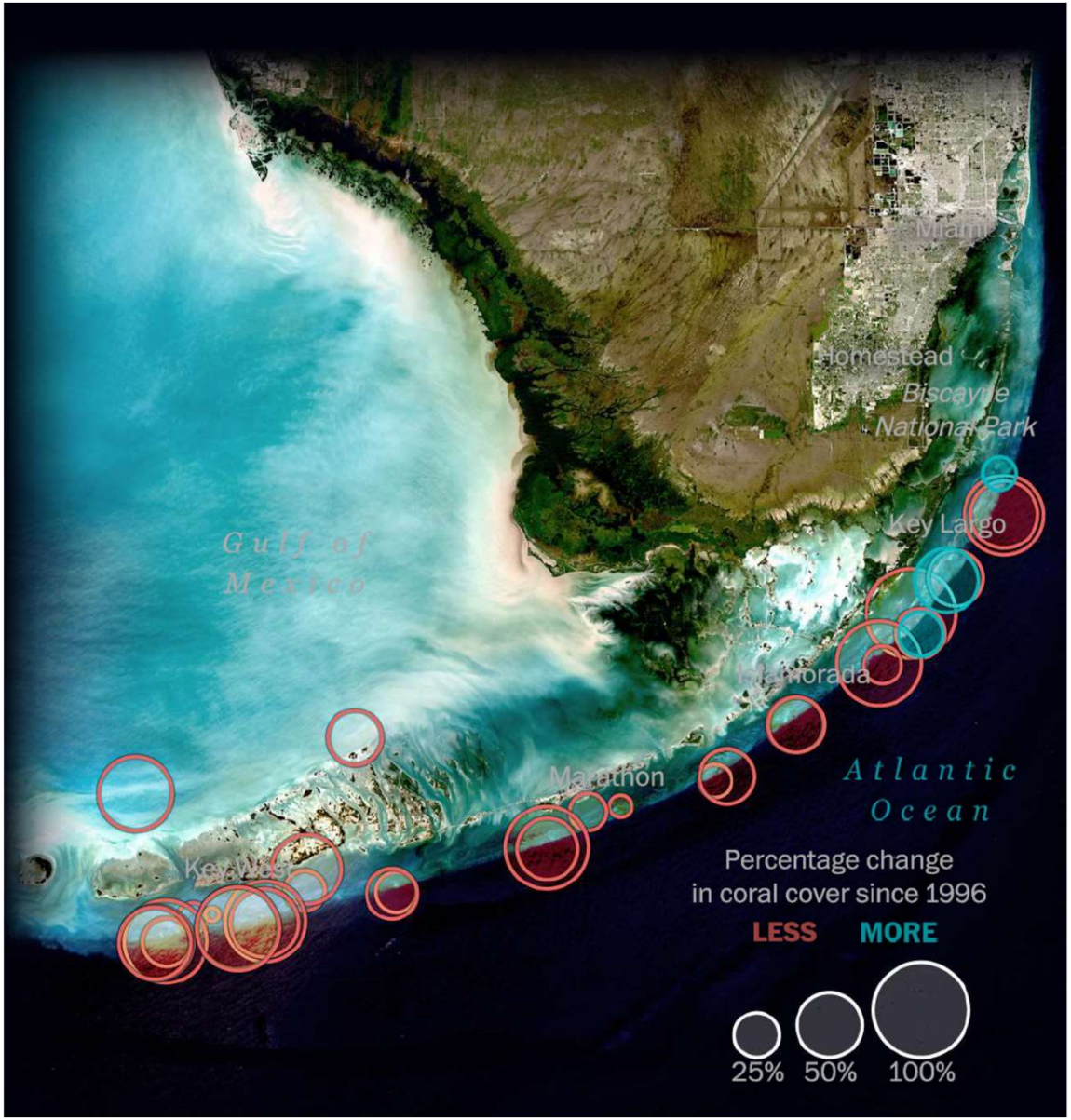
About 1/3 of CO_2 added to atmosphere is quickly taken up by the surface layer of the oceans (roughly, the top 80 meters).



World Bank / Potsdam Institute Nov 2012

Rebutting the wafflers

Growing harm: Death of coral reefs in Florida Keys



Florida's coral reefs are being devastated by multiple stresses, of which warming water and acidification are the most important.

Less than 10% of the reef system is now covered by living coral. (Red circles show percentage declines since 1996.)

NASA Aqua satellite imagery. Washington Post, 26 June 2017

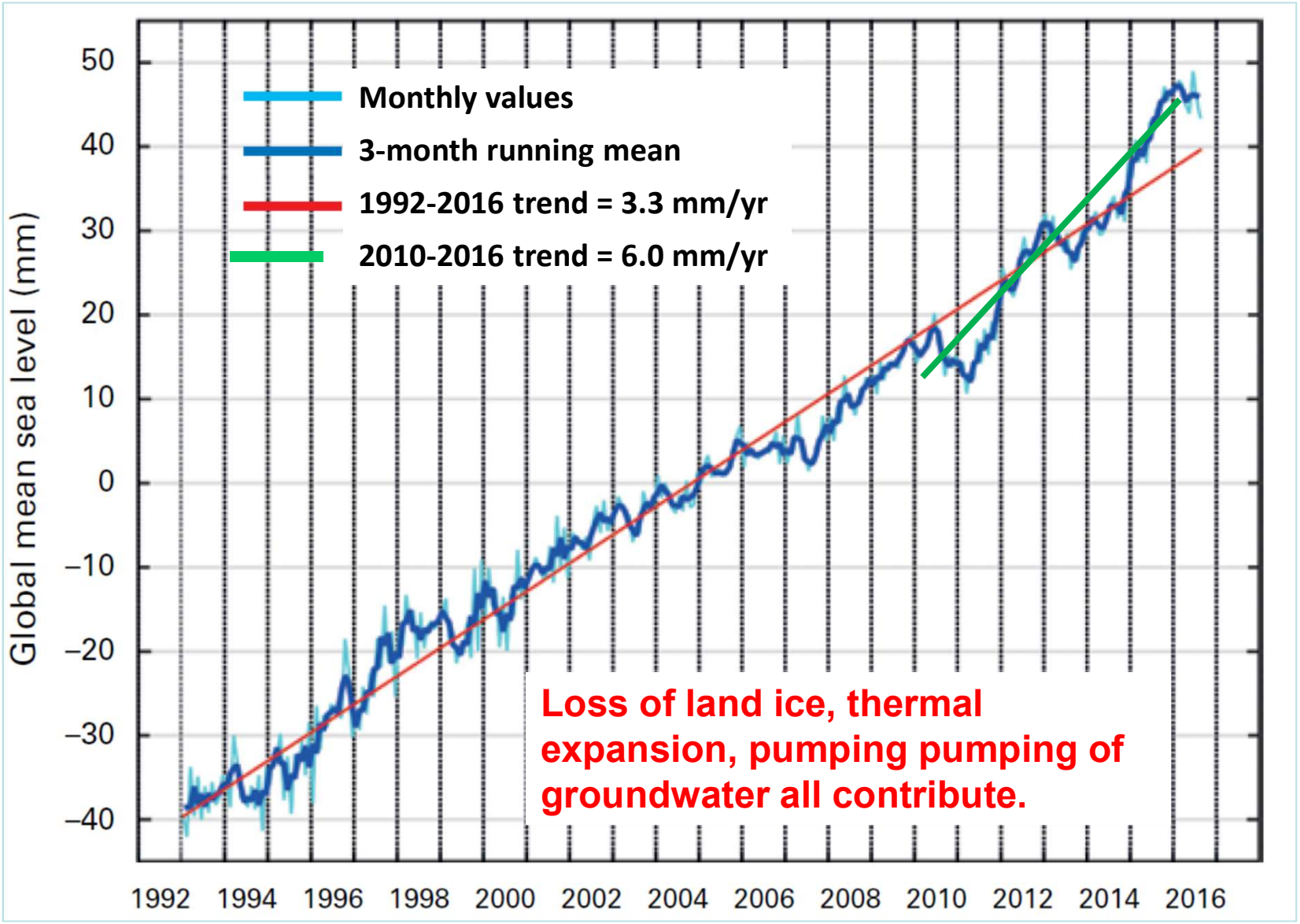
Rebutting the wafflers

Growing harm: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

Rebutting the wafflers

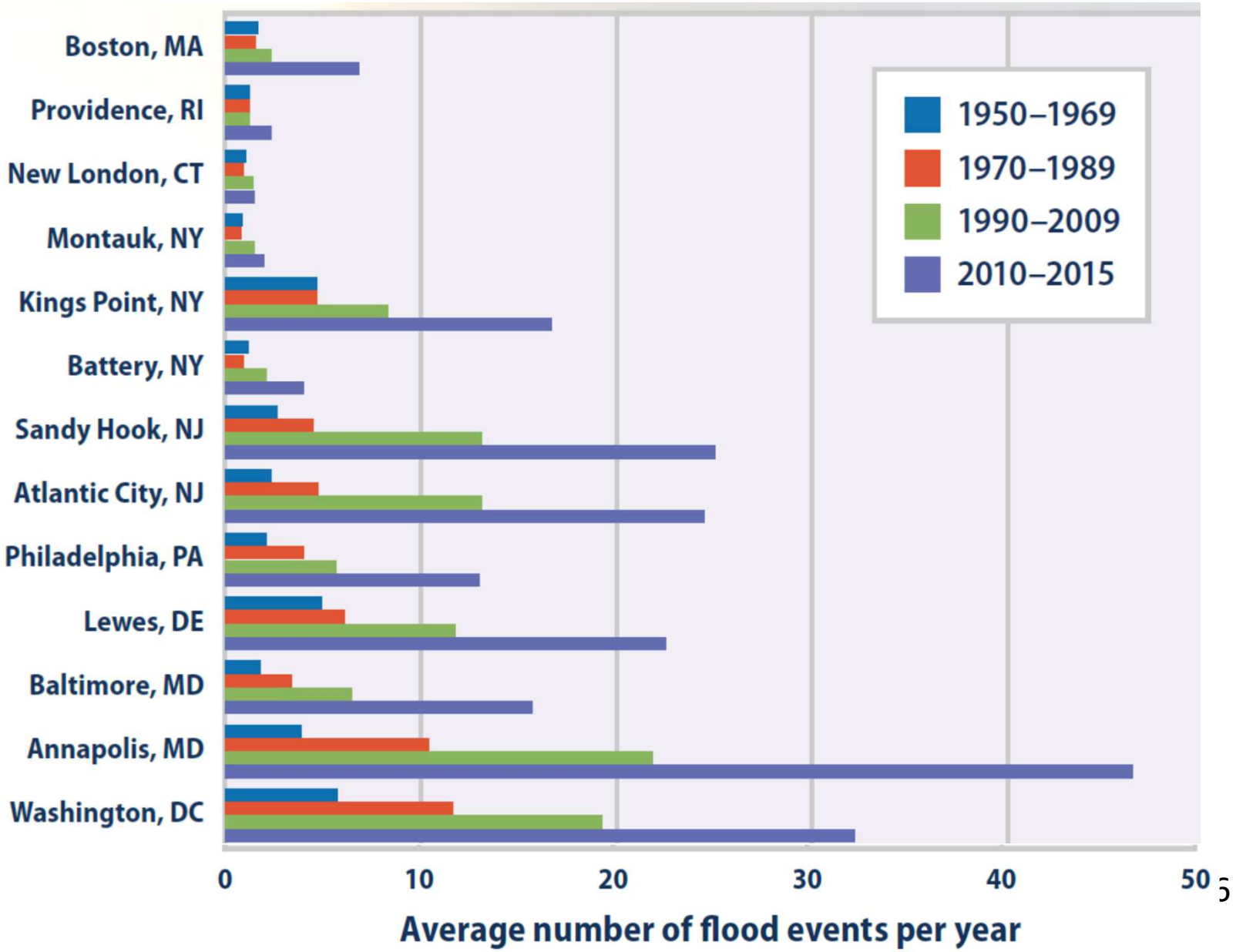
Growing harm: Accelerating sea-level rise



WMO 2017

Rebutting the wafflers

Growing harm: rising sea → coastal inundation



Rebutting the wafflers

Growing harm: Rising sea → Coastal erosion

Rebutting the wafflers

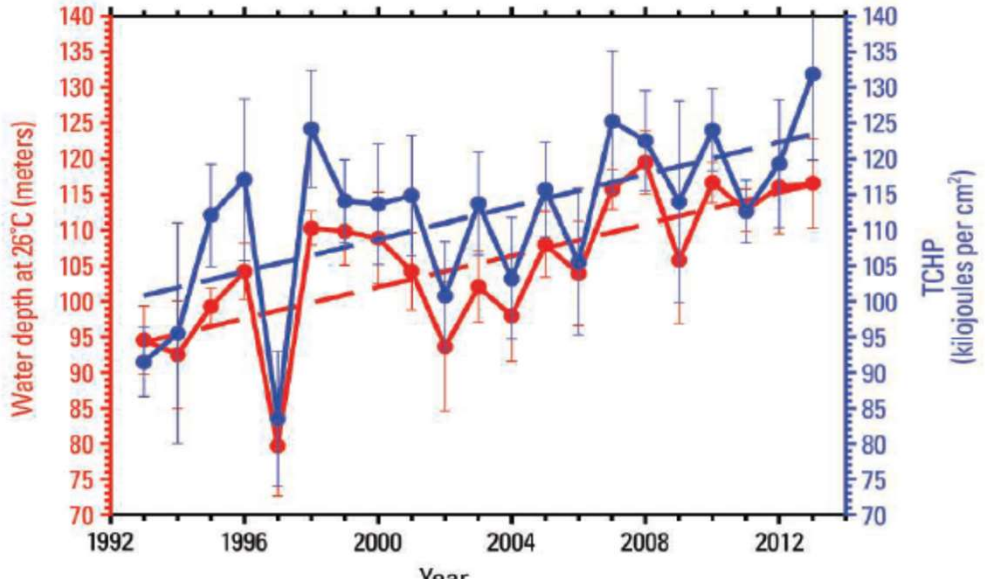
Growing harm: Stronger tropical storms

- 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
- 10/17: Ophelia, strongest in E Atlantic

Rebutting the wafflers

More-devastating cyclones are not coincidence

- Tropical cyclones get their energy from the warm surface layer of the ocean (which is getting warmer and 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 higher local sea level is, the worse the storm surge from any given cyclone will be.

Rebutting the wafflers

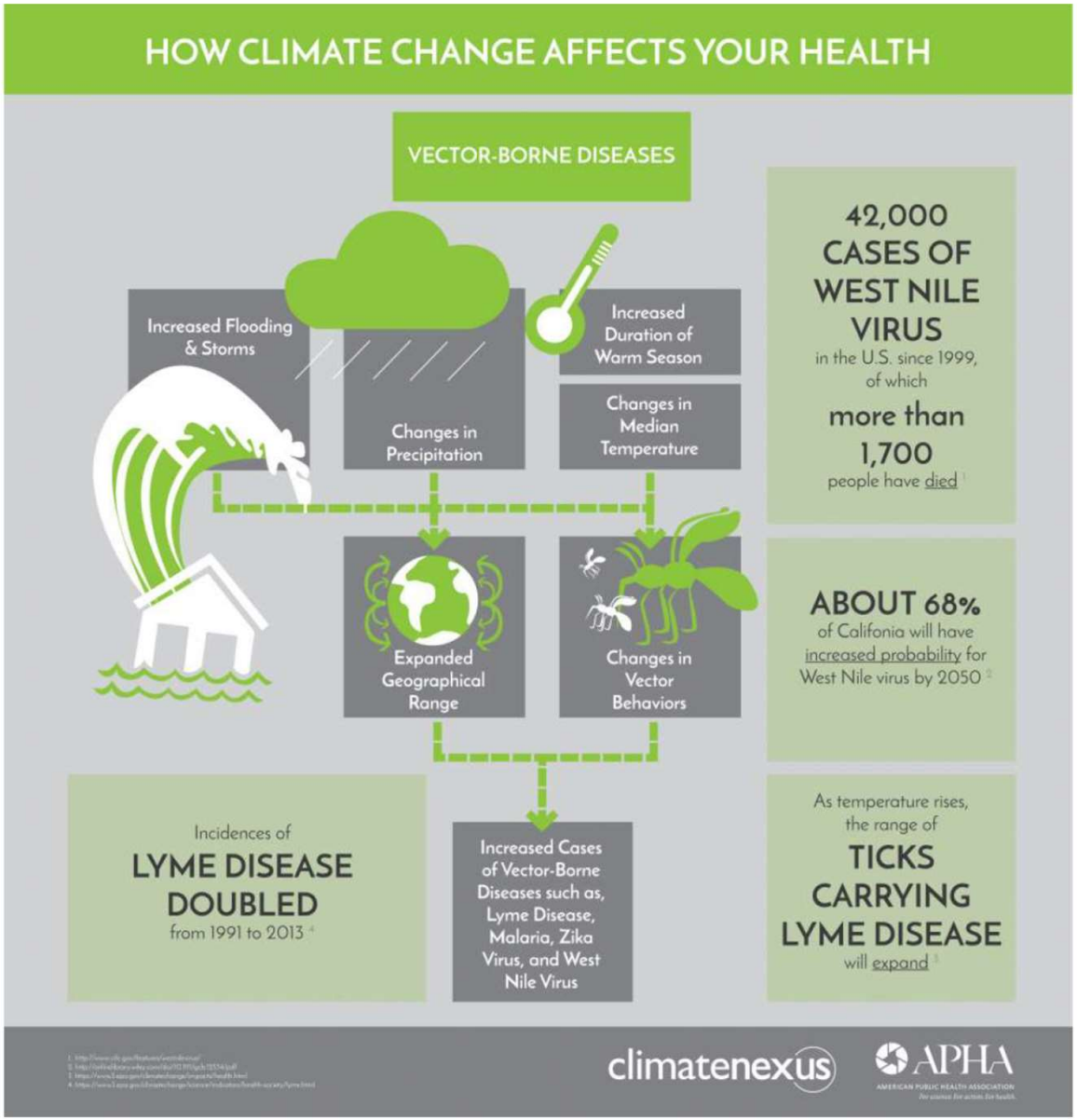
Growing harm: Pest outbreaks

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

USGCRP 2009

Rebutting the wafflers

Growing harm: Disease vectors & pathogens



Rebutting the wafflers

Growing 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

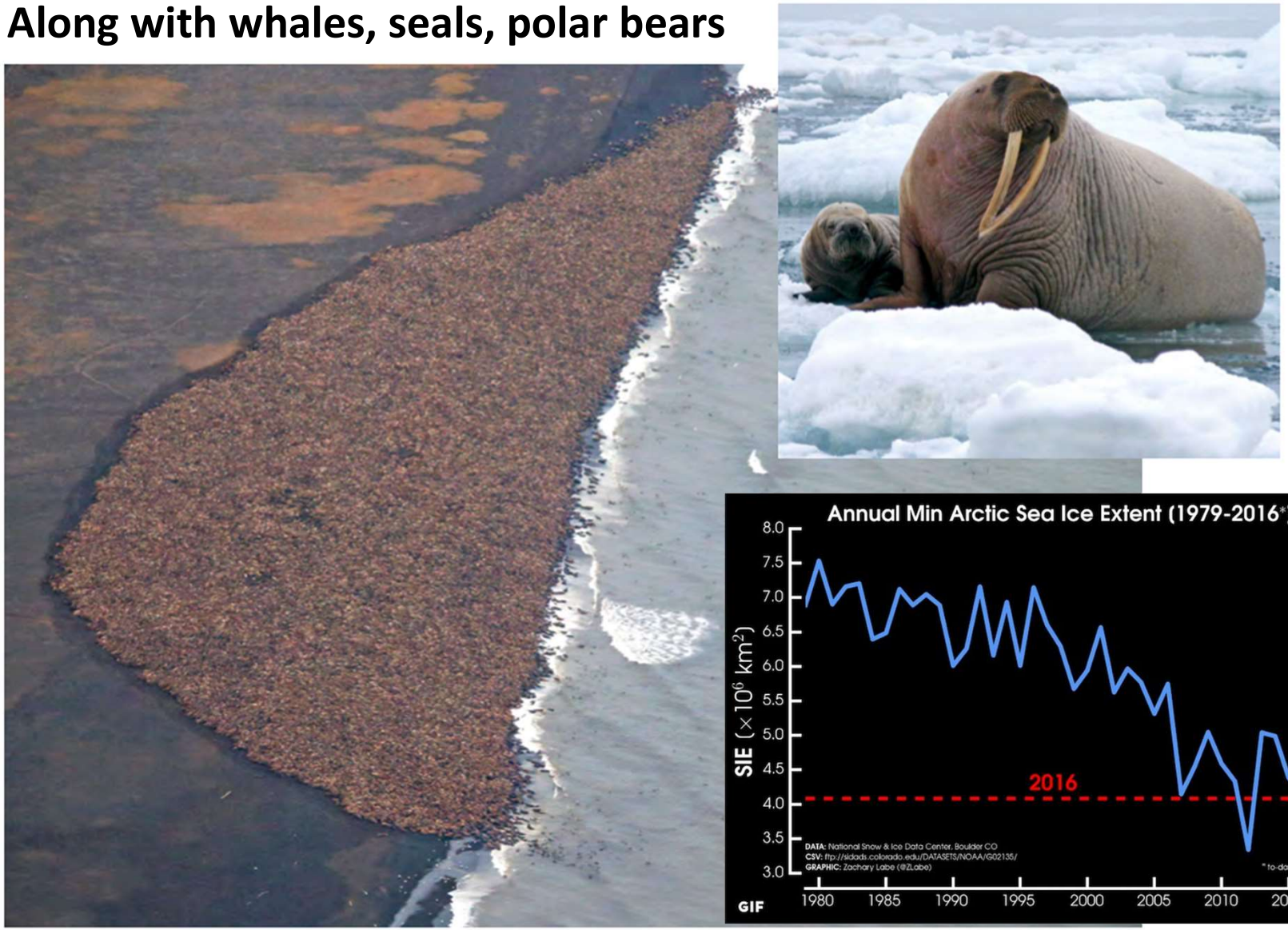
Nathan J. Mantua[1]

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

Rebutting the wafflers

Valued species: Walruses impacted by shrinking sea ice

Along with whales, seals, polar bears



Courtesy Fran Ulmer

In the face of these observed & growing impacts, the arguments of some wafflers that climate change is "good for us" seem perverse

- Some places may benefit from longer growing seasons, warmer winters, & increased CO_2 fertilization of plants for a few decades, but that can't compensate for all the harms.
  - Longer growing seasons are counteracted by effects of increases in extreme heat, drought, hailstorms, & pests.
  - Many fewer people die of extreme cold in winter than from extreme heat in summer, and the gap is growing.
  - CO_2 fertilization only works for some plants and only when water & other nutrients are in adequate supply. And it's counteracted by heat, drought, storms, & pests.

Wafflers are wrong to suggest some "balance" between good & bad.

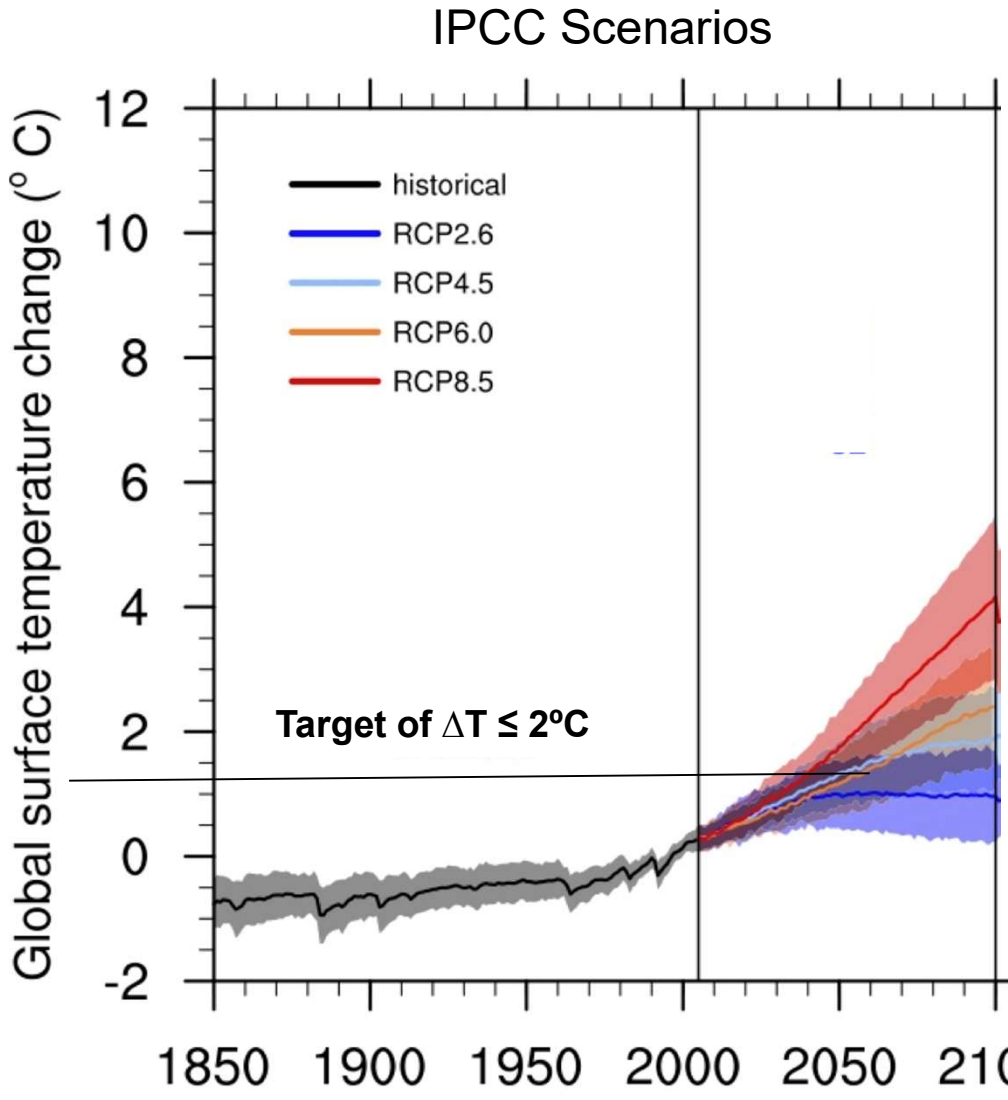
Rebutting the wafflers

Wafflers also underestimate what's coming

Global average T continues to increase under all plausible scenarios.

Momentum in the climate system means T continues to go up even after atmospheric conditions stabilize.

And sea level continues to go up even after T stabilizes.



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

Rebutting the wafflers

What's coming: Increases in heat extremes

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]

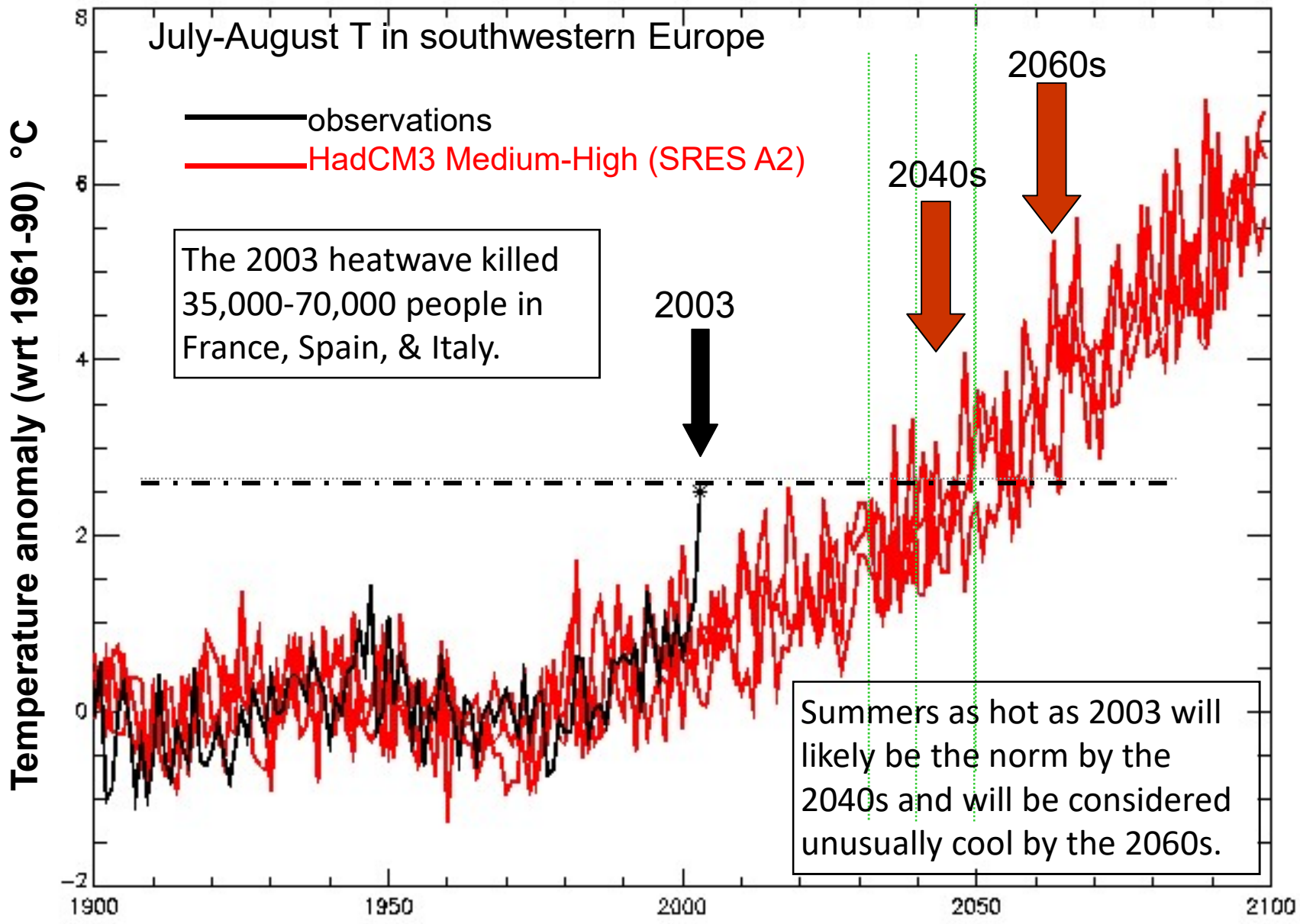
NATURE CLIMATE CHANGE | VOL 5 | JULY 2015 | www.nature.com/natureclimatechange

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]

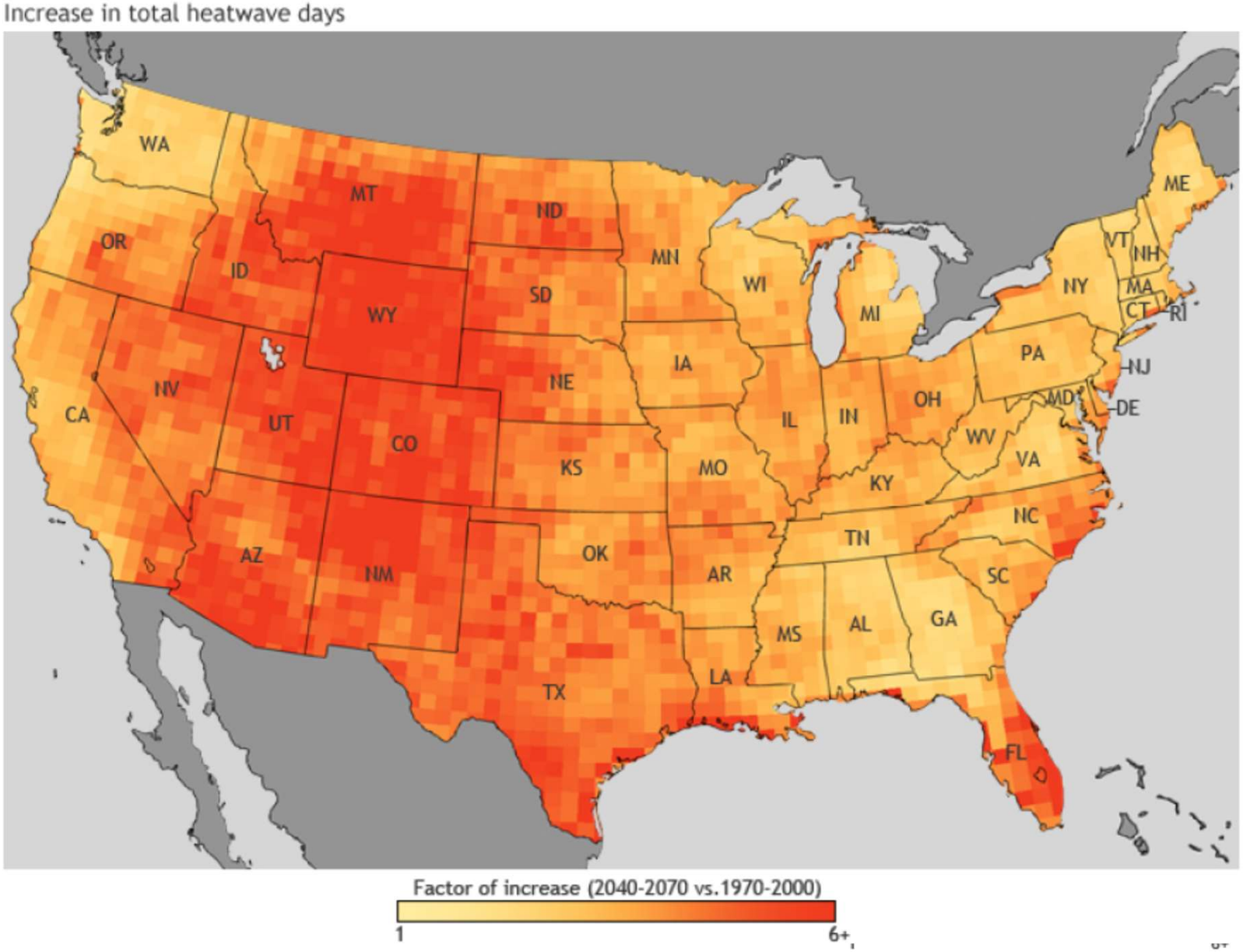
Rebutting the wafflers

Summer heat in SW Europe—history & BAU future



Rebutting the wafflers

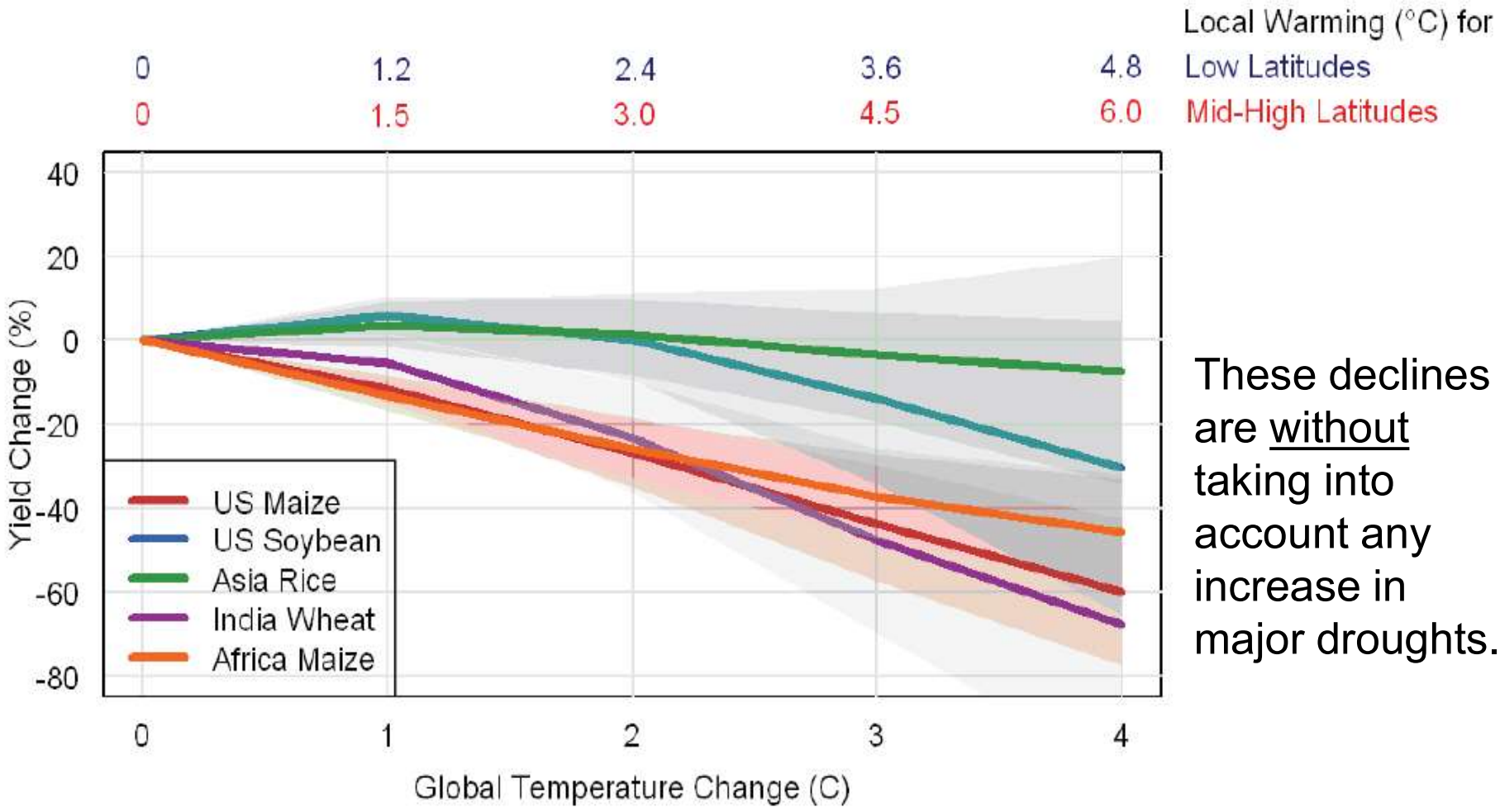
US heatwaves at mid-century under BAU



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

Rebutting the wafflers

What's coming: Declining crop yields



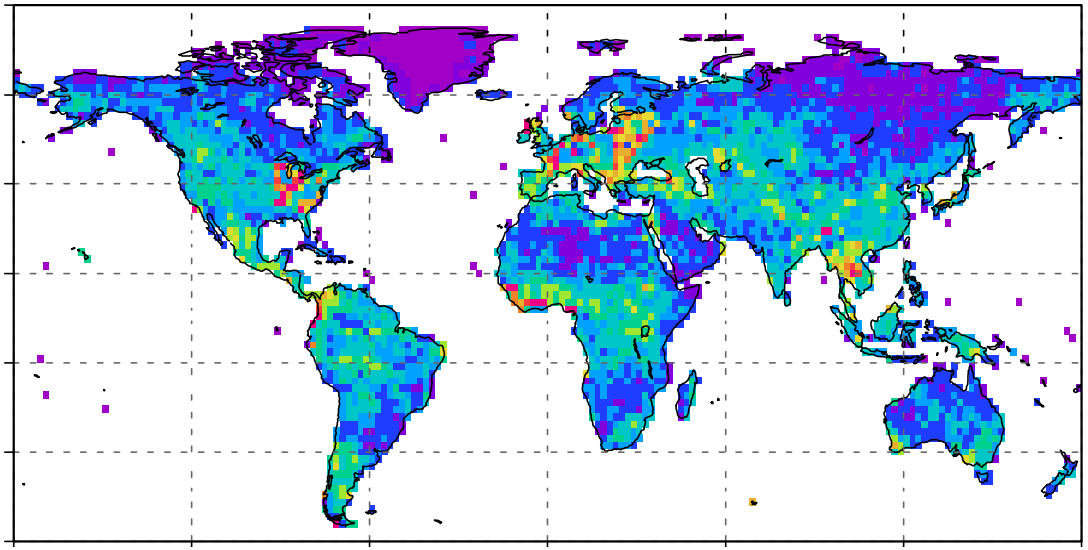
These declines are <u>without</u> taking into account any increase in major droughts.

National Academies, Stabilization Targets, 2010

Rebutting the wafflers

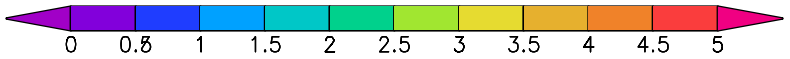
What's coming: Huge increases in drought

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



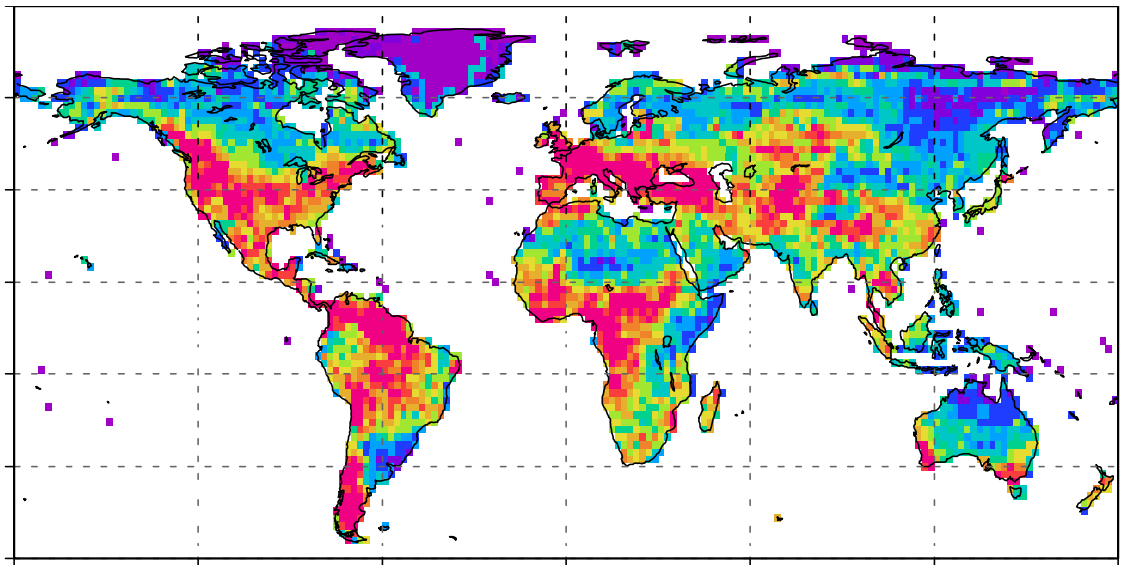
1961-1990

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



events per 30 years

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



2070-2099, IPCC A2 scenario

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

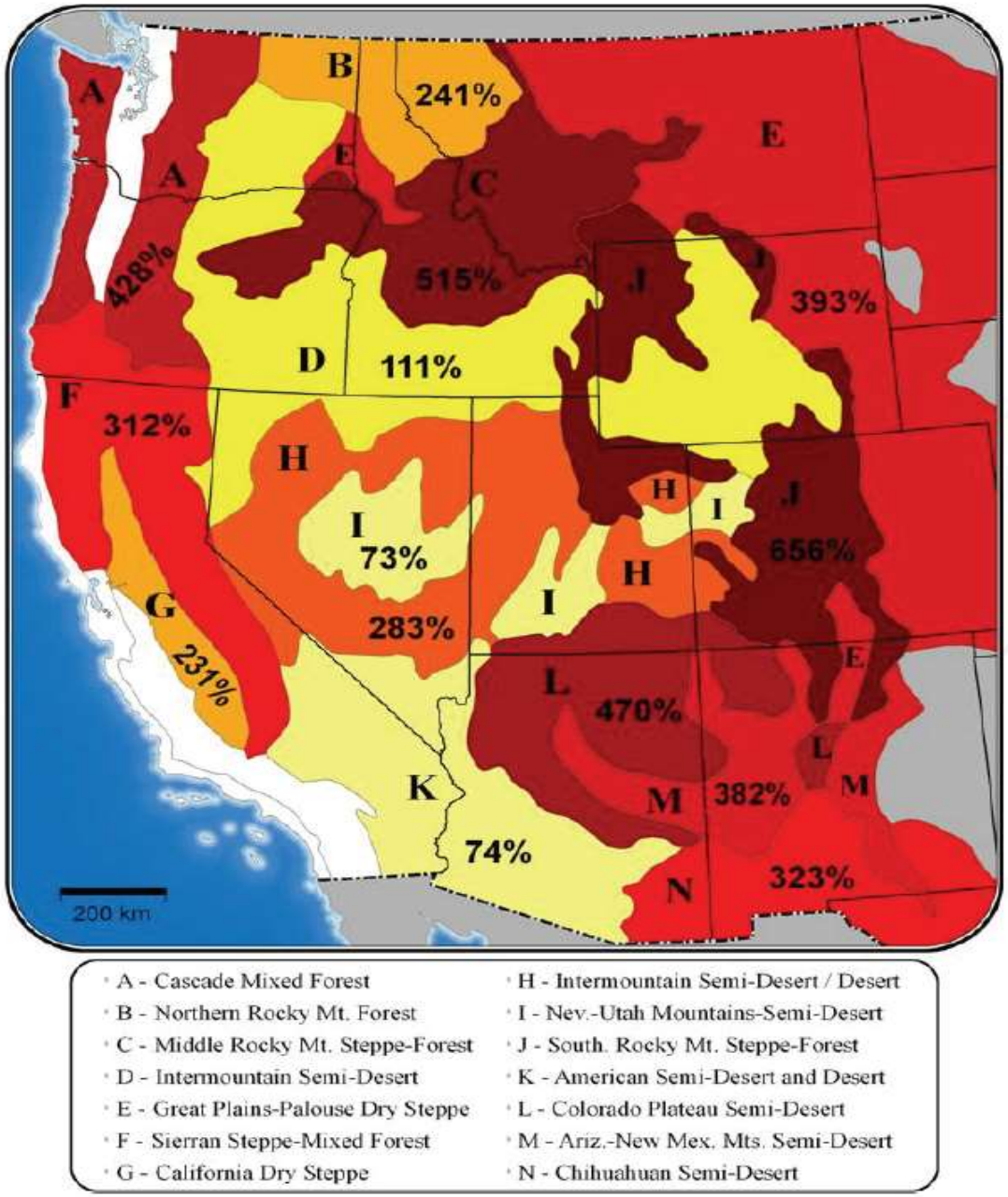
Rebutting the wafflers

What's coming: Worse wildfires

Area burned by wildfires, already up substantially, is projected 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



Rebutting the wafflers

What's coming: Increased storminess

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]

Rebutting the wafflers

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).

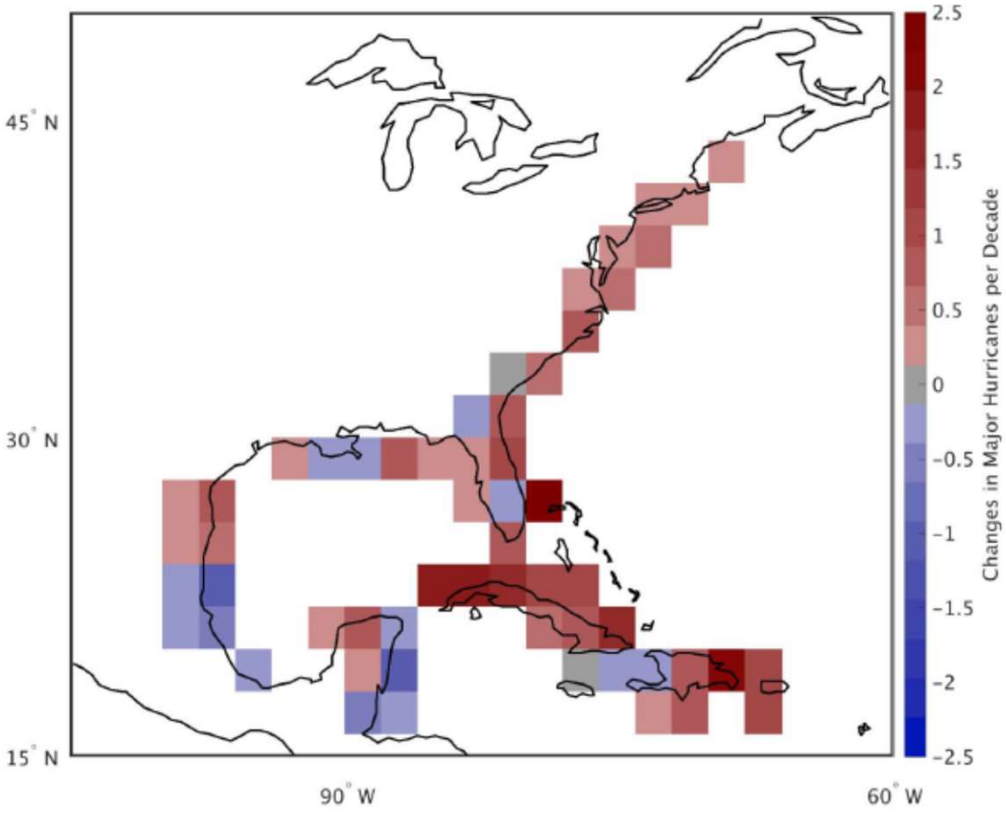


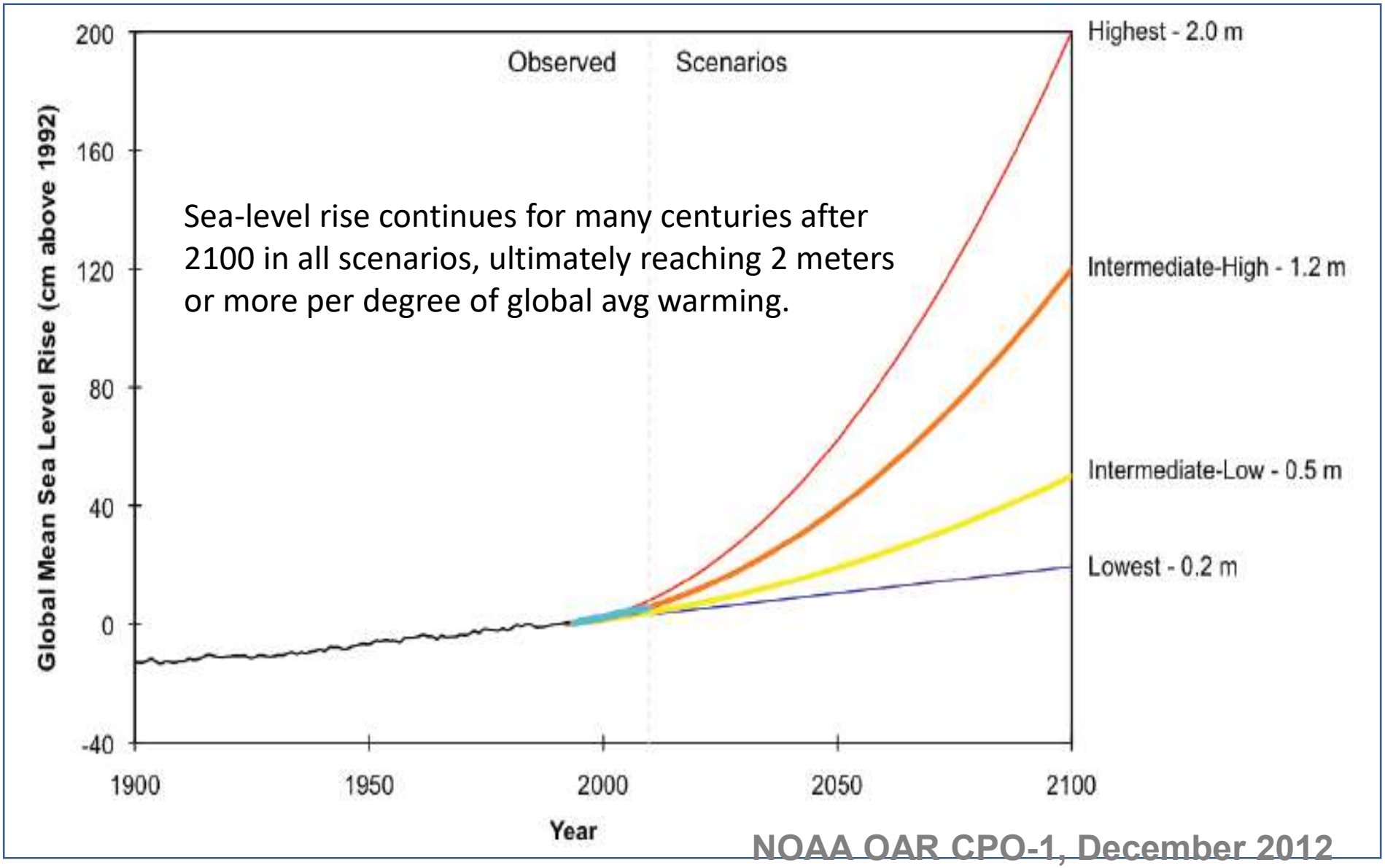
Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

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

Bhatia and Vechhi, Princeton U, 5 April 2017

Rebutting the wafflers

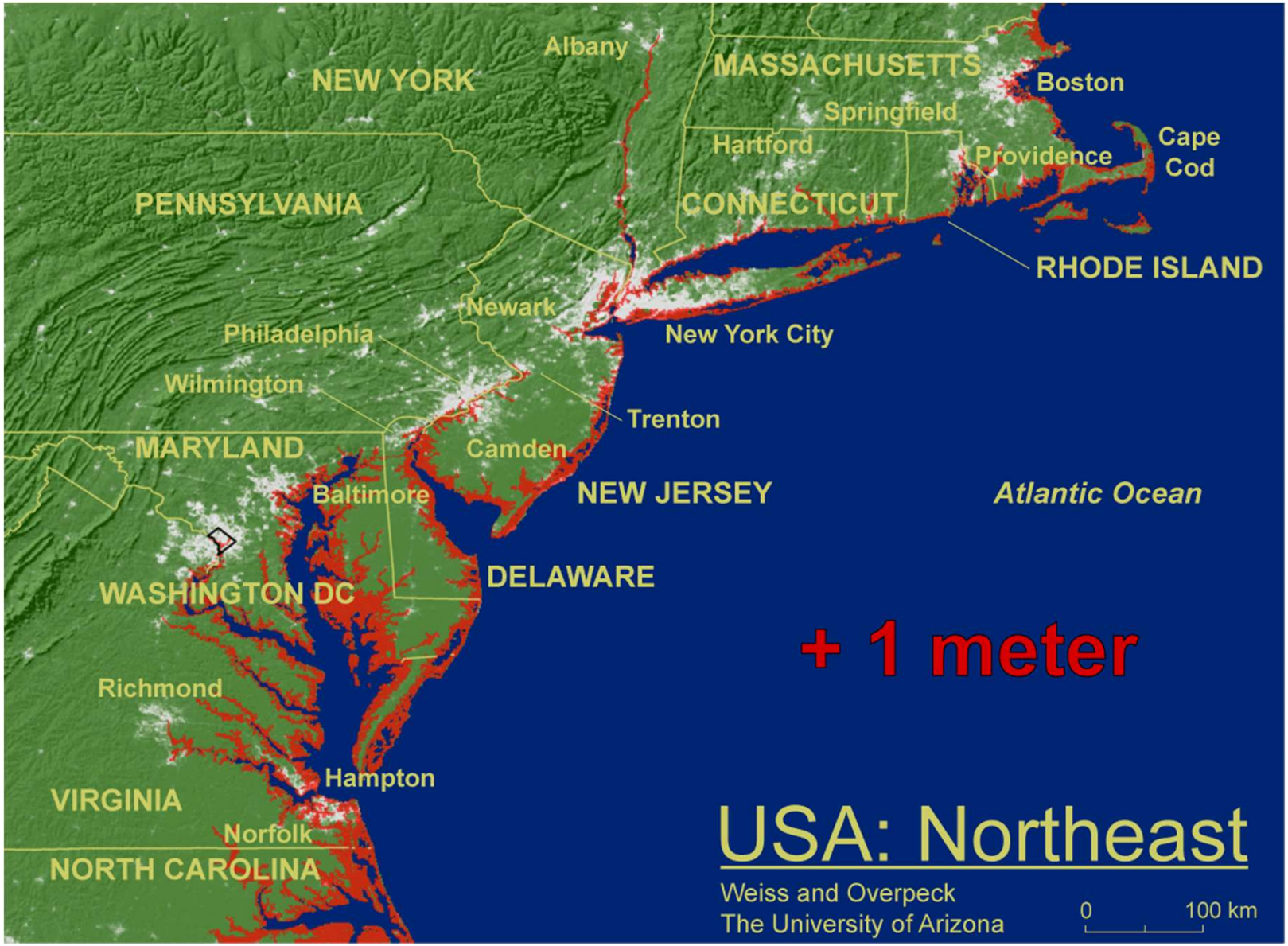
What's coming: Sea level could rise 1-2 m by 2100



NOAA OAR CPO-1, December 2012

Rebutting the wafflers

Sea level: Flooded area with 1 meter rise



Rebutting the wafflers

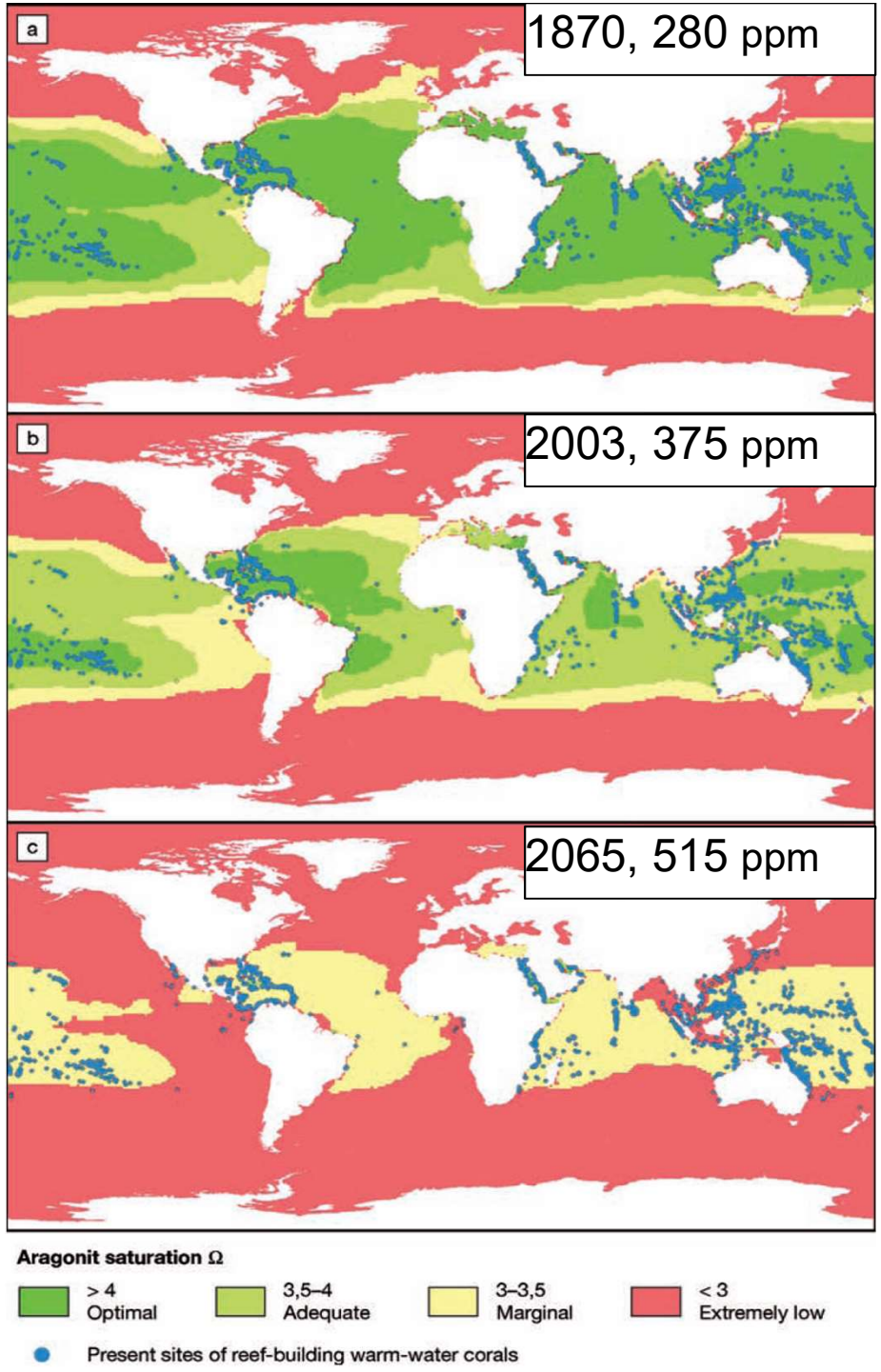
What's coming: Continued drop in ocean pH, with big impacts on marine life

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.

Steffen et al., 2004



Rebutting the wafflers

The wafflers also minimize what could happen

- Greatly accelerated sea-level rise from rapid disintegration of Greenland and Antarctic ice sheets
- Rapid CH_4 and CO_2 release from thawing permafrost & warming Arctic sediments, accelerating all climate-related impacts
- Massive drying & fires in the (formerly) moist tropics, with huge damage to local peoples & biodiversity
- Ocean fisheries crash caused by combination of warming, acidification, oxygen depletion, toxics, overfishing…
- Collapse of the Atlantic Meridional Overturning Circulation, shutting down the Gulf Stream

All of these become more likely as ΔT rises above 1.5°C.

The wafflers views on what to do

The wafflers mostly want to postpone aggressive action to reduce emissions starting now in favor of….

- research & development (R&D) on better technologies so emissions reductions can be made more cheaply in the future
- accelerating economic progress in the developing countries as the best way to reduce their vulnerability to climate change
- counting on adaptation as needed, going forward, to limit the damage from whatever changes in climate materialize

(Of course, the deniers and the wafflers in the top positions in the Trump administration are, with surpassing cynicism, busy cutting support for all of these approaches.)

The wafflers views on what to do (continued)

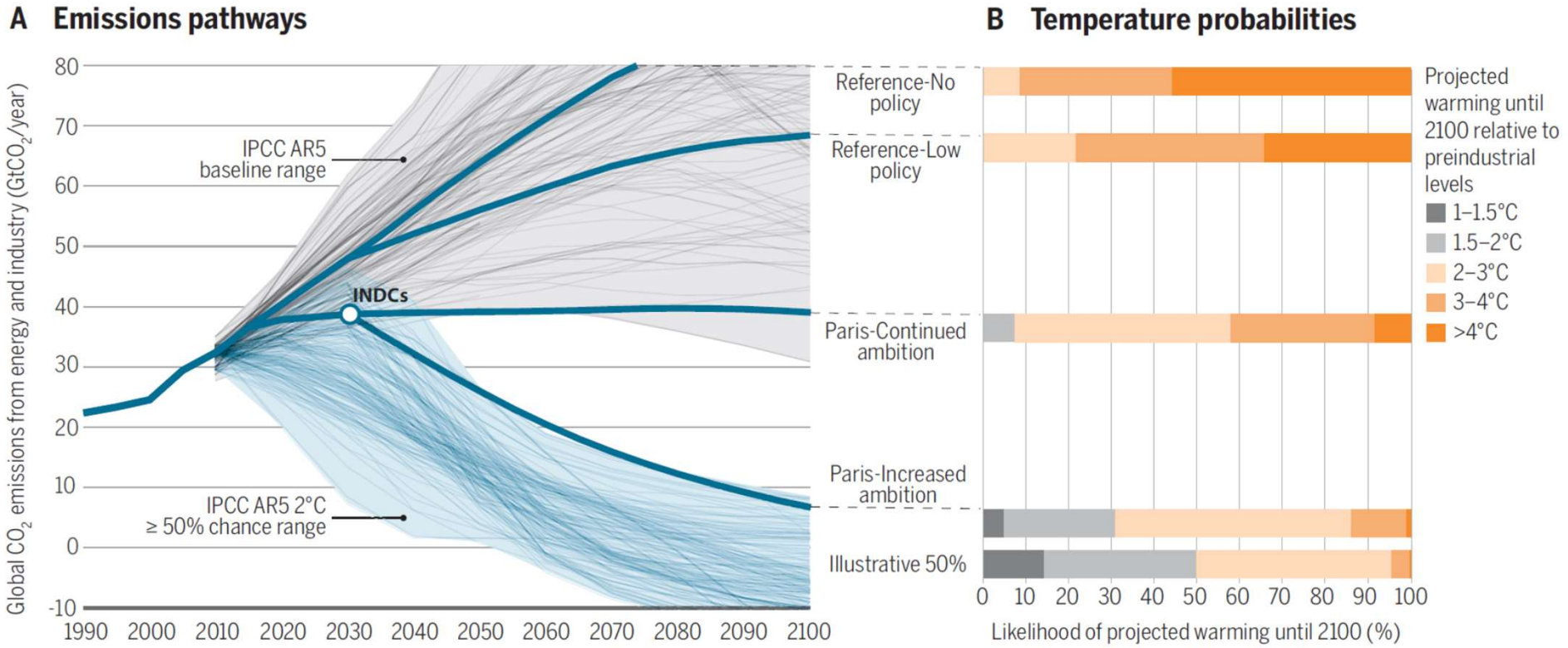
Even if implemented, the wafflers' favored approaches would be grossly inadequate.

- Clean-energy R&D is essential to provide options for the next stage of deep emissions reductions, but we need to be reducing now with the technologies we already have.
- Economic development and climate-change mitigation & adaptation are not "either-or" but must be pursued together. Energy for development and new infrastructure need to be climate-friendly & resilient.
- Adaptation gets more difficult, more expensive, and less effective the larger are the changes in climate to which society must adapt.

Rebutting the Wafflers

Deep emission reductions must start now

Emissions pathways & ΔT probabilities



Fawcett et al., SCIENCE, December 4, 2015

Rejecting Surrender

“Climate change is not just a great challenge; it’s a great opportunity”

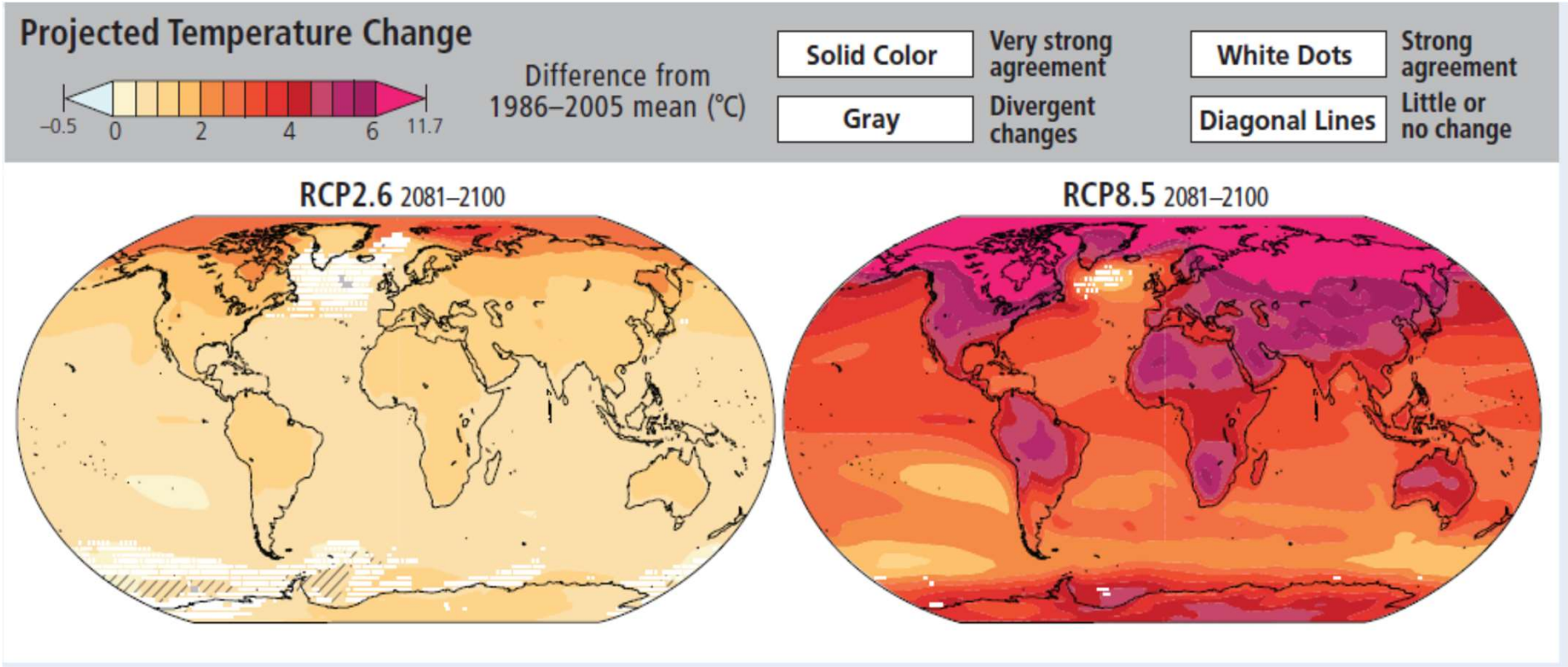
Countless wise observers

About society's options

- The options are mitigation, adaptation, & suffering.
- Society is already doing some of each.
- What's up to us 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. Because…
  - Mitigation alone won't work because climate change is already occurring & can't be stopped quickly.
  - And 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.

Rejecting Surrender

Low future emissions produce far less climate change than high future emissions.



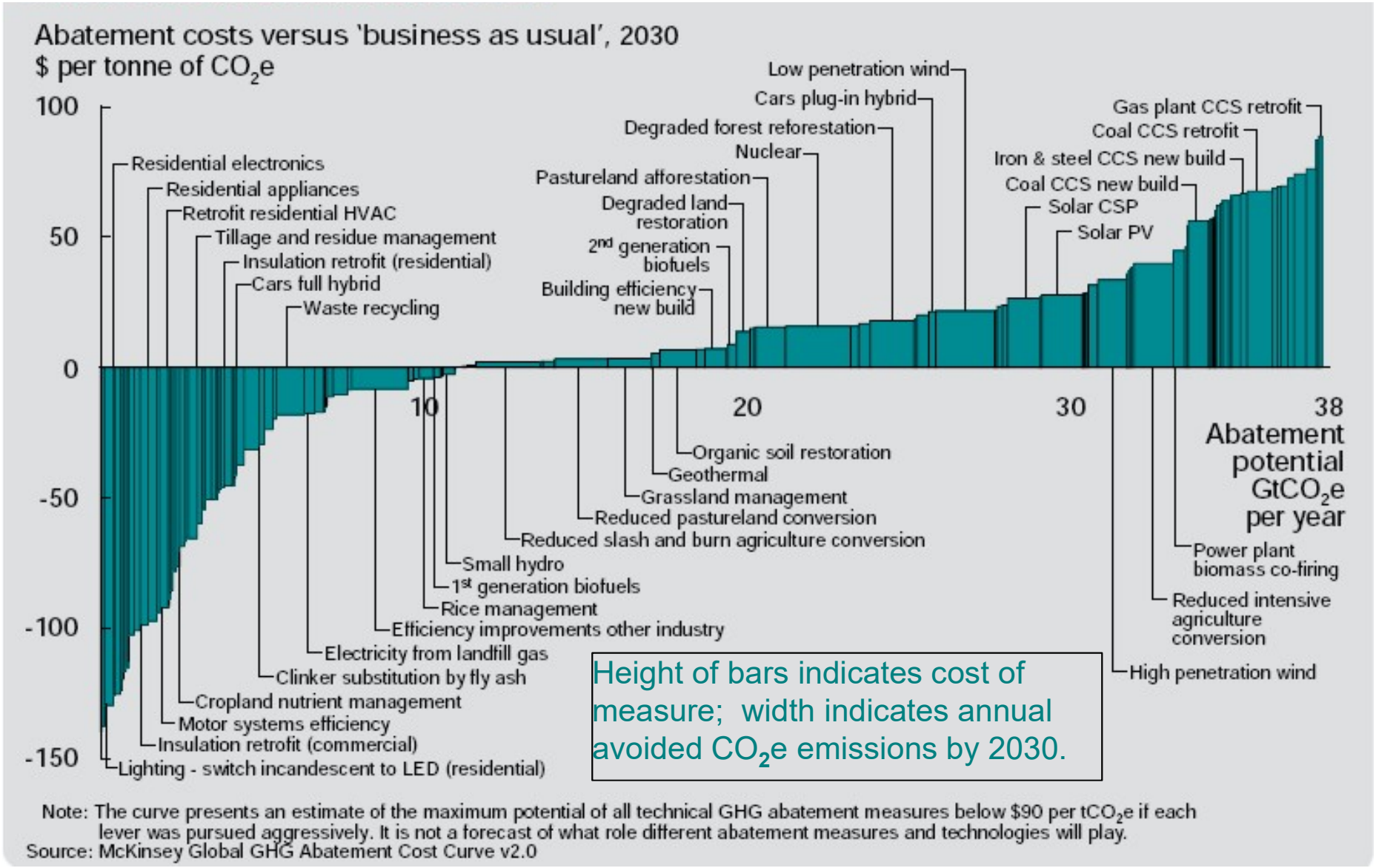
IPCC WGII, 2014

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

Rejecting Surrender

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

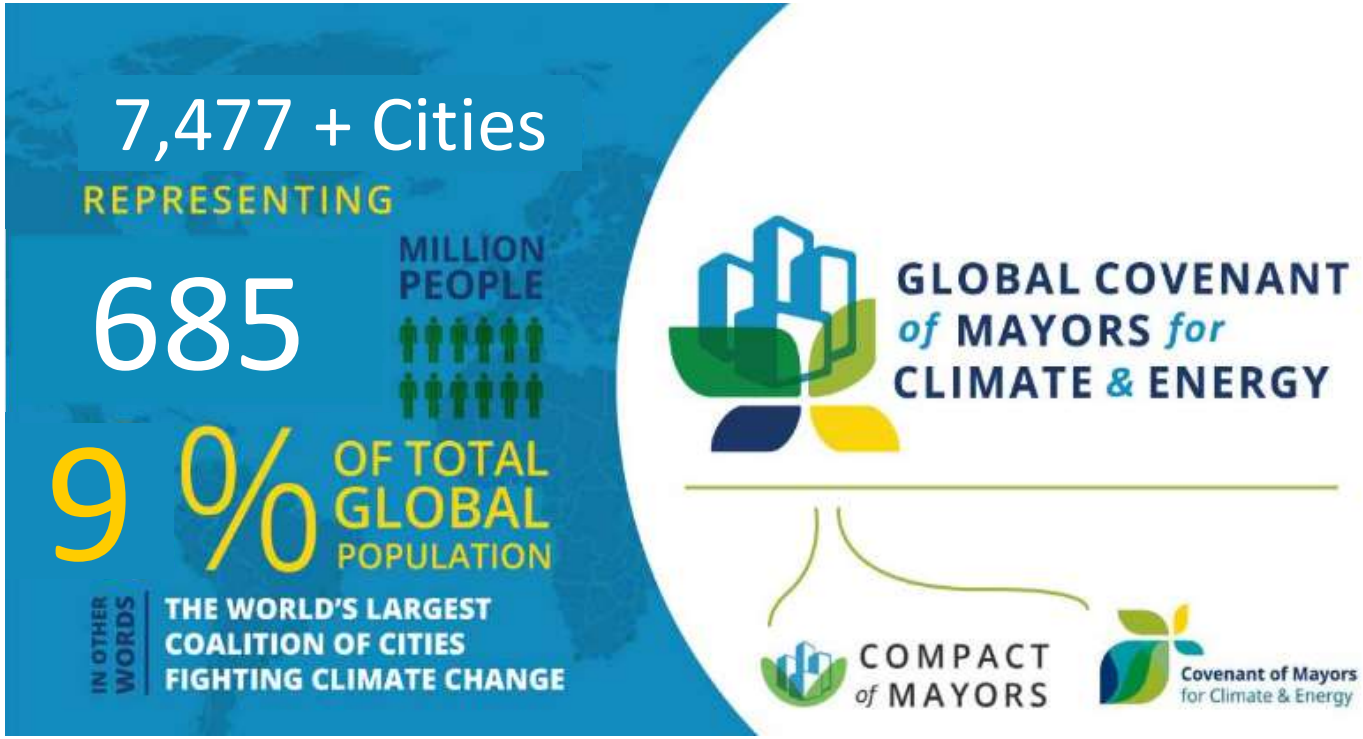
Is this much mitigation affordable?

- 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 is not 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.
- These costs are not a dead loss, just a choice of how society allocates its resources.
- Most economic models find aggressive mitigation reduces GWP by 2-3% of GWP in 2100, but they underestimate innovation.

Economics of climate action (continued)

- Many adaptation measures would make economic sense even if climate were not changing:
  - There have always been heat waves, floods, droughts, wildfires, powerful storms, crop pests, and outbreaks of vector-born disease, and society has always suffered from being underprepared.
  - It's particularly perverse that the Trump administration has been reversing even the "win-win" adaptation-preparedness-resilience measures adopted under Obama.
- Virtually all reputable studies suggest that the economic damages from not adequately addressing climate change would far exceed the costs of adequately addressing it.
- This and the economic opportunities in clean & resilient technologies are why cities and businesses support aggressive climate action.

Rejecting Surrender



Rejecting Surrender

One thousand companies and investors have signed the Business Backs Low-Carbon USA statement since November 2016. Companies and investors wishing to add their name to the statement can do so by registering here. For media inquires, please contact: Peyton Fleming fleming@ceres.org or Melanie Gade melanie.gade@wwfus.org.

Dear President Trump, Members of the US Congress, and Global Leaders:

Rejecting Surrender

The idea that society cannot afford to address climate change is wildly wrong.

“Trend is not destiny.”

Rene Dubos

Thank you!