Global Climate-Change and U.S. Interests:
What We Know, What We Expect,
What We Should Do

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(January 2009 – January 2017)

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The essence of the energy-climate challenge

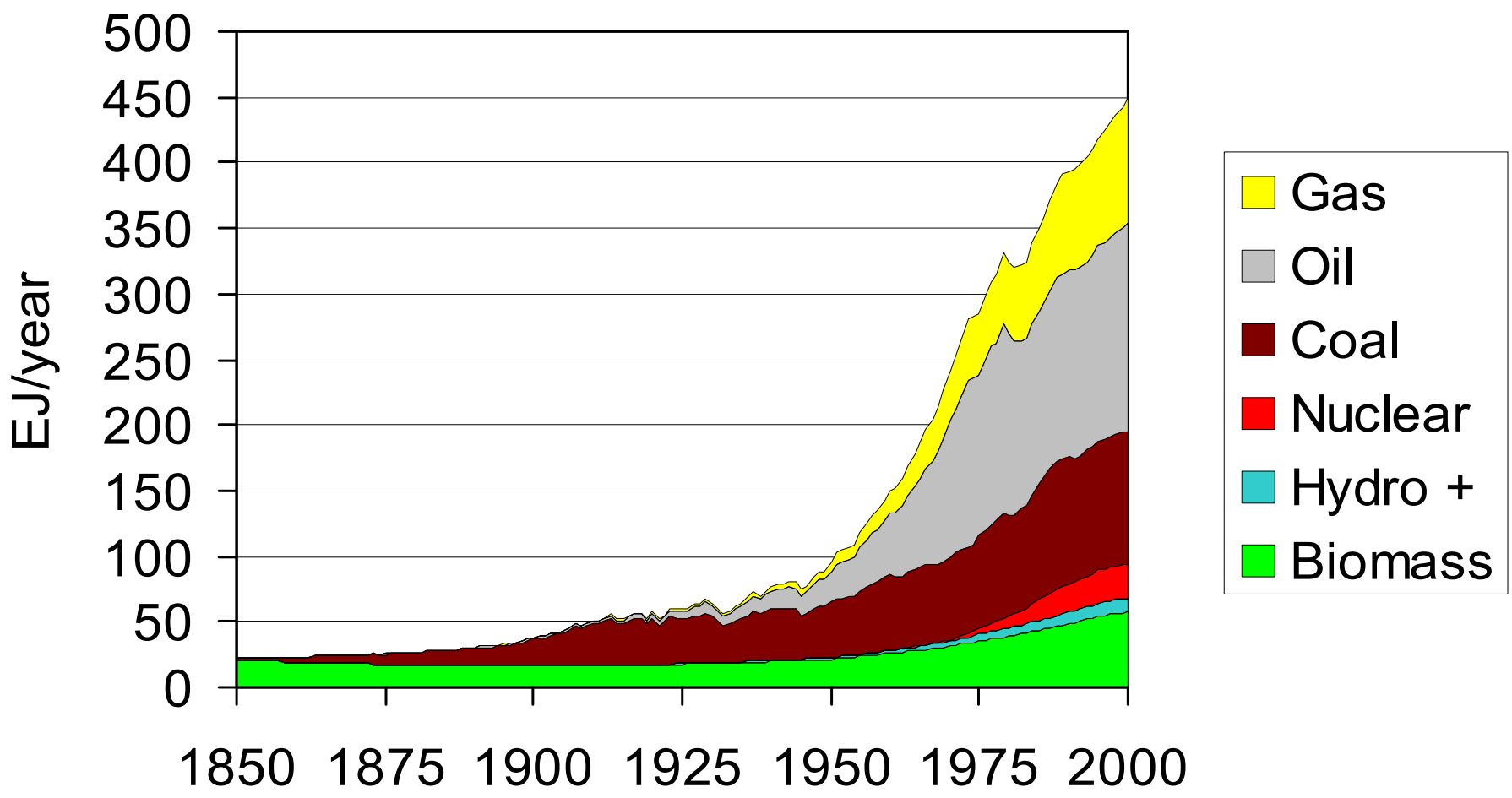
- Without energy there is no economy
- Without climate there is no environment
- Without economy <u>and</u> environment there is no material well-being, no civil society, no personal or national security

The essence of the challenge is that the world has long been getting most of the energy its economies need in ways that are now seriously disrupting the climate its environment needs.

In the rest of this talk I'll address..

- The origins of human-caused global climate change
- The character of the change
- The U.S. interests at stake
- The harm that's already occurring
- Future outcomes: expectations & possibilities for low-emission & high-emission futures
- Society's options for affecting these outcomes
- What Obama did
- What Trump is doing
- What we should do

Growth of world population & prosperity from 1850 to 2000 brought a 20-fold increase in energy use.



Most of the growth 1850-1950 came from coal; most of the 2x faster growth 1950- 2000 came from oil and natural gas..

Economy, energy & CO_2 in 2015

	population (millions)	ppp-GDP (trillion $)	energy (EJ)	fossil E (percent)	fossil CO_2 (MtC)
World	7343	113.3	613	82%	9290
China	1371	19.4	139	84%	2570
USA	319	17.4	101	86%	1500
India	1311	7.9	39	74%	610
Russia	144	3.5	31	88%	420
Japan	127	4.9	20	92%	340

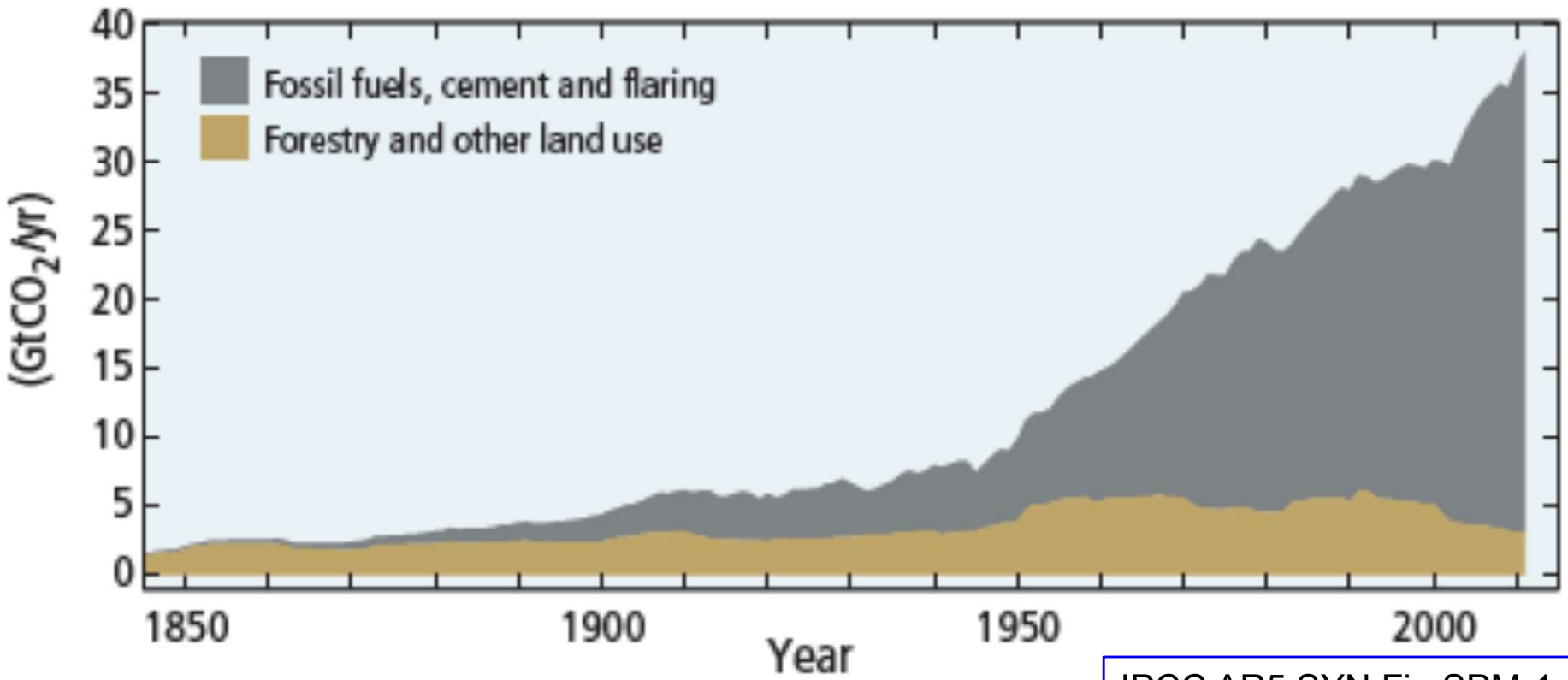
World Bank 2016, BP 2016

Today the world <u>remains</u> overwhelmingly dependent on fossil fuels.

Origins of human-caused climate change

CO_2 emissions from fossil-fuels & deforestation changed the composition of the atmosphere

Roughly, coal is CH, oil is CH_2, natural gas is CH_4, wood is CH_2O. Burning them makes CO_2 and H_2O, all of it (with current technology) ending up in the atmosphere. The H_2O additions have a tiny effect on the natural water cycle, but the CO_2 additions have significantly altered the natural carbon cycle.



IPCC AR5 SYN Fig SPM-1

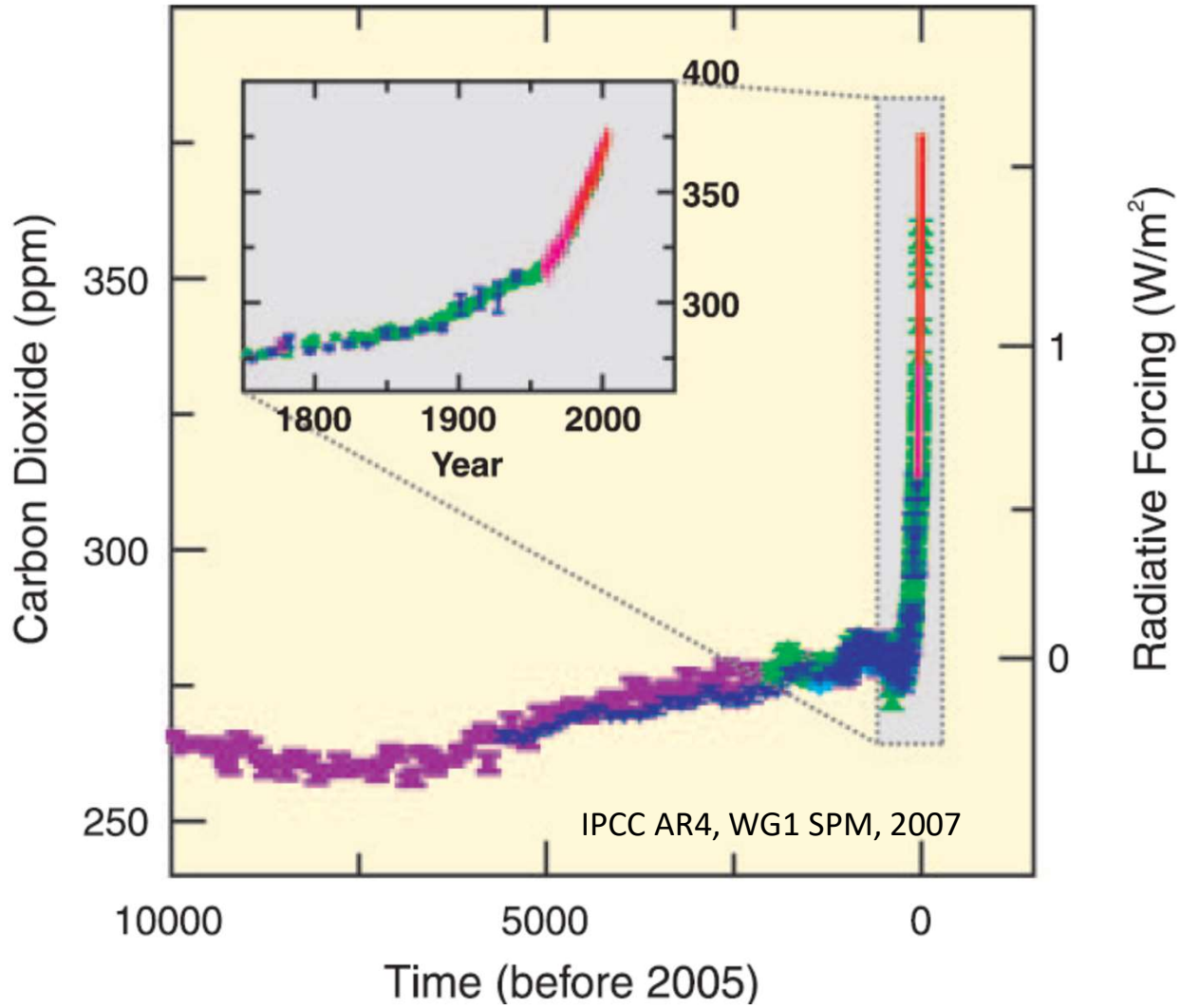
Origins of human-caused climate change

Heat-trapping CO_2 in the atmosphere has soared

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.

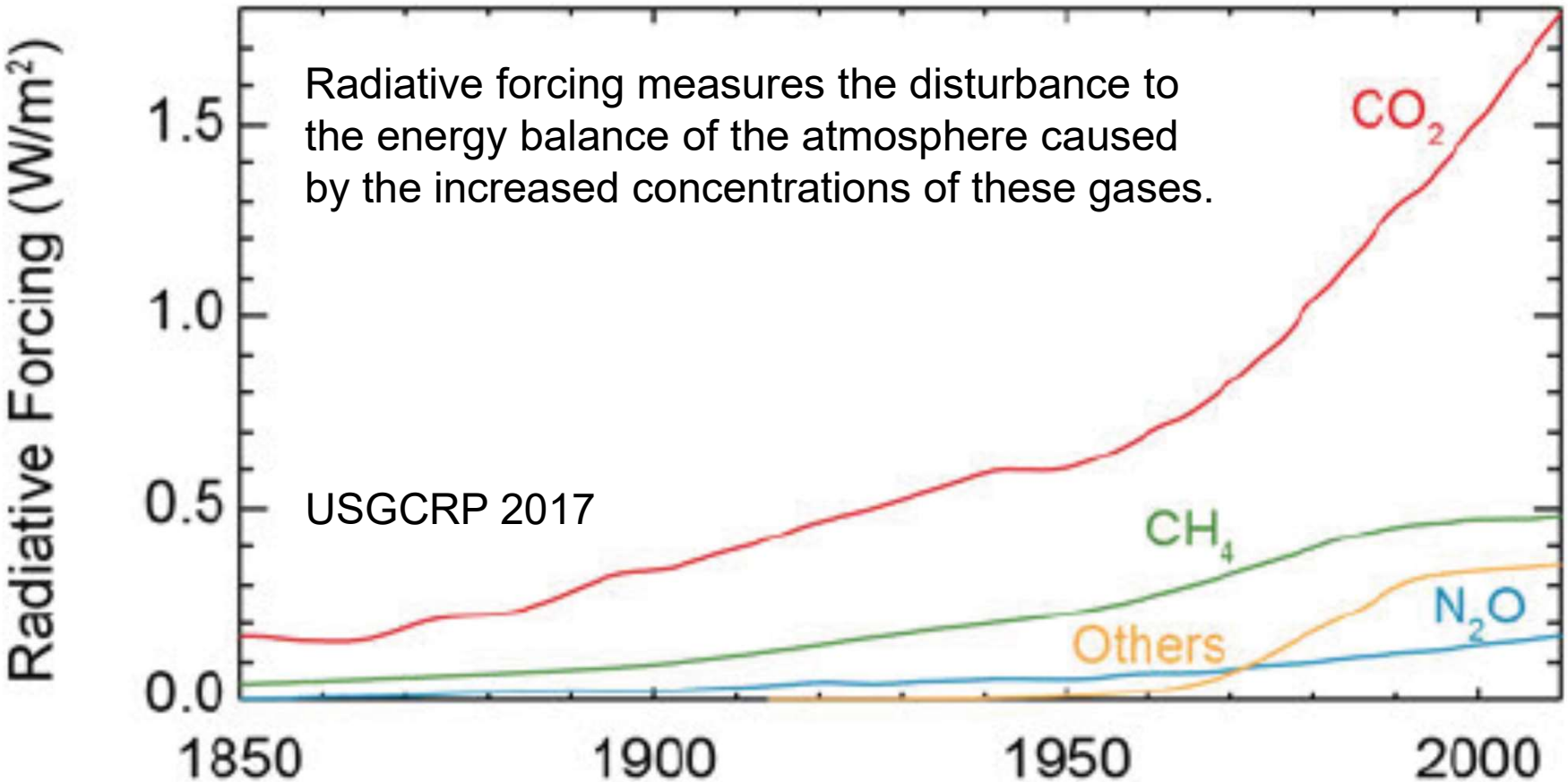
By 2016, the CO2 concentration had reached 403 ppmv, 45% above its value in 1750.

CO_2 vs time from ice cores & direct measurement



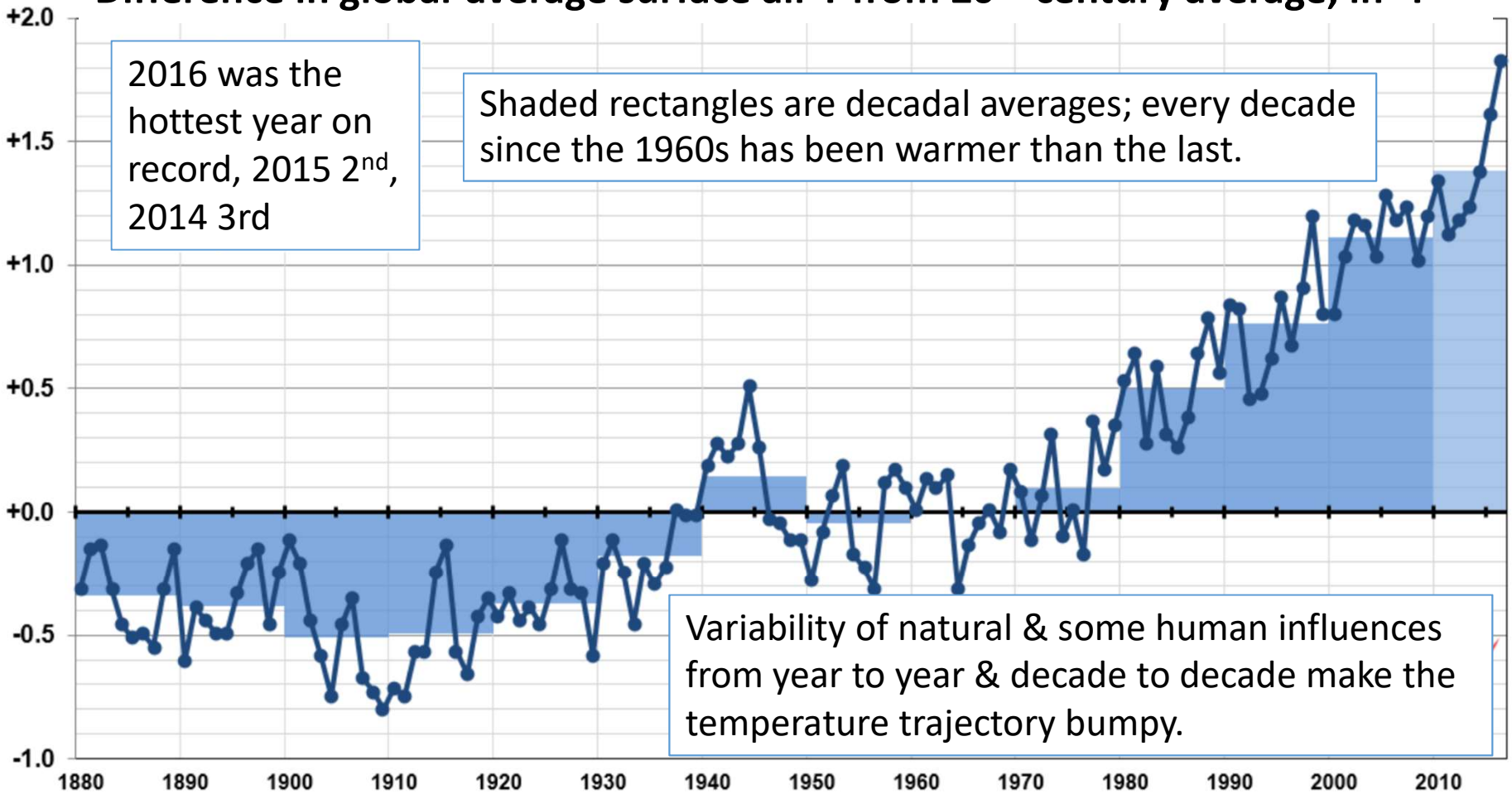
Humans have added other heat-trapping gases too

Notably methane (CH_4) & nitrous oxide (N_2O) from energy systems & agriculture, as well as CFCs and HFCs from consumer products & industry



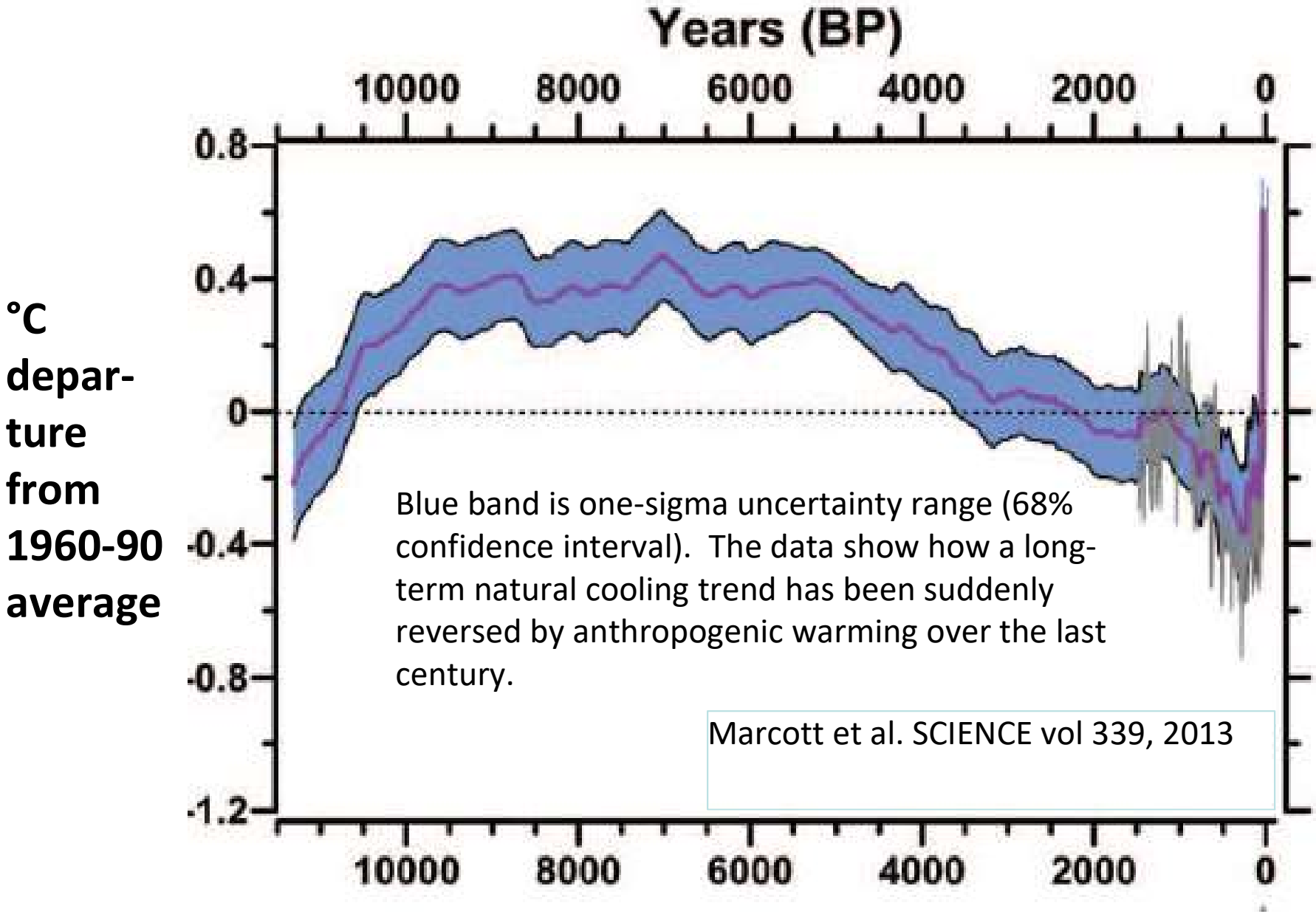
This GHG forcing has been warming the Earth

Difference in global-average surface air T from 20th-century average, in °F



Origins of human-caused climate change

Humans reversed of 6,500 years of natural cooling



But "global warming" is something of a misnomer

That term implies something…

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

What's actually happening is…

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

A more descriptive term is "global climate disruption".

Character of human-caused climate change

Climate change is not just about temperature.

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

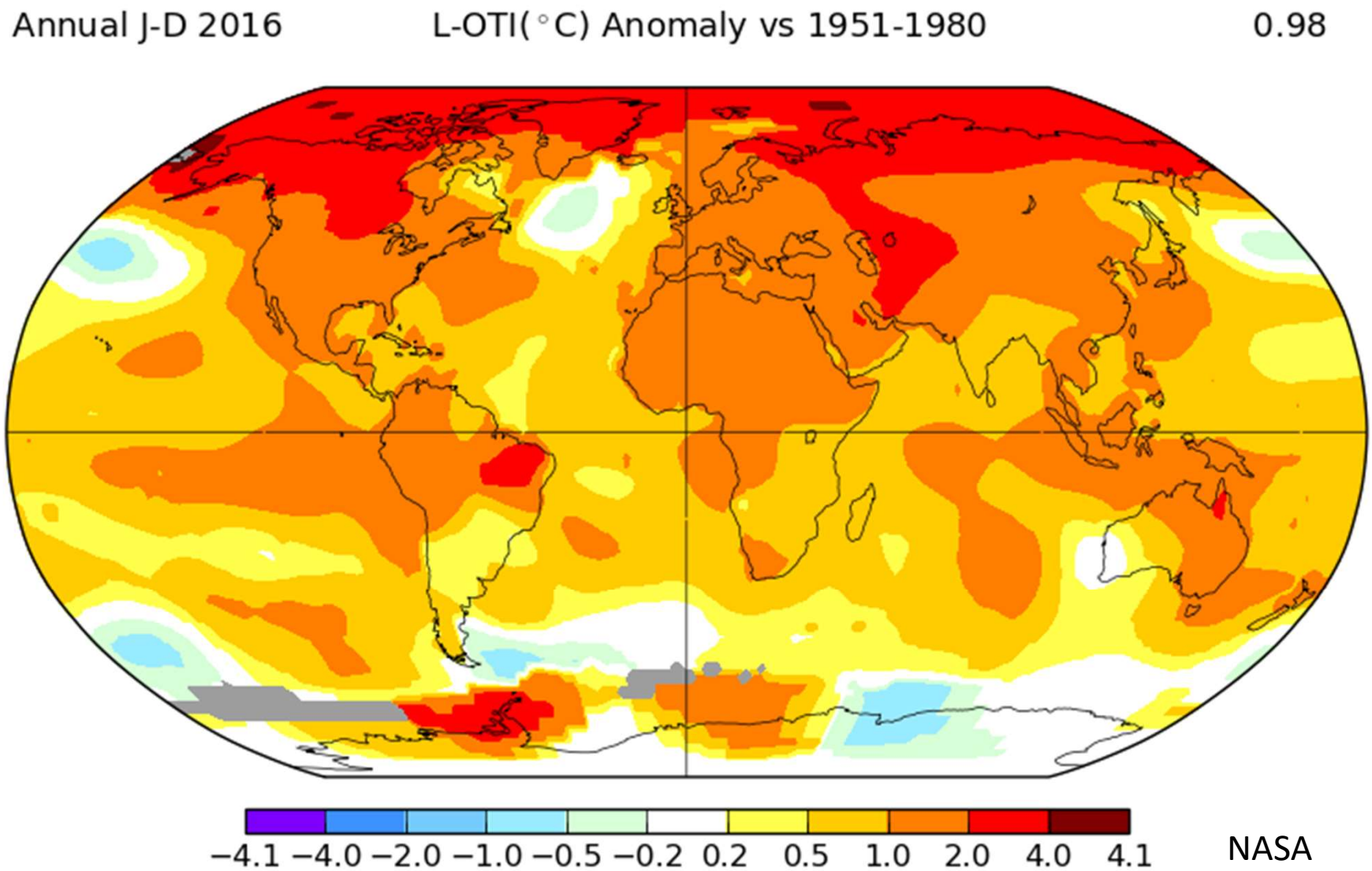
- hot & cold
- cloudy & clear
- humid & dry
- drizzles, downpours, & hail
- snowfall, snowpack, & snowmelt
- breezes, blizzards, tornadoes, & typhoons

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).

Character of human-caused climate change

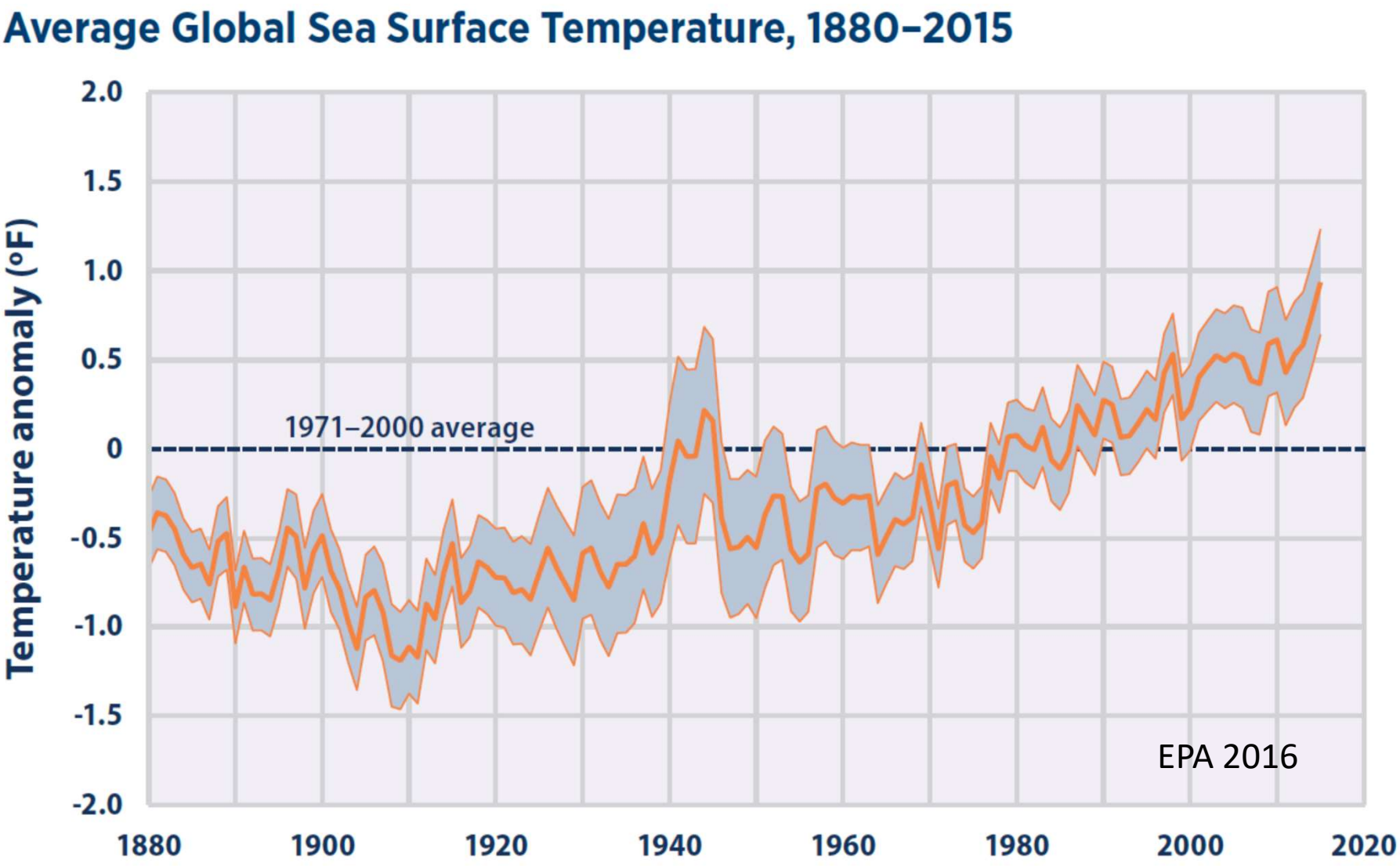
The changes are highly non-uniform



NASA

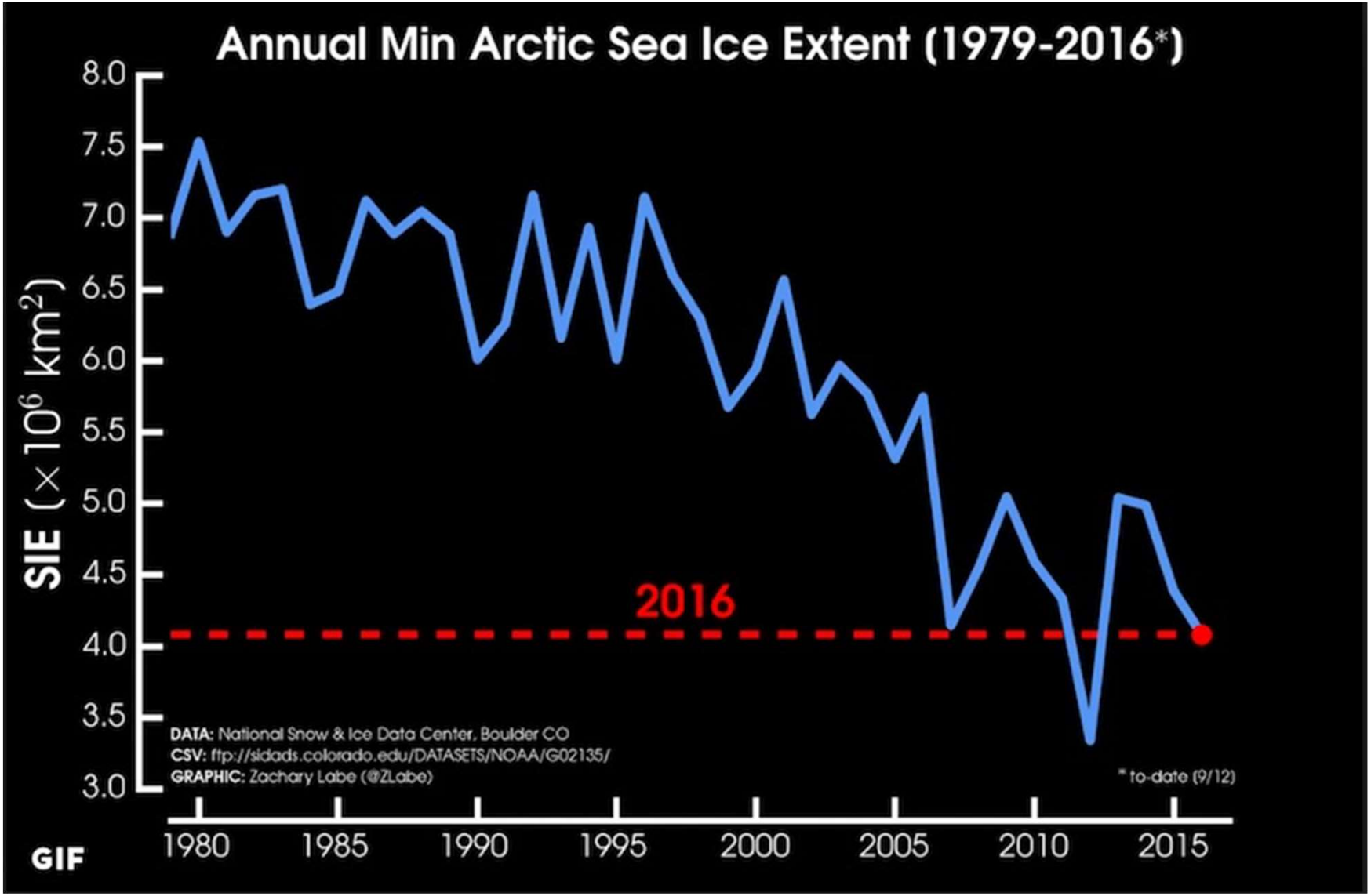
Character of human-caused climate change

The changes include: A warming ocean



Character of human-caused climate change

The changes include: Shrinking Arctic sea ice



Character of human-caused climate change

The changes include: Disappearing glaciers

Muir Glacier, Alaska, 1941-2004

August 1941

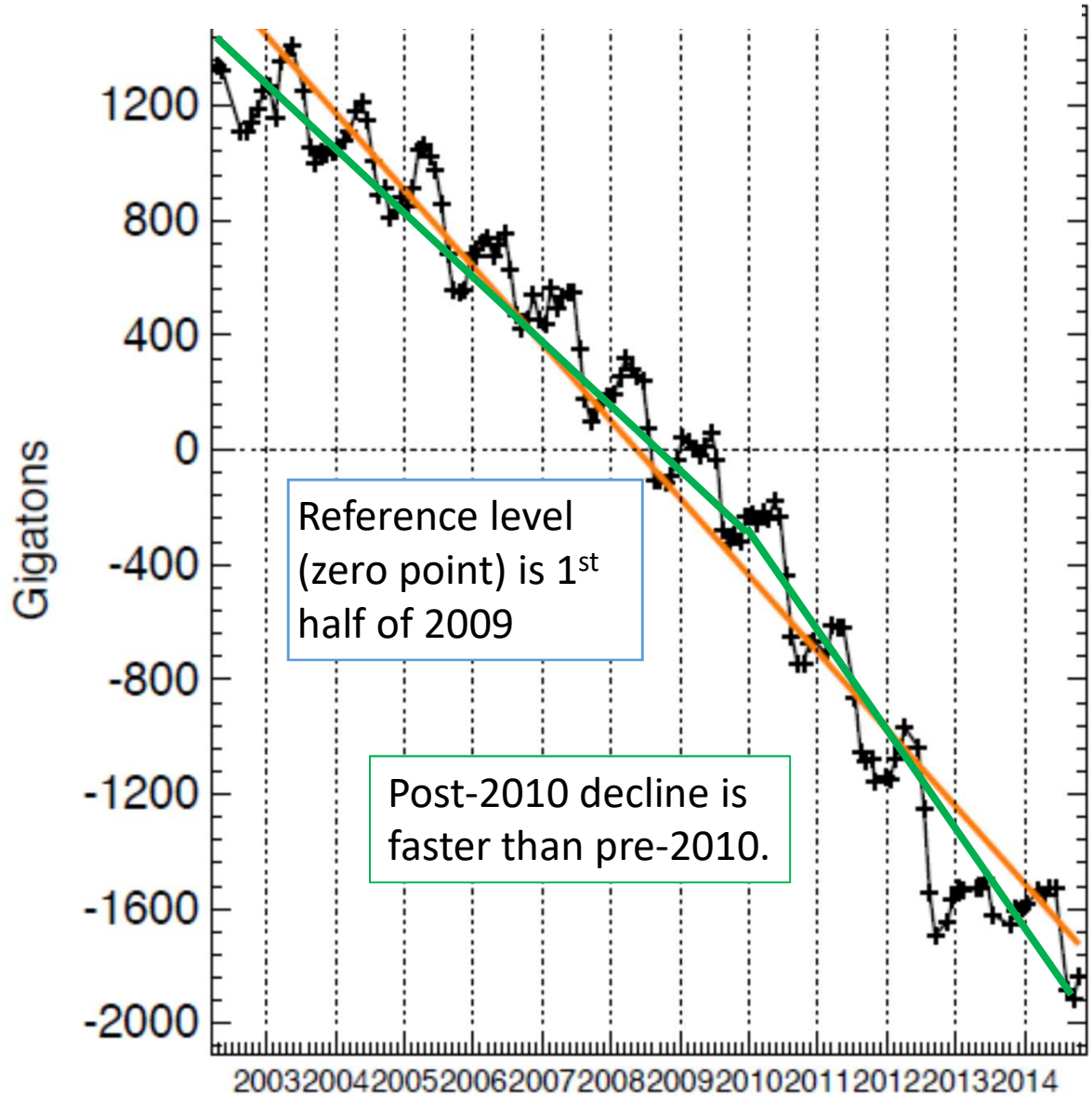
August 2004

NSIDC/WDC for Glaciology, Boulder, compiler. 2002, updated 2006. *Online glacier photograph database.* Boulder, CO: National Snow and Ice Data Center.

Character of human-caused climate change

The changes include: accelerating losses from the Greenland Ice Sheet

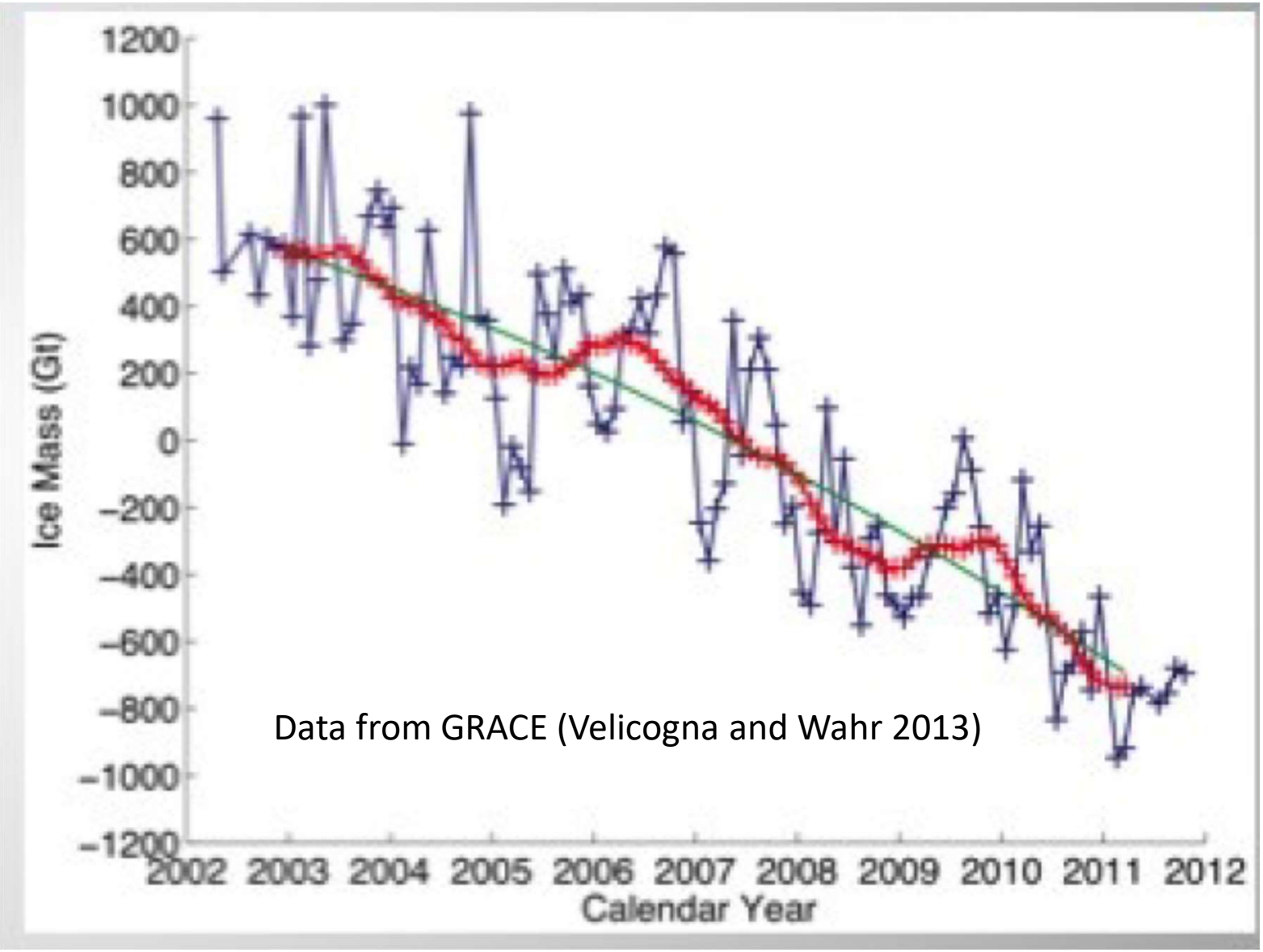
Land-ice loss from melting & accelerated calving of icebergs raises sea level.



Waleed Abdalati, from GRACE, December 2014

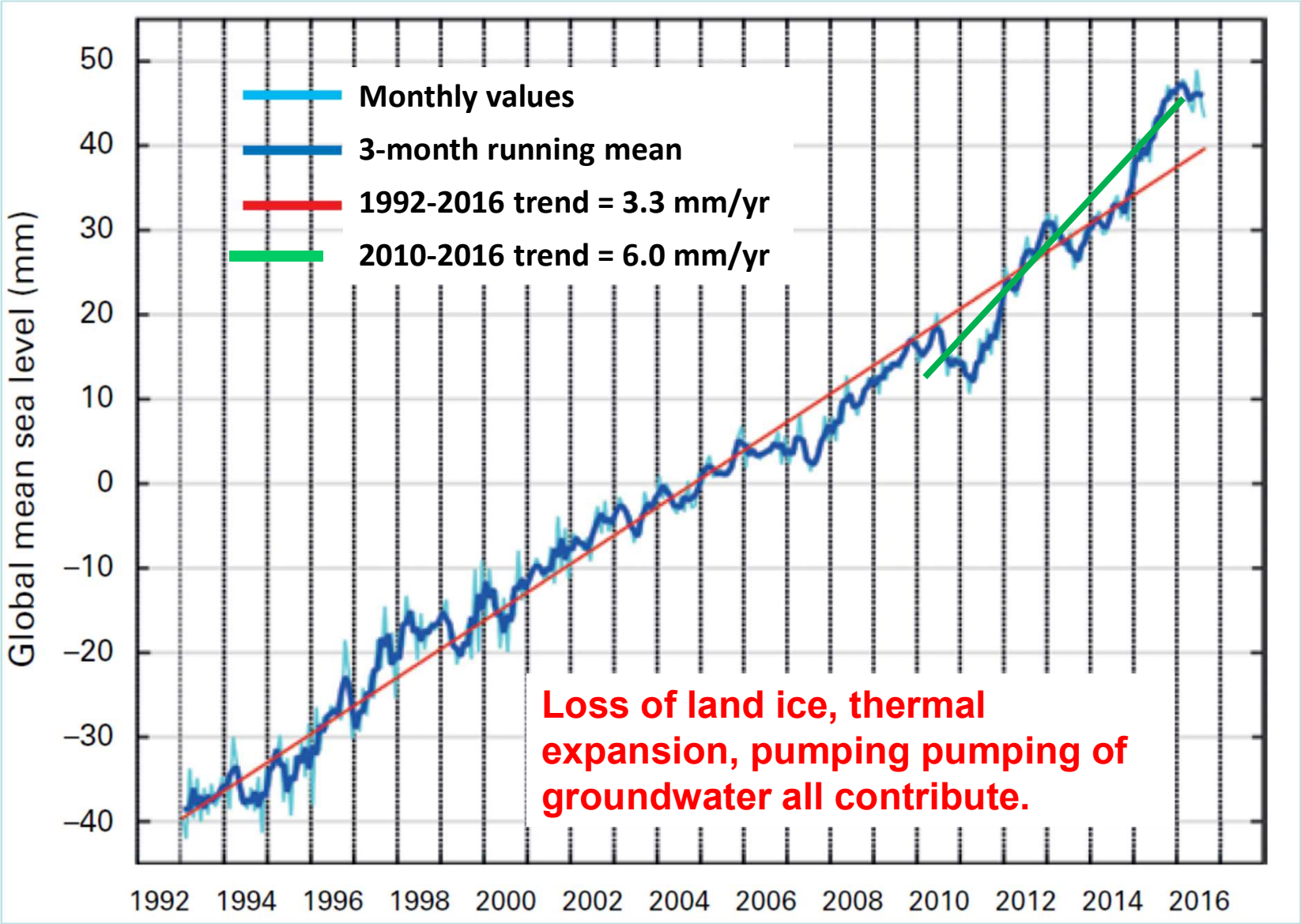
Character of human-caused climate change

The changes include: Ice loss from Antarctica



Character of human-caused climate change

The changes include: Accelerating sea-level rise

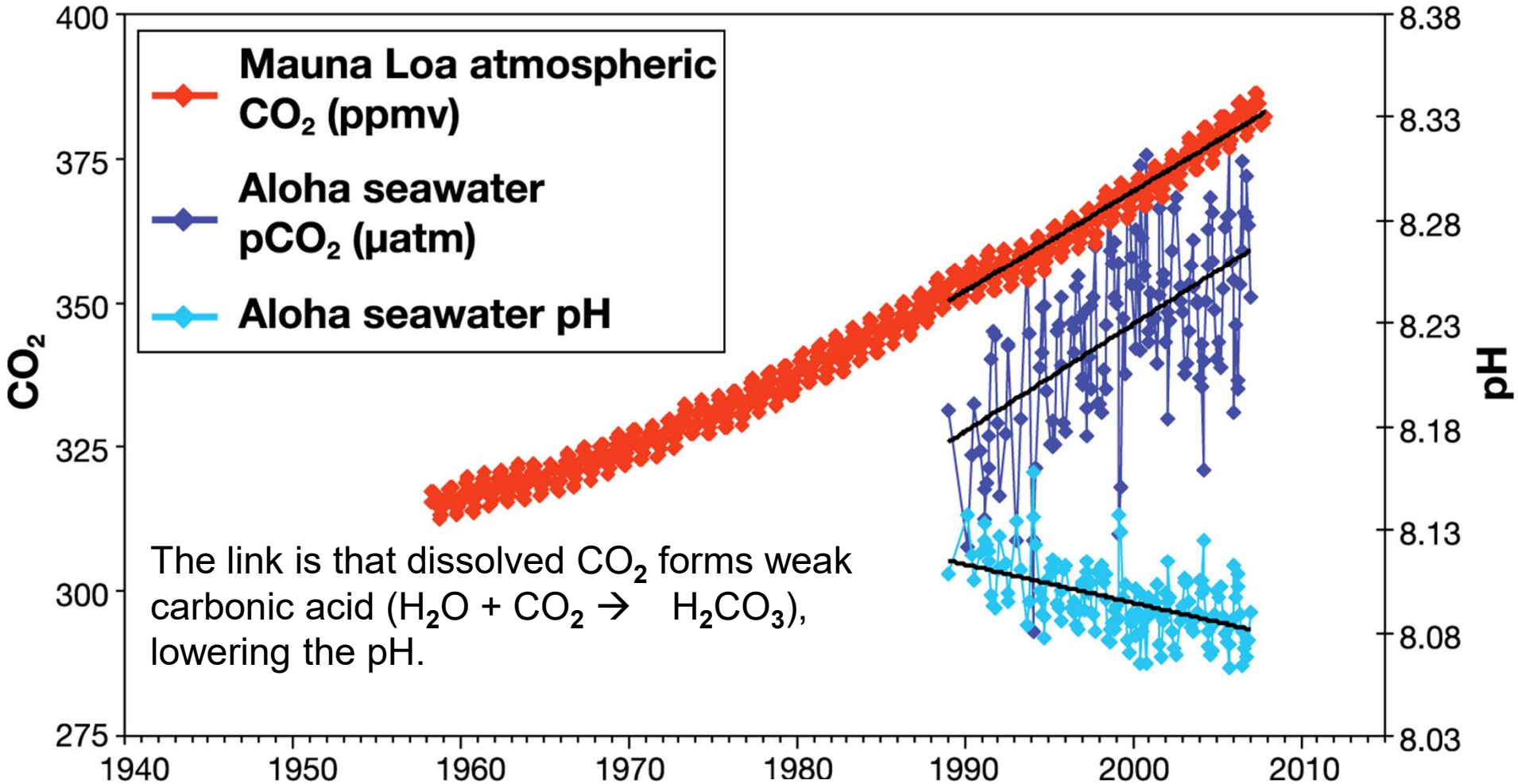


WMO 2017

Character of human-caused climate change

And human CO2 additions are acidifying the ocean

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).



The link is that dissolved CO_2 forms weak carbonic acid ($H_2O + CO_2 \rightarrow H_2CO_3$), lowering the pH.

World Bank / Potsdam Institute Nov 2012

U.S. Interests at Stake in Global Climate Change

U.S. Interests

Why worry? What harm can it do?

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

How global climate change & responses to it affect the United States

ENVIRONMENT

- Damage to life, health, property, & ecosystem services from increased frequency and/or intensity of heatwaves, wildfires, powerful storms, torrential downpours, floods, sea-level rise, and ocean acidification

NATIONAL SECURITY

- Potential for conflict drawing in the United States resulting from climate-driven political instability in & refugee flows from other countries
- Additional demands on U.S. forces for rescue & recovery after climate-linked weather disasters
- Impacts of climate change on bases and capabilities

How global climate change & responses to it affect the United States

ECONOMY

- Impacts of climate change on economic infrastructure, wealth, income, & livelihoods
- Economic benefits of U.S. leading in technological innovation to reduce emissions in ways that create jobs, save energy & thus money, and create economically valuable side benefits (e.g., reduced smog)
- Economic risk of conceding leadership in climate-mitigation and –adaptation technologies to other countries, forcing United States to import these technologies rather than making & exporting them.

The Harm That’s Already Occurring

Harm Already Occurring

It's too late to avoid "dangerous interference"

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

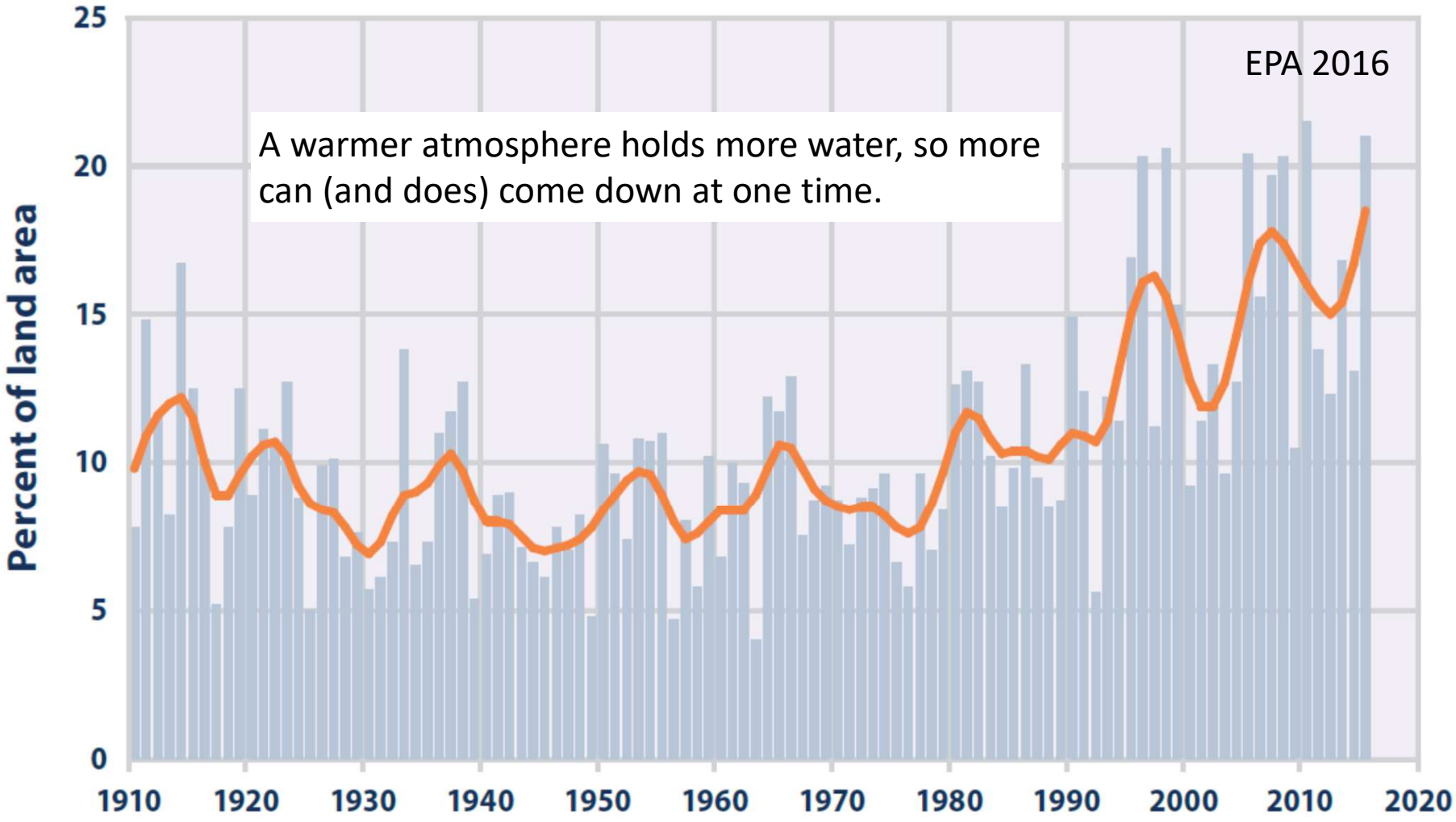
- floods
- drought
- wildfires
- heat waves
- pest outbreaks
- coral bleaching
- permafrost subsidence
- coastal erosion & inundation
- power of the strongest storms

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

Harm already occurring

Ongoing harm: heavier downpours → flooding

Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2015



Harm Already Occurring

Downpours → Flooding (continued)

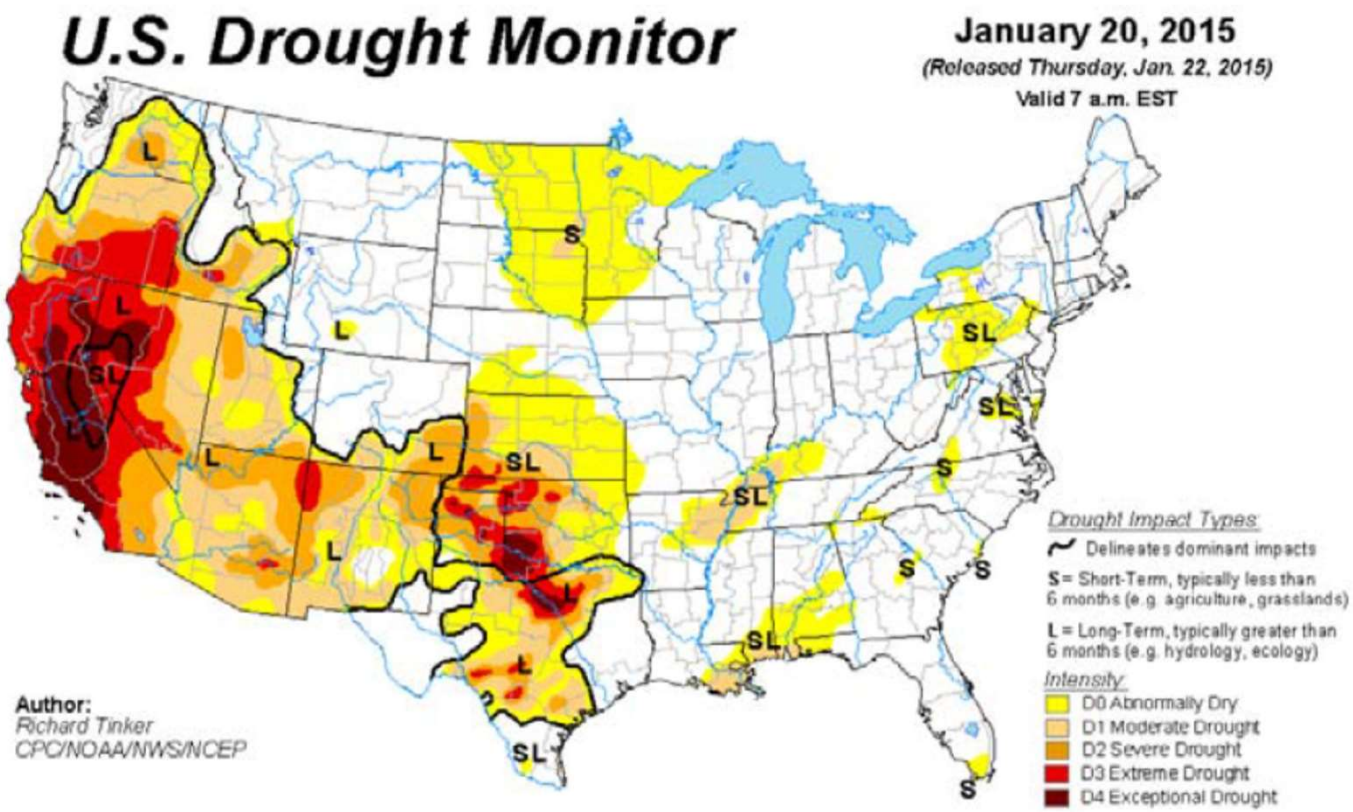
"Thousand-year" floods are now occurring much more frequently than that.

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

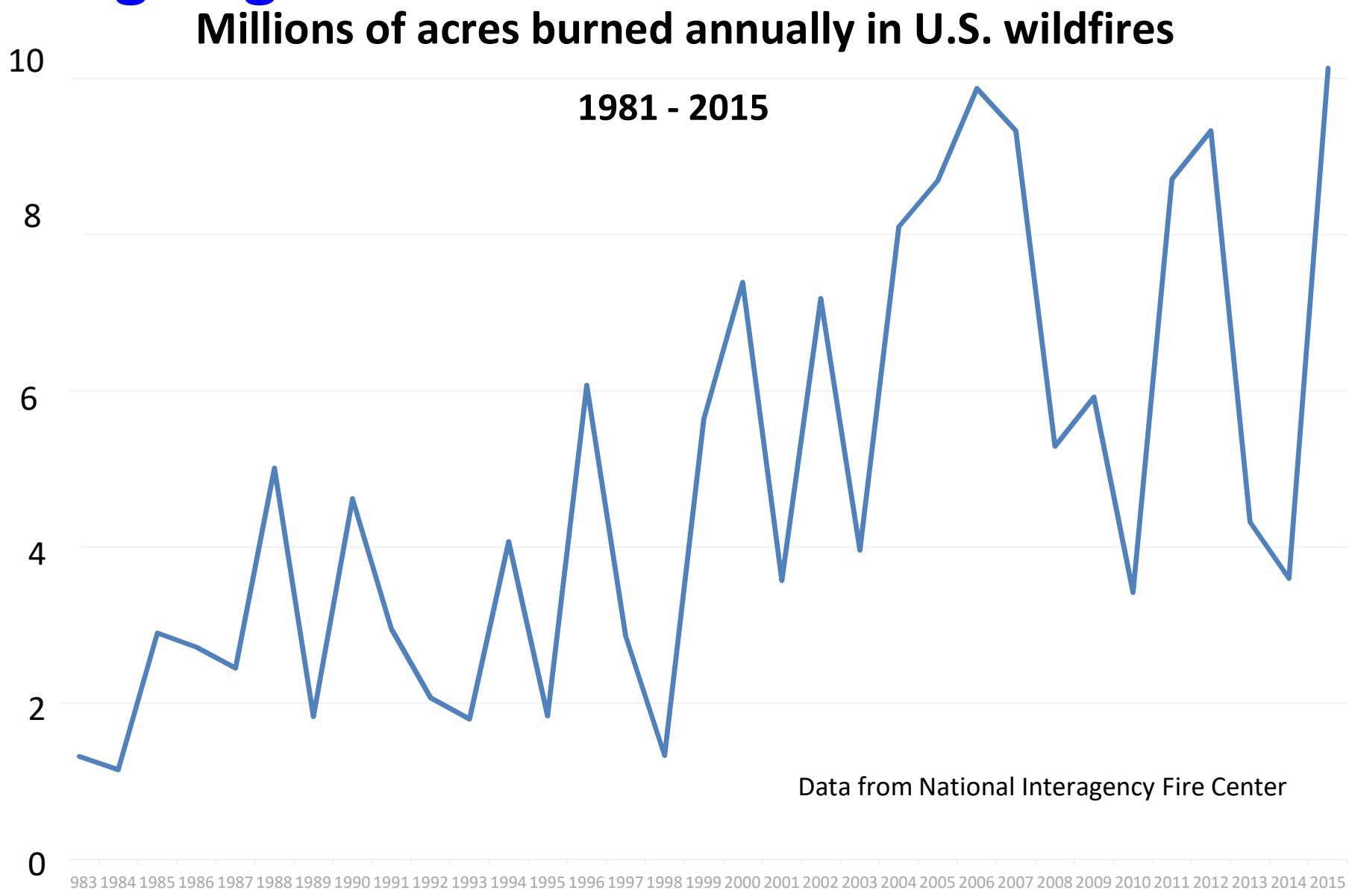
Harm Already Occurring

Ongoing harm: drought

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

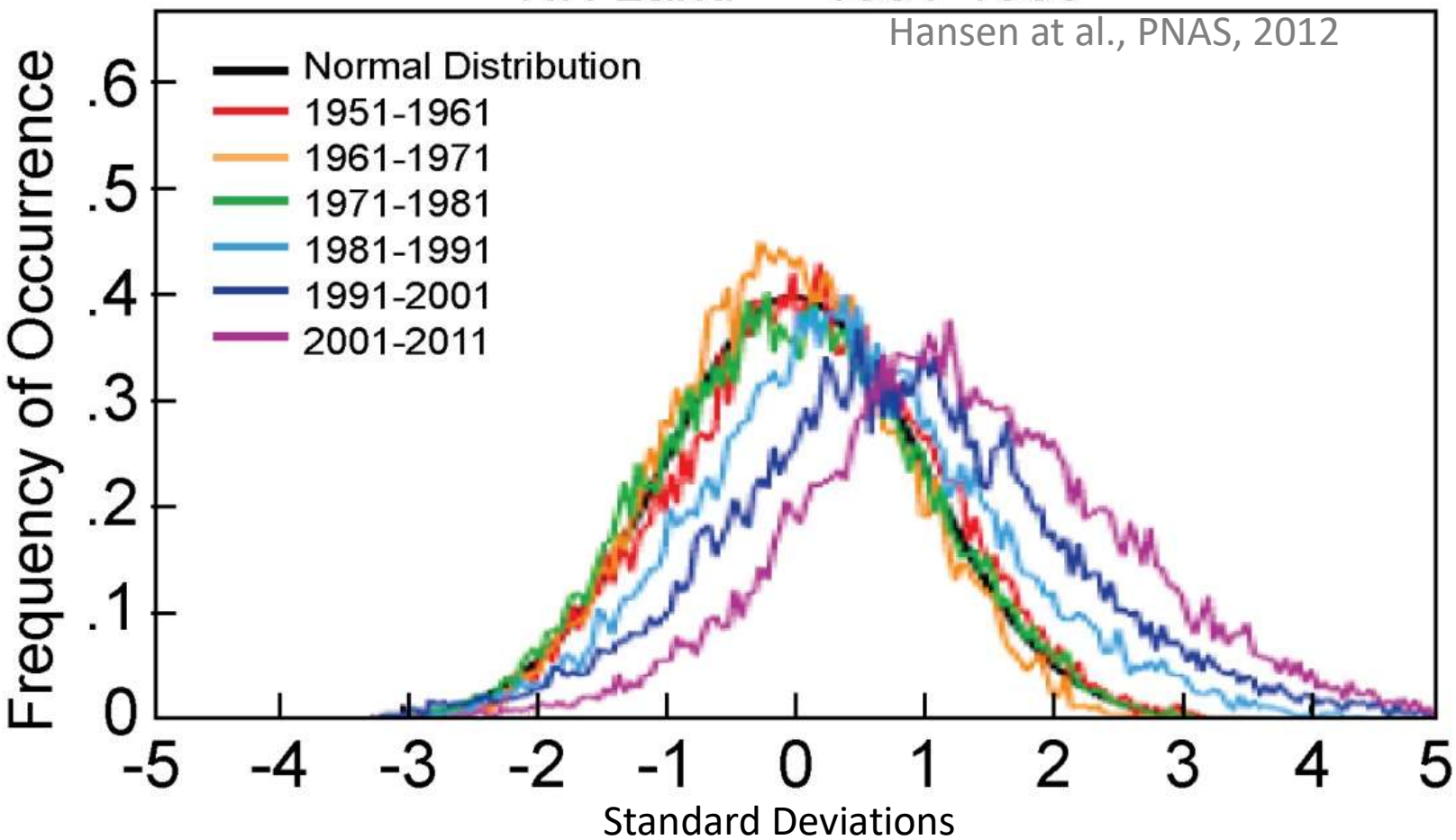


Ongoing harm: wildfires



Ongoing harm: heat waves

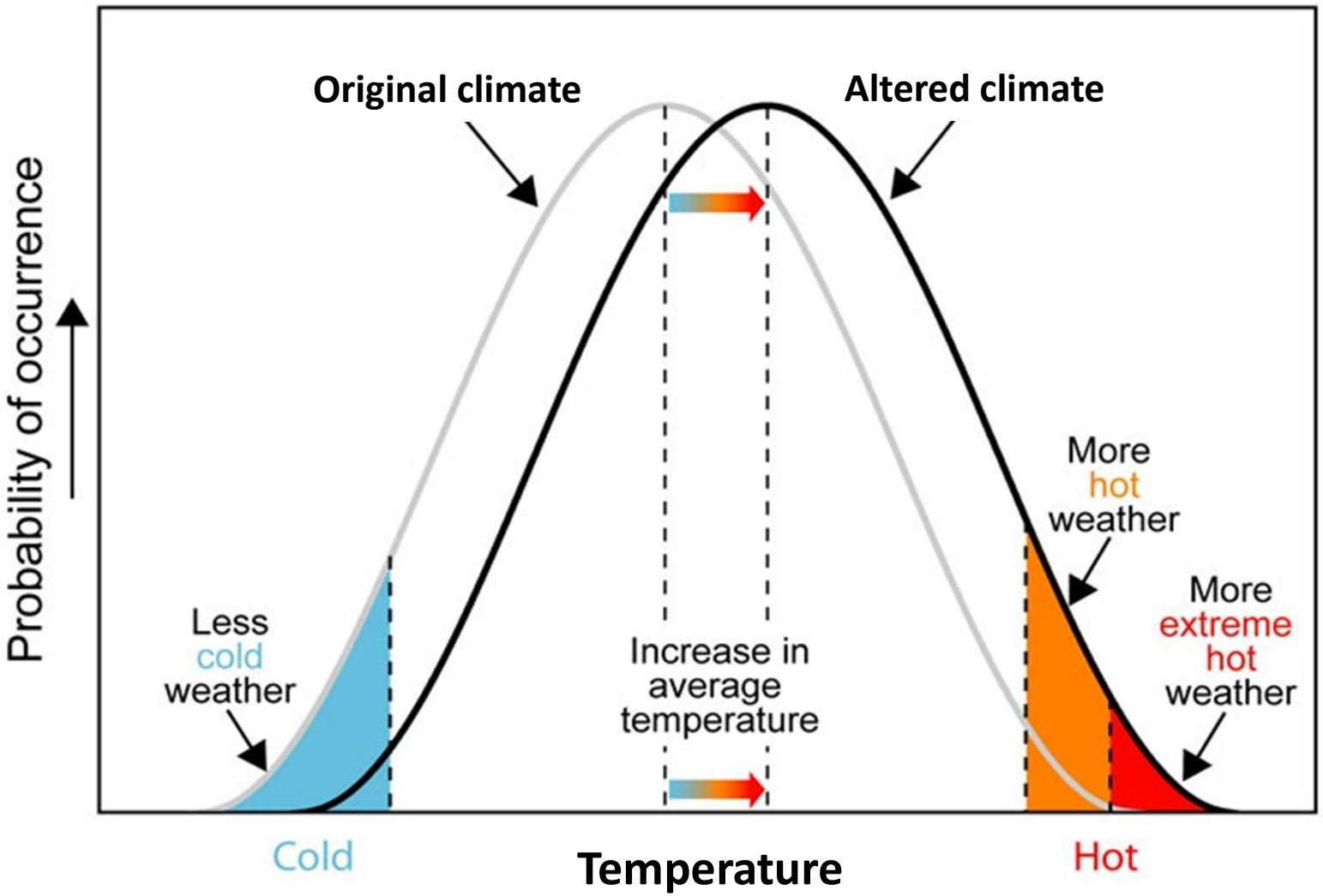
Probability distribution for Jun-Jul-Aug temperature anomaly on land in the Northern Hemisphere. Baseline normal distribution is for 1951-80.



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.

Ongoing impacts on people and ecosystems

The observed changes—big increases in extremes with small shift in average T—were to be expected.



This is a fundamental property of the "normal" distribution of anything.

Harm Already Occurring

Ongoing harm: Pest outbreaks

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

USGCRP 2009

Harm Already Occurring

Ongoing harm: coral bleaching

Jarvis Reef, South Pacific (courtesy WHOI)

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

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

Harm Already Occurring

Ongoing harm: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

Harm Already Occurring

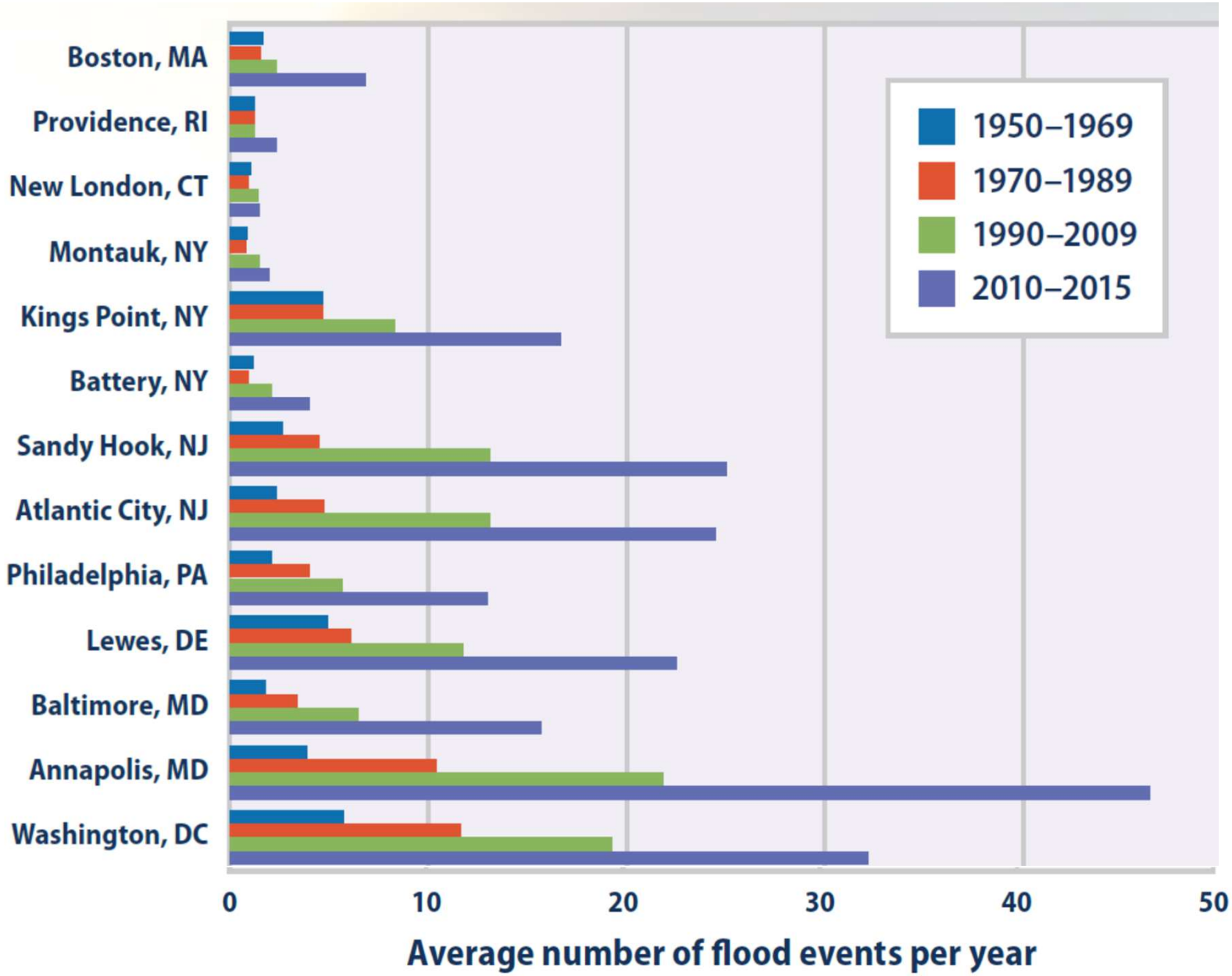
Ongoing harm: rising sea → coastal erosion

Shishmaref, Alaska

Courtesy Gary Braasch

Harm Already Occurring

Rising sea → coastal inundation



Stronger storms

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

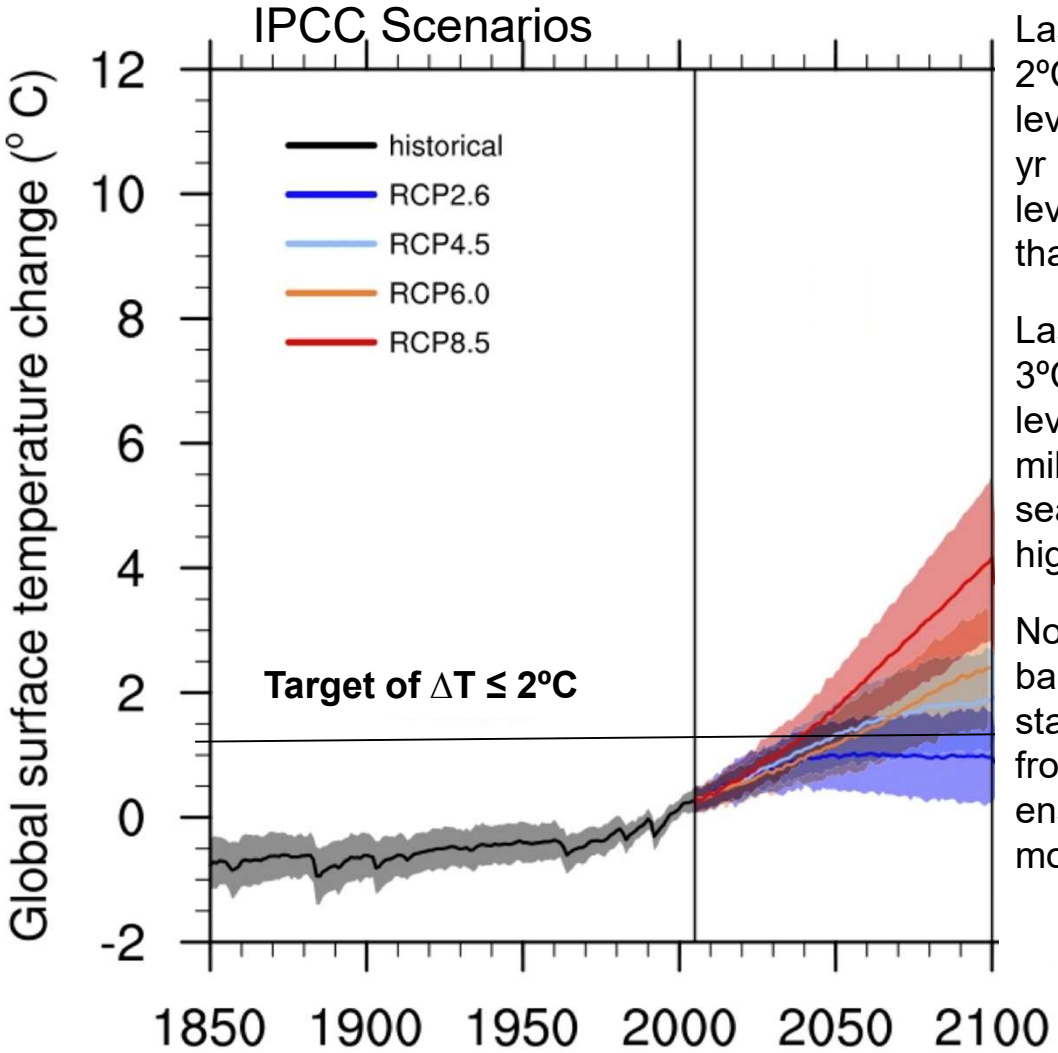
Science: Plausible Projections
(Likely True Under Assumed Emissions)

"Prediction is difficult…especially about the future."

attributed to Yogi Berra and Neils Bohr

Science: Plausible Projections

Looking ahead: T and impacts grow for decades under all scenarios.



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

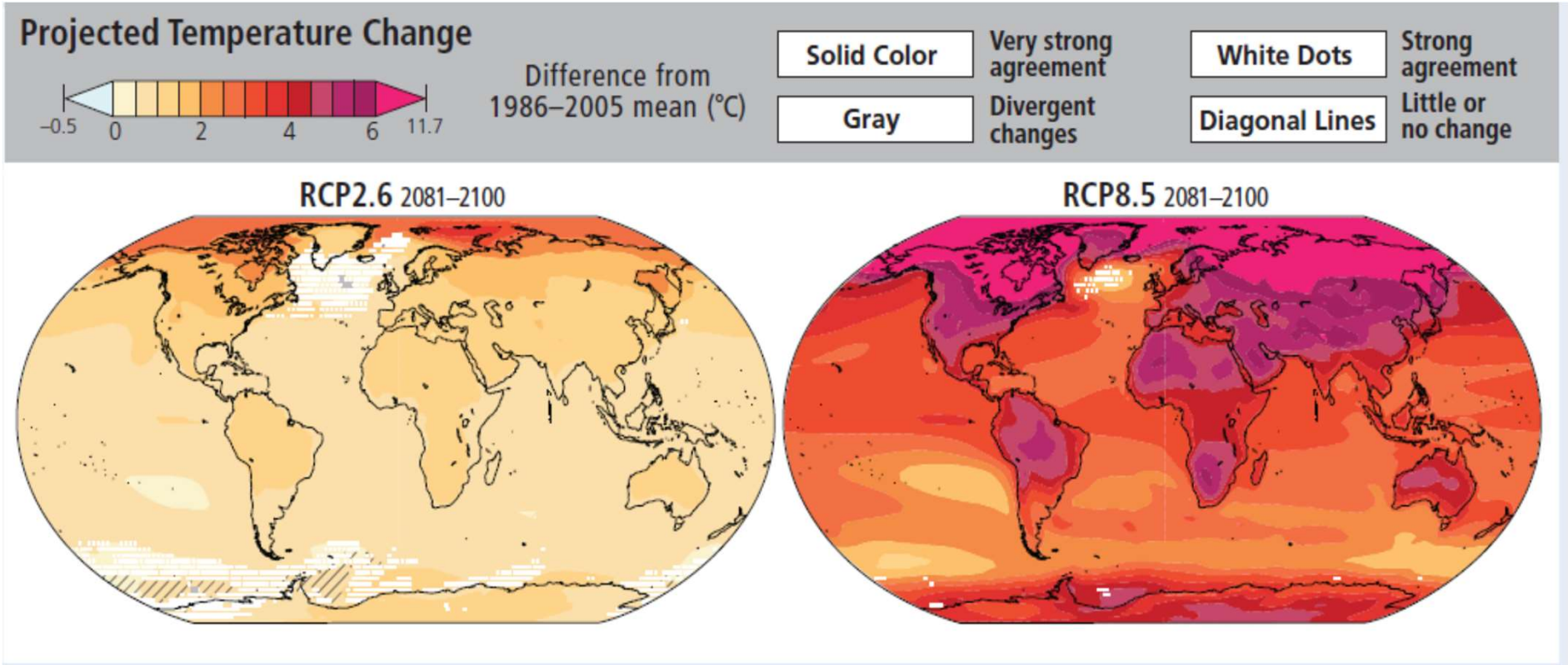
Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

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

IPCC 2013

Science: Plausible Projections

But there's a big difference in expected harm depending on the action society takes



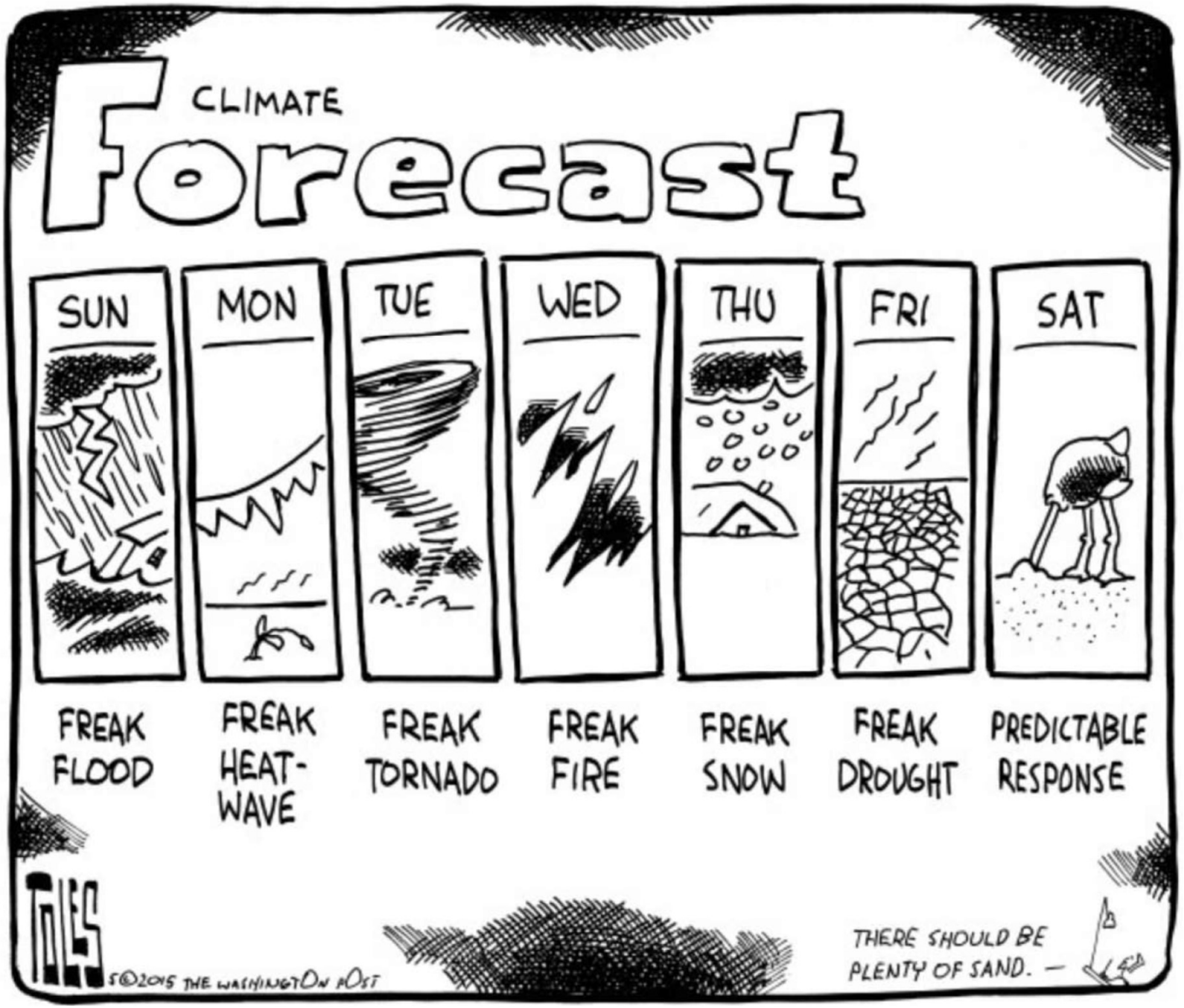
IPCC WGII, 2014

The high-emissions scenario, with global avg T increase of 5°C or more, would entail catastrophic impacts.

Science: Plausible Projections

For example, in the high-emissions (BAU) case:

- By the second half of this century…
  - heat waves of the sort that killed 70,000 people in Europe in 2003 would be the summer norm;
  - in much of the world, working or exercising outside in the hottest part of year would risk death;
  - regions prone to drought & wildfires would experience multiples of today's worst;
  - the world's coral reefs and the biodiversity they support would mostly be gone.
- Sea-level rise…
  - could reach 2 meters by 2100;
  - would likely reach 10 m or more in later centuries.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Forecast
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FREAK FIRE
FREAK SNOW
FREAK DROUGHT
PREDICTABLE RESPONSE
TALES
©2015 THE WASHINGTON POST
THERE SHOULD BE PLENTY OF SAND. —

Science: Possibilities

(Plausible Mechanisms, Unknown Probabilities)

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

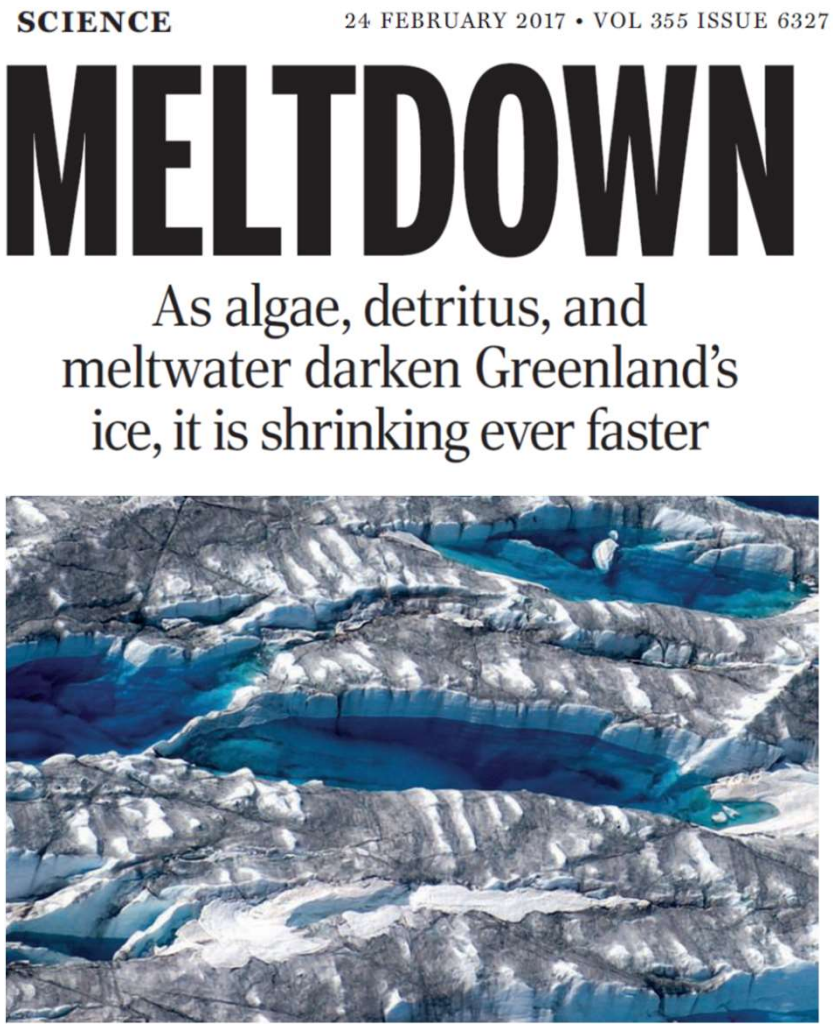
Various

The most worrisome possibilities

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

Science Possibilities: Could Sea-Level Rise Accelerate Sharply?

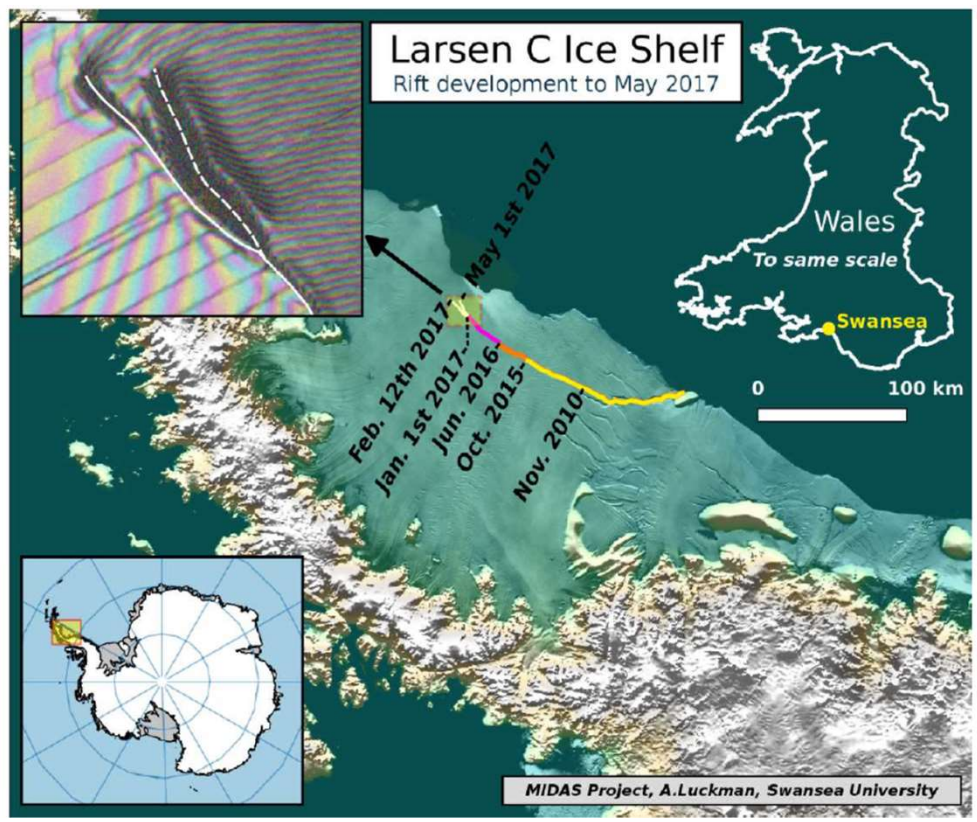
Recent studies have shed new light on mechanisms for rapid ice loss from Greenland & Antarctica


SCIENCE 24 FEBRUARY 2017 • VOL 355 ISSUE 6327

MELTDOWN

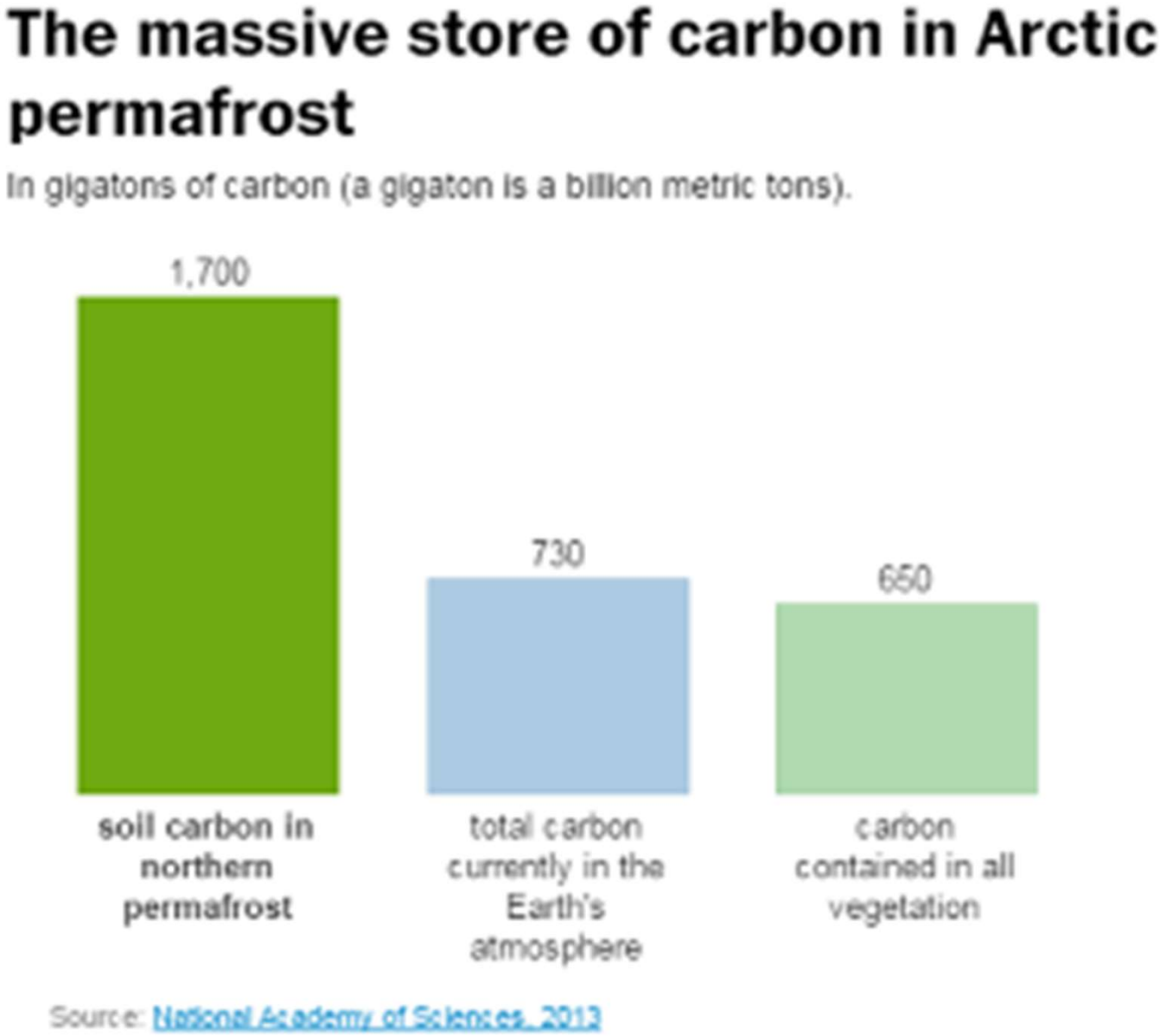
As algae, detritus, and meltwater darken Greenland's ice, it is shrinking ever faster

Disintegration of the fringing sea-ice shelves in Antarctica could greatly accelerate flow of land ice to the sea.



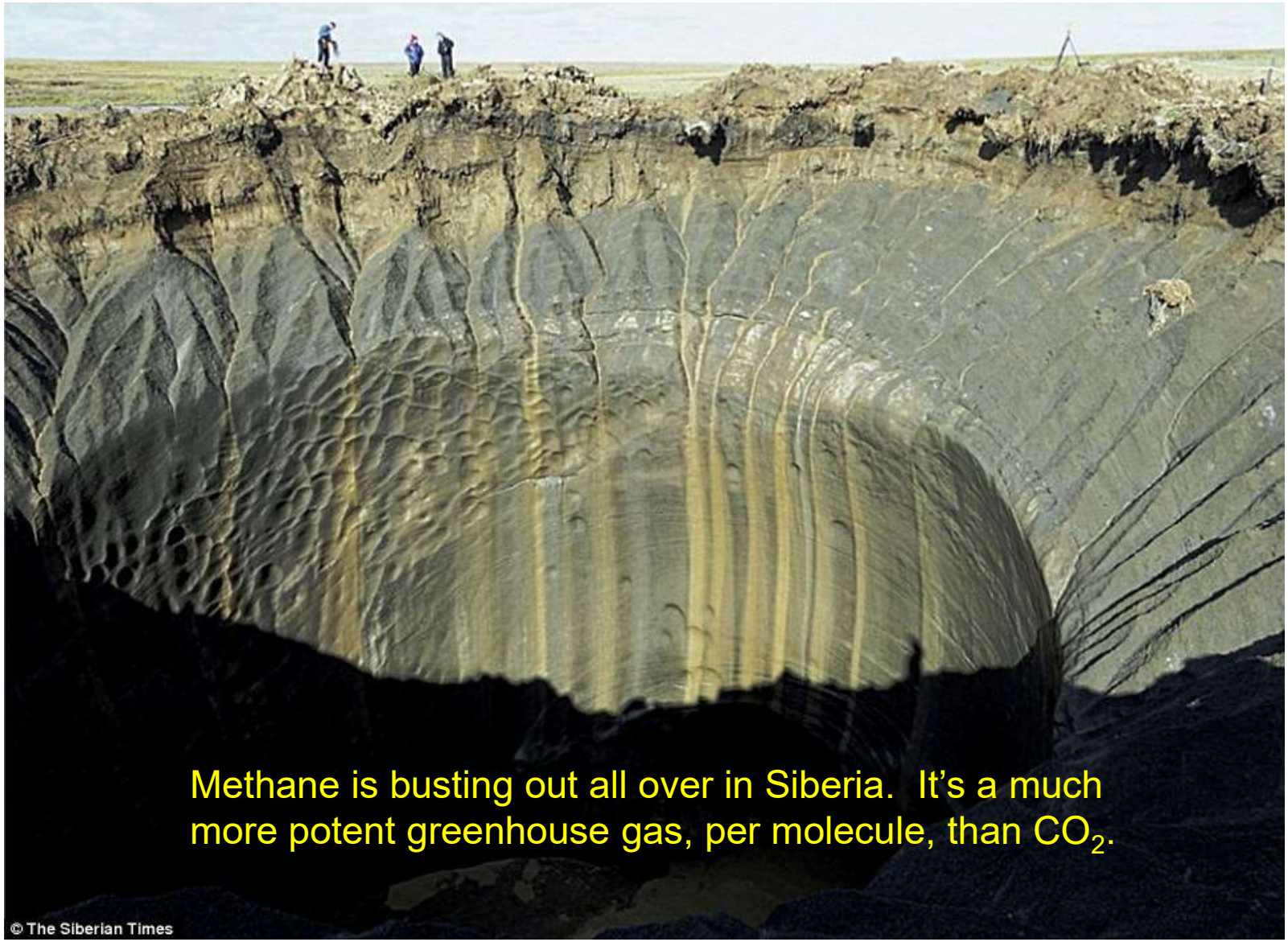
Science Possibilities: Could emissions from Arctic soils spike?

CO_2 & CH_4 from Arctic soils could wreck the climate



Science: Possibilities: Could emissions from Arctic soils spike?

Methane-burst crater in the Siberian tundra



Society's Options
For Affecting These Outcomes

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

Lao Tzu

What can we do?

There are only three options:

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

Concerning the three options…

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

Adaptation possibilities include…

- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Preserving & enhancing "green infrastructure" (ecosystem features that protect against extremes)
- Preparing hospitals & transportation systems for heat waves, power outages, and high water.
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

Many are "win-win": They'd make sense in any case.

Mitigation possibilities include…

(CERTAINLY)

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

(CONCEIVABLY)

- "Scrub" greenhouse gases from the atmosphere technologically
- "Geo-engineering" to create cooling effects offsetting greenhouse heating

How much mitigation, how soon?

- Limiting ΔT_{avg} to ≤2ºC is now considered by many the most prudent target that still may be attainable.
  - EU embraced this target in 2002, G-8 & G-20 in 2009
  - Paris added 1.5°C as "aspirational goal" in 2015
- To have a >50% chance of staying below 2ºC:
  - atmospheric concentration of heat-trapping substances must stabilize at around 450 ppm CO_2 equivalent (CO_2e);
  - to get there, developed-country emissions needed to peak around 2015 and decline rapidly thereafter, and
  - developing-country emissions must peak no later than 2025 and decline rapidly thereafter.

What Did Obama Do?

"The first law of holes: When you're in one, stop digging"

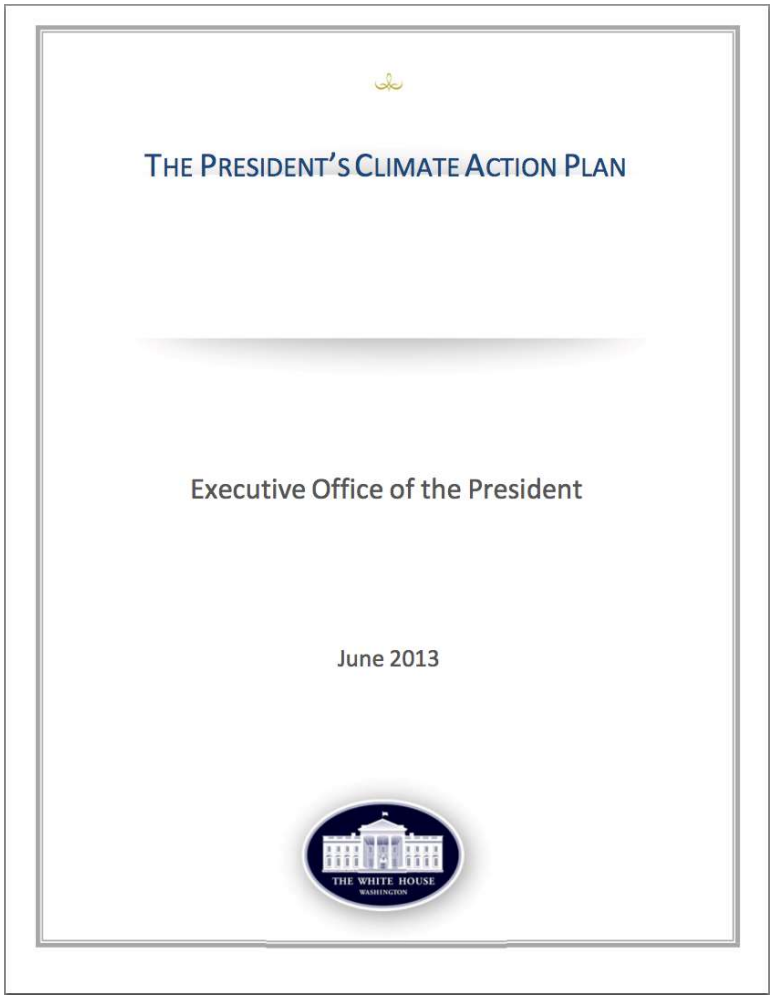
Will Rogers

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 six 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

The 2nd term: Obama's Climate Action Plan

Georgetown University, June 2013



THE PRESIDENT'S CLIMATE ACTION PLAN

Executive Office of the President

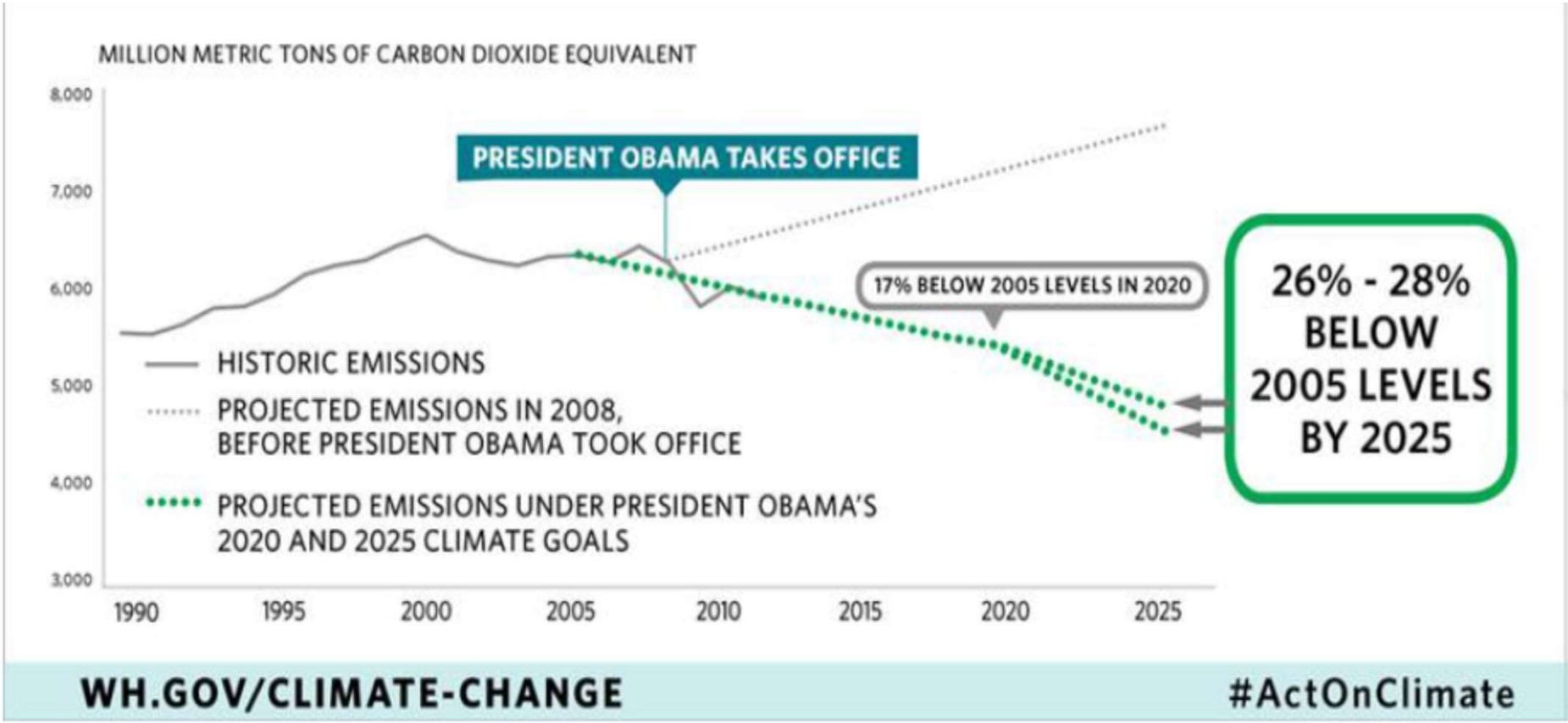
June 2013

THE WHITE HOUSE
WASHINGTON

- 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 U.S. emission target for 2025 announced by President Obama in Beijing in Nov 2014



The U.S. energy-climate record under Obama

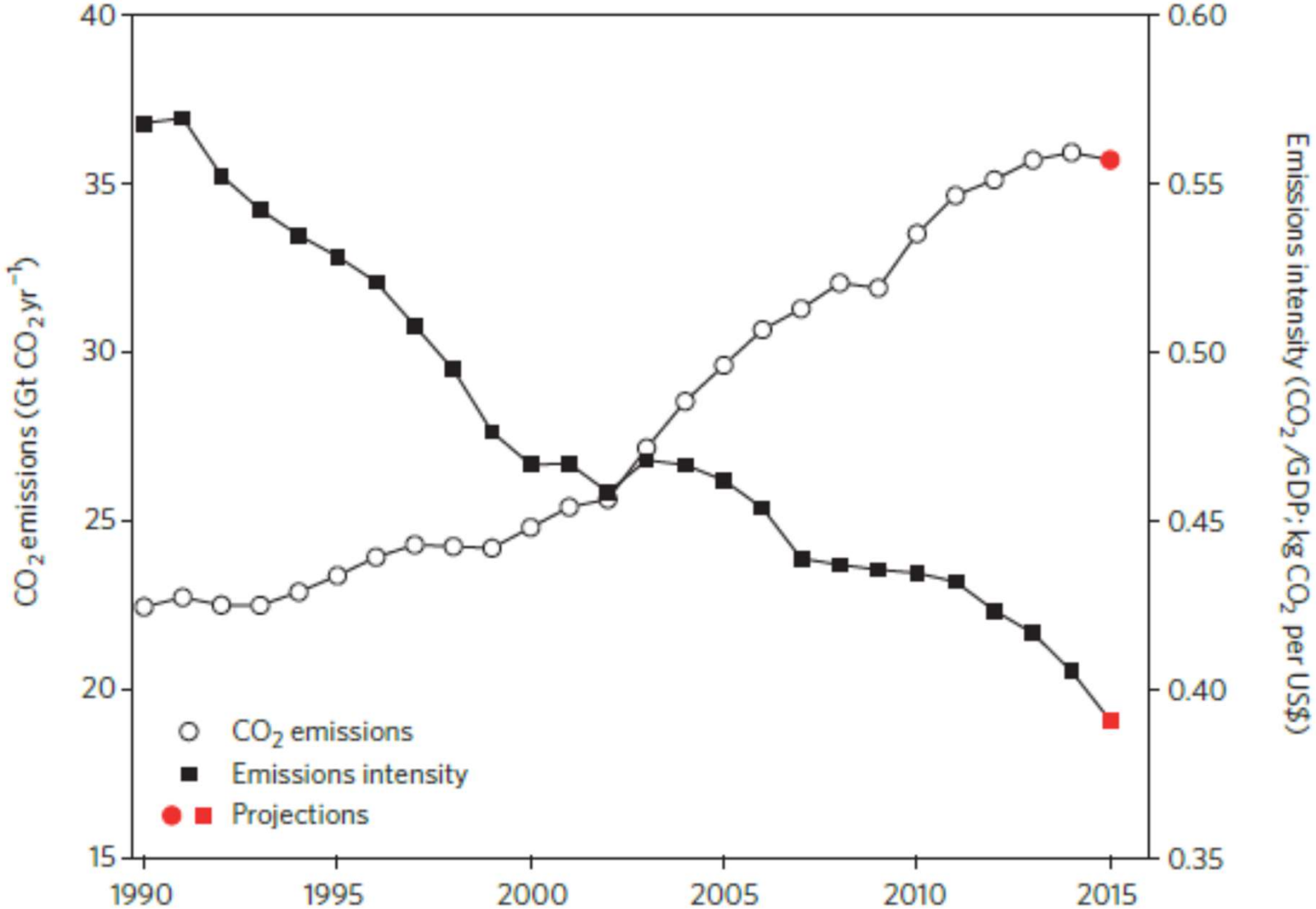
	2008	2016	change
Fossil E (quads)	83.2	78.6	-5.5%
Renewable E (quads)	7.2	10.2	+41.7%
Total E (quads)	98.9	97.4	-1.5%
Coal electricity (kWh)	1986	1240	-37.6%
Gas electricity (kWh)	883	1380	+56.3%
Wind electricity (kWh)	55.4	226.5	+4.1-fold
Solar electricity (kWh)	0.9	36.8	+42.5-fold
Total electricity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

EIA Monthly Energy Review, 03-28-17

The Paris agreement (December 2015)

- 195 nations embraced Intended Nationally Determined Contributions for emissions reductions out to 2025 or 2030.
- Accounting and reporting provisions were made legally binding (but achieving the voluntary target is not).
- All countries will revisit commitments at 5-year intervals with a view to increased ambition.
- Mitigation & adaptation assistance to countries in need pledged to reach $100B/year by 2020 and remain at that level or more until at least 2025.
- Under a side agreement called “Mission Innovation”, 20 developed countries agreed to double gov’t clean-energy R&D over 5 years.

Global industrial CO2 emissions through 2015



Jackson et al., Nature Climate Change, January 2016

Looking Ahead:
What Is Trump Doing?
What Should <u>We</u> Do?)

"We're not spending money on [climate change] any more.
We consider that to be a waste of your money."

Trump OMB Director Mick Mulvaney

Looking Forward: What will Trump do?

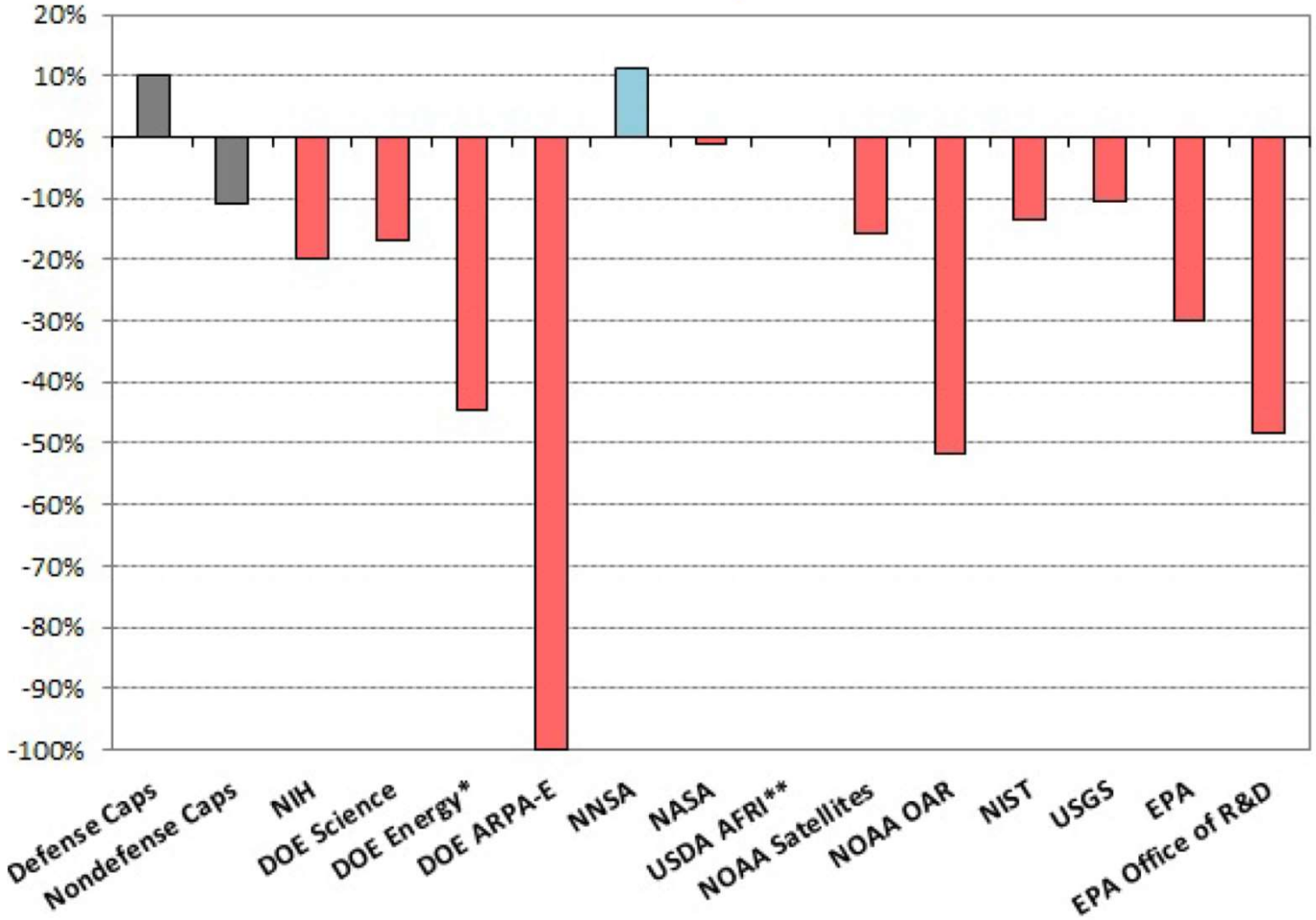
What Trump is doing (or proposing) so far

- Appointment of climate contrarians to key posts
- Drastic cuts in budget & authority for EPA
- Other cuts in climate-change monitoring & analysis
  - Zeroing important Earth-observation and climate-monitoring satellite missions at NASA
  - Cutting ocean grants & programs by $250M (NOAA)
- Cuts in energy R&D at DOE
  - Zeroing ARPA-E
  - Cutting other energy R&D by $2B
- Roll-back / “re-examination” of Obama climate EOs
  - Clean Power Plan, methane strategy, climate/NEPA, SSC
  - Adaptation/Resilience support: USA & international

What Trump has done (or proposed) so far

Agency S&T Budgets

Trump proposed FY18 versus FY16 (% change in nominal dollars)



*Includes renewables and efficiency, nuclear, fossil, grid research. **Flat-funded in FY18 request.
NOTE: FY 2016 is used as a baseline given lack of final FY 2017 appropriations.
Based on initial AAAS assessment of the FY 2018 budget summary and past agency budget data. March 16, 2017 | AAAS

What should the S&T community do?

- Keep doing our work, while looking for alternatives to Federal government funding (states, firms, philanthropy)
- Keep talking about the results and their implications
- Get better at explaining the science to laypeople, not just what we know & why it matters, but…
  - How we know it
    - Diversity & robustness of reinforcing lines of evidence
    - Sources of credibility in science
  - The imprudence of ignoring it
    - Two-sidedness of uncertainties
    - Rarity of "revolutions" overturning scientific consensus
- Tithe 10% of our time to public & policy-maker education and policy/political activism
  - Provide citizens & legislators with the knowledge they need to defend respect for science in policy-making

“Trend is not destiny.”

Rene Dubos