Climate Change and Cape Cod:
What We Know. What We Expect. What We Can Do.

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Presentation for the

Association to Preserve Cape Cod

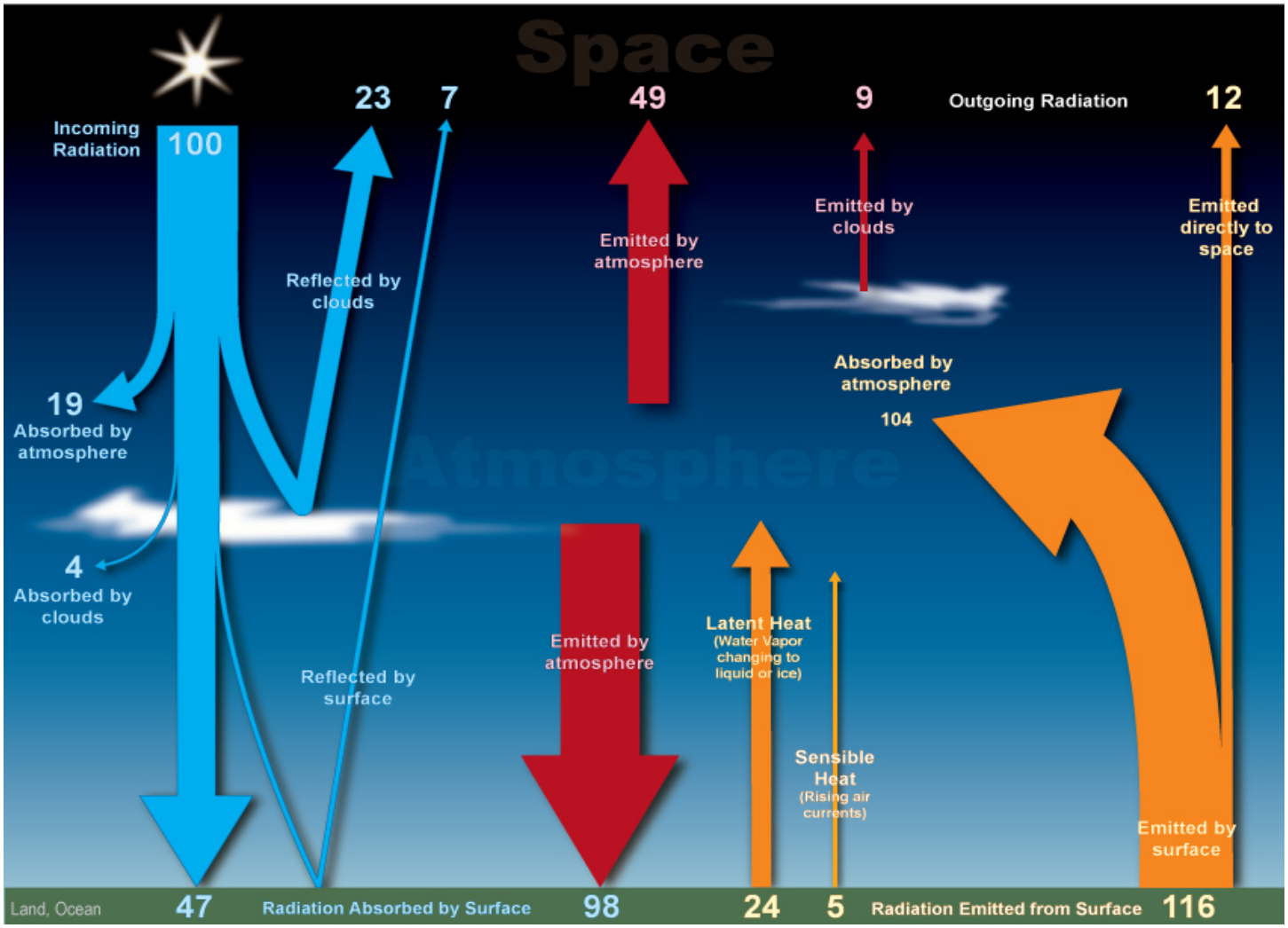
Chatham • July 11, 2019

What We Know

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

Daniel Patrick Moynihan

Earth's temperature depends on the balance between incoming & outgoing energy

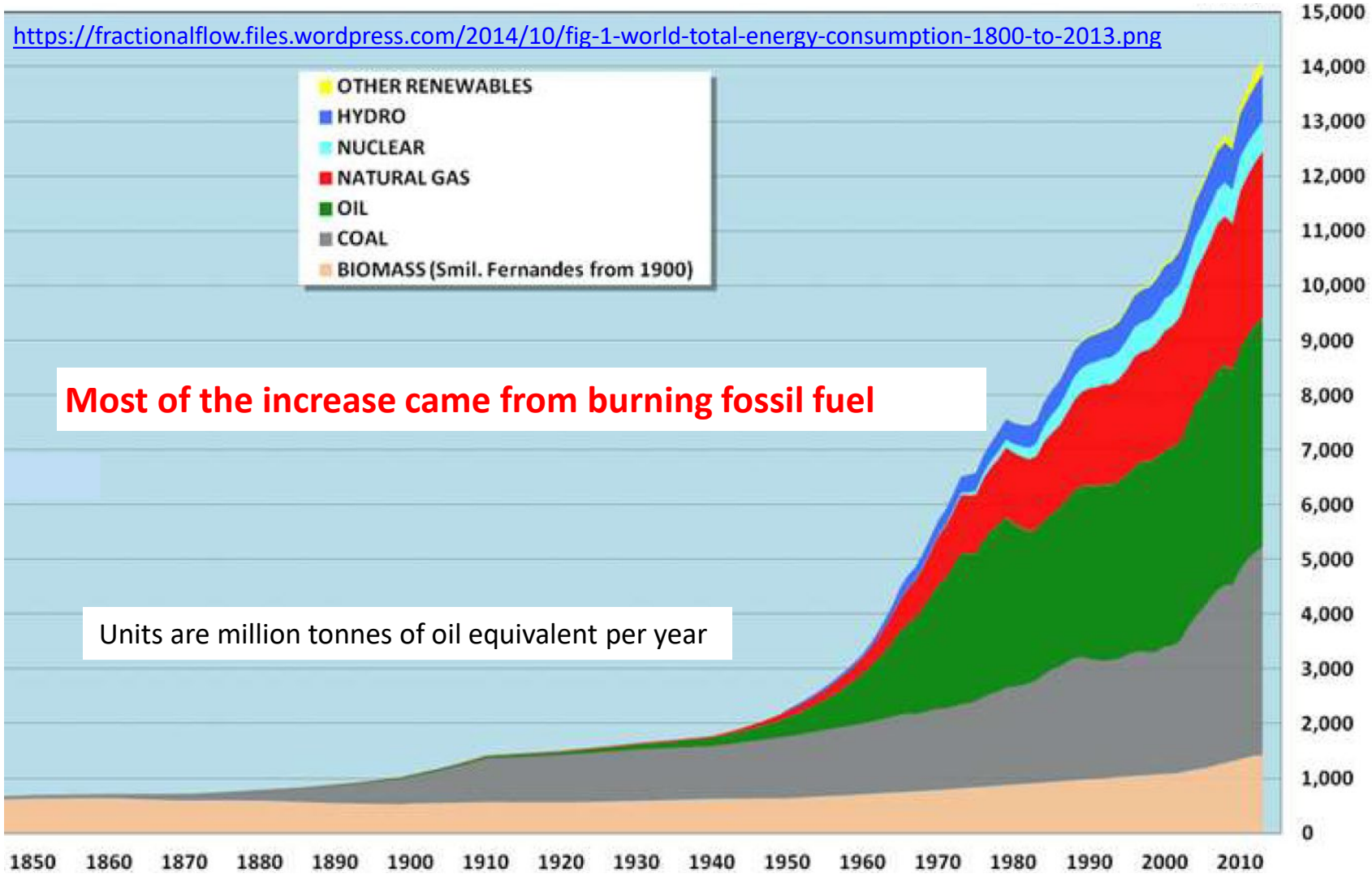


The quantity of "greenhouse gases" in the atmosphere influences this balance.

Some greenhouse gases exist in the atmosphere naturally; some are added by human activities.

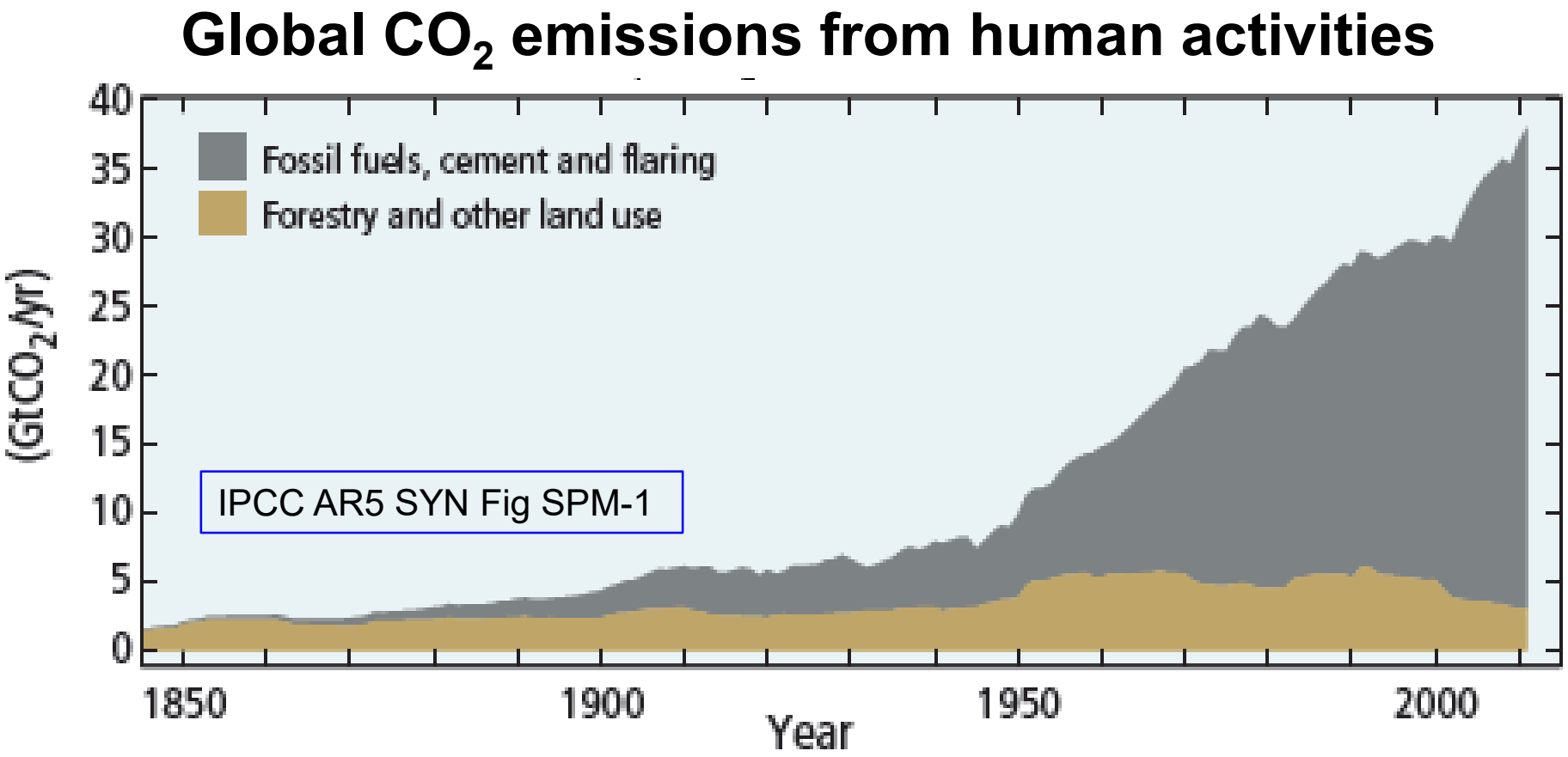
- The most important naturally occurring greenhouse gases are water vapor (H_2O) and carbon dioxide (CO_2).
- Without them, the surface of the Earth would be too cold to support life as we know it.
- When humans burn coal, oil, and natural gas ("fossil fuels") or wood, the combustion products—mostly CO_2 and H_2O—go into the atmosphere.
- The H_2O remains in the atmosphere only briefly and so adds little to the natural water vapor there.
- But much of the CO_2 remains for decades to millennia, so its concentration in the atmosphere builds up over time as fossil fuels and forests are burned.

Growth of population & prosperity from 1850 to the present increased world energy use by over 20-fold



In 2019, coal, oil, & natural gas still supply about 80% of world energy consumption and two-thirds of electricity generation.

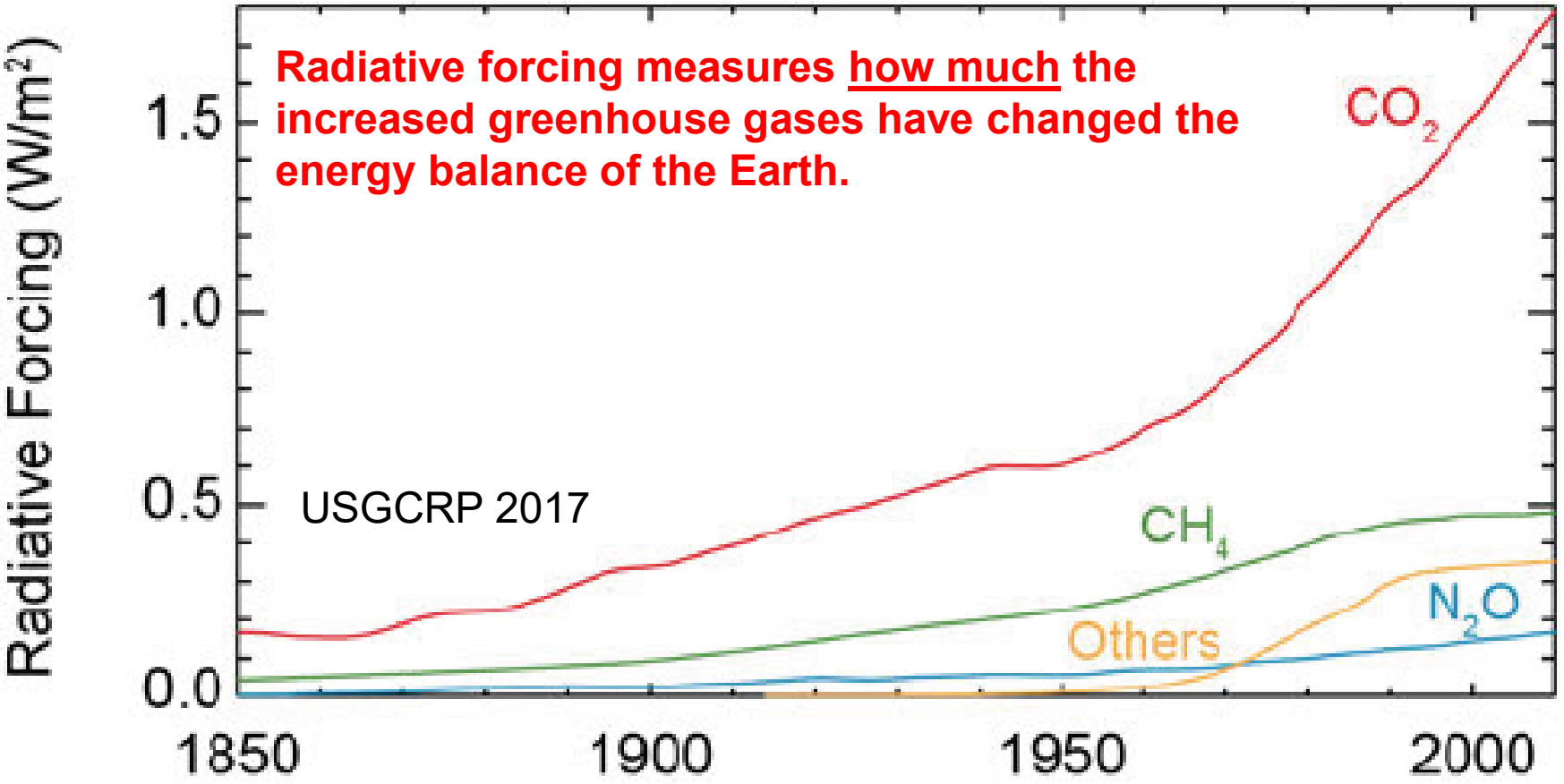
Civilization's CO_2 emissions grew along with fossil-fuel use



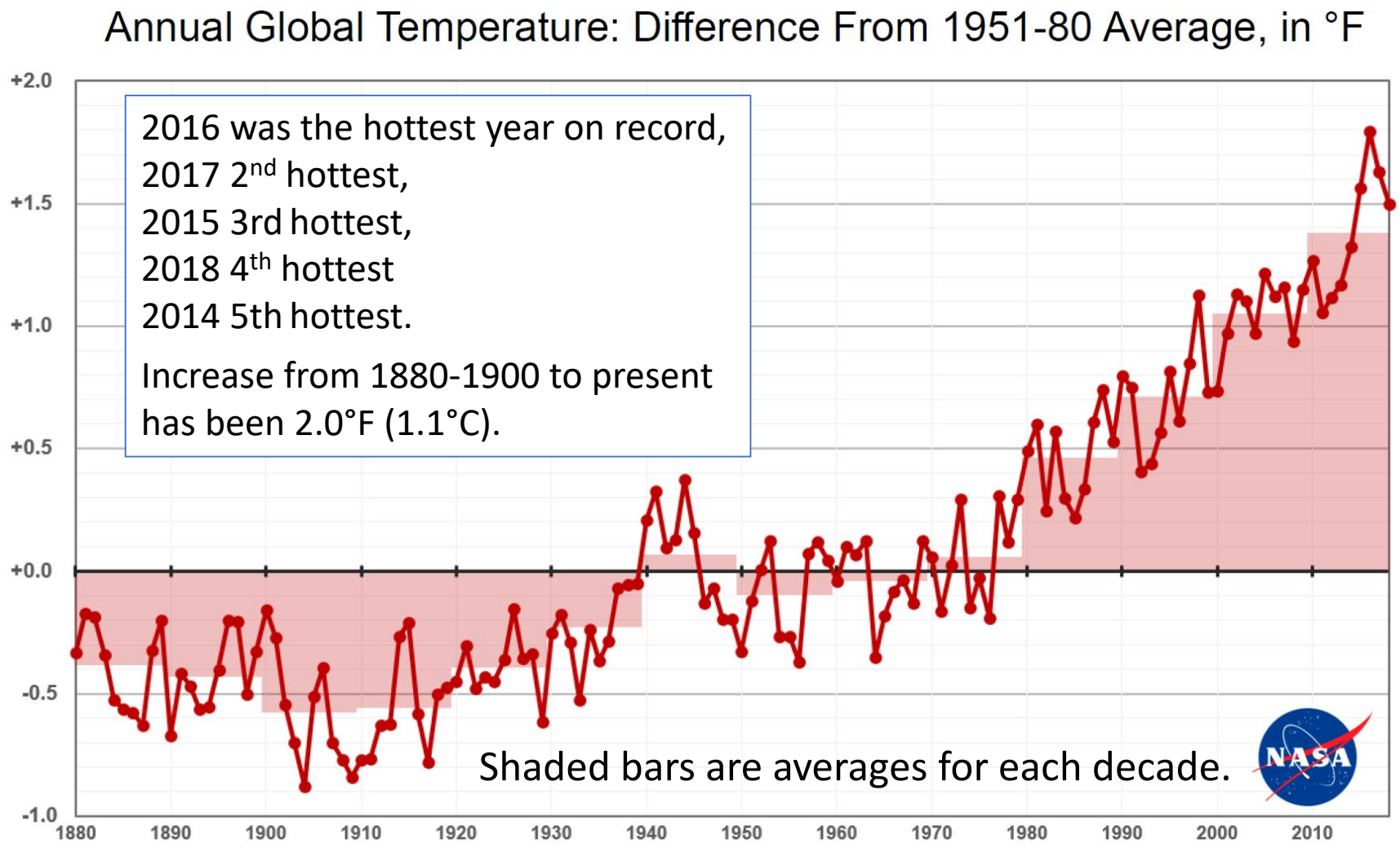
Land-use change emits CO_2 when previously living vegetation is burned and when cultivation speeds up decomposition of soil organic matter.

The increase of CO_2 and other greenhouse gases in the atmosphere has changed Earth's energy balance

Methane (CH_4) and nitrous oxide (N_2O) come from energy & agriculture; other heat-trapping gases come from industry

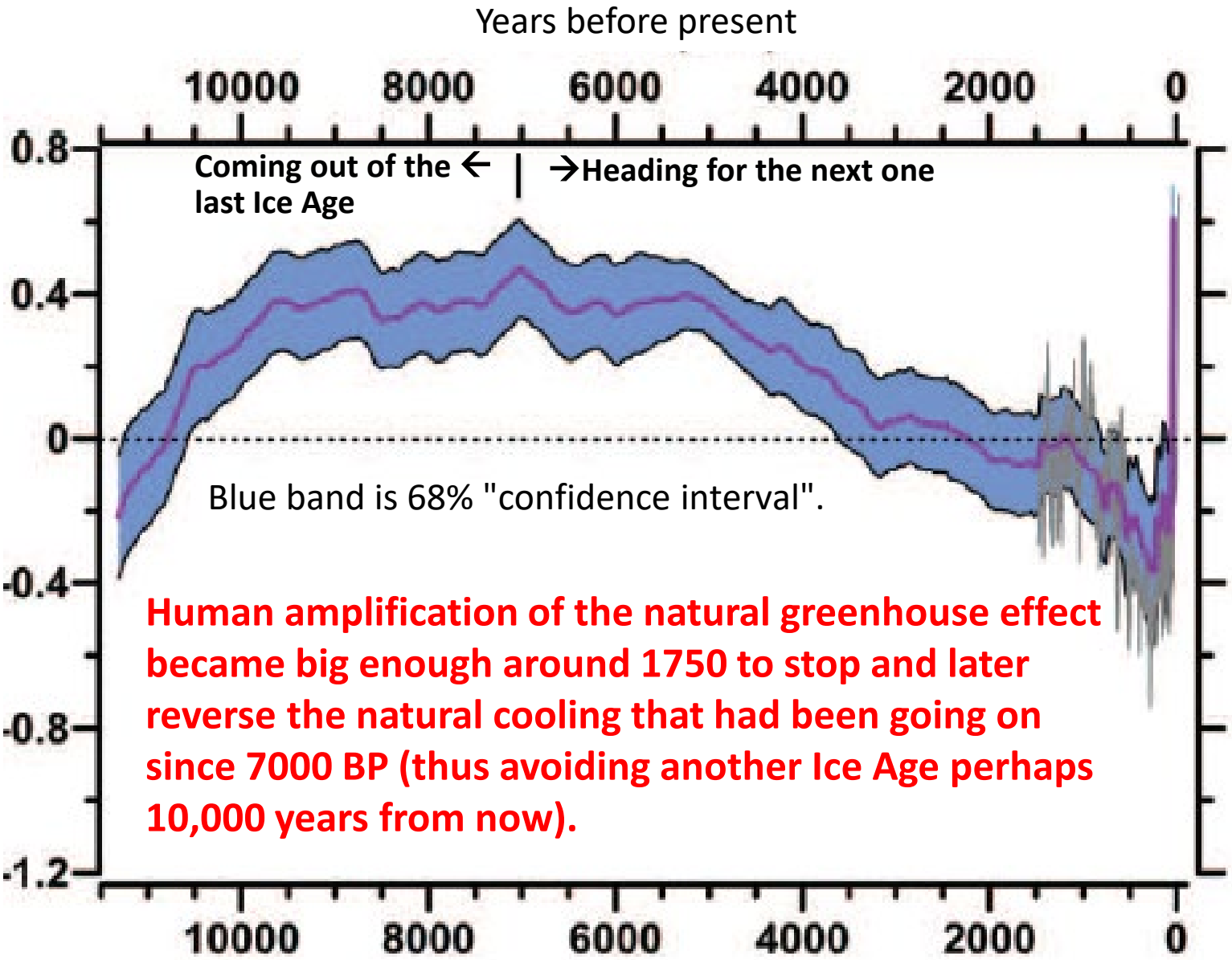


"Forcing" by human-added GHGs warmed the Earth



Earth has been warming more or less steadily for the last 100+ years, as the increasing forcing from the human-caused GHGs became more important than natural variability.

Human warming reversed 6750 years of natural cooling



Still, "global warming" is a misleading term

That term implies something…

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

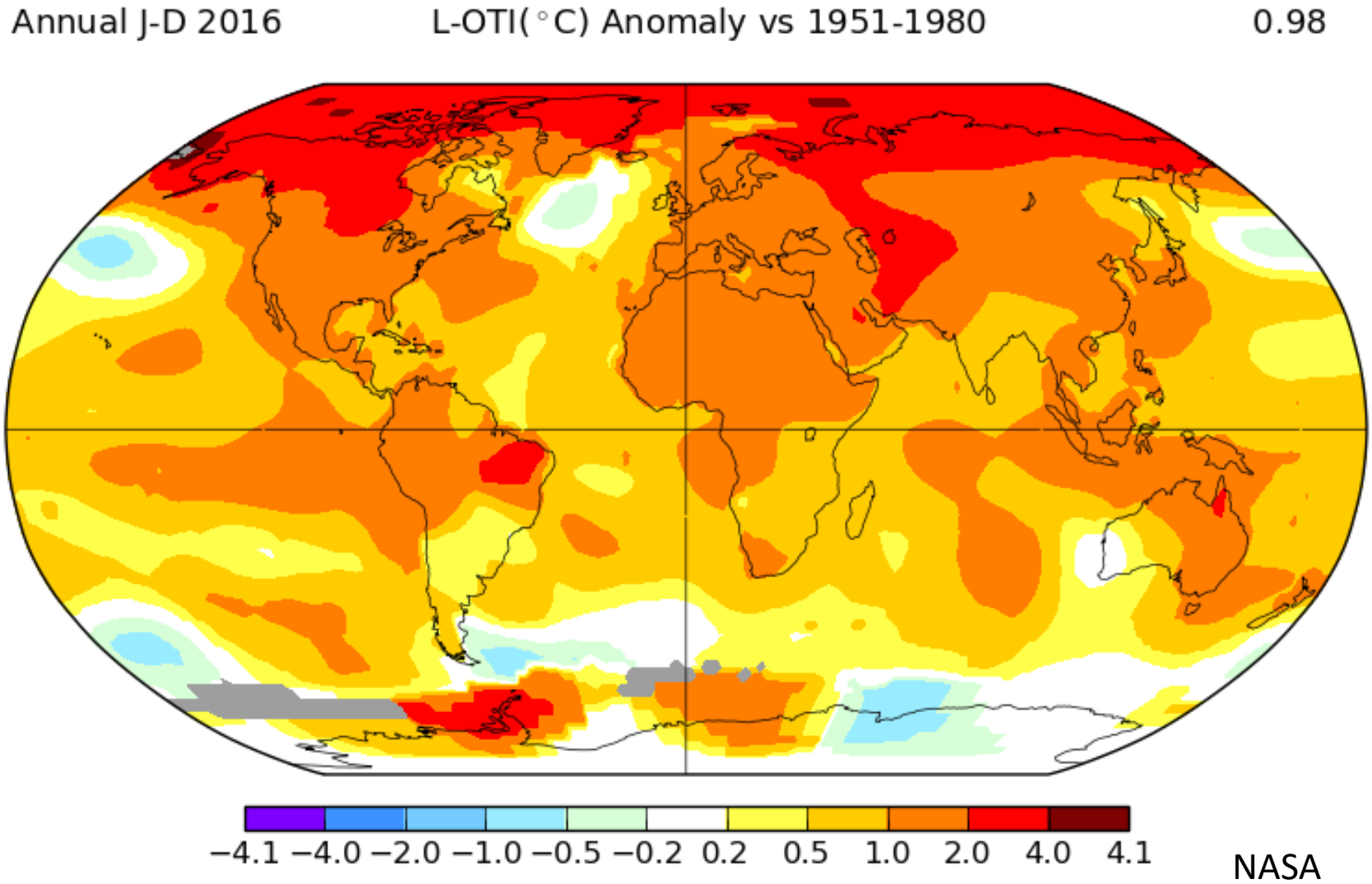
This seems to have confused people.

What's actually happening is…

- highly nonuniform,
- not just about temperature,
- rapid compared to capacities for adjustment
- harmful for most places and times

A better term would be "global climate disruption".

The T change has been non-uniform geographically



NASA

Biggest warming is in Arctic and West Antarctic Ice Sheet.

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).

These changes matter because…

Climate governs (so altering climate affects)

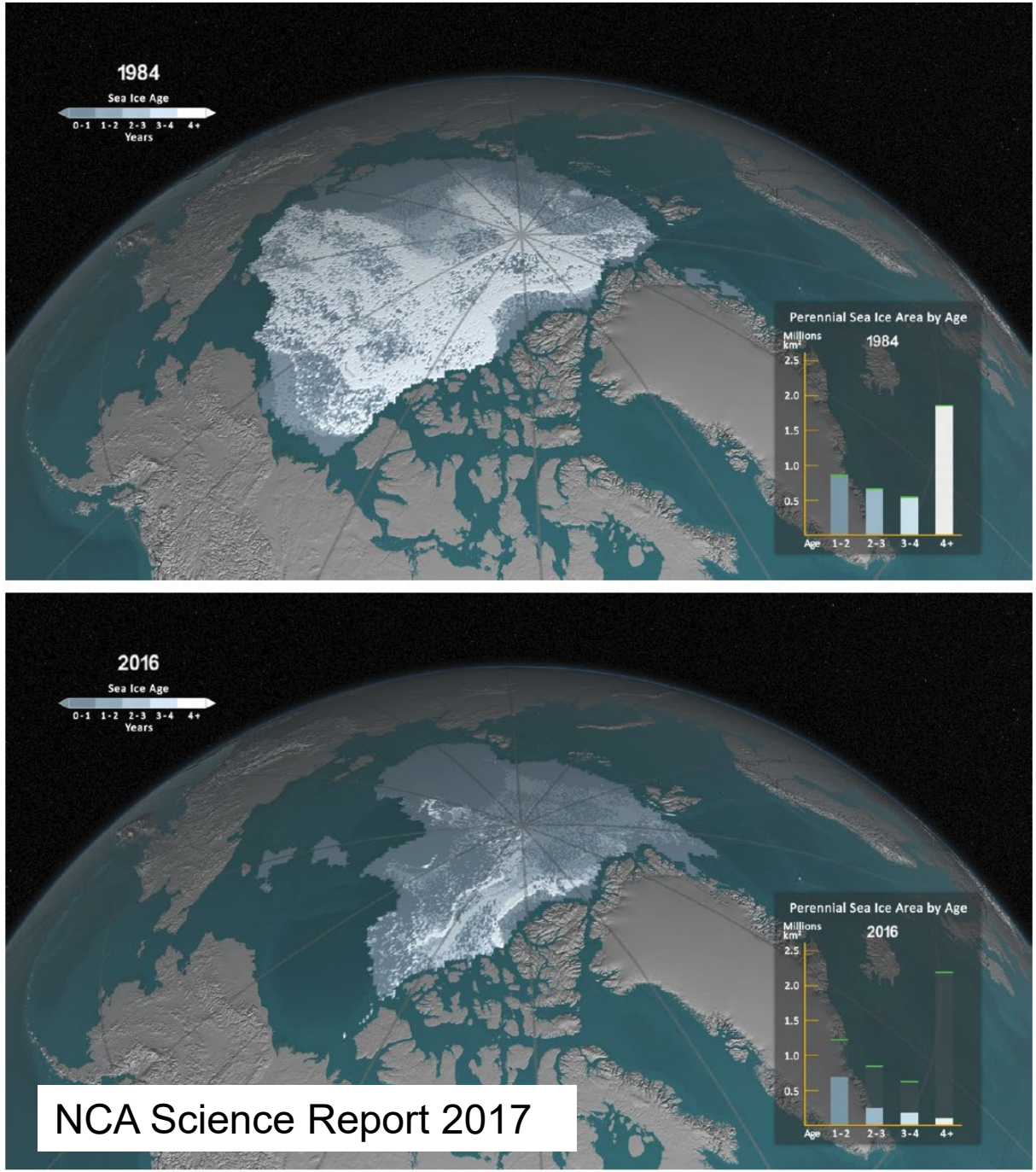
- availability of water
- productivity of farms, forests, & fisheries
- prevalence of oppressive heat & humidity
- formation & dispersion of air pollutants
- geography of disease
- damages from storms, floods, droughts, wildfires
- property losses from sea-level rise
- expenditures on engineered environments
- distribution & abundance of species (those we need, those we love, those we hate)

Manifestations of ongoing change

Extent & thickness of Arctic sea ice are shrinking

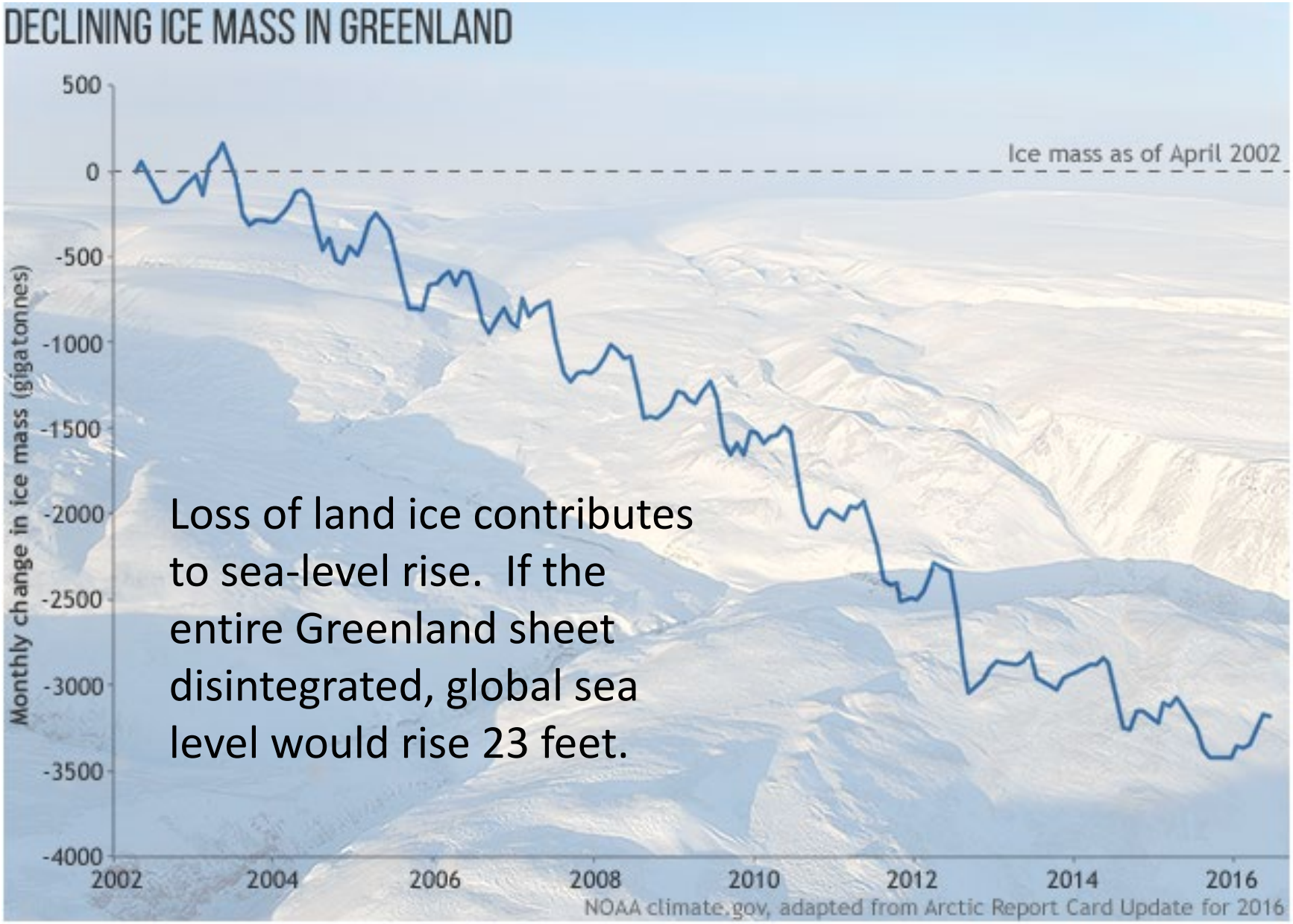
Sea ice is floating ice, so its shrinkage doesn't affect sea level.

But the change from ice to open water affects regional temperatures, winds, storm damage, valued species, and weather in mid-latitudes.



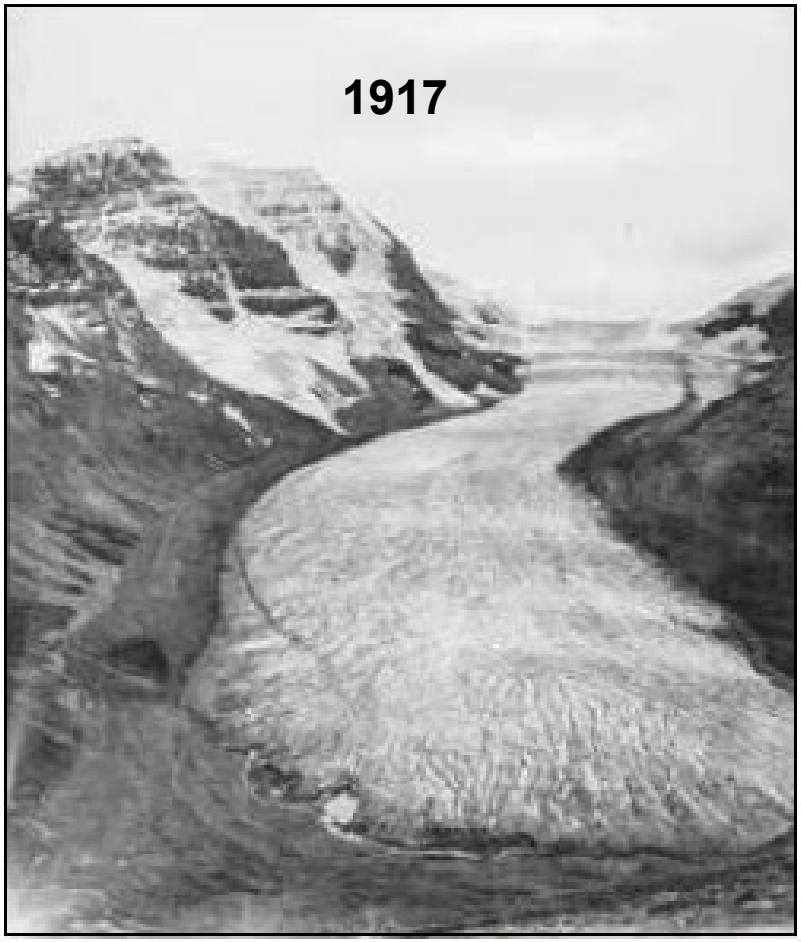
NCA Science Report 2017

Greenland Ice Sheet is rapidly losing ice



Loss of land ice contributes to sea-level rise. If the entire Greenland sheet disintegrated, global sea level would rise 23 feet.

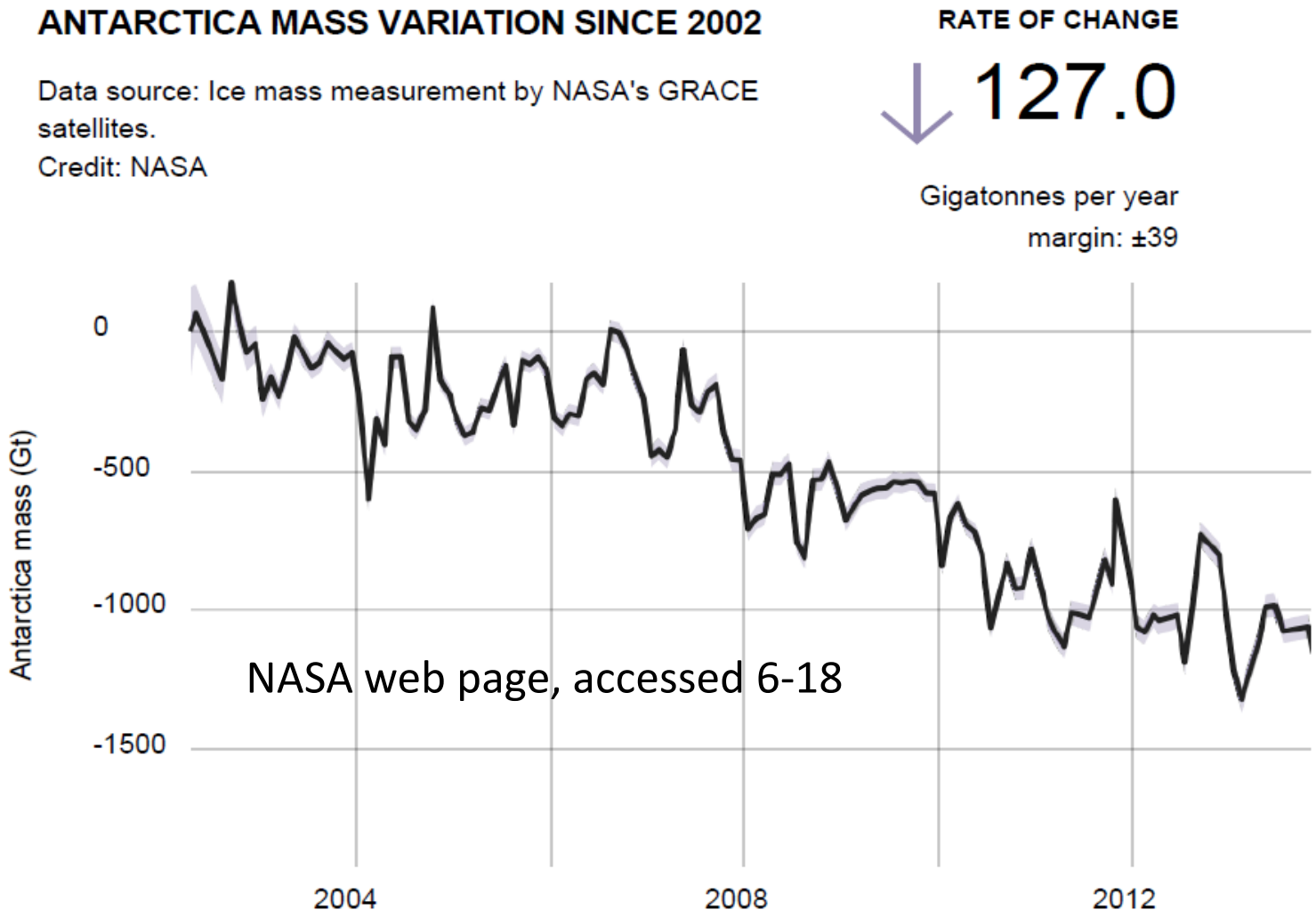
Mountain glaciers are shrinking worldwide



The Athabasca Glacier from Wilcox Pass, Jasper NP, Alberta.
Historic B&W: 1917, A.O. Wheeler, Interprovincial Boundary Survey.
Modern image: 2011, Mountain Legacy Project.

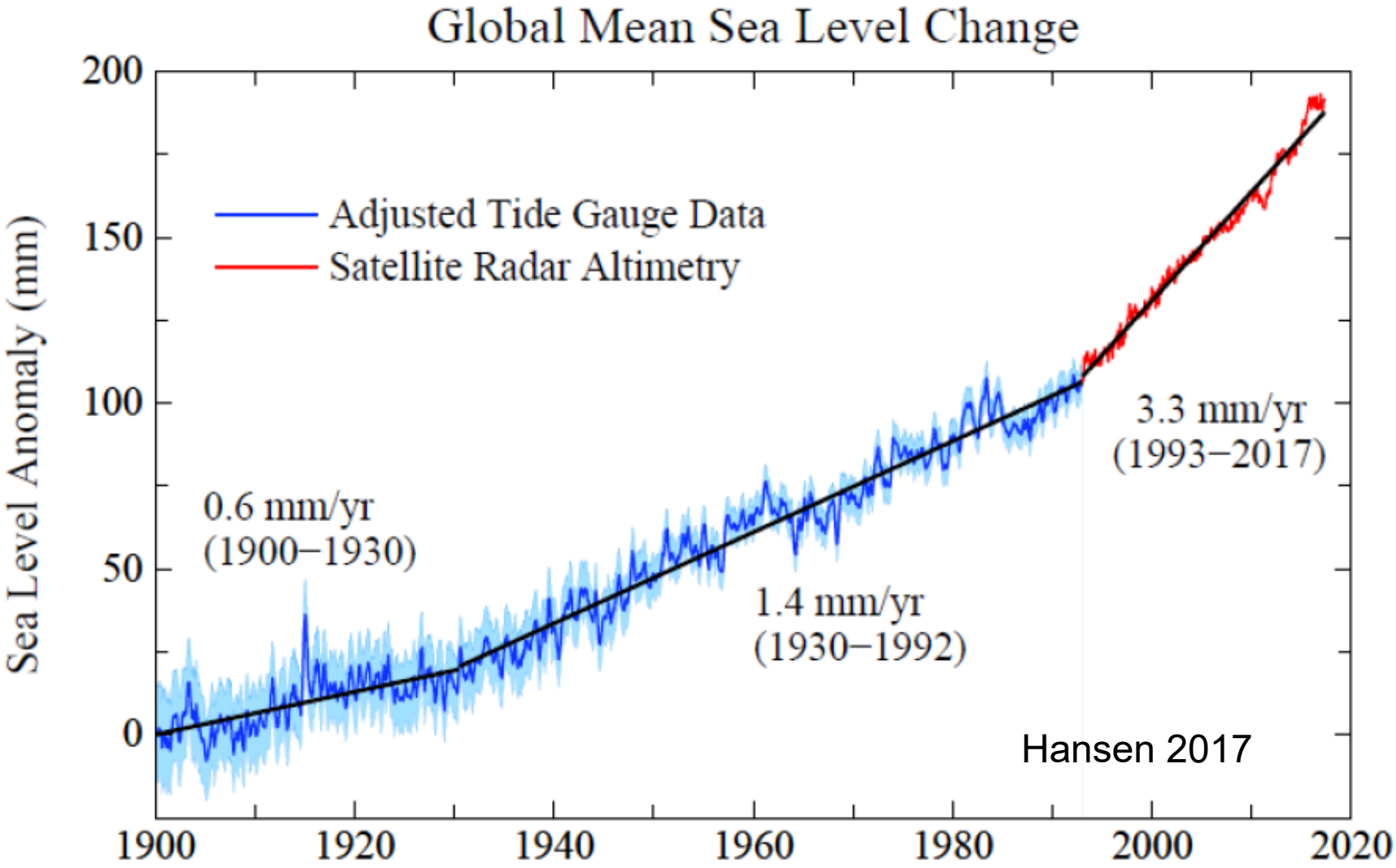
State of the Mountains 2018

It's now clear Antarctica is also losing ice



One 2019 NASA study showed loss reaching 240 Gt/yr in 2018.

Rate of sea-level increase is accelerating



Post-2010 rate is actually 5.5 mm/yr!

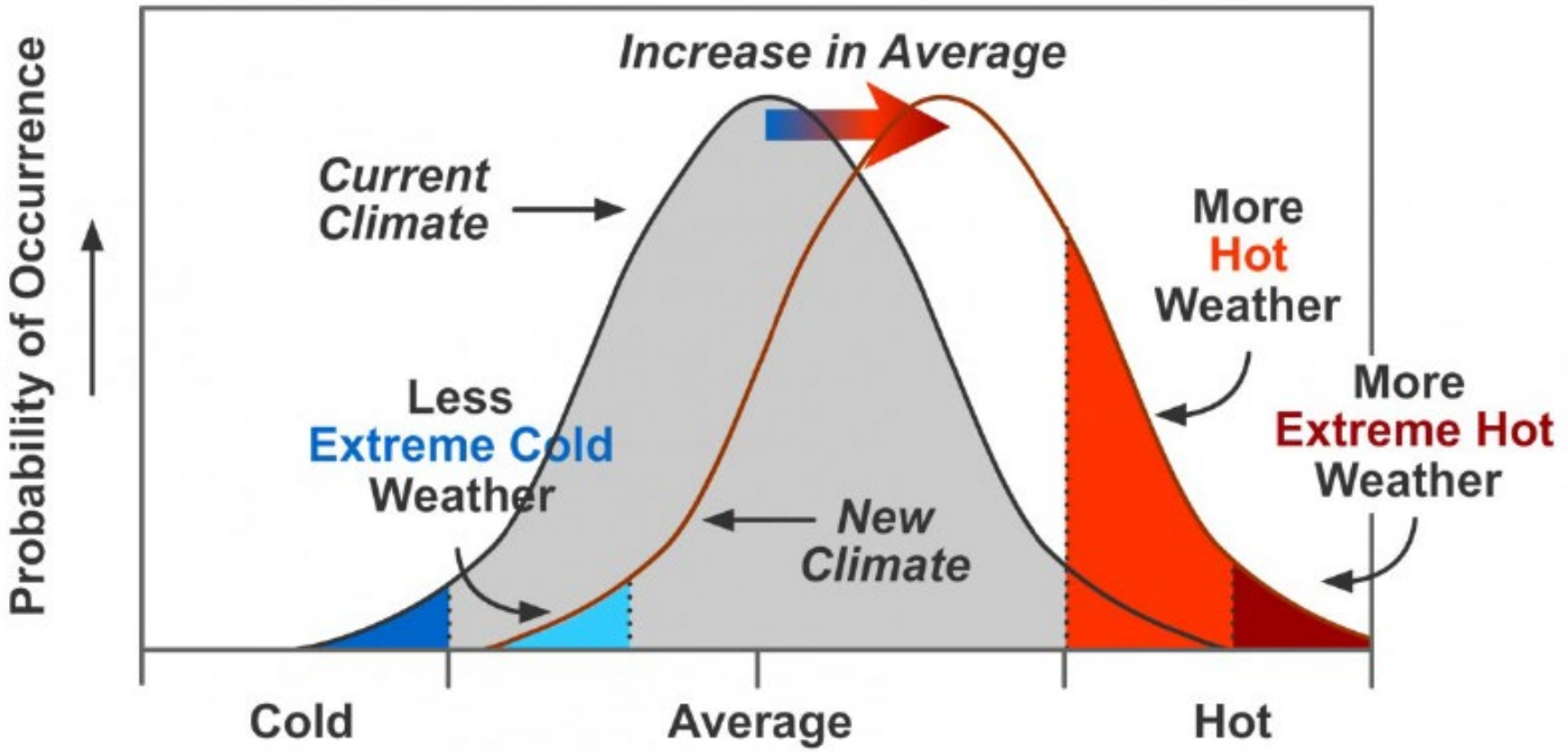
Climate change is already causing growing harm

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

- floods
- drought
- wildfires
- power of strongest storms
- heat waves and heat stress
- other harm to human health
- impacts of crop & forest pests
- coastal erosion and inundation
- permafrost thawing & subsidence
- impacts of ocean acidification, warming, altered currents, loss of sea ice on distribution/abundance of valued species

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

Weather extremes change much faster than average temperature



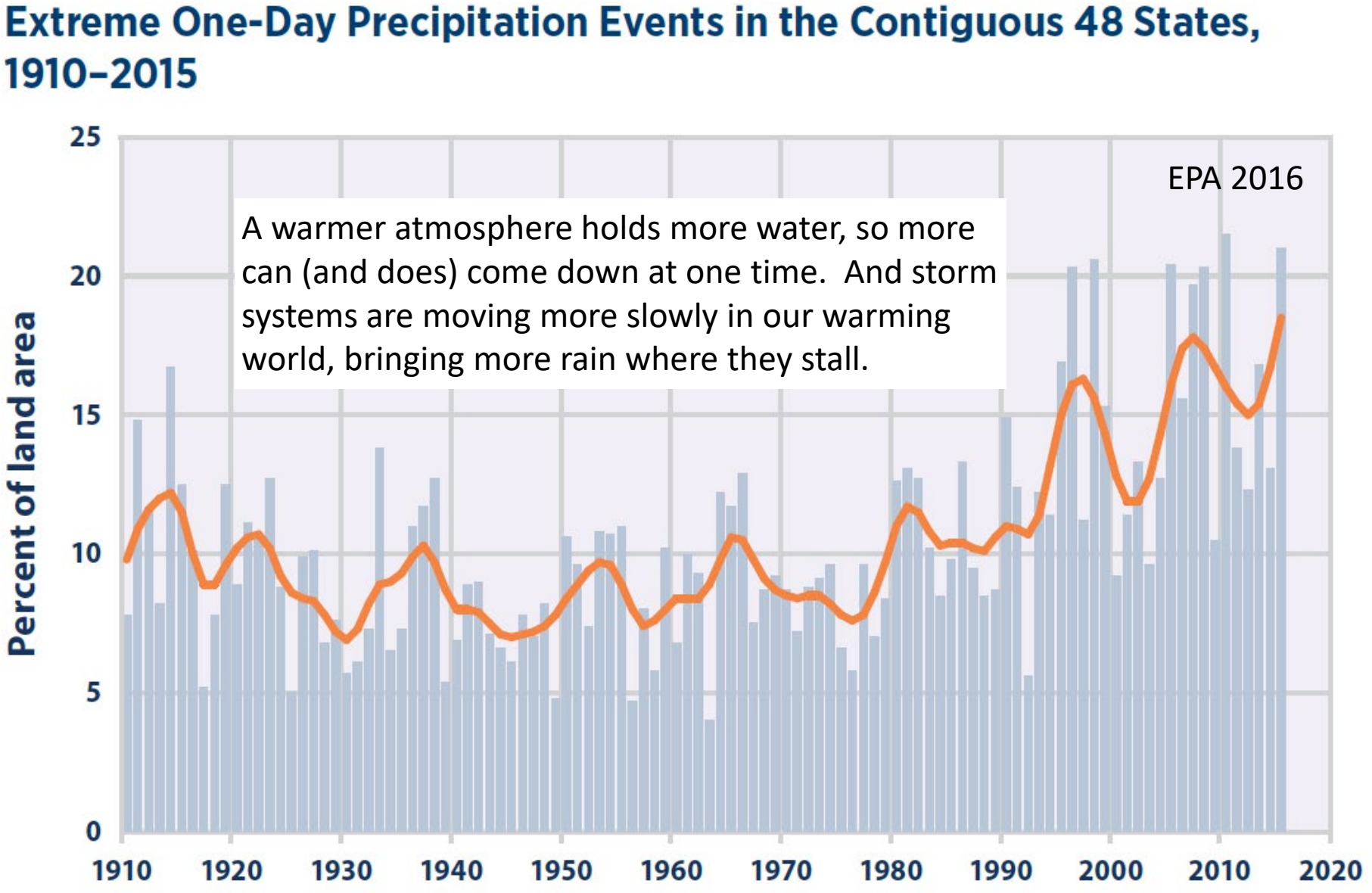
In a modestly warmer climate, extremes that previously occurred rarely or not at all now occur much more often. (The “bell curve” or “normal probability distribution”, shown, applies to all weather variables.)

Some all-time high temperatures reached in 2017-18

• Iran	129°F	June 2017
• Pakistan	128°F	May 2017
• South Africa	122°F	Nov 2018
• Spain	117°F	July 2017
• Chile	113°F	Jan 2017
• Los Angeles	111°F	July 2018
• Argentina	110°F	Jan 2017
• Shanghai	106°F	July 2017
• San Francisco	106°F	Sept 2017
• Denver	105°F	June 2018
• Hong Kong	102°F	Aug 2017

Already, working outdoors in the hottest months risks heat stroke in many regions.

Warming causes bigger torrential downpours



Downpours bringing 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.

Flooding in the Midwest in March 2019 set new records for the region.

Tim Gruber for the New York Times

Hamburg, Iowa, March 2019

DAVE DILDINE/WTOP/ASSOCIATED PRESS

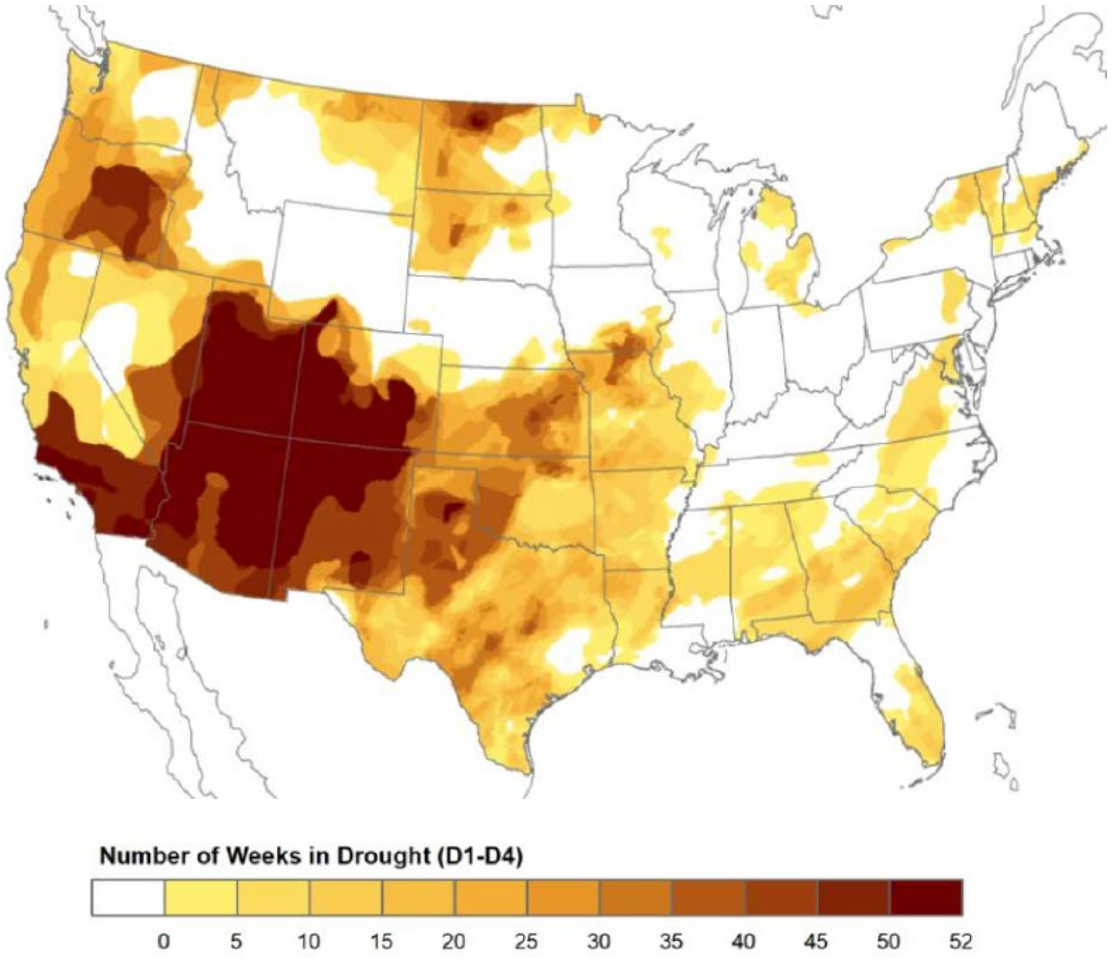
Canal Rd, Washington DC, July 2019

Current impacts on people and ecosystems

Droughts are worse under climate change

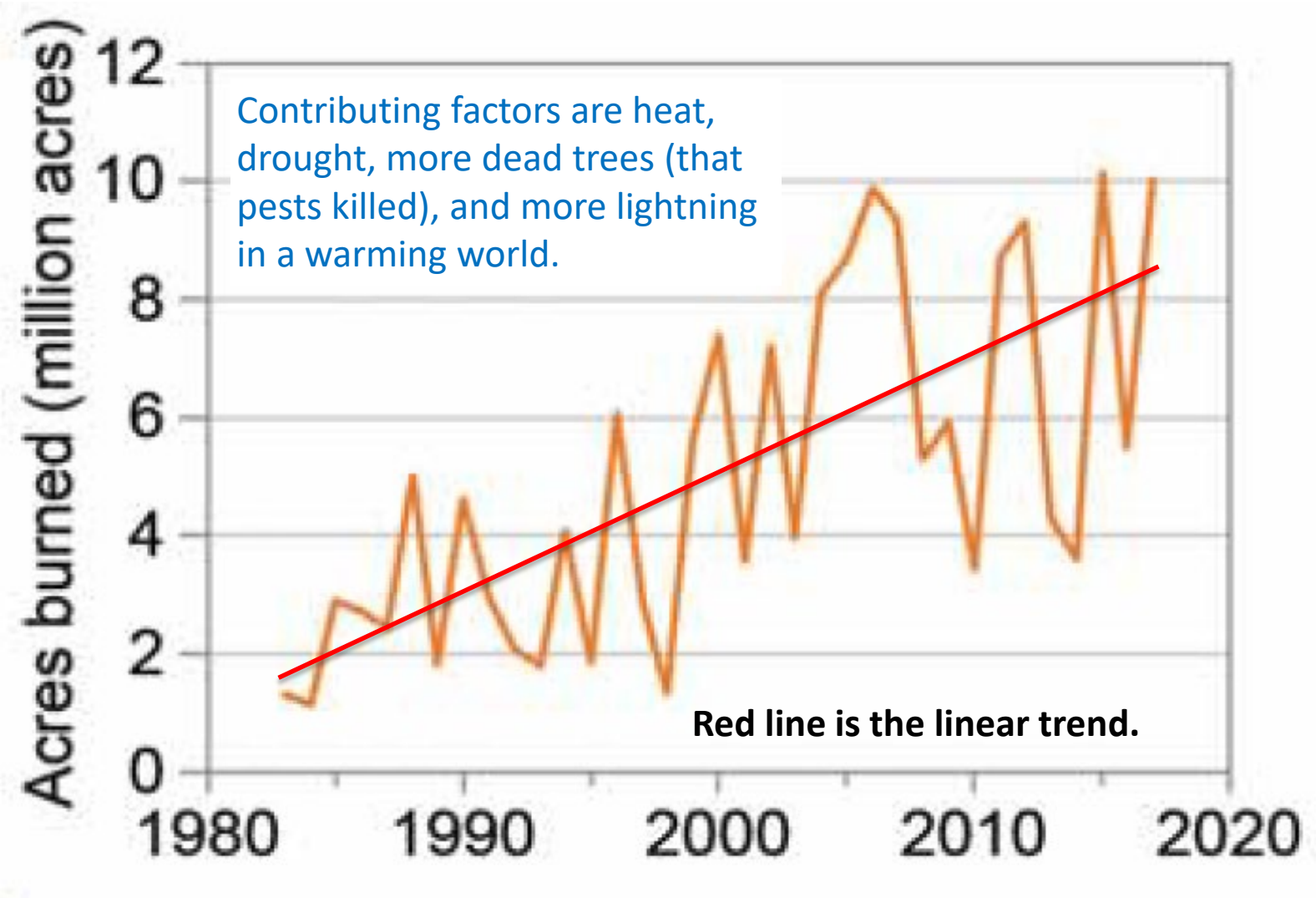
- Higher temperatures = bigger losses to evaporation.
- More of the rain falling in extreme events = more loss to flood runoff, less moisture soaking into soil.
- Mountains get more rain, less snow, yielding more runoff in winter and leaving less for summer.
- Earlier spring snowmelt also leaves less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

U.S Drought in 2018



Nat'l Centers for Environmental Information 2019

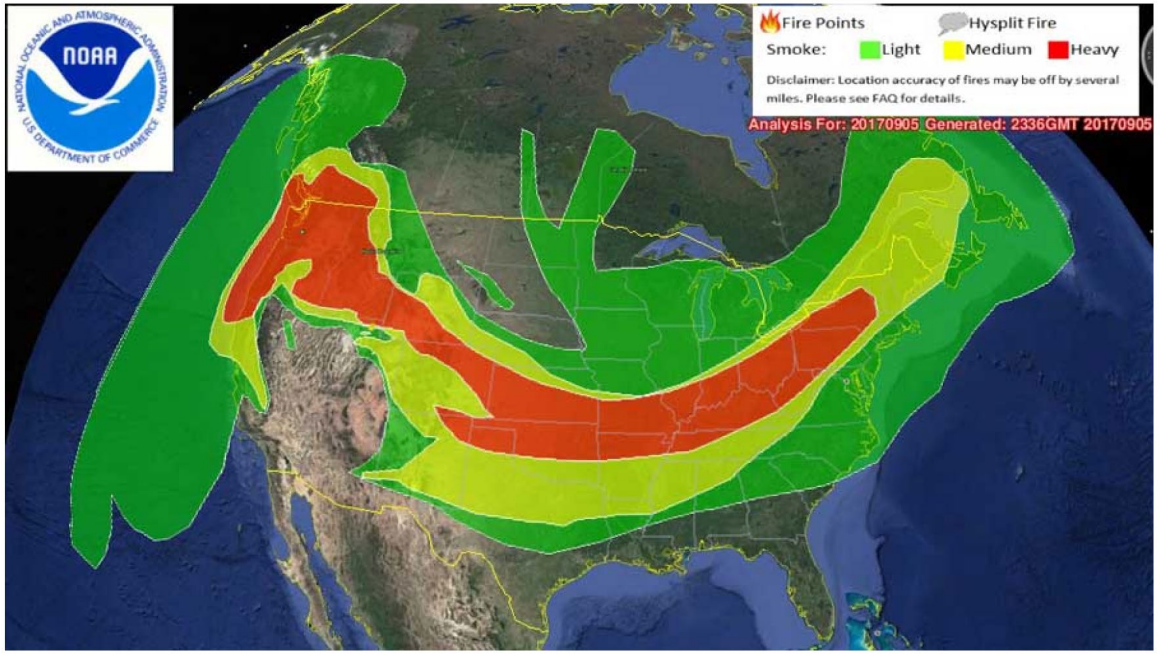
Wildfires are worsening under climate change



Average area burned increased more than 4-fold since 1985.

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 took place since 2004 (the other in 1997).
- In Alaska, even the tundra is burning.
- Smoke from today's big fires harms health over huge areas.



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

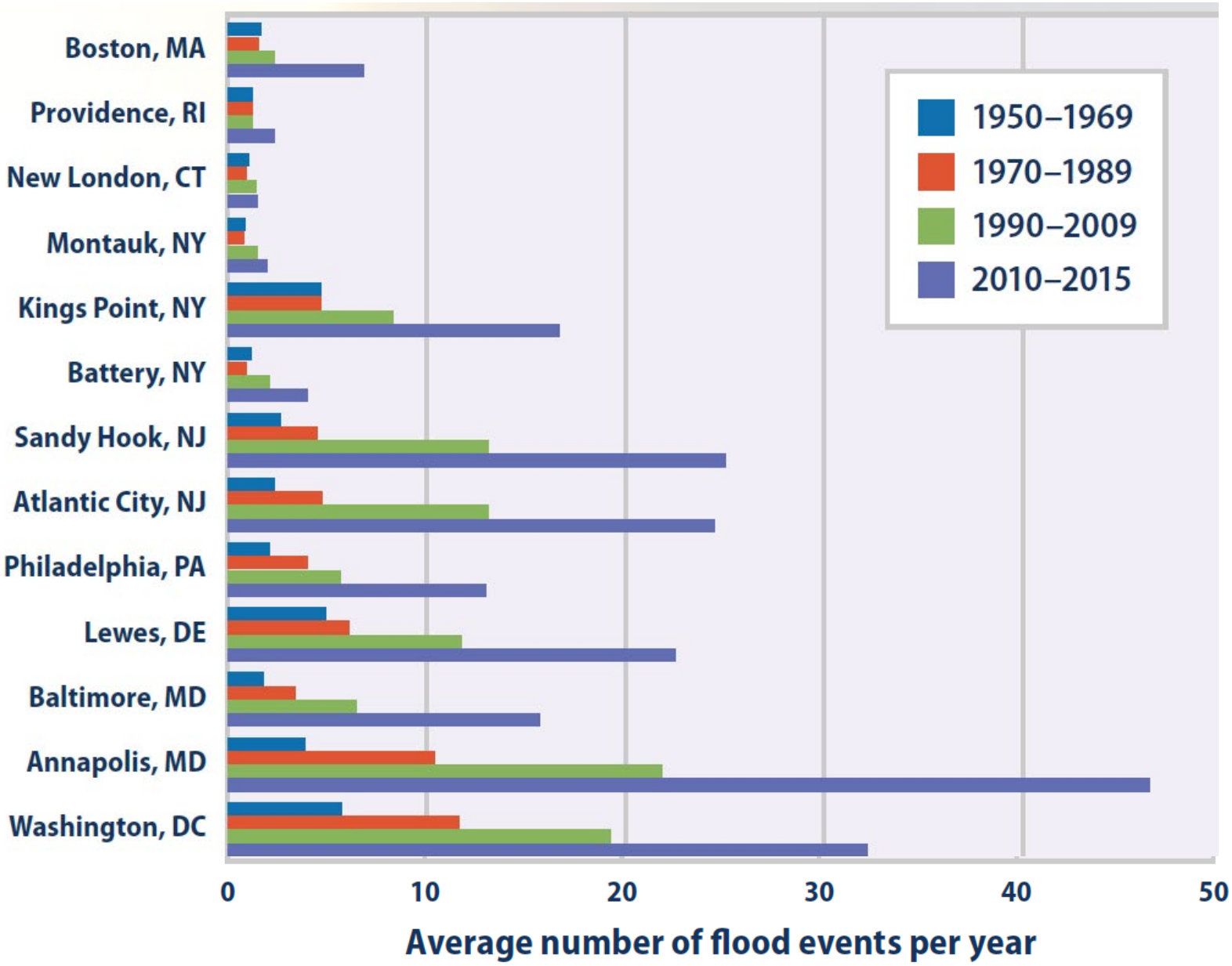
Hurricanes / typhoons getting stronger

- 10/12: Sandy, largest ever in Atlantic
- 11/13: Haiyan, strongest ever in N Pacific
- 10/15: Patricia, strongest ever worldwide
- 10/15: Chapala, strongest ever to strike Yemen
- 02/16: Winston, strongest ever in S Pacific
- 04/16: Fantala, strongest ever in Indian Ocean
- 10/17: Ophelia, strongest ever in E Atlantic

Their energy comes from the warming surface layer of the ocean.

Current impacts on people and ecosystems

Rising sea level → coastal inundation



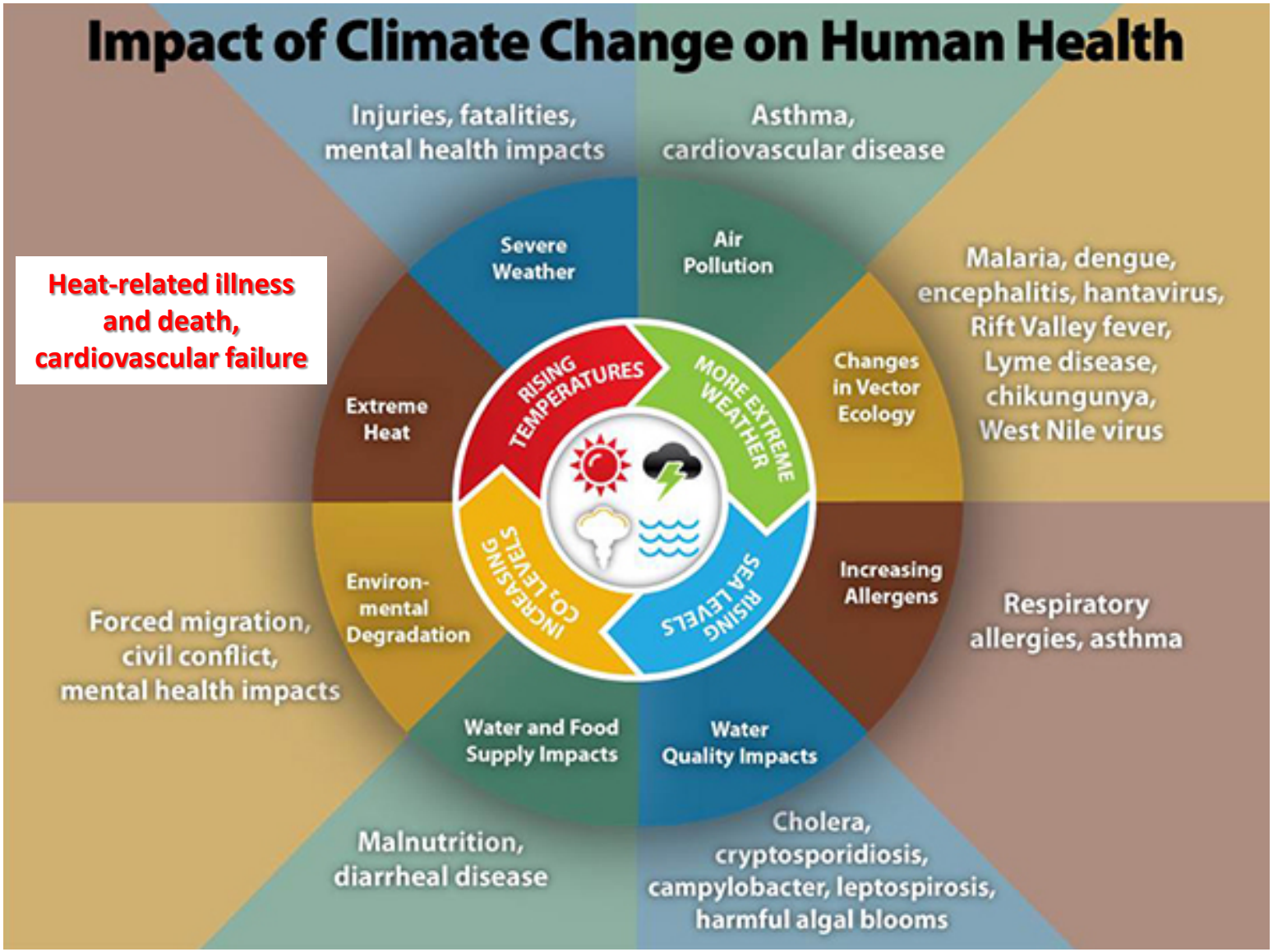
Current impacts on people and ecosystems

Rising sea level → coastal erosion

Cape Cod loses 33 acres per year to inundation and coastal erosion.

Current impacts on people and ecosystems

Direct impacts on human health



Centers for Disease Control & Prevention 2018

Current impacts on people and ecosystems

Coral bleaching in a warming ocean

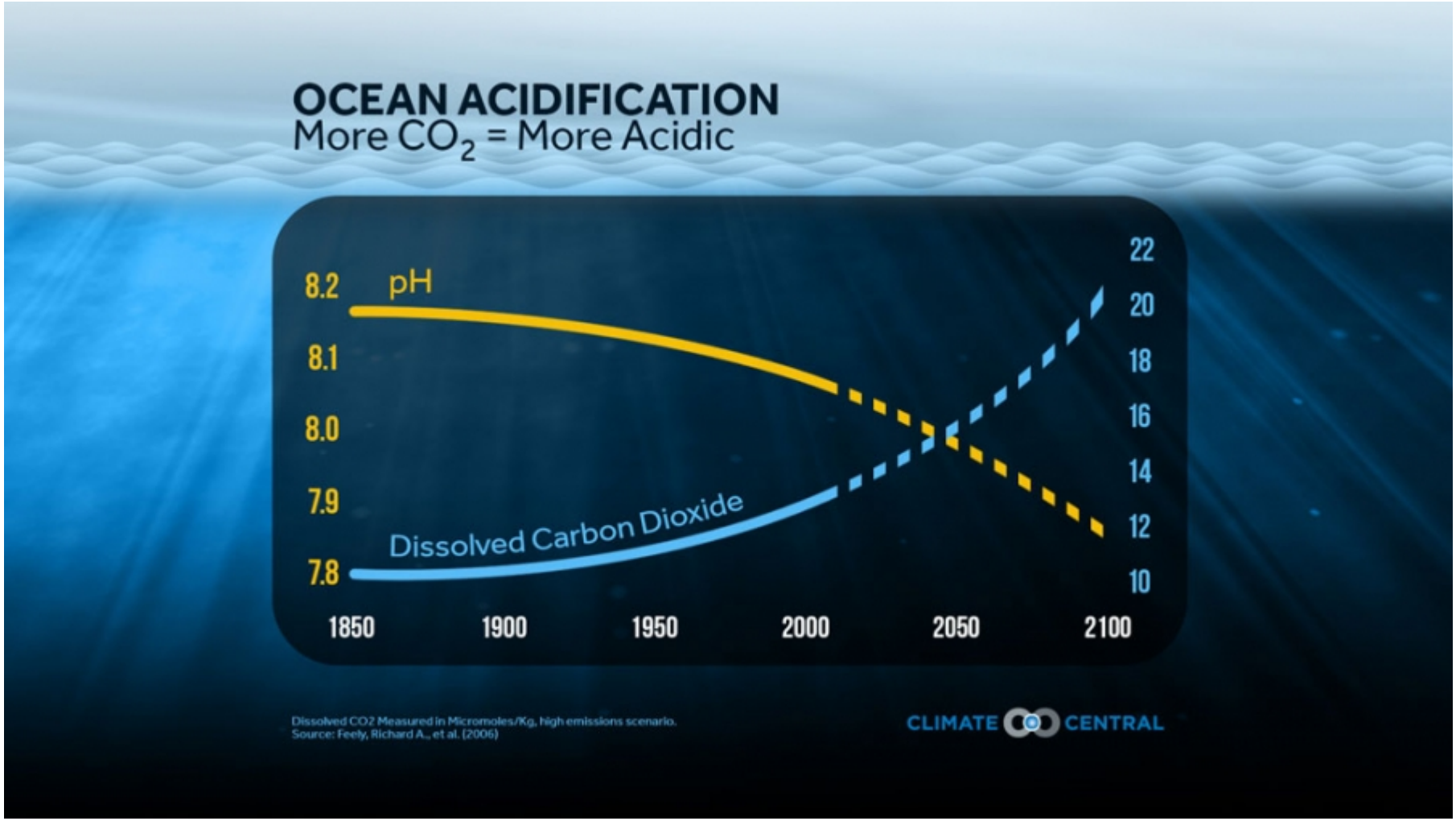
"As of February 2017, the ongoing global coral bleaching event continues to be the longest and most widespread ever recorded."

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

Current impacts on people and ecosystems

Ocean acidification

Some of the excess CO_2 in the atmosphere dissolves in the ocean, forming carbonic acid: $CO_2 + H_2O = H_2CO_3$



This harms corals, zooplankton, shrimp, oysters, crabs, clams, and more.

Other 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

What We Expect

The future of climate change and its impacts

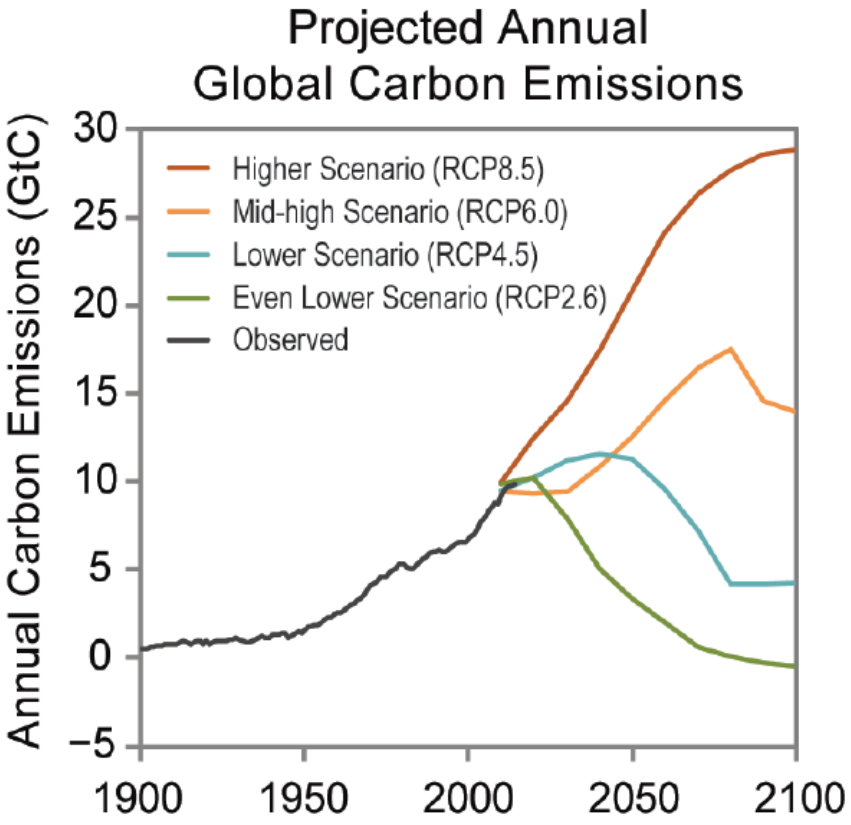
"If you don't change direction, you'll end up where you're heading."

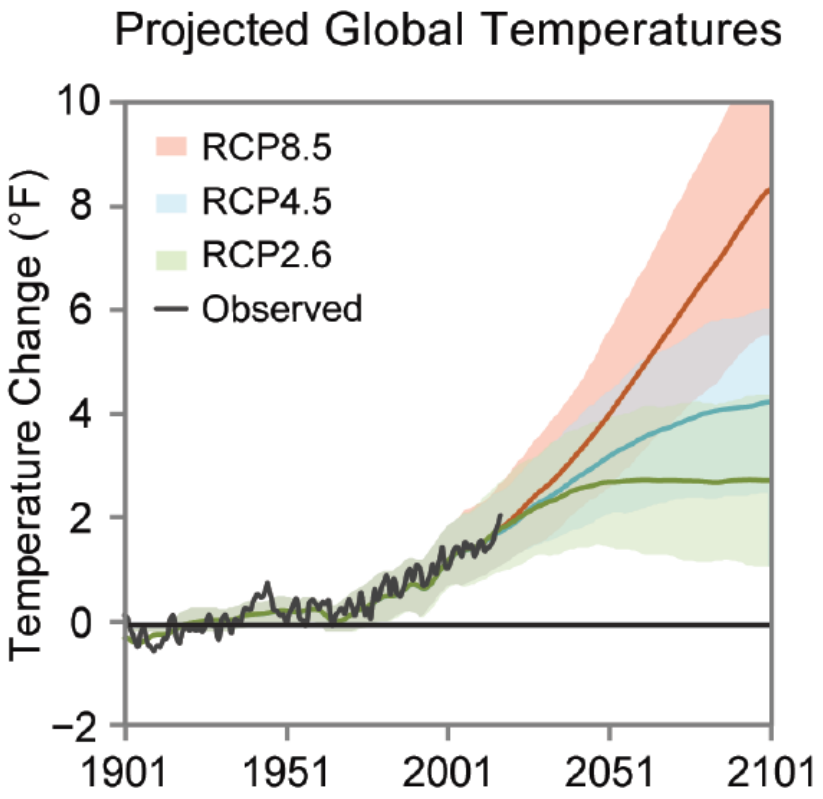
Lao Tzu

What we expect

Temperatures will continue to rise

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





Note how soon & steep is the green emissions-reduction path needed to stabilize ΔT near 2°C.

NCA4 Science Report, 2017

The biggest uncertainty in the climate future is how much action society takes.

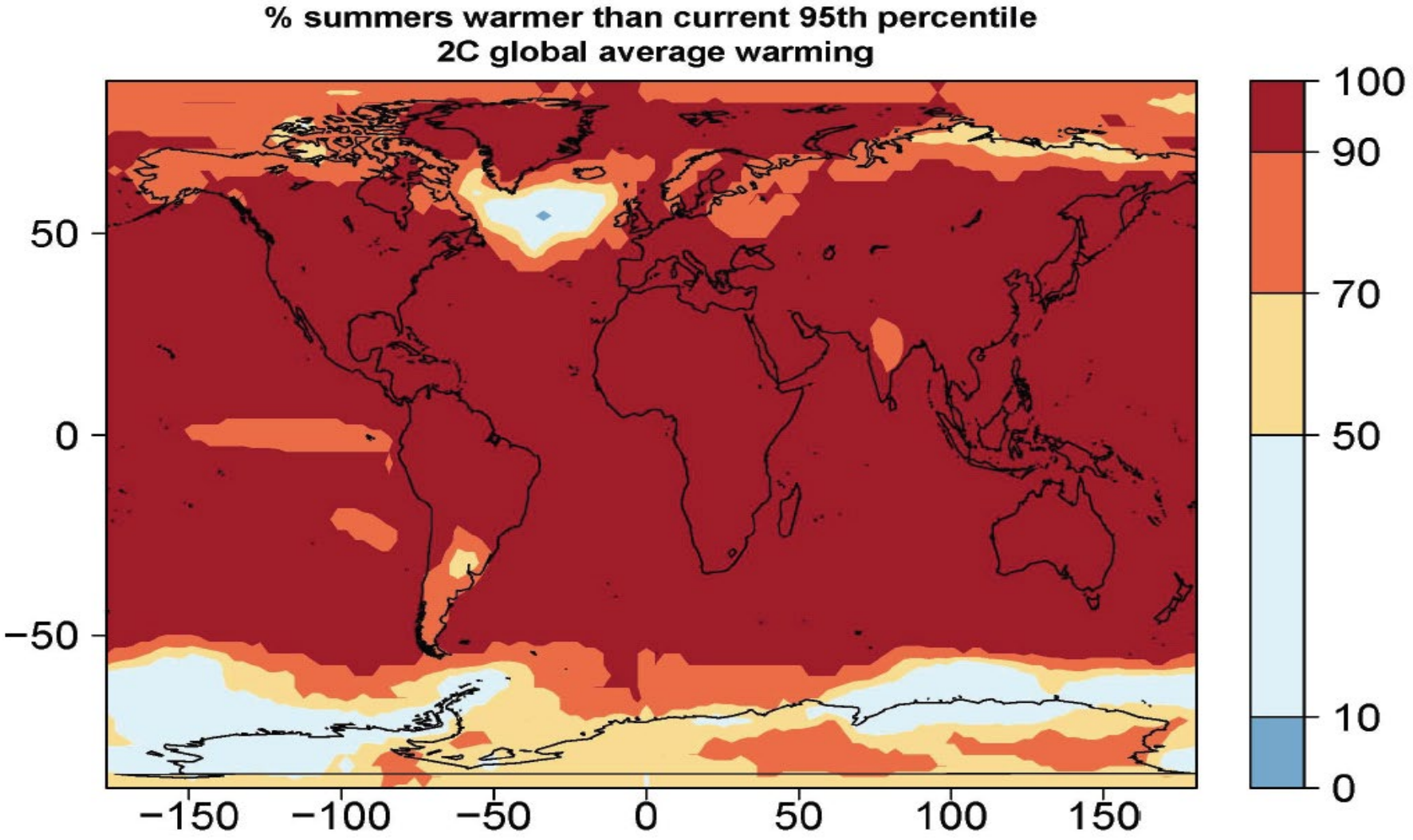
What we expect

Absent big emission reductions, we can expect…

- Large further increases in heat waves
- Big expansion in area burned by wildfires
- Bigger torrential downpours & more flooding
- Destruction of most of the world's coral reefs
- Wider disruption of marine food webs & fisheries
- Bigger thunderstorms, hailstorms, and tornadoes
- More Cat 3-5 hurricanes/typhoons making landfall
- Further increases in frequency & intensity of droughts
- Falling agricultural yields for corn, wheat, rice, soybeans
- More sickness & death from heat stress, tropical diseases
- Sea-level rise that might reach ~1 m by 2050, ~2 m by 2100

And, as a result, much bigger flows of environmental refugees

Hotter summers



U.S. National Academies, Stabilization Targets, 2010

Without big emissions cuts, we could reach ΔT ≈ 2°C in 20 years.

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).

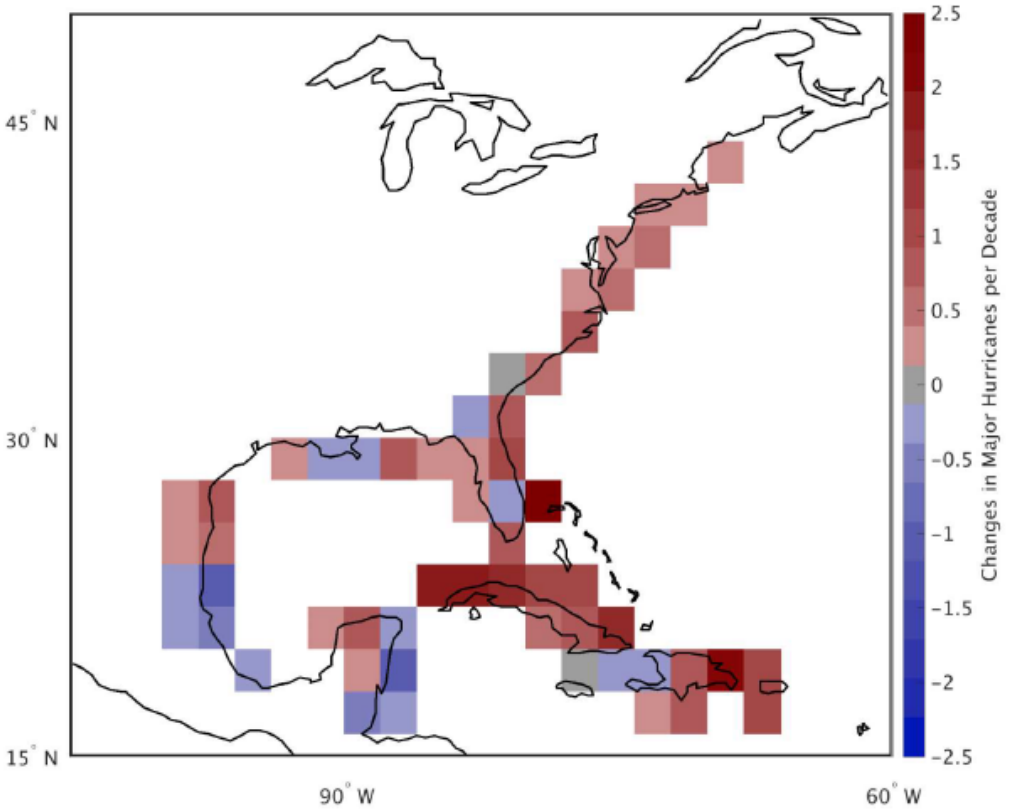
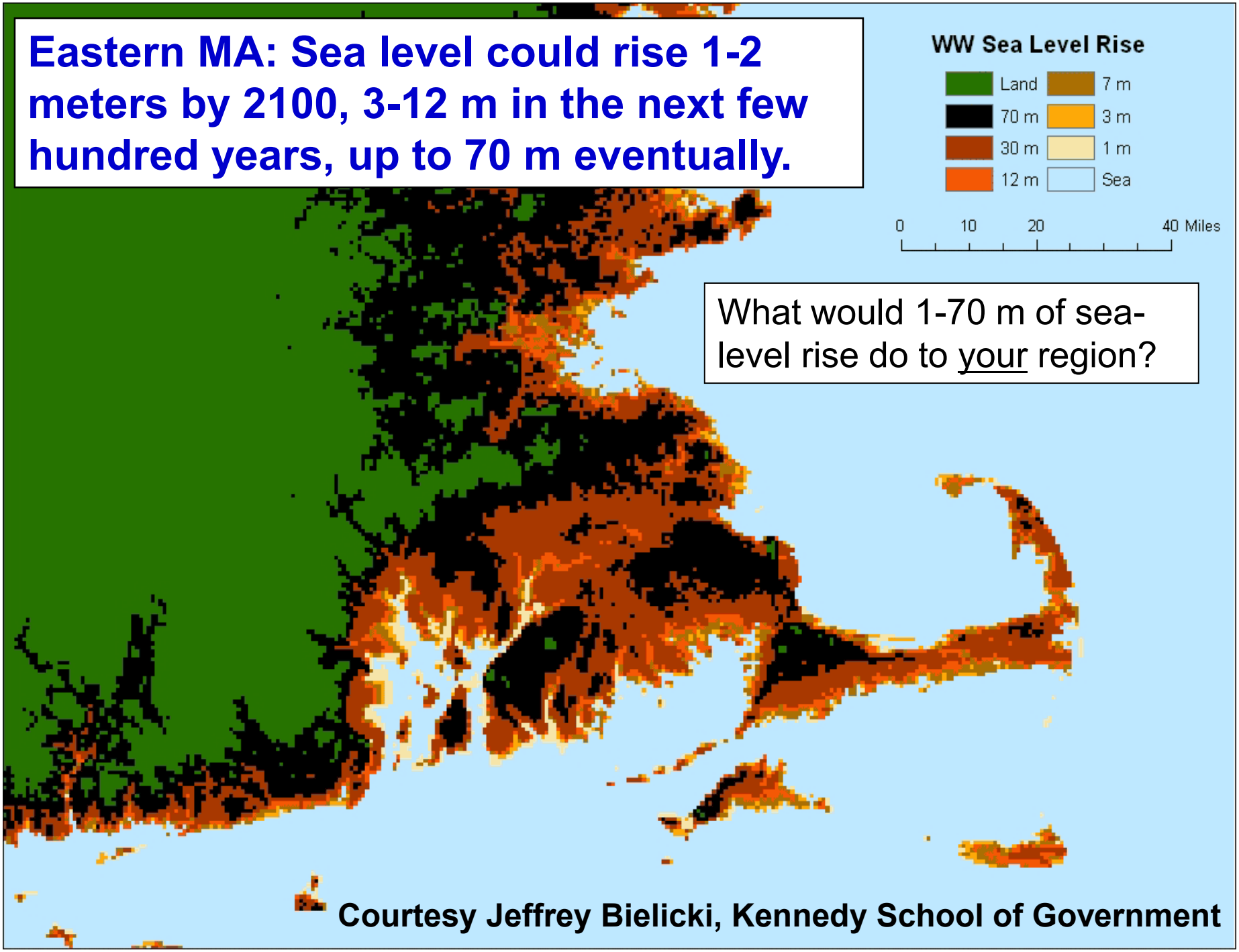


Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

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

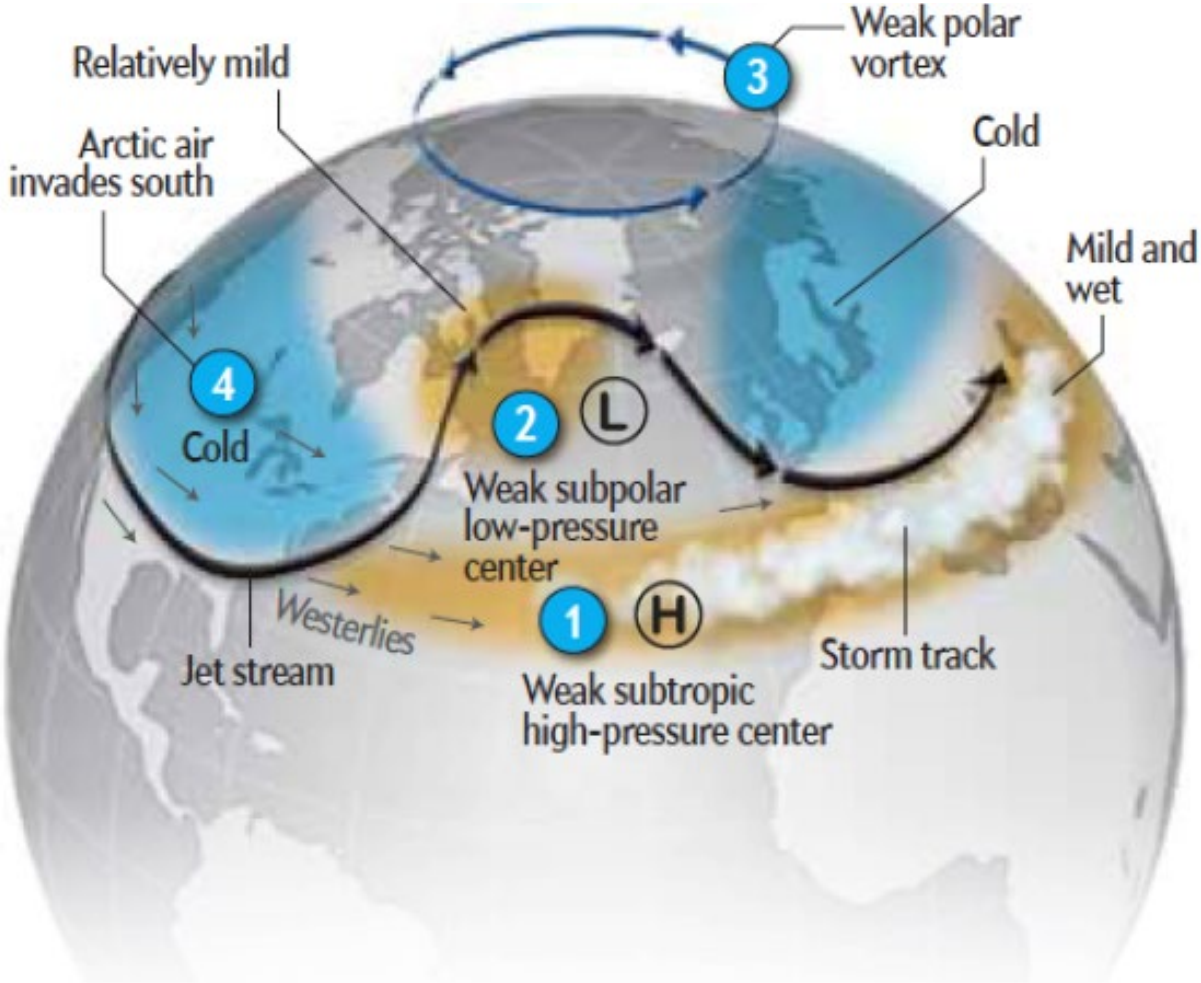
Bhatia and Vechhi, Princeton U, 5 April 2017


Eastern MA: Sea level could rise 1-2 meters by 2100, 3-12 m in the next few hundred years, up to 70 m eventually.
WW Sea Level Rise
Land
7 m
70 m
3 m
30 m
1 m
12 m
Sea
0
10
20
40 Miles
What would 1-70 m of sea-level rise do to your region?
Courtesy Jeffrey Bielicki, Kennedy School of Government

Other impacts likely to affect Cape Cod

- Saltwater intrusion into freshwater wetlands and aquifers (compounded by increased groundwater pumping to serve a growing population)
- More frequent, more intense, longer red tides / shell-fishing closures (the algal species involved like warm water)
- Additional threats to lobsters and mollusks from bacterial & other diseases flourishing in warm water
- Damage to native marine species by invasives from warmer regions
- Reduced abundance of Northeast bird species
- Increased winter weather extremes

More NE winter extremes from weak polar vortex



Graphic by XNR Productions

Rapid Arctic warming weakens polar vortex. The resulting wavy jet stream allows alternating southward incursions of cold air and northward incursions of warm air. Collision of cold Arctic air with moisture-laden air over warmed Atlantic can cause extreme snowfall in the Northeast.

Scientific American blog, January 2014

What We Can Do

"Between fatalism and complacency lies urgency."

Jake Sullivan, National Security Advisor
to Vice President Biden

Society's options

There are only three:

- 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.

Mitigation possibilities include…

(CERTAINLY)

- Reduce emissions of greenhouse gases & soot from the energy sector
- Reduce deforestation; increase reforestation & afforestation
- Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon

Some will be costly, but less so than unmitigated climate change.

(CONCEIVABLY)

- "Scrub" greenhouse gases from the atmosphere technologically **(very high cost)**
- "Geo-engineering" to create cooling effects offsetting greenhouse heating **(limited efficacy, possible side effects)**

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 would make sense in any case even absent climate change.

About mitigation, adaptation, and suffering

- We're already doing some of each.
- What's at stake today 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.

How much mitigation is needed to avoid disaster?

- The community of nations agreed in 2009 on a goal of holding the increase in global average surface temperature to 2°C (3.6 °F) above the pre-industrial level.
- That target was picked not because it would keep the world "safe", but because it was the lowest figure experts thought might be achievable.
- The adverse impacts already being experienced at today's 1°C led the hardest-hit countries to argue in 2015 in Paris that 2°C would be devastating and the world should aim for 1.5°C.
- The October 2018 IPCC report on a 1.5°C target underscored this but noted the lower goal would require very steep emissions reductions worldwide starting almost immediately.

The role of Federal leadership

THE OBAMA ADMINISTRATION…

- Boosted climate research & monitoring
- Invested in clean-energy R&D and R&D incentives for business
- Enacted aggressive energy-efficiency standards
- Promoted climate-change adaptation
- Launched the “Climate Action Plan” with further mitigation, adaptation, & international initiatives
- Reached agreement with China in November 2014 on climate leadership, which enabled…
- The December 2015 Paris agreement, in which 195 countries agreed to emissions reductions, plus assistance on both mitigation & adaptation to countries in need

Federal leadership: Trump, alas, has opted out

THE TRUMP ADMINISTRATION…

- Put climate-change contrarians in charge at Office of Management & Budget, Environmental Protection Agency, Department of Interior, and Department of Energy
- Proposed deep budget cuts in climate science & clean-energy R&D (of which Congress agreed to some)
- Cancelled Obama's Climate Action Plan
- Rescinded all of Obama's Executive Orders on adaptation
- Announced withdrawal from Paris accord and immediately halted U.S. actions to comply with it, including assistance on mitigation & adaptation to countries in need
- Loosened regulation of fossil-fuel exploitation

What's needed now to meet the 2°C target or better

- A massive program of technological innovation on clean energy and energy efficiency, advanced through partnerships among government, industry, & universities, and including…
  - CO_2 capture & sequestration for fossil & biomass power plants
  - Sustainable biofuel production for power plants & aviation
  - Cheaper wind & solar power and better electricity storage
  - Innovation to try to make nuclear energy safer & more affordable
  - Pursuit of practical fusion power
- A similarly massive set of public-private-university partner-ships focused on developing & implementing adaptation measures to limit the harm from the changes in climate that can no longer be prevented.

What's needed now (concluded)

- A global carbon tax starting soon at around \$30/tCO_2e and increasing to at least \$100/tCO_2e by 2030 (preferably collected by national governments and rebated on a per-capita basis).

  This would incentivize using best available low- and no-emission technologies now and investing in research to get better ones.

* * * * *

The political will to get all this done could materialize faster than many think, as the combination of

rapidly increasing damages from climate change

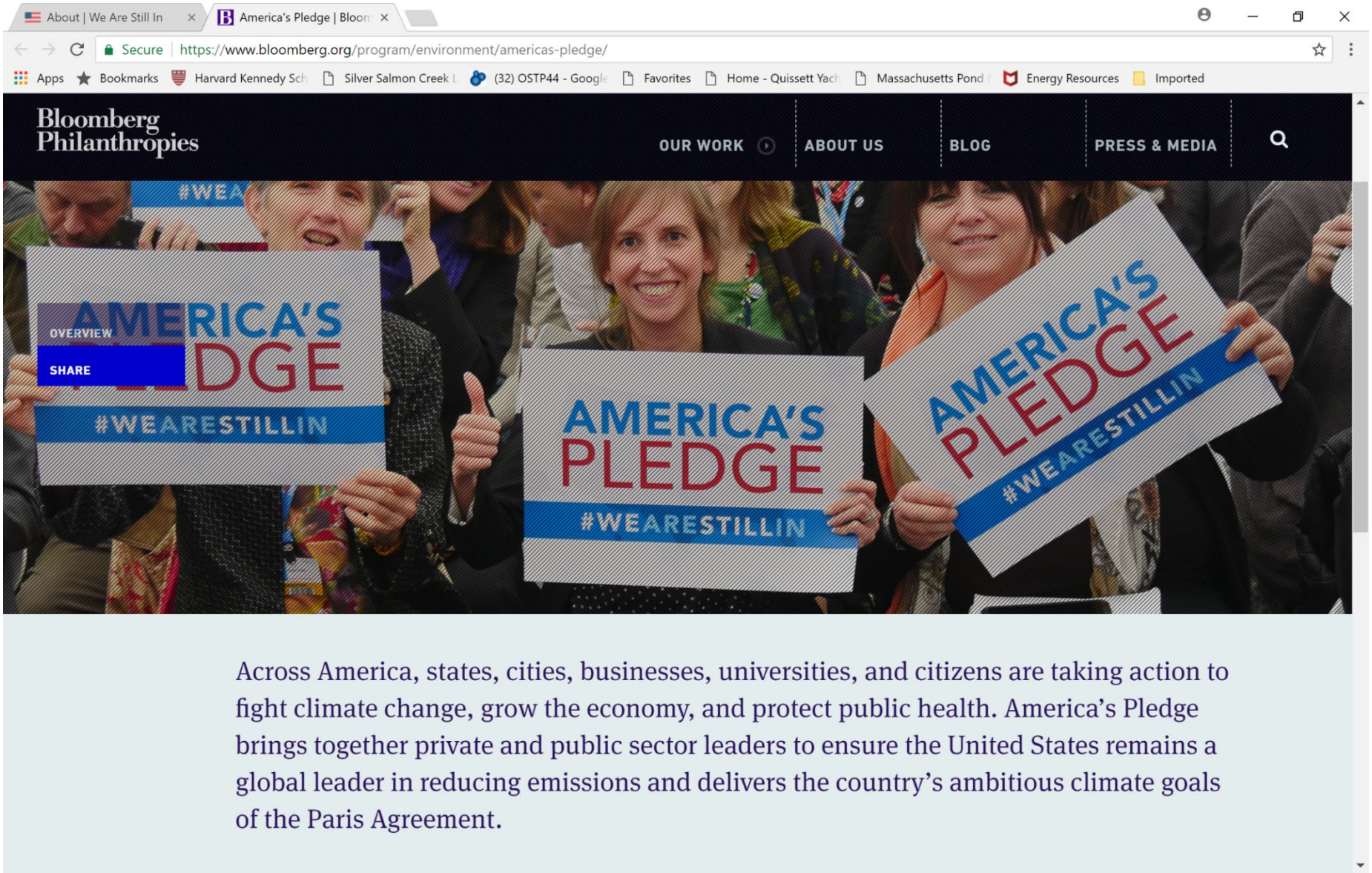
and

declining costs of remedial action (as a result of innovation)

makes ever clearer that action is much cheaper than inaction.

What we can do

Many states, cities, businesses, universities, citizens are “in”



What everybody should do

- Increase your understanding of the climate-change challenge and the remedies
- Share those insights with colleagues, friends, & neighbors
- Reduce the “carbon footprint” of your home and your transportation habits
- Encourage climate-change mitigation & adaptation activities undertaken by your state & local governments
- Support businesses and civil-society organizations that are taking constructive action
- Vote (and, even better, work) for political candidates who understand the climate challenge and pledge to act

“Trend is not destiny.”

Rene Dubos