The Science & Policy of Climate Change:
An Update on the Challenge and the Opportunity

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(January 2009 – January 2017)

Keynote Address

Low-Emissions Solutions Conference

University of San Francisco • 11 September 2018

Bottom lines

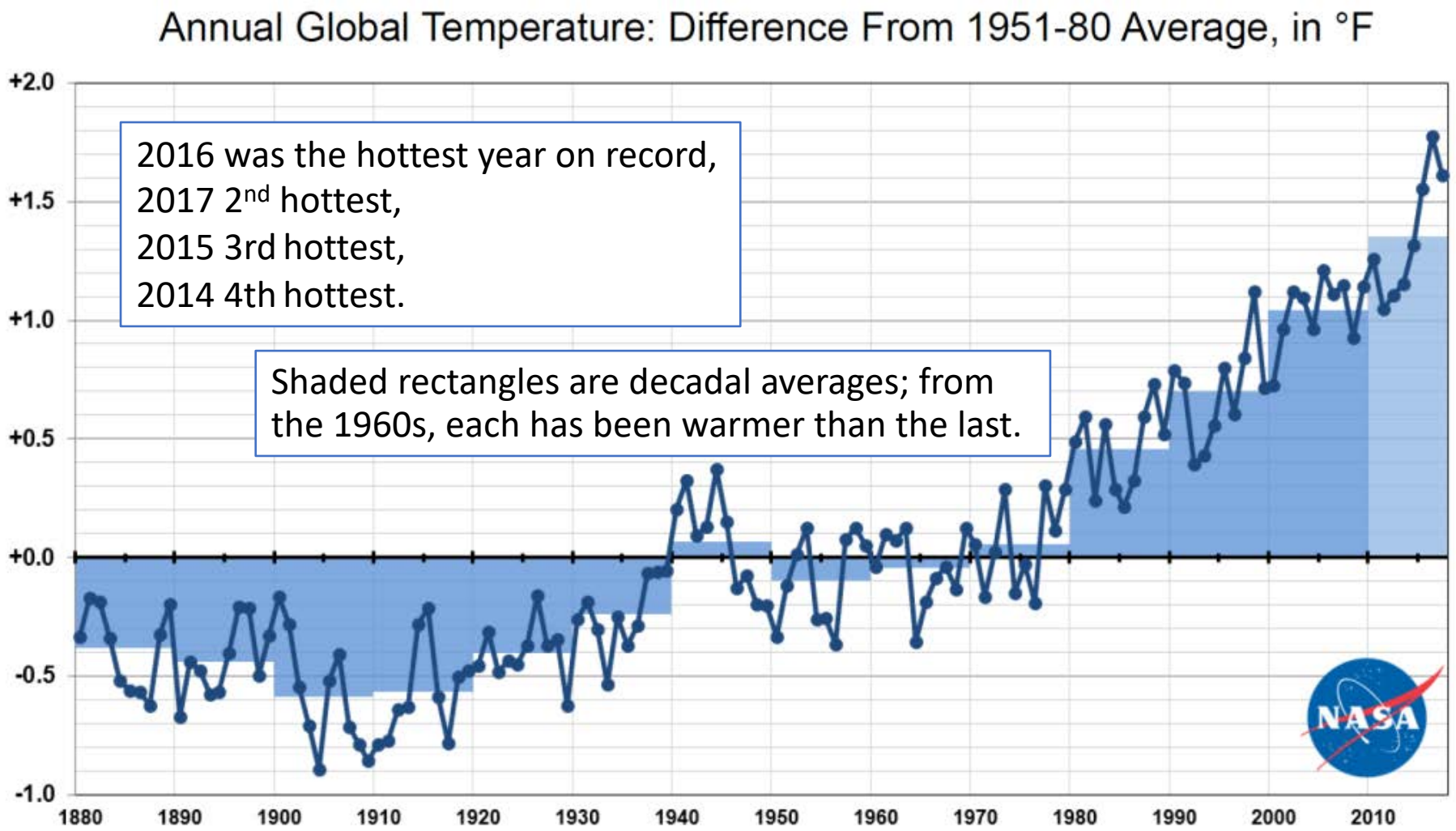
- The challenge is much bigger--and the time left to take aggressive action much shorter--than most people think.
- The opportunities for such action are more abundant and economical than most people think.
- President Obama was on the right track, but President Trump is trying to derail the train.
- For now, it is up to Congress, state & local government, the private sector, academia, civil society, and individual citizens to move ahead.
- A somewhat different composition of Congress would be a benefit (think 2018 midterms).

Outline

- Climate-change indicators & impacts today
- Some forecasts of what's coming
- Society's options
- U.S. federal policies under Obama and Trump
- Some observations on the path forward

Climate-Change Indicators and Impacts Today

Global-average surface air temperature 1880-2017

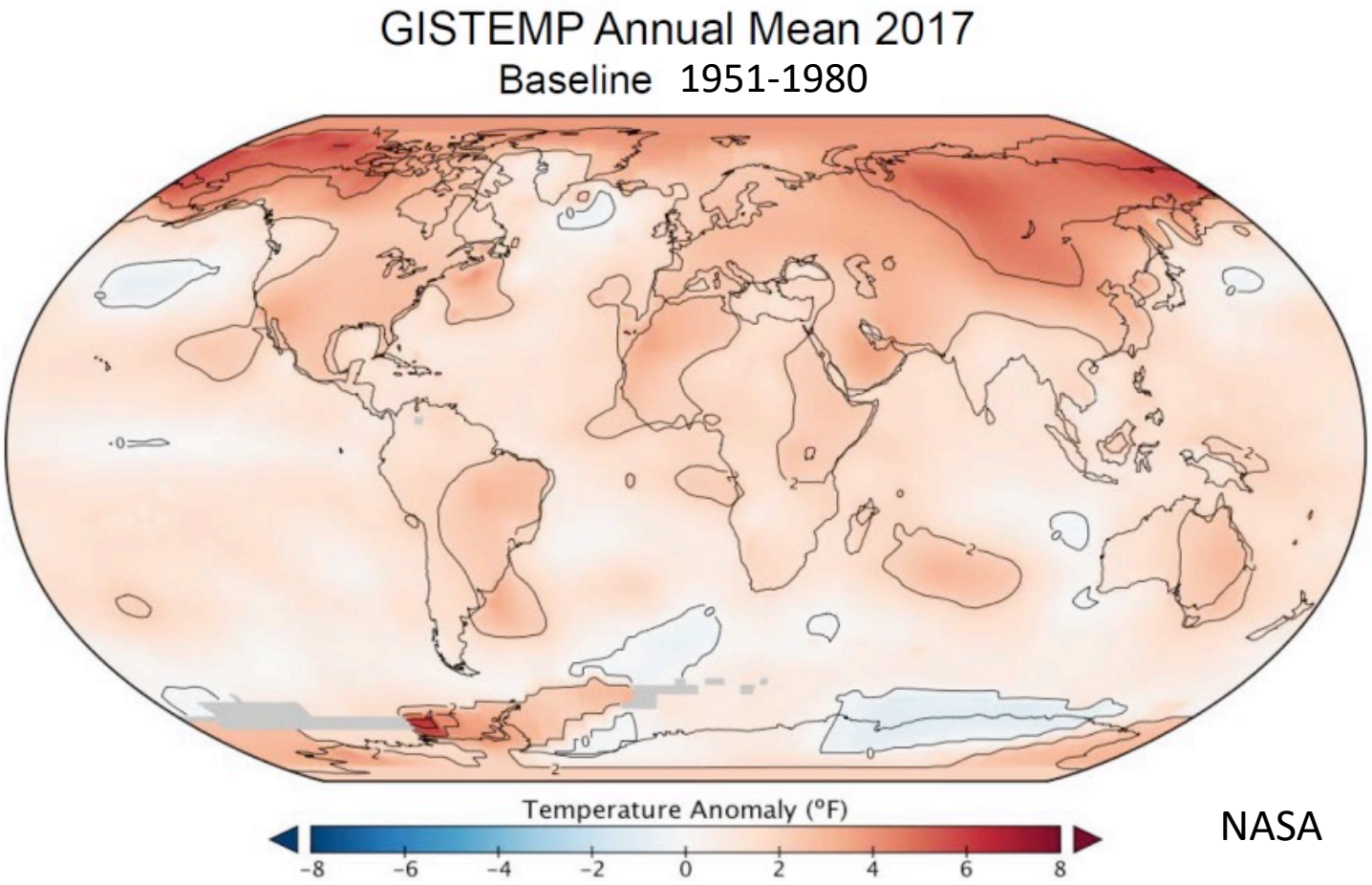


Earth has been warming more or less steadily for the last 100+ years, as the increasing forcing from the human-caused GHG buildup came to dominate natural variability. The 1998-2012 "hiatus" was a slowdown in rate of warming, not a halt.

Distribution of surface air temp anomalies, 2017

2017:
0.9°C / 1.6°F above 1951-80 average

2nd Warmest year of NASA GISTEMP record



NASA

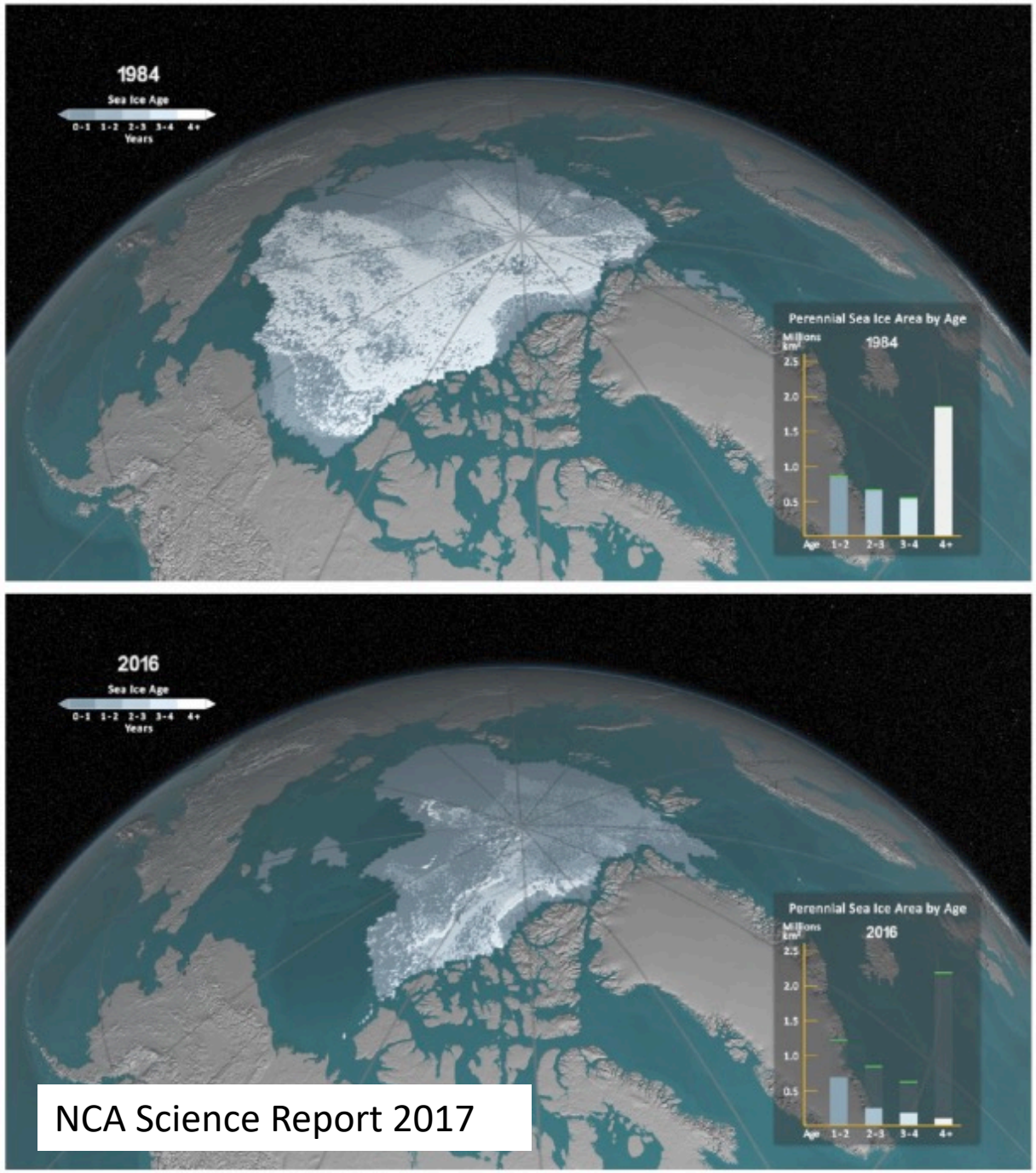
The Arctic on average is warming at >2 times the global rate, and in some parts of the region at 3-4 times the global rate. West Antarctic Ice Sheet is similar.

Indicators

Extent & thickness of Arctic sea ice, Sept 1984 and Sept 2016

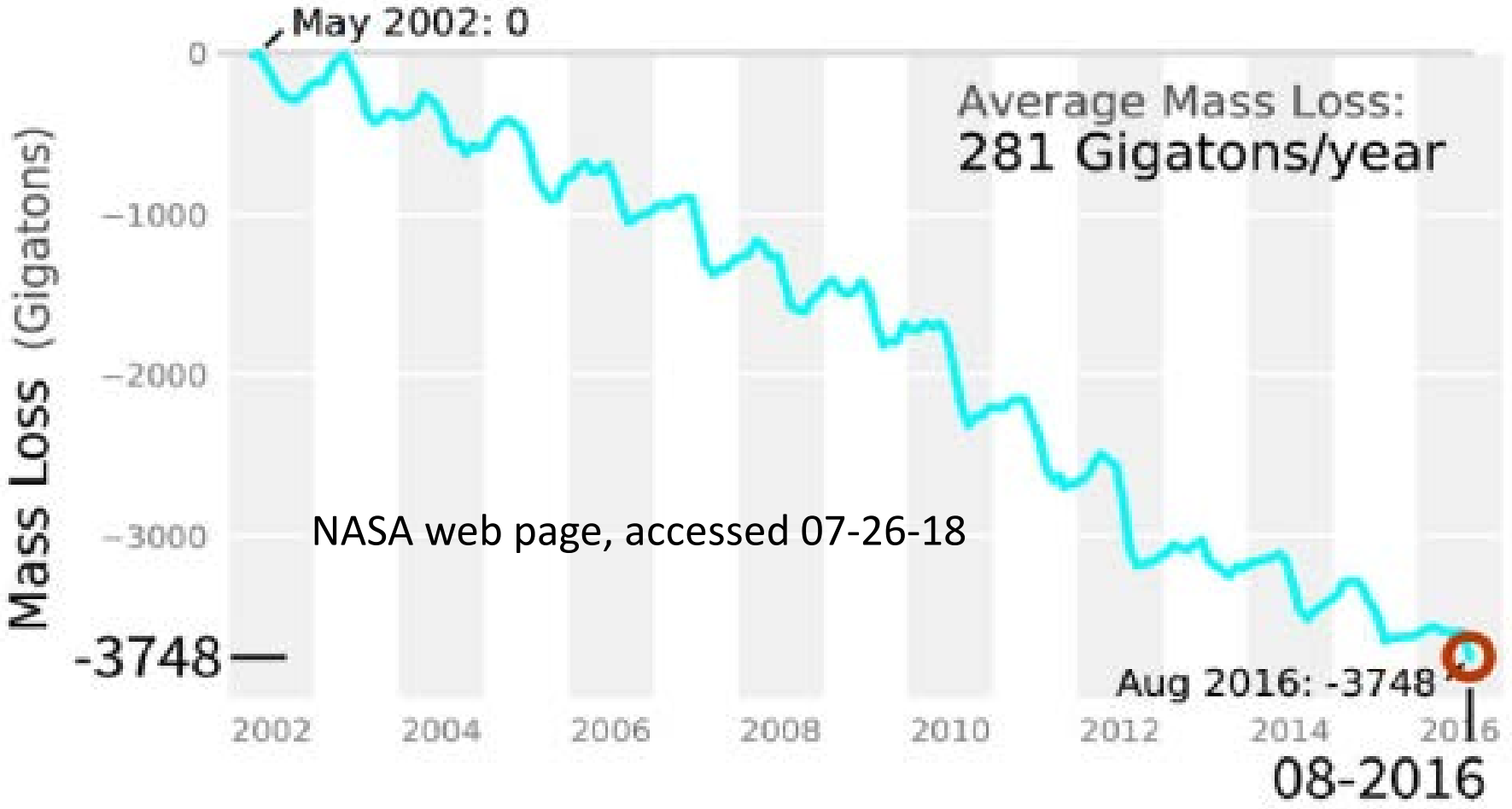
Sea ice floats, so its shrinkage doesn't affect sea level.

But the change from ice to open water, while offering some economic opportunities, has drastic effects on regional temperatures, winds, storm impacts, and valued species.



NCA Science Report 2017

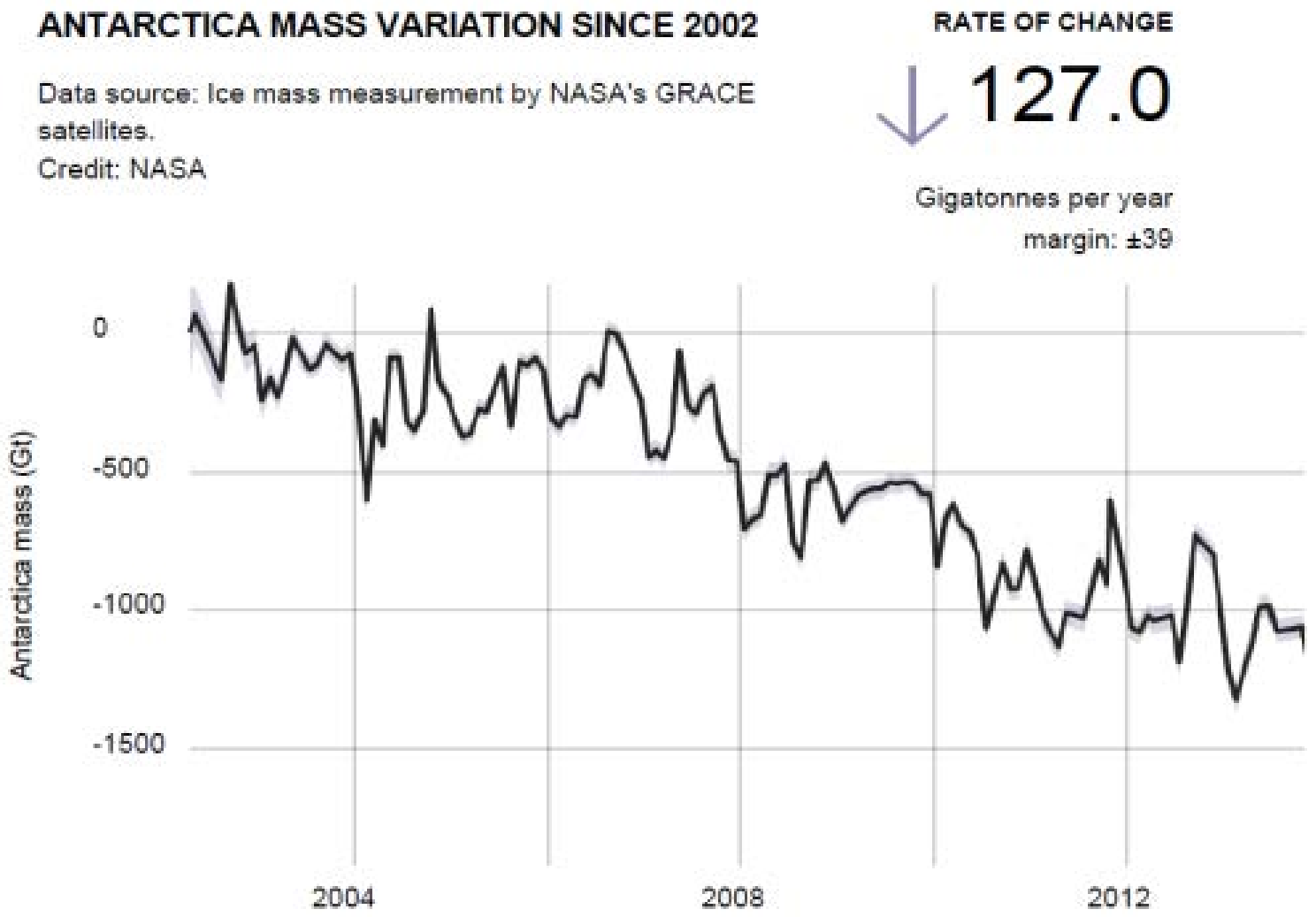
Greenland is steadily losing its land ice



NASA web page, accessed 07-26-18

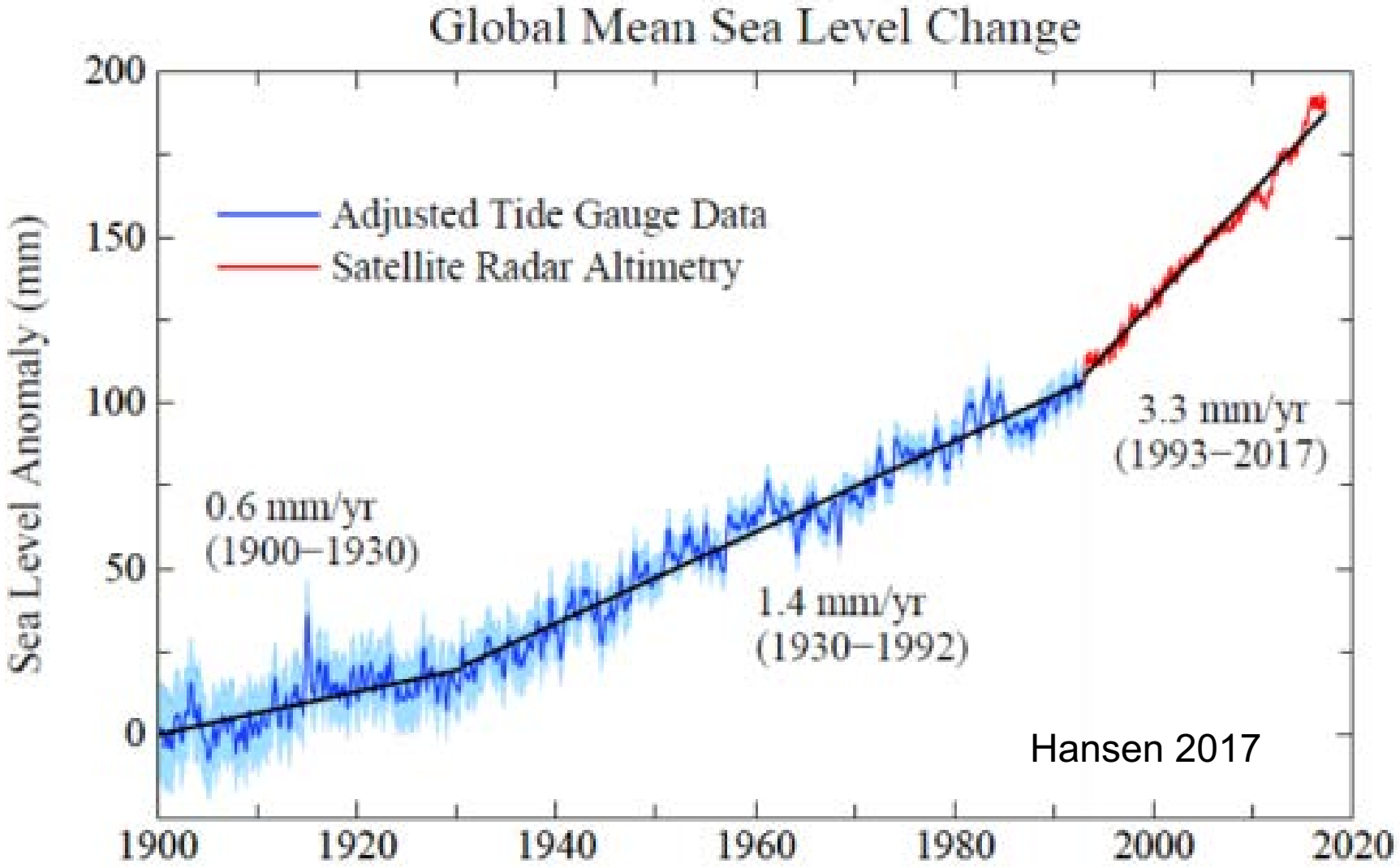
Ice losses from land ice sheets & glaciers contribute to sea-level rise.

It's now clear Antarctica is also losing ice



NASA web page, accessed 6-18

Rate of sea-level increase is accelerating



Post-2010 is actually 5.5 mm/yr!

At $\Delta T \approx 1^{\circ}C$, serious harm is already a reality

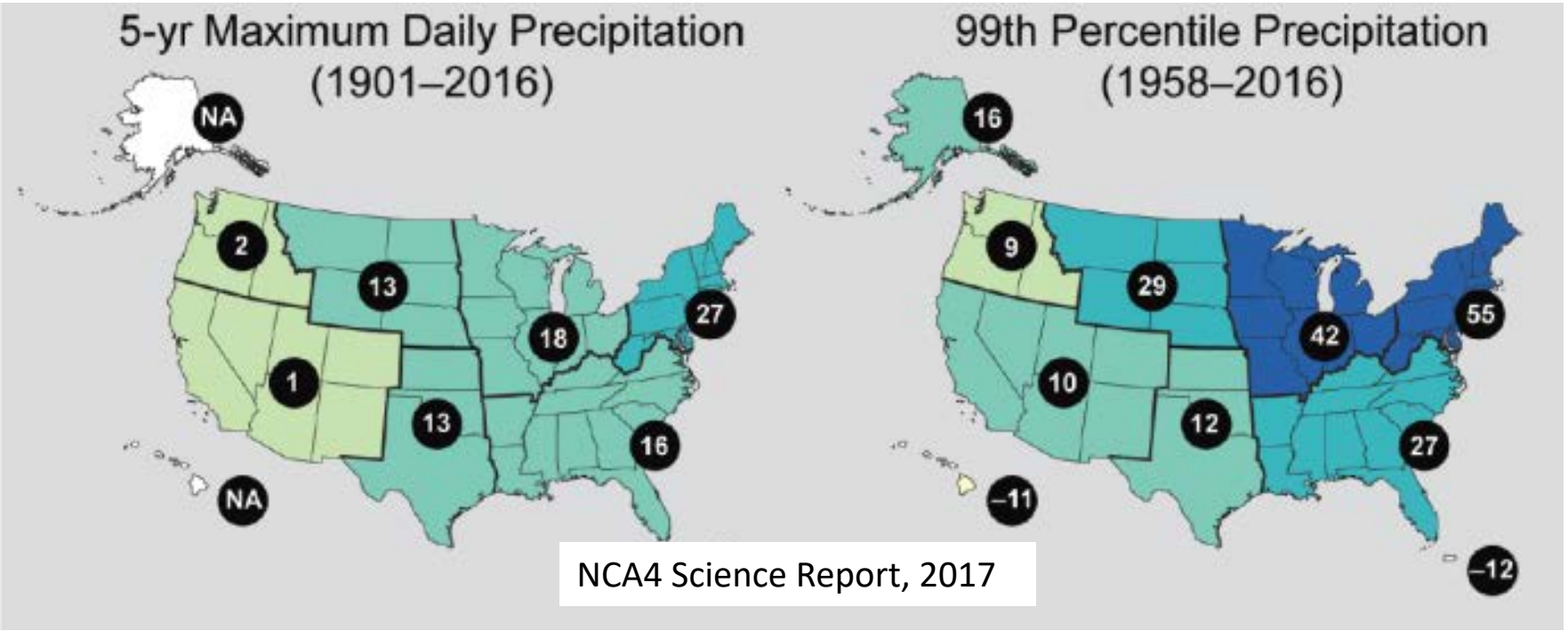
Around the world we're seeing, variously, increases in

- flooding
- wildfires
- droughts
- heat waves
- coastal erosion
- coral bleaching events
- power of the strongest storms
- permafrost thawing & subsidence
- expanding impacts of pests & pathogens
- impacts on distribution & abundance of valued species

All plausibly linked to climate change by theory, models, "fingerprints"… and many growing faster than previously predicted.

Impacts today

Heavier downpours are leading to more floods



Left: Magnitude of largest daily precipitation in successive 5-year periods
Right: Amount of precipitation in top 1% of daily precipitation events in each year

Why? A warmer atmosphere holds more water, so more can come down at one time.

Downpours and floods (continued)

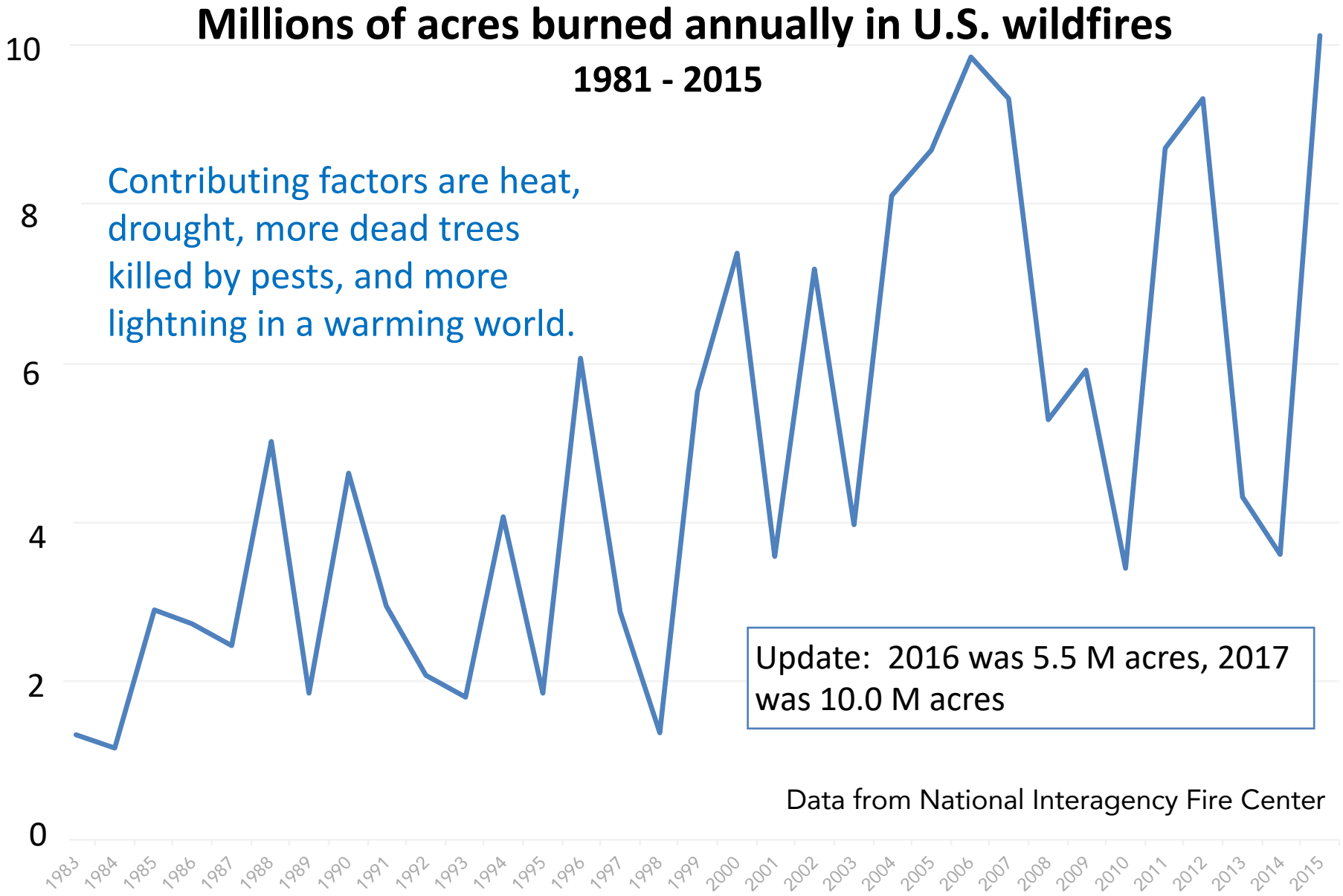
"Hundred-year" floods now occur once a decade or more in many places.
Three "five-hundred-year" floods occurred in Houston in three years.

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.

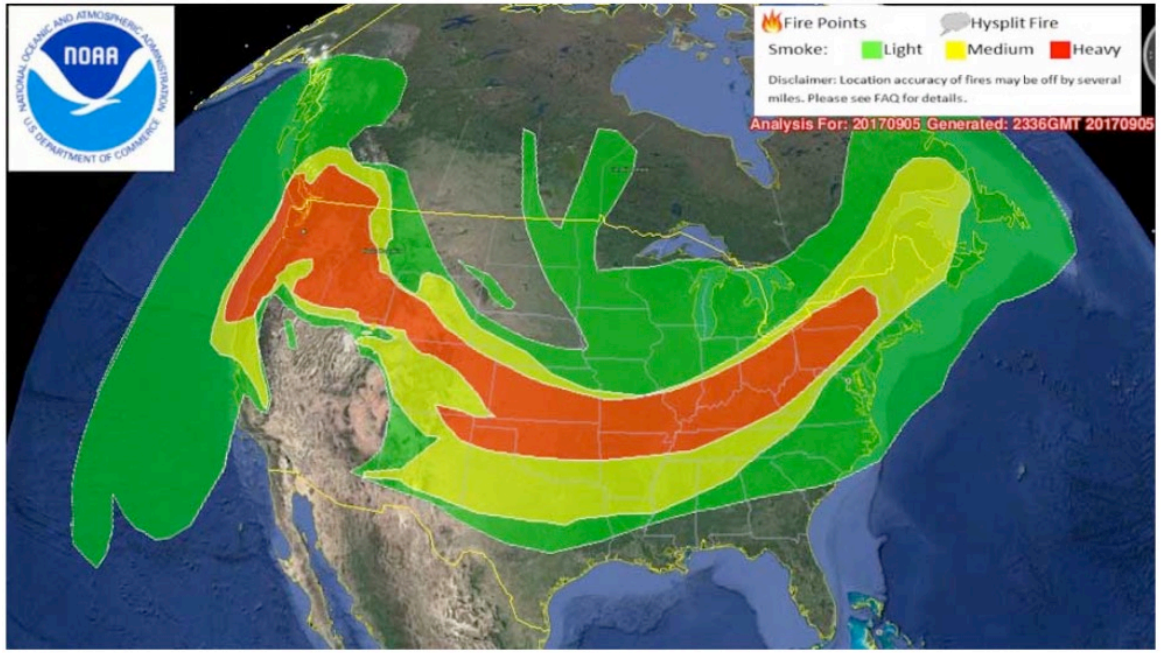
Impacts today

Wildfires are increasing dramatically



Wildfires (continued)

- US fire season ≥3 months longer than 40 years ago.
- Average fire much bigger & hotter than before.
- Nine of 10 biggest U.S. wildfires since 2004 (the other in 1997).
- Five these were in Alaska, where now even the tundra burns.
- Smoke from today's big fires impacts health 1000s of miles away.

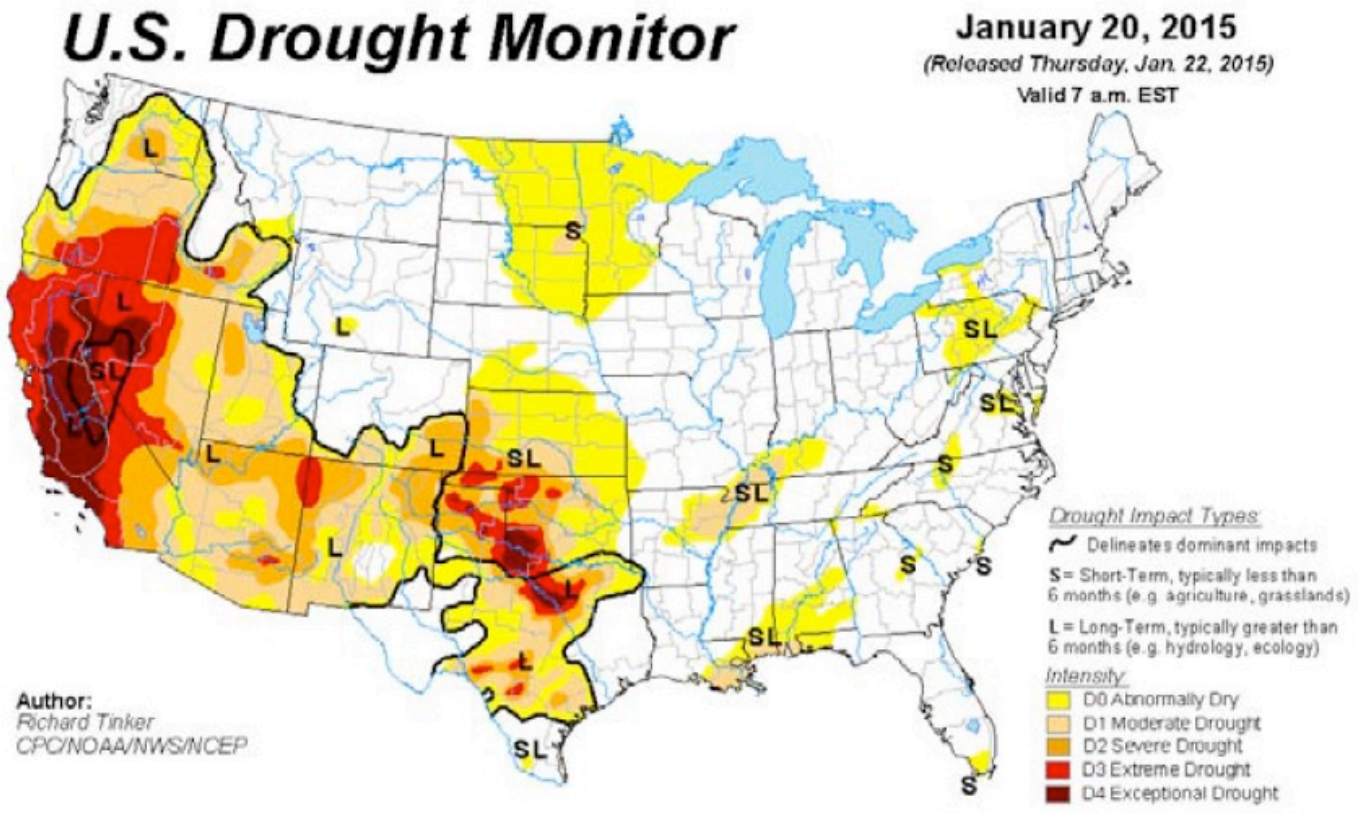


Wildfire smoke map, created at 5:36 p.m. MDT September 5, 2017. NOAA.

Impacts today

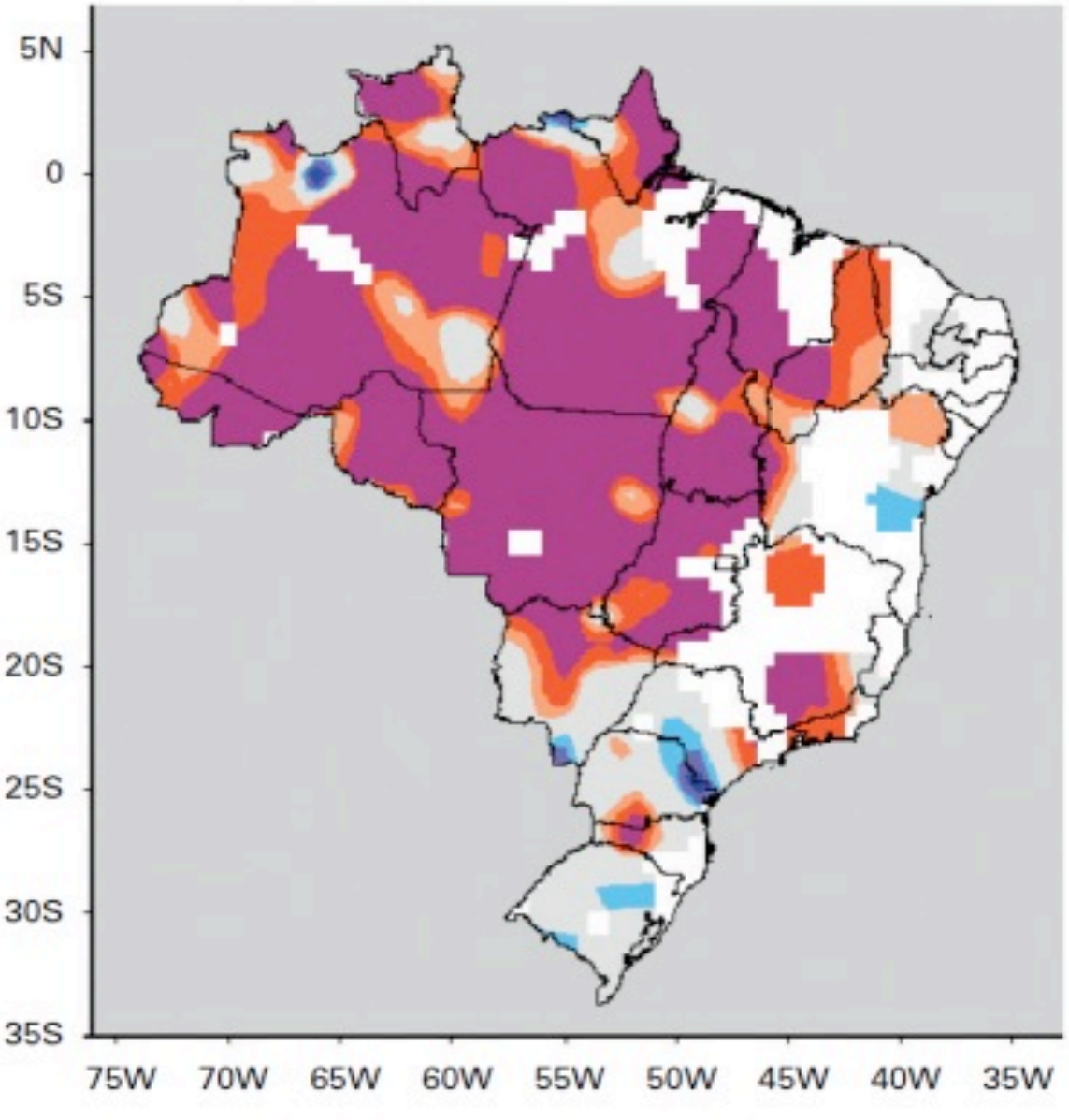
Climate change is exacerbating drought

- 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 also play a role.



Impacts today

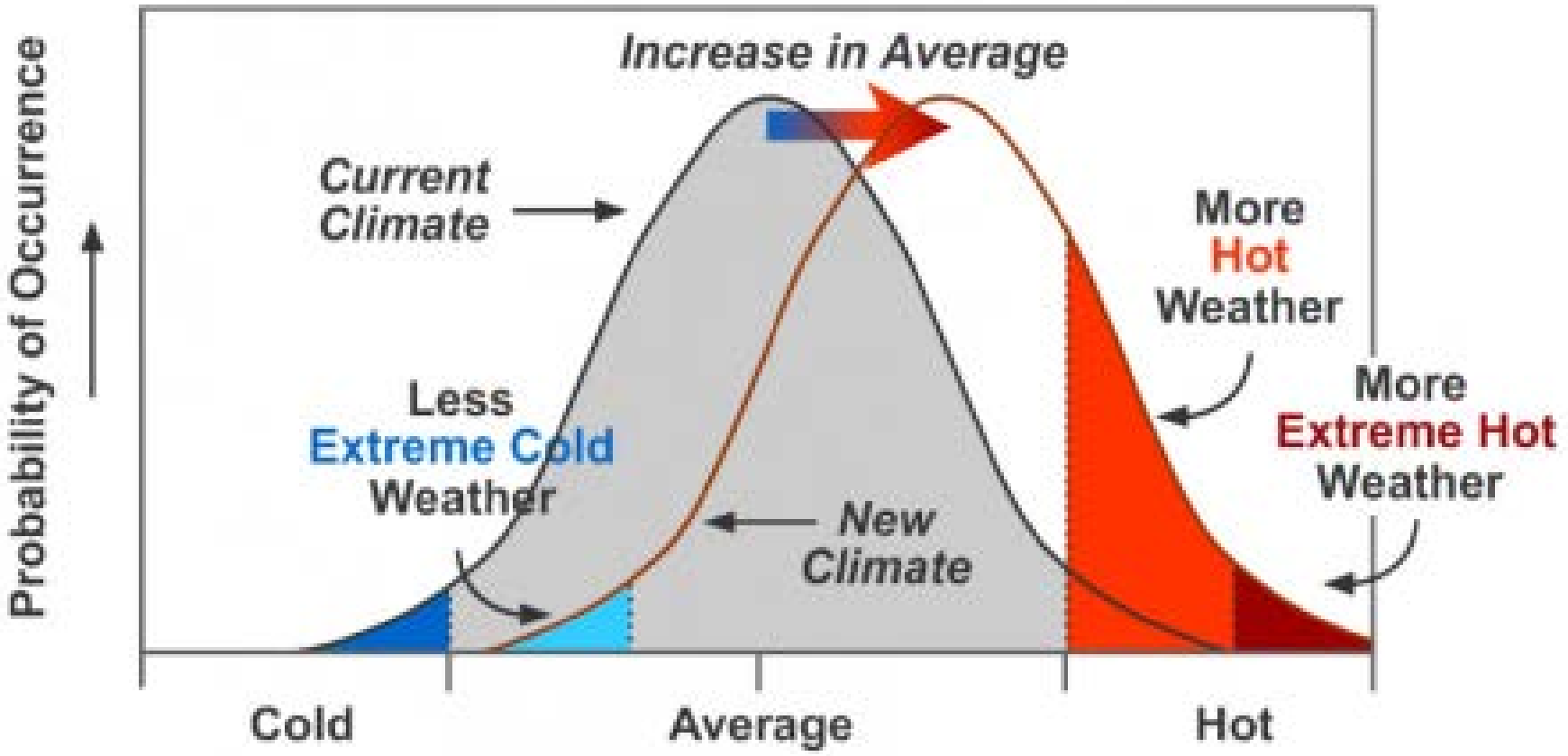
Drought is worsening in many regions



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

WMO 2017

Modest change in average temperature has led to enormous change in heat extremes



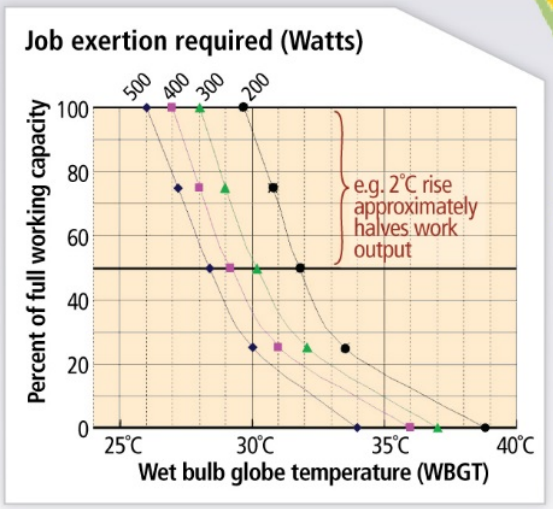
Thus, in a warmer climate, high-T extremes that previously had probability of occurrence near zero occur with some regularity.

All-time high temps occurring in 2017 & 2018

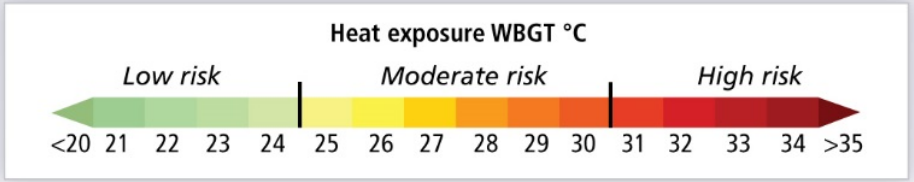
• Iran	129°F	June 2017
• Pakistan	128°F	May 2017
• Africa	124°F	July 2018
• Spain	117°F	July 2017
• Chile	113°F	Jan 2017
• Los Angeles	111°F	July 2018
• Argentina	110°F	Jan 2017
• Armenia	108°F	July 2018
• Shanghai	106°F	July 2017
• San Francisco	106°F	Sept 2017
• Denver	105°F	June 2018
• Hong Kong	102°F	Aug 2017
• Scotland	92°F	June 2018

Impacts today

Increasing heat already makes working outdoors dangerous in summer in many regions



Wet Bulb Global Temperatures (WGBT) are 1980-2009 averages for hottest month.



IPCC AR5, WGII, Figure 11-5

Impacts today

Coral bleaching is worsening rapidly

Jarvis Reef, South Pacific (courtesy WHOI)

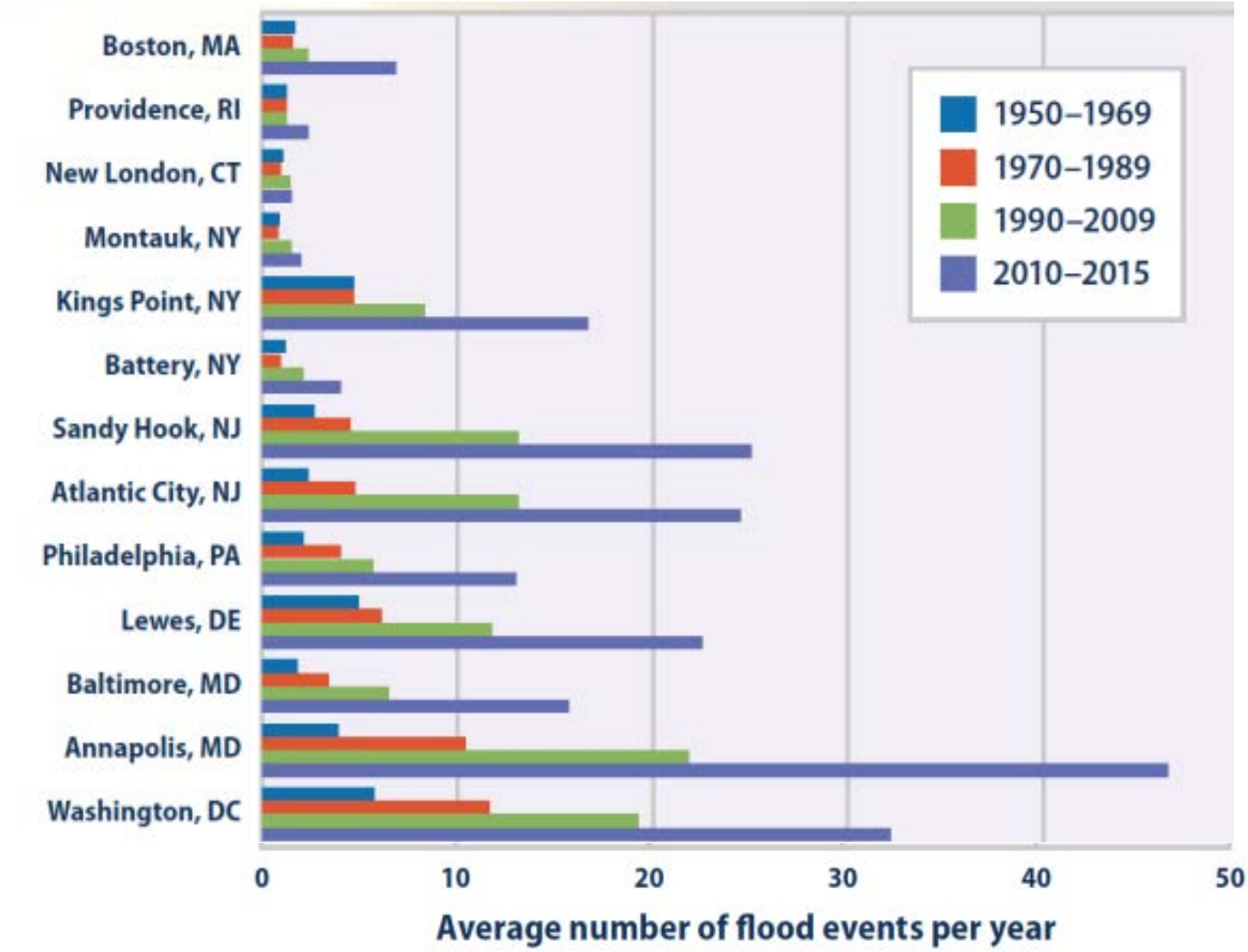
"As of February 2017, the ongoing global coral bleaching event continues to be the longest and most widespread ever recorded."

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

Warmer ocean → 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

Rising sea → coastal inundation



Impacts today

Distribution & abundance of 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

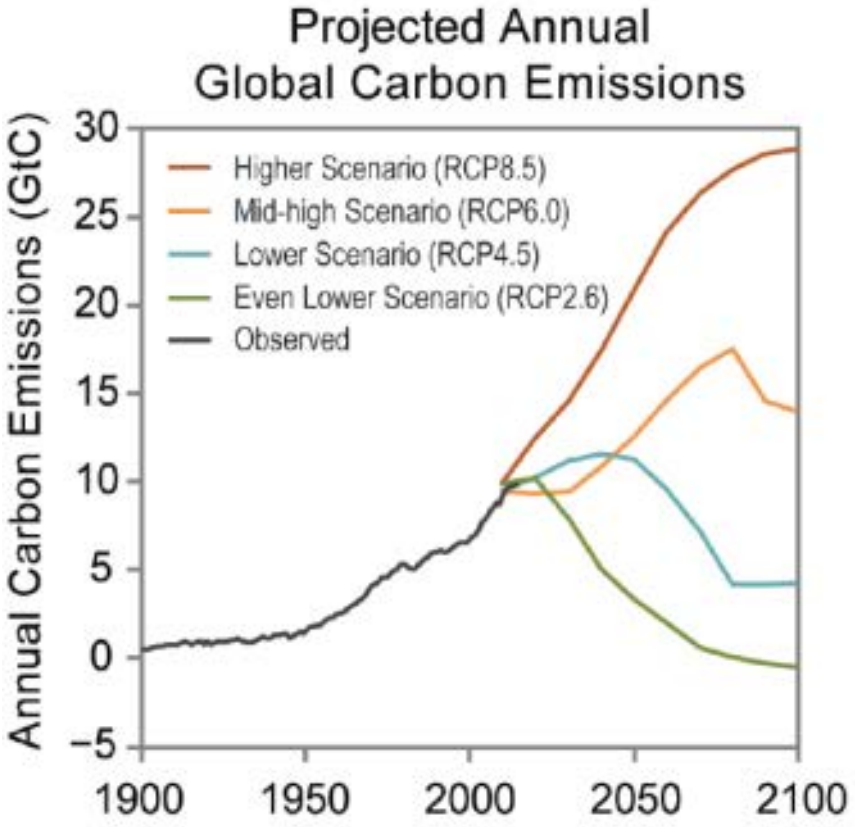
Nathan J. Mantua[1]

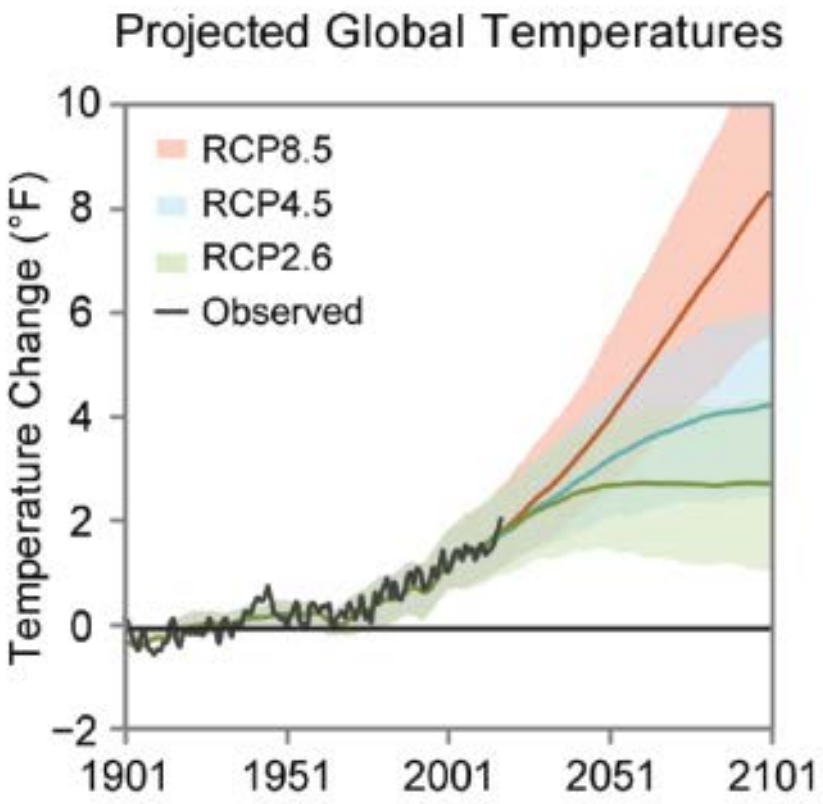
Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Santa Cruz, CA 95060

Some Forecasts of What's Coming

Temperatures rise under all scenarios

But <u>how much</u> they rise depends strongly on emissions.



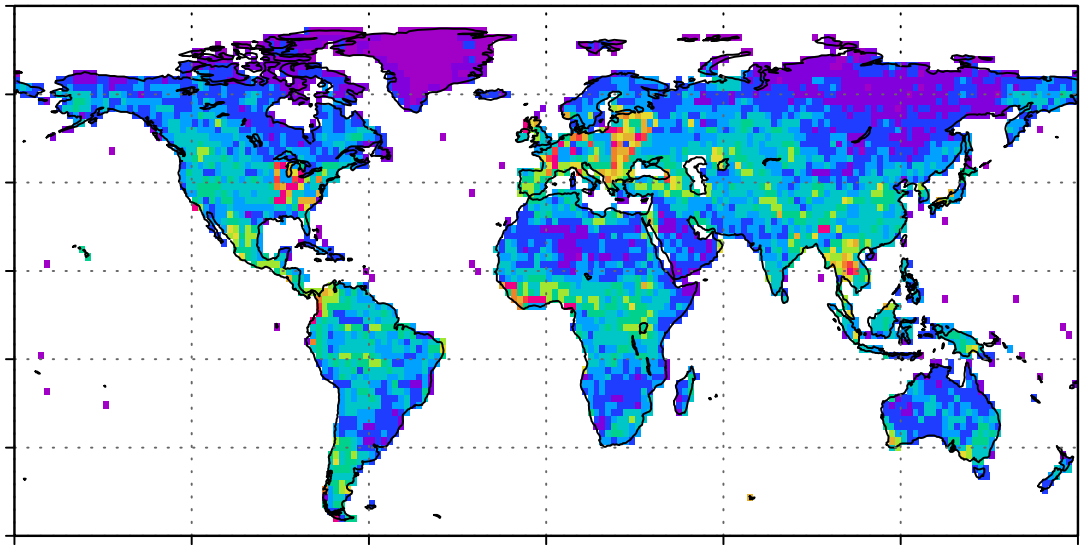


NCA5 Science Report, 2017

Forecasts

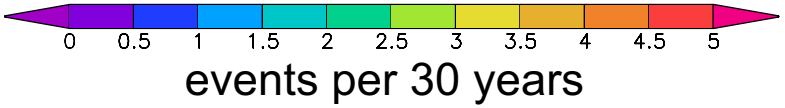
Under BAU: Drought frequency soars

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

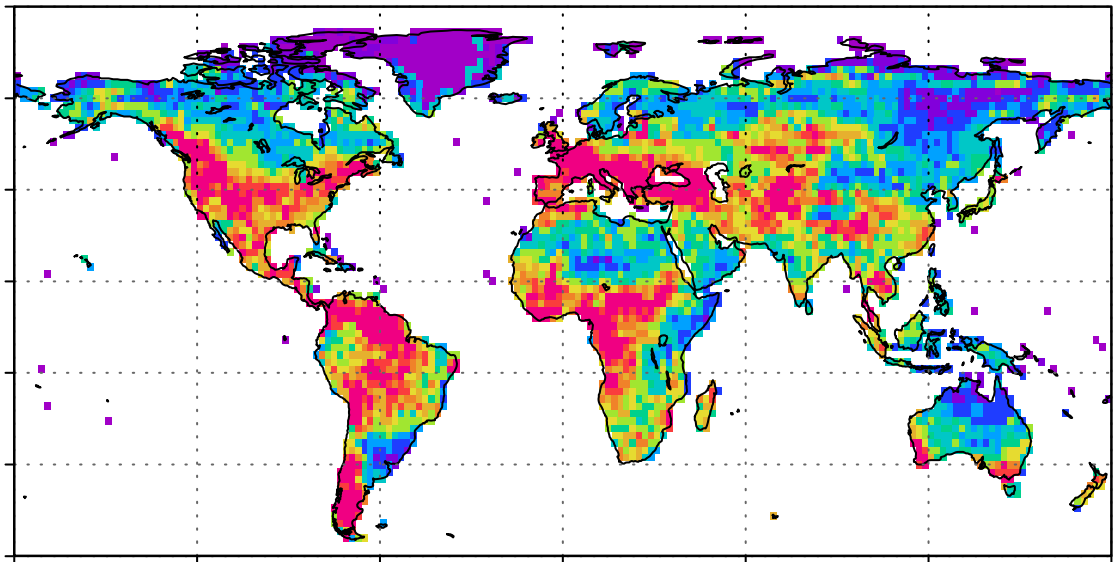


1961-1990

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



Results shown are the mean of 8 global climate models.

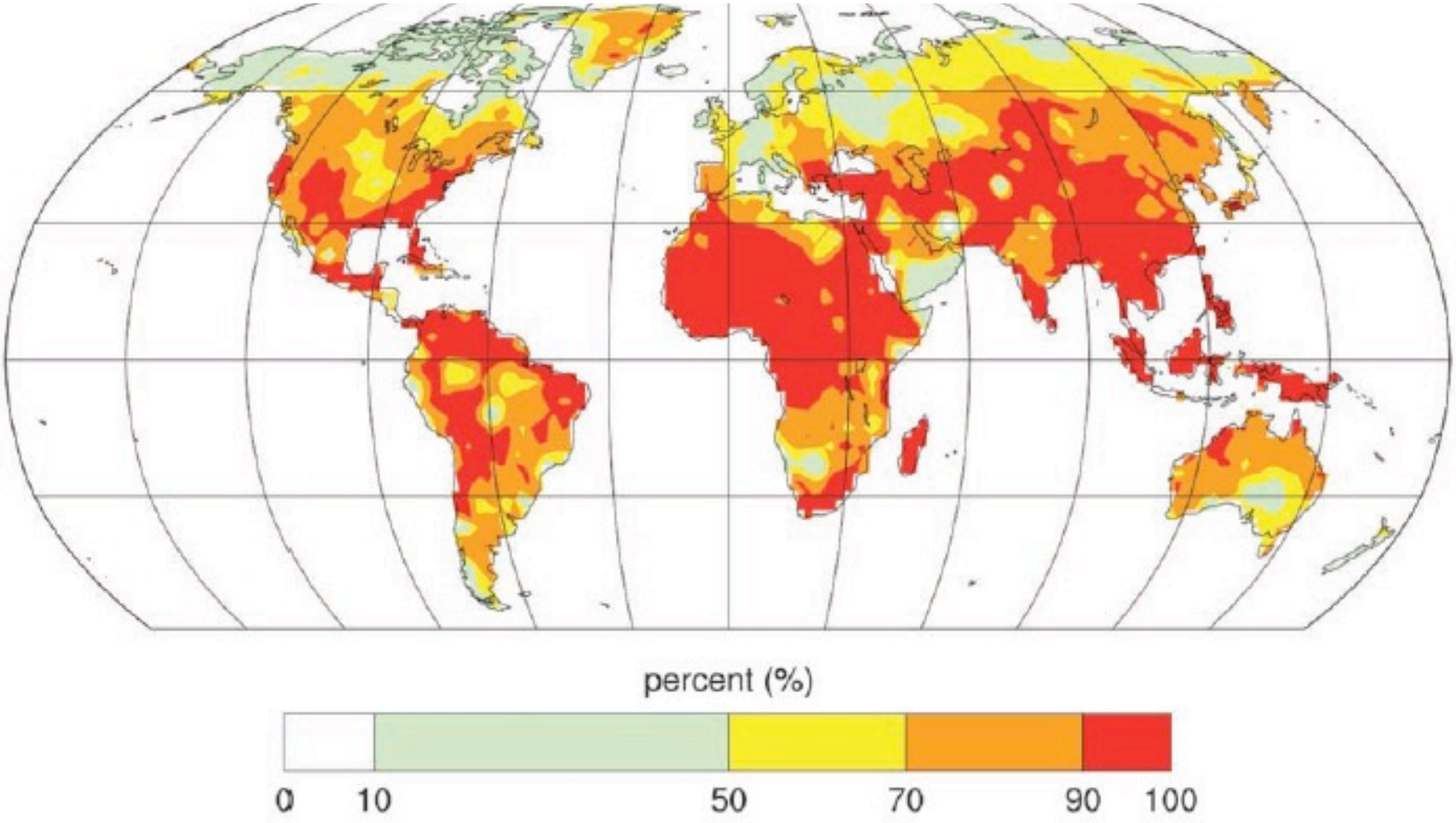


2070-2099, IPCC A2 scenario

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

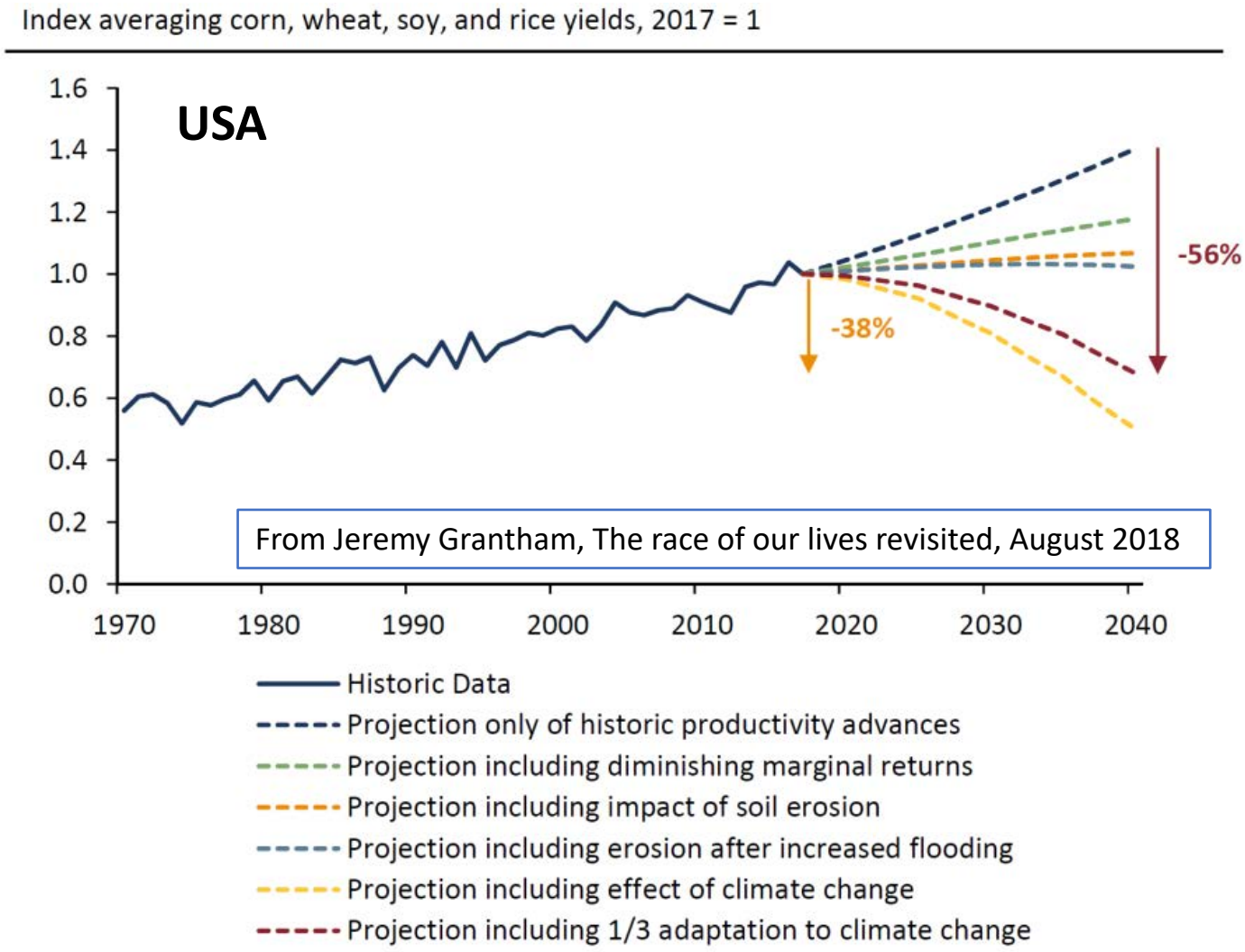
Under BAU: Record heat is the new normal

Summers in 2080-2100 warmer than warmest on record 1900-2006



Battisti & Naylor, SCIENCE, 9 January 2009, using IPCC A1B emission scenario

Under BAU: agriculture output plummets



As of 4/30/18
Source: USDA NASS, Rhodes 2014, Liang et al 2017, GMO

Most other countries will do worse.

Forecasts

Under BAU: Significant direct impacts on health

Table 1.3 Additional deaths attributable to climate change,[a] under A1b emissions and the base case socioeconomic scenarios, in 2050

WHO 2017

Region	Undernutrition[b]	Malaria	Dengue	Diarrhoeal disease[c]	Heat[d]
Asia Pacific, high income		0 (0 to 0)	0 (0 to 0)	1 (0 to 1)	2504 (1868 to 3046)
Asia, central	314 (66 to 563)	0 (0 to 0)	0 (0 to 0)	26 (12 to 38)	1889 (1077 to 2173)
Asia, east	700 (–427 to 1828)	0 (0 to 0)	31 (25 to 42)	72 (33 to 107)	17 882 (11 562 to 24 576)
Asia, south	16 530 (–1582 to 34 642)	9343 (2998 to 13 488)	209 (140 to 246)	7717 (3522 to 11 421)	24 632 (20 095 to 31 239)
Asia, south-east	3049 (605 to 5494)	287 (265 to 334)	0 (0 to 0)	383 (172 to 575)	7240 (5883 to 10 290)
Sub-Saharan Africa, central	18 273 (–12 372 to 48 918)	0 (0 to 0)	1 (1 to 1)	5473 (2473 to 8174)	1363 (1139 to 1598)
Sub-Saharan Africa, eastern	26 480 (4936 to 48 024)	22 194 (18 747 to 26 002)	5 (4 to 5)	6951 (3138 to 10 392)	4543 (3497 to 5957)
Sub-Saharan Africa, southern	1032 (–516 to 2580)	0 (0 to 0)	0 (0 to 0)	267 (121 to 396)	706 (553 to 857)
Sub-Saharan Africa, western	16 105 (–19 500 to 51 709)	524 (524 to 524)	1 (1 to 1)	11 174 (5039 to 16 723)	3469 (2887 to 4261)
World	84 697 (–29 203 to 163 989)	32 695 (22 786 to 40 817)	282 (195 to 342)	32 955 (14 914 to 49 151)	94 621 (70 775 to 126 684)

Forecasts

Increased storminess in all scenarios

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]

Forecasts

Continued ocean acidification in all scenarios

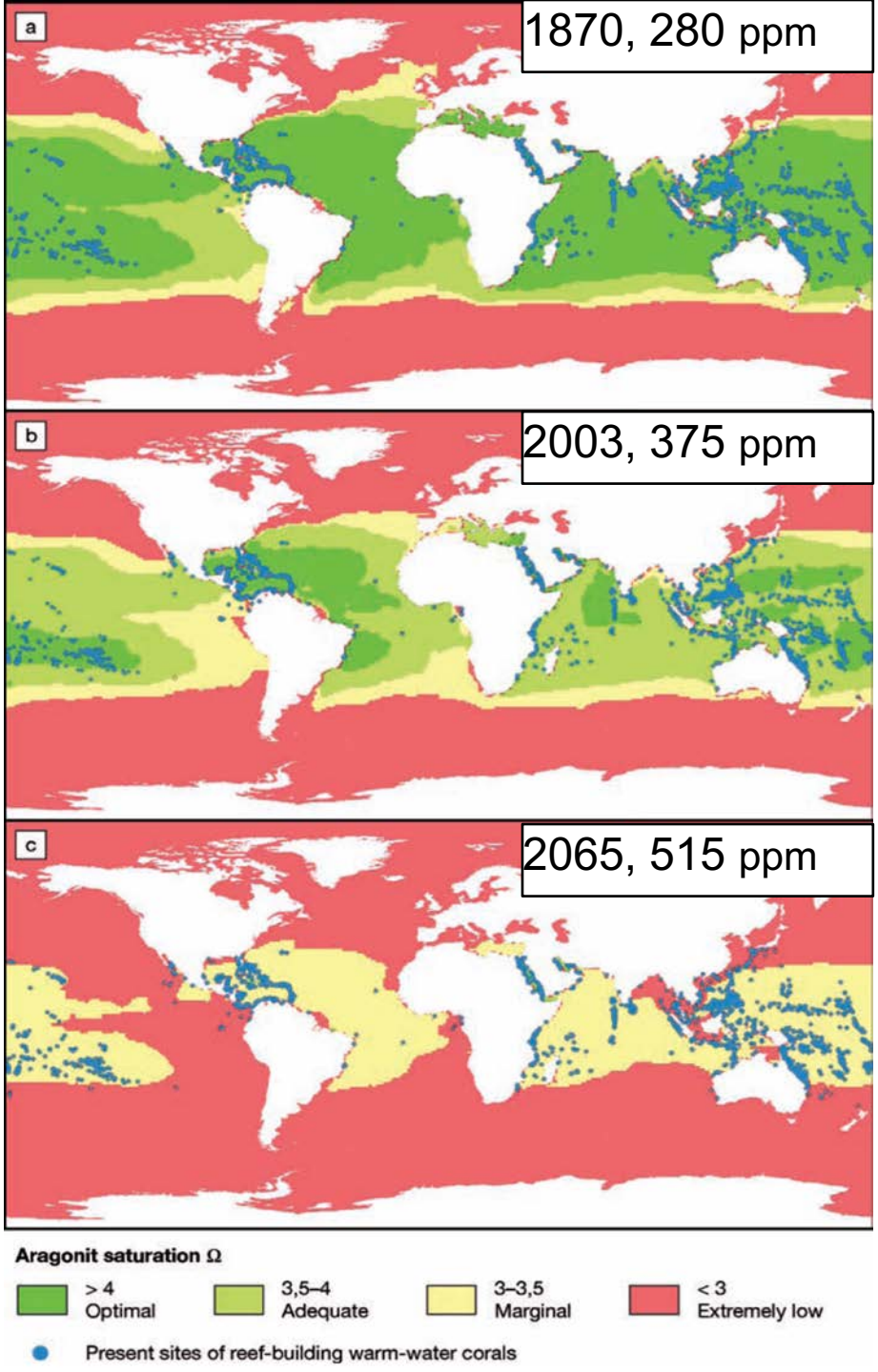
Increased acidity lowers availability of $CaCO_3$ to organisms using it for forming their shells & skeletons (corals, shrimp, clams, oysters…).

Adverse effects already being observed.

Adds to warming, pollution, etc. in stressing ocean life

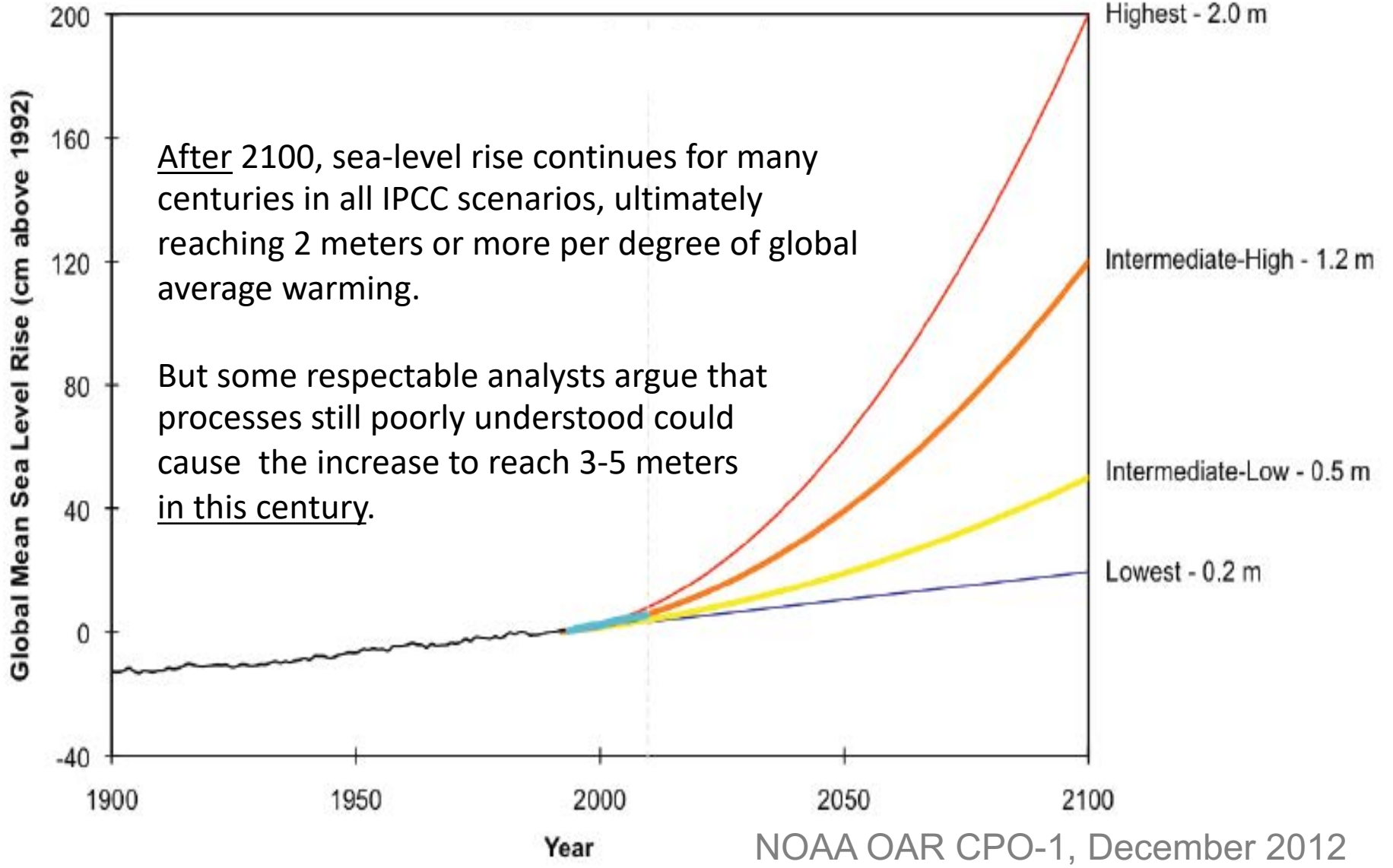
Coral reefs could be dead or in peril over most of their range by mid to late 21st century.

Steffen et al., 2004



Forecasts

Continued sea-level rise in all scenarios



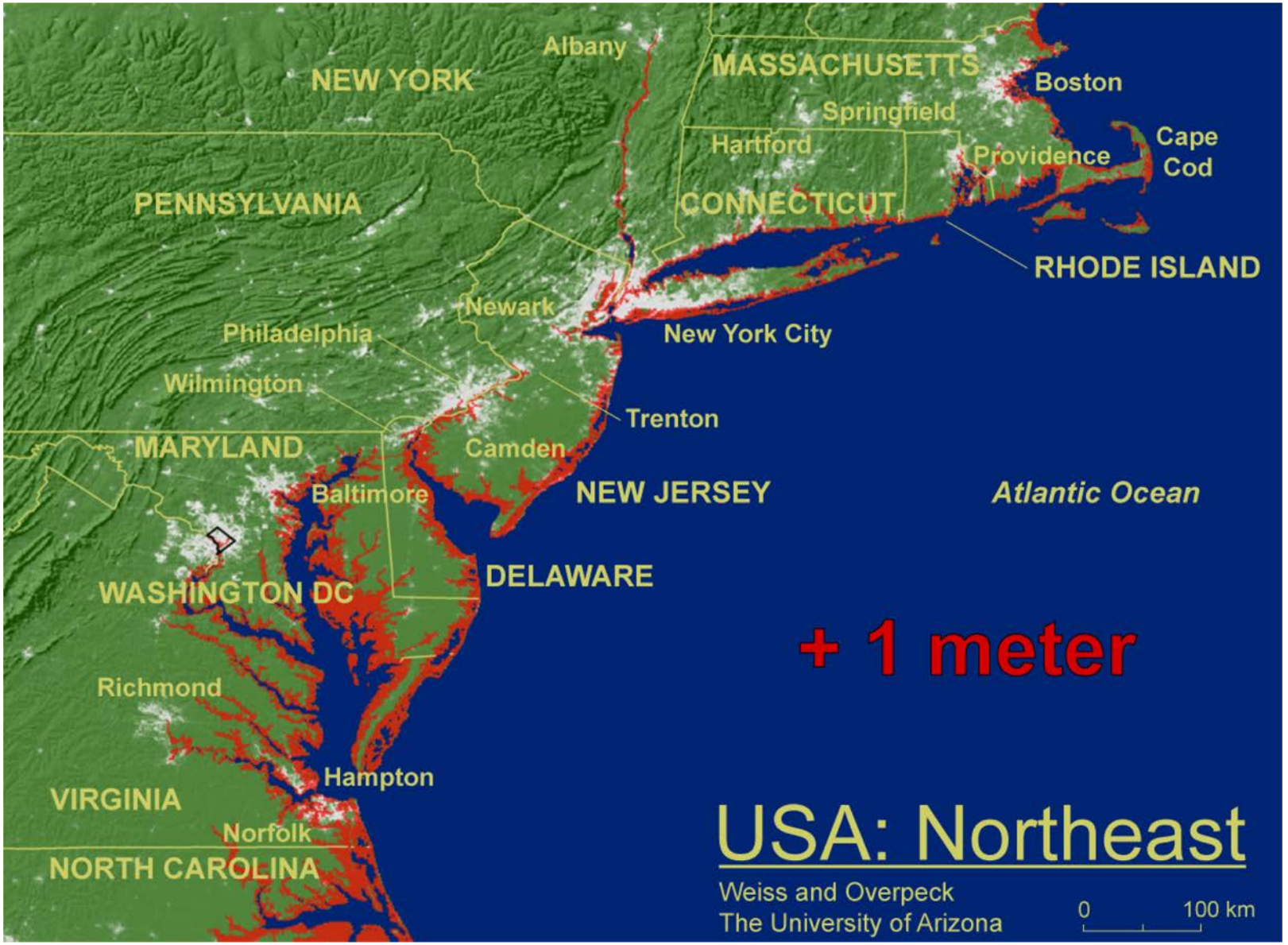
After 2100, sea-level rise continues for many centuries in all IPCC scenarios, ultimately reaching 2 meters or more per degree of global average warming.

But some respectable analysts argue that processes still poorly understood could cause the increase to reach 3-5 meters in this century.

NOAA OAR CPO-1, December 2012

Forecasts

Sea level: Flooded area with 1 meter rise



Currently unquantifiable potential tipping points

- 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
- Greatly accelerated sea-level rise from rapid disintegration of Greenland and Antarctic ice sheets
- 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.

Society's Options
and Progress Implementing Them

Facing the climate-change challenge…

Society has only three options:

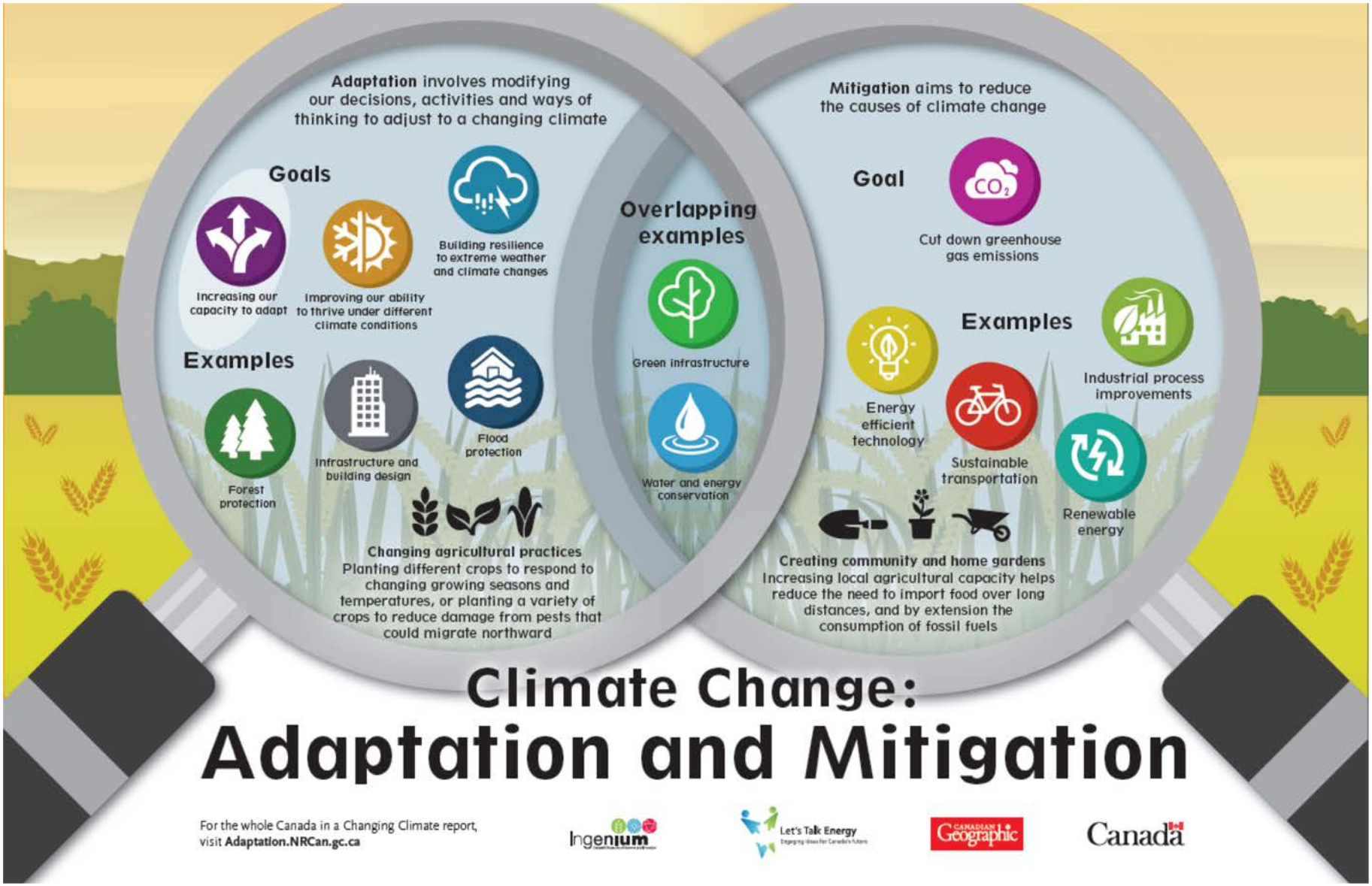
- Mitigation (measures to reduce pace & magnitude of changes in global climate being caused by human activities)
- Adaptation (measures to reduce adverse impacts on human well-being from the changes in climate that mitigation does not avoid)
- Suffering the adverse impacts and societal disruption that the combination of mitigation and adaptation fail to avoid

Concerning these three…

- 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 unmanage-able, enough adaptation to manage the unavoidable.

Options

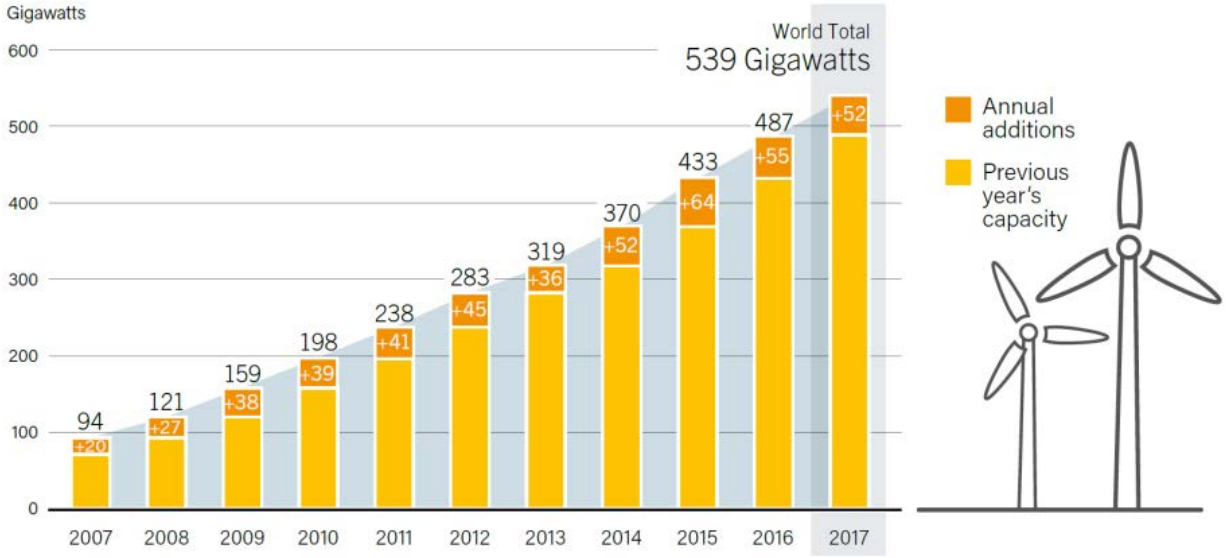
Mitigation, adaptation, and their overlap



Progress: Mitigation

Wind & solar electricity both soaring globally

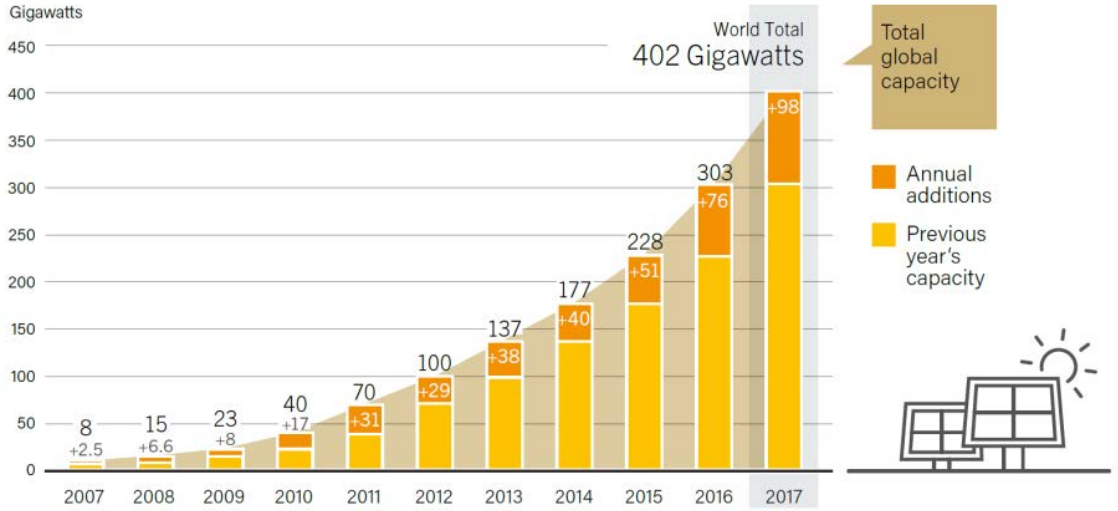
FIGURE 34. Wind Power Global Capacity and Annual Additions, 2007-2017



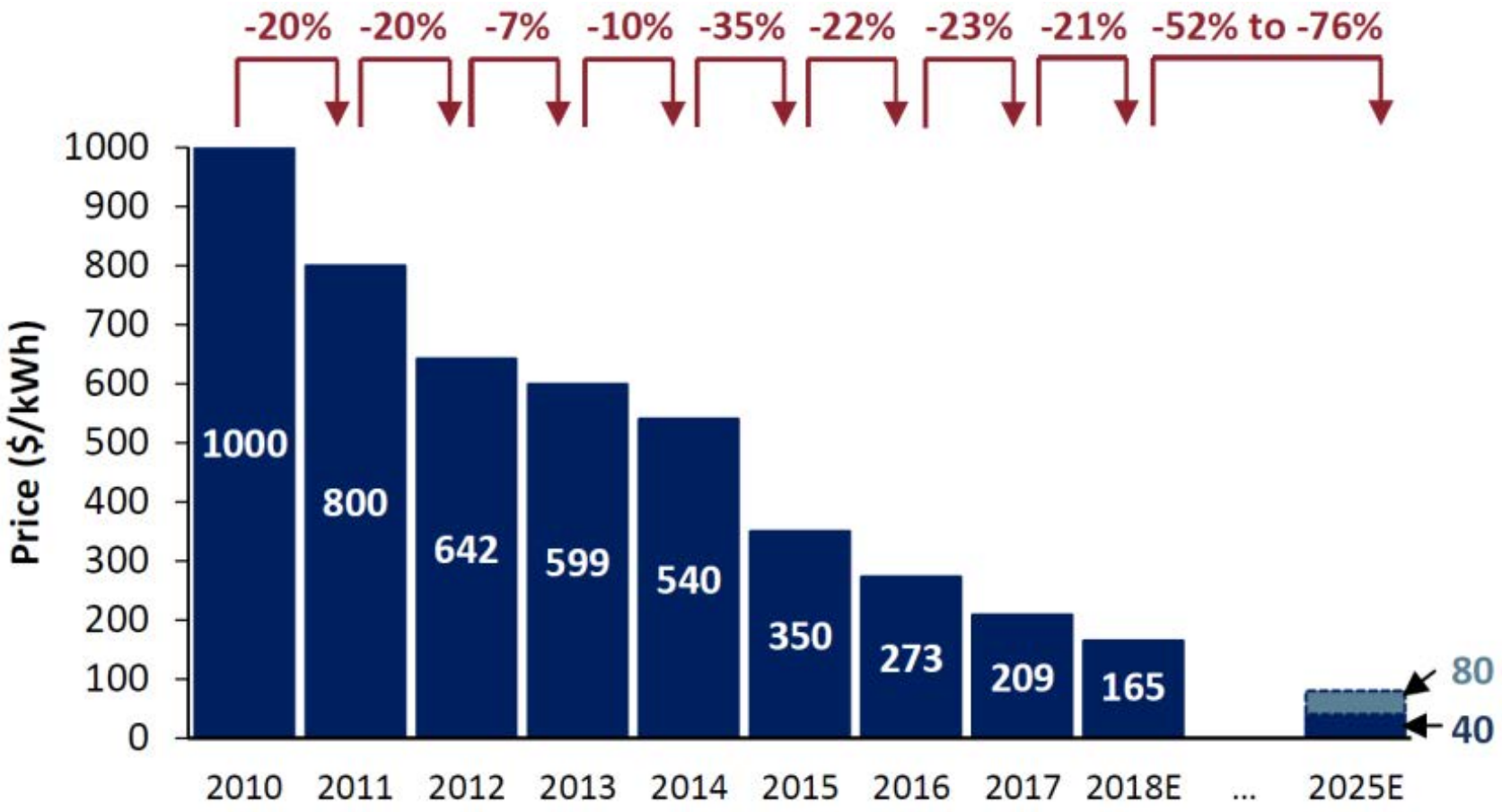
REN21 2018 report

Declining costs for these technologies have been the key factor

FIGURE 24. Solar PV Global Capacity and Annual Additions, 2007-2017



Storage technologies are getting cheaper too

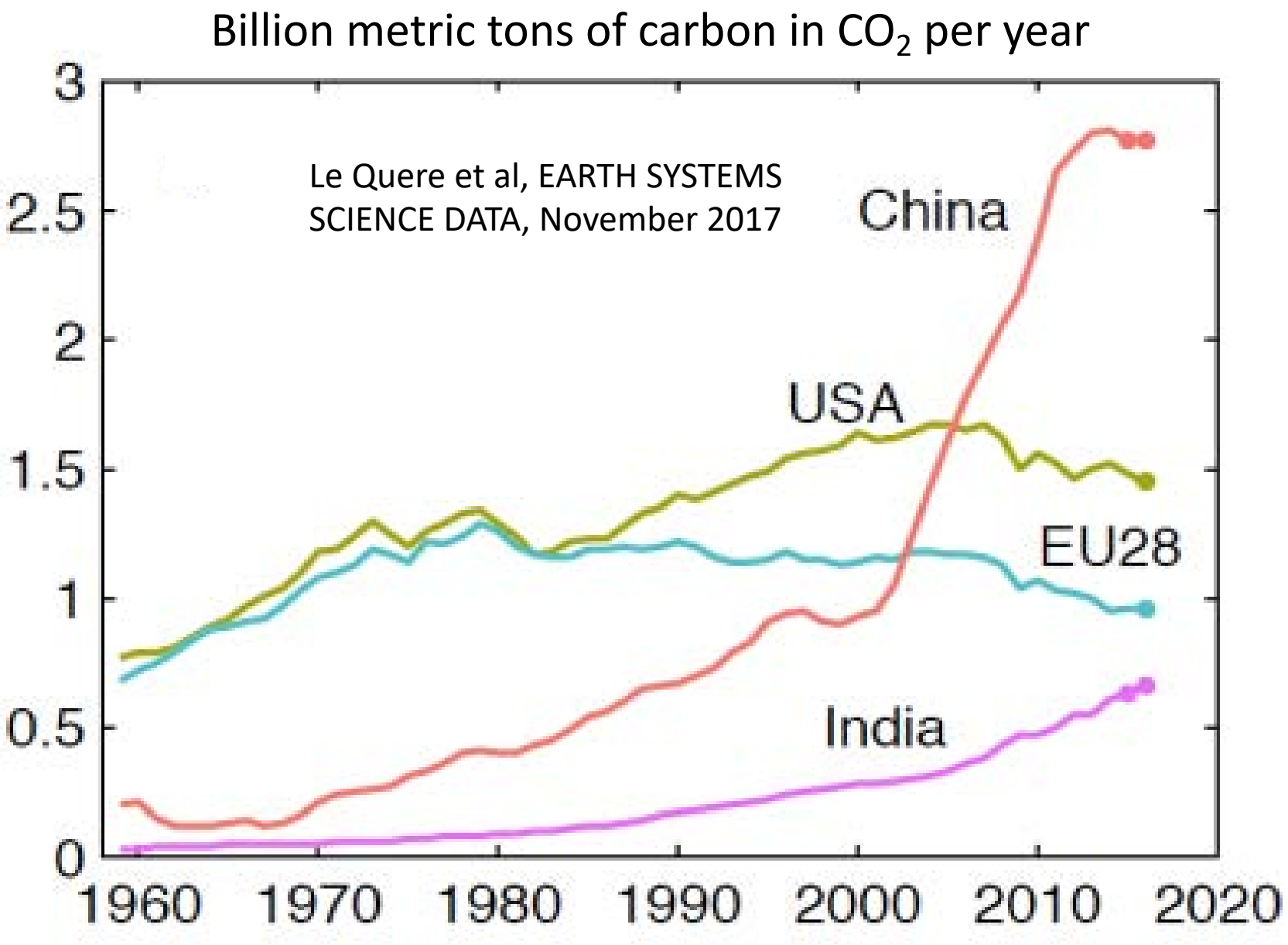


Source: Bloomberg New Energy Finance, GMO
Low end of 2025 estimate range, at $40/kWh, assumes adoption of next-generation solid-state battery technology.

Via Jeremy Grantham, *The Race of Our Lives Revisited*, 2018

Progress: Mitigation

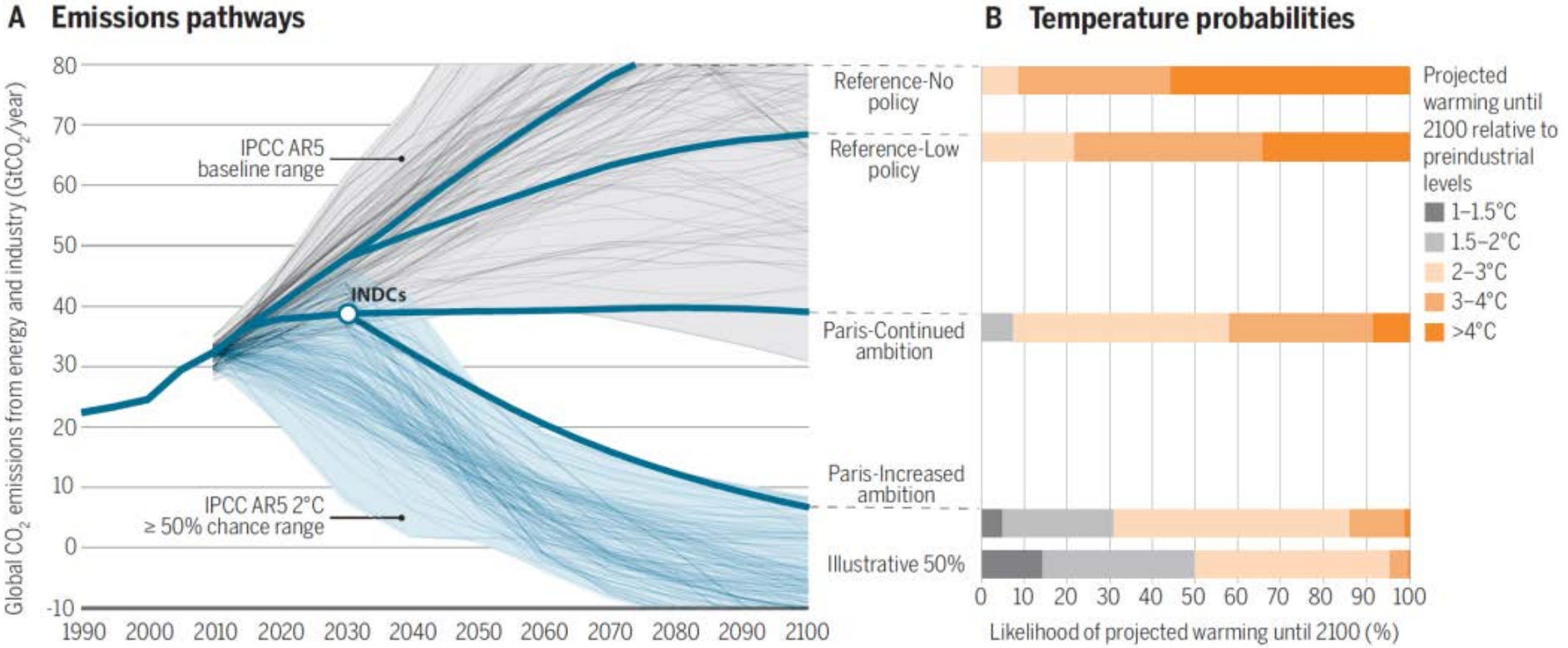
CO_2 emissions in some countries are declining



Progress: Mitigation

But much faster emission reductions are needed soon

…even if the goal is the inadequate one of $\Delta T < 2°C$



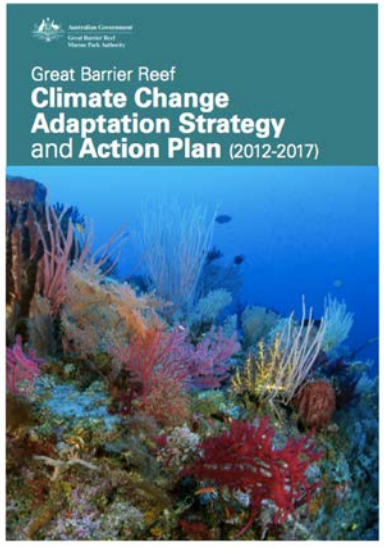
Fawcett et al., SCIENCE, December 4, 2015

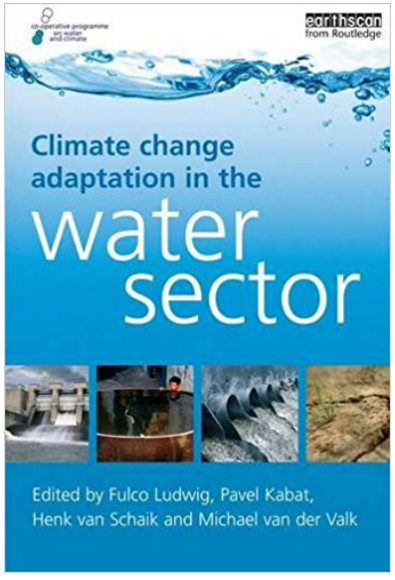
"Low Policy" case gives ~35% chance of $\Delta T>4°C$ by 2100.

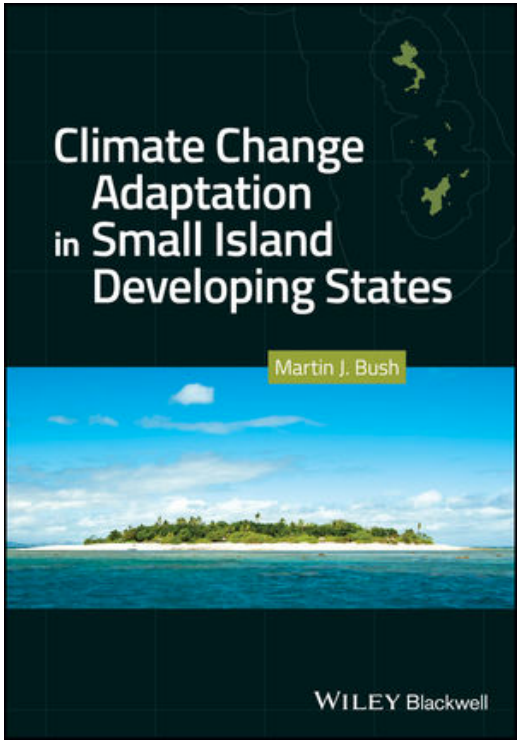
"Paris Increased Ambition" case gives only ~30% chance of $\Delta T<2°C$ by 2100.

Progress: Adaptation

Lots of studies and toolkits







Climate Change Impacts in the United States

CHAPTER 28
ADAPTATION

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Progress: Adaptation

But efforts are at a much earlier stage than mitigation

The 3rd National Climate Assessment (2014) found that…

1. Substantial adaptation planning is occurring in the public and private sectors and at all levels of government; however, few measures have been implemented and those that have appear to be incremental changes.

2. Barriers to implementation of adaptation include limited funding, policy and legal impediments, and difficulty in anticipating climate-related changes at local scales.

3. There is no "one-size fits all" adaptation, but there are similarities in approaches across regions and sectors. Sharing best practices, learning by doing, and iterative and collaborative processes including stakeholder involvement, can help support progress.

4. Climate change adaptation actions often fulfill other societal goals, such as sustainable development, disaster risk reduction, or improvements in quality of life, and can therefore be incorporated into existing decision-making processes.

5. Vulnerability to climate change is exacerbated by other stresses such as pollution, habitat fragmentation, and poverty. Adaptation to multiple stresses requires assessment of the composite threats as well as tradeoffs among costs, benefits, and risks of available options.

6. The effectiveness of climate change adaptation has seldom been evaluated, because actions have only recently been initiated and comprehensive evaluation metrics do not yet exist.

Can society afford to do what's needed?

- Most integrated-assessment models suggest that achieving the emissions trajectories needed for $\Delta T \leq 2°C$ would cost 1-5% of world GDP over much of the current century.
- These models notoriously underestimate innovation, so the cost is likely to be less than that. They also tend to under-estimate co-benefits of mitigation technologies. Some analyses suggest it can be done at no net cost to GDP.
- Cost of adaptation is more uncertain and more scenario dependent, but note that many adaptation measures also bring big co-benefits.
- It's overwhelmingly likely that the combined cost of mitigation & adaptation will be much less than the cost of climate damages if society fails to take the needed actions.

U.S. Federal Policies Under Obama and Trump

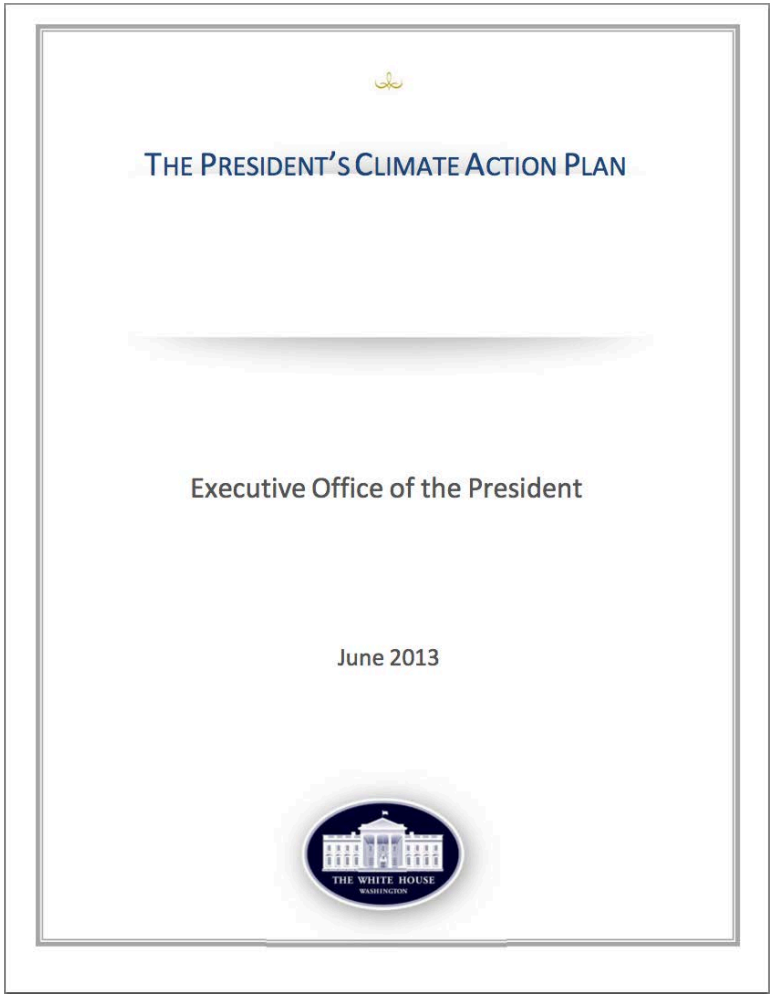
The energy-climate nexus: Obama 1st-term

- $80 billion for clean & efficient energy in the Recovery Act
- $100s of millions for Advanced Research Projects Agency-Energy (ARPA-E) and five new Energy Innovation Hubs
- first-ever fuel-economy/CO_2 tailpipe standards for light-duty vehicles, plus fuel-economy standards for trucks
- multiple building & appliance energy-efficiency stds
- interagency task force led by OSTP, CEQ, NOAA to coordinate govt's climate-adaptation activities
- re-invigoration of USGCRP; launch of new NCA
- 1st govt calculation & use of Social Cost of Carbon
- 1st National Oceans Policy & National Oceans Council

Obama

2nd term: The Climate Action Plan

Georgetown University, June 2013



- Cutting carbon pollution in America (mitigation)
- Preparing the United States for the impacts of climate change (adaptation)
- Leading international efforts to address climate change

http://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf

The Climate Action Plan (continued)

- Mitigation in the United States
  - Clean Power Plan to reduce CO_2 emissions from coal power plants
  - Strategy & regulations to reduce methane & HFC emissions
  - Doubling down on renewables, end-use efficiency, grid
- Adaptation in the United States
  - Agencies to integrate adaptation into all policies & programs
  - Interagency Council & State/Local Tribal Leaders Task Force
  - Standards & partnerships for flood, drought, wildfire, crop, and urban resilience
- International support for mitigation & adaptation
  - U.S.-China agreement (11-14) → Paris Accords (12-15)
  - Partnerships & commitments for mitigation/adaptation assistance
  - Mission Innovation: 20 countries to double clean-energy R&D

The U.S. energy-climate record under Obama

	2008	2016	change
Fossil E (quads)	83.2	78.6	-5.5%
Renewable E (quads)	7.2	10.2	+41.7%
Total E (quads)	98.9	97.4	-1.5%
Coal electricity (kWh)	1986	1240	-37.6%
Gas electricity (kWh)	883	1380	+56.3%
Wind electricity (kWh)	55.4	226.5	+4.1-fold
Solar electricity (kWh)	0.9	36.8	+42.5-fold
Total electricity (kWh)	4119	4079	-1.0%
CO_2 from energy (Gt)	5809	5170	-11.0%

EIA Monthly Energy Review, 03-28-17

What Trump has done so far

- Appointed climate-change deniers or minimizers to many key Executive Branch posts, notably
  - Mick Mulvaney at Office of Management & Budget; Scott Pruitt at EPA; Ryan Zinke at Interior Department
- Proposed big cuts to Federal climate research and energy R&D, including
  - Elimination of ARPA-E
  - Another $1.6B from DOE Energy R&D, $200M from EPA science & technology
- Proposed eliminating much Earth observation/analysis
  - At NASA, zeroing Earth-observation functions of DISCOVR, canceling three climate-monitoring satellite missions, cancelling the national Carbon Monitoring System
  - Cutting NOAA ocean grants & programs by $250M

Trump so far (continued)

- Rejected Paris accord & Mission Innovation
- Rescinded all of Obama's Executive Orders on climate change
  - Clean Power Plan: coal-plant emissions, methane strategy
  - Climate-change adaptation: USA and international
  - Social Cost of Carbon in gov't decision-making
- Loaded Federal courts with right-wing judges who will rule against regulation when given the opportunity
- Encouraged agencies to drop or alter many of their websites on climate change

All of this has stimulated an exodus of many of the Federal government's most talented climate scientists & analysts, particularly from EPA and the Department of Interior.

Damage by recent steps is significant but limited

- USA cannot formally withdraw from Paris accord until 2020, but Trump has halted most of Federal efforts to comply.
- The most damaging consequences are
  - Loss of U.S. credibility and moral authority globally
  - Cuts to U.S. climate-change assistance to other countries
  - Elimination or weakening of Federal government standards affecting U.S. emissions (being challenged in court)
  - Cuts to government-funded climate research, Earth observation, & energy R&D (if Congress accepts Trump's proposals)
  - Loss of climate-savvy talent from the Federal government
- Somewhat offsetting all this, many states, cities, companies, universities, & civil-society organizations are increasing their efforts toward meeting U.S. Paris commitments.

Some Observations on the Path Forward

The path forward

Scientists, engineers, techies, & citizens should...

ADVOCATE FOR:

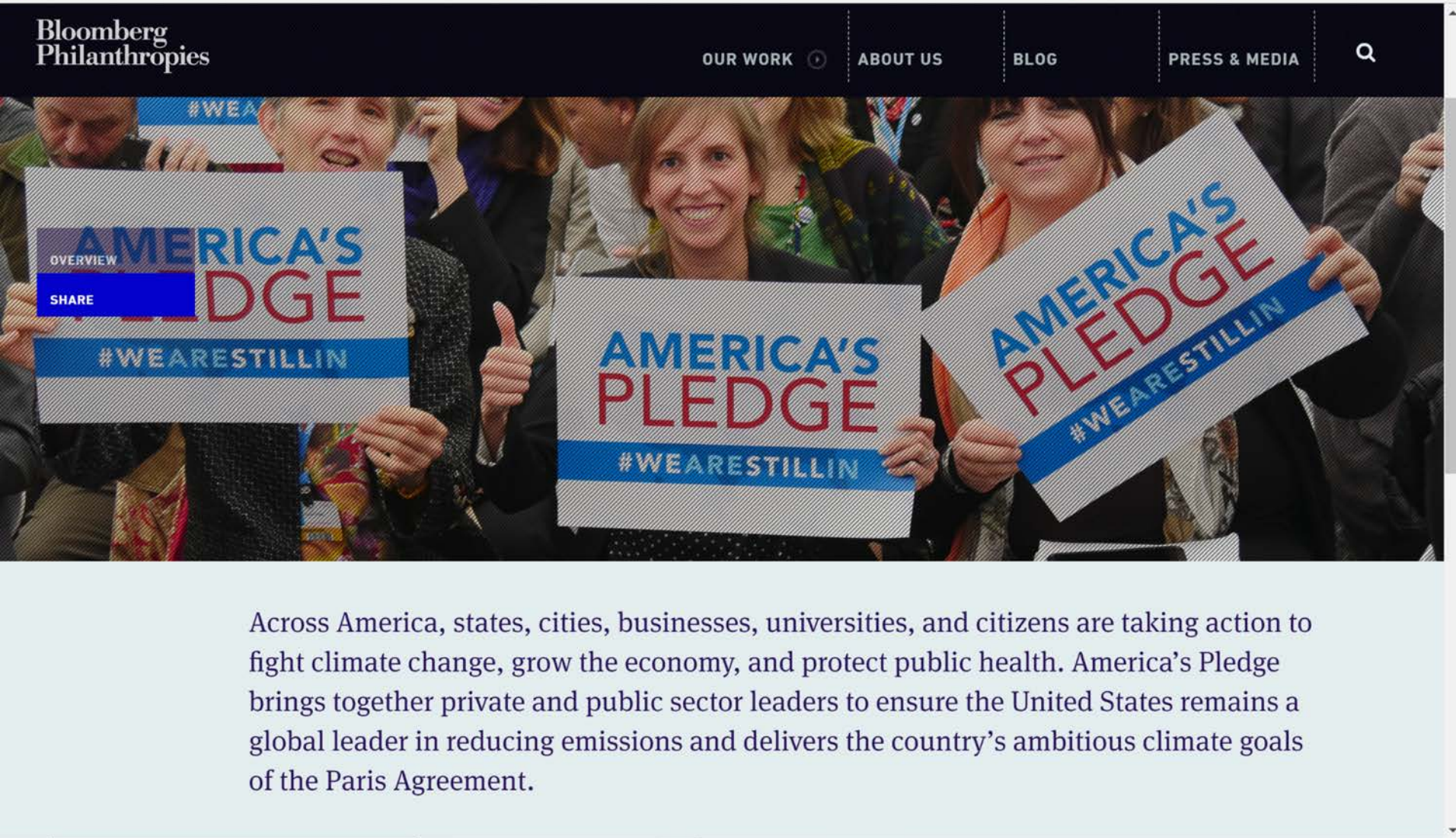
- States, communities, businesses, & universities to devise and implement their own mitigation & adaptation plans (as many already have been doing)
- Congress to reject Trump's budget cuts and boost Federal funding for climate monitoring & research and advanced energy-supply & energy-efficiency options
- Philanthropies to step up funding to address the energy-climate challenge, including, insofar as possible, filling gaps left by Federal shortfalls

ENERGETICALLY ENGAGE IN NATIONAL POLITICS TO:

- Support candidates in 2018 who show understanding of the energy-climate challenge and willingness to act.
- Consider running for elected office next time yourself.

The path forward

Many Americans are working to counter Trump's backsliding



“Trend is not destiny.”

Rene Dubos