The Climate-Change Challenge Today:
An Update on Science and Policy
(with good news & bad news on each)

John P. Holdren

Teresa & John Heinz Professor of Environmental Policy
Harvard University
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(January 2009 – January 2017)

Keynote Lecture

The M.I.T. Climate-Change Symposium

Airlie House • March 29, 2017

Science

GOOD NEWS

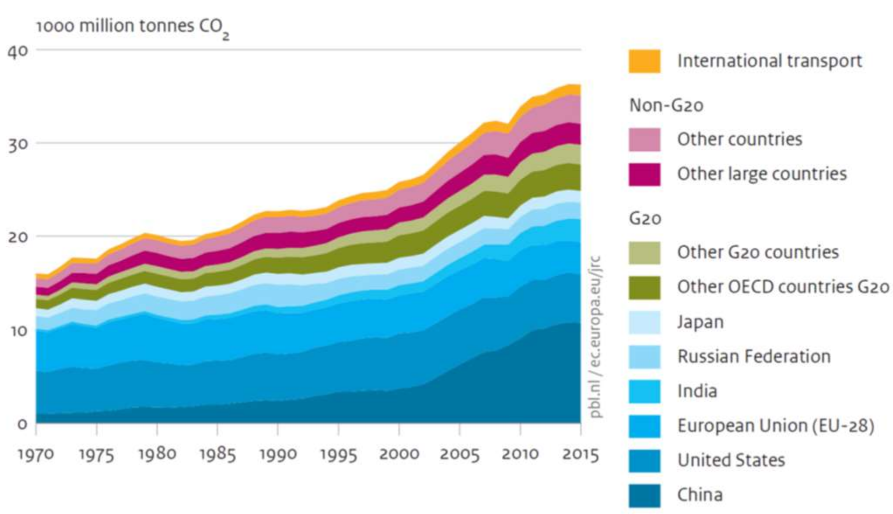
- Continuing observations & paleoclimatological analyses are clarifying what is extraordinary about current climate change.
- GCMs & integrated-assessment models are improving and shedding new light on challenges & options.

BAD NEWS

- Most of the new insights from additional observations, better GCMs, and new analyses indicate that the reality is worse rather than better than previously supposed.
- Runs of current integrated-assessment models under-score that any delay in implementing rapid & deep emissions-reductions worldwide will likely entrain an unmanageable degree of climate change.

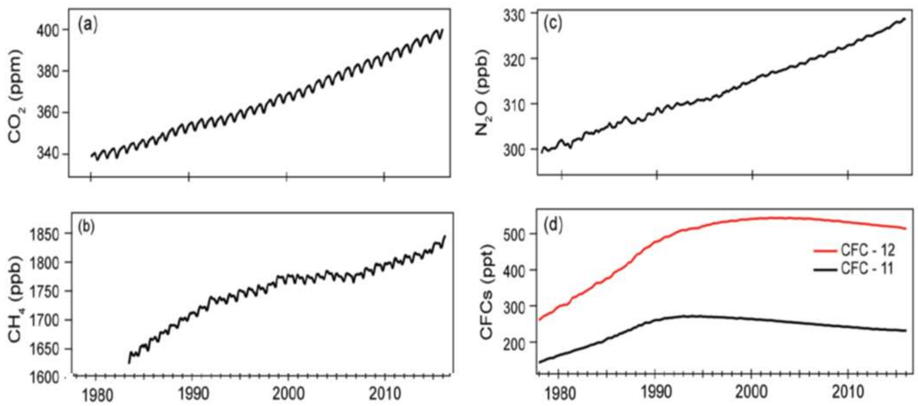
Science: Realities

Global emissions: leveling off



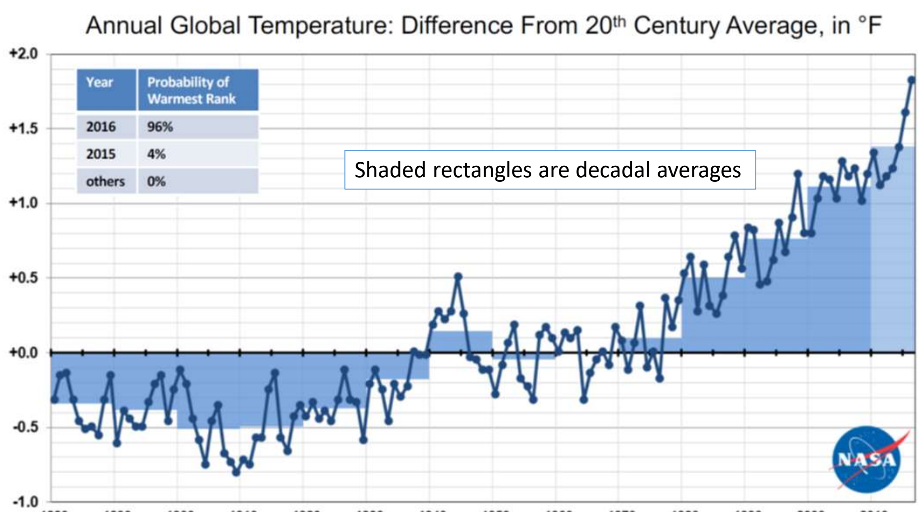
European Commission Joint Research Centre 2016

Concentrations: mostly still rising



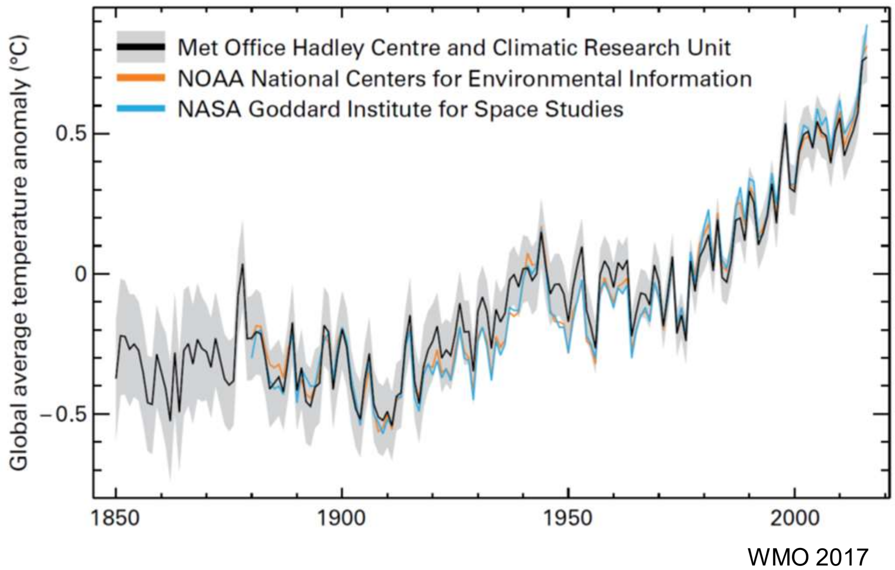
State of the Climate 2015, BAMS, 2016

Surface temperature: rising rapidly



January 2017 | NOAA/NASA – Annual Global Analysis for 2016

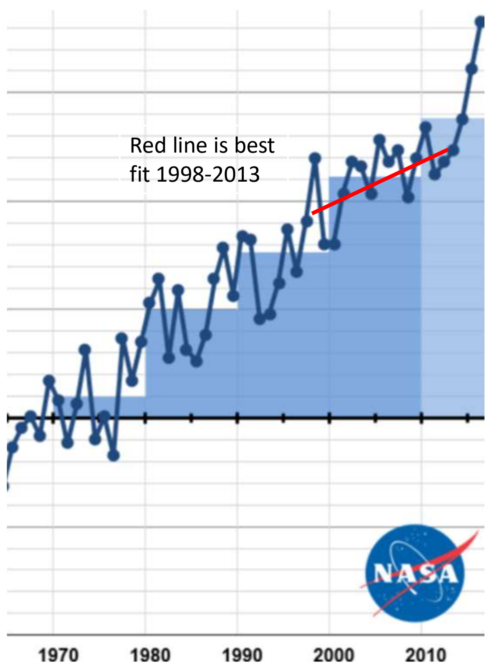
The major T datasets are in good agreement



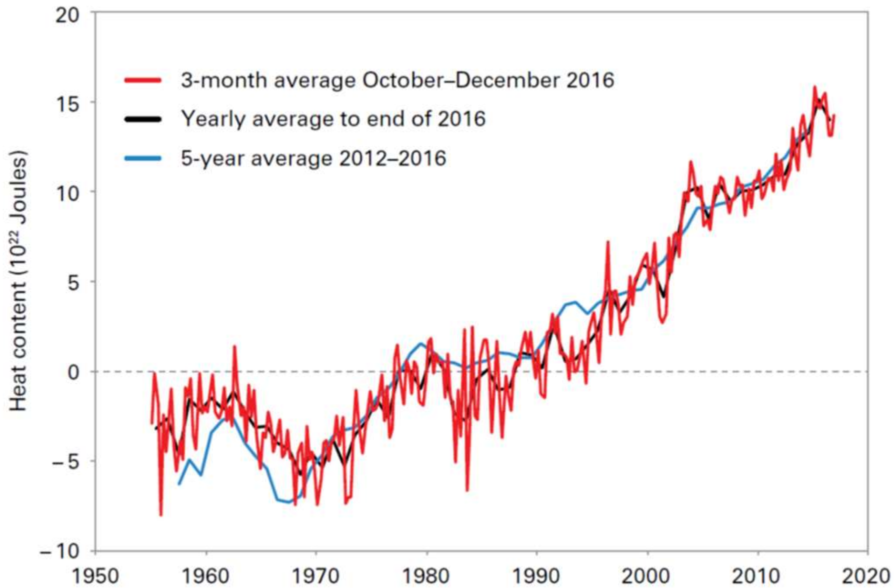
A "hiatus"?

"Hiatus means "pause". Some claimed there was a pause in warming for 10-15 years after 1998, because the anomalously high T that year (boosted by a strong El Niño) was about the same as the 2009 and 2013 values.

This claim "cherry picks" specific dates to compare. The scientific procedure is to find the best-fit straight line through the period of interest. By that standard, warming was slower between 1998 and 2013 than in the preceding 15 years, but didn't pause. And it has accelerated since.

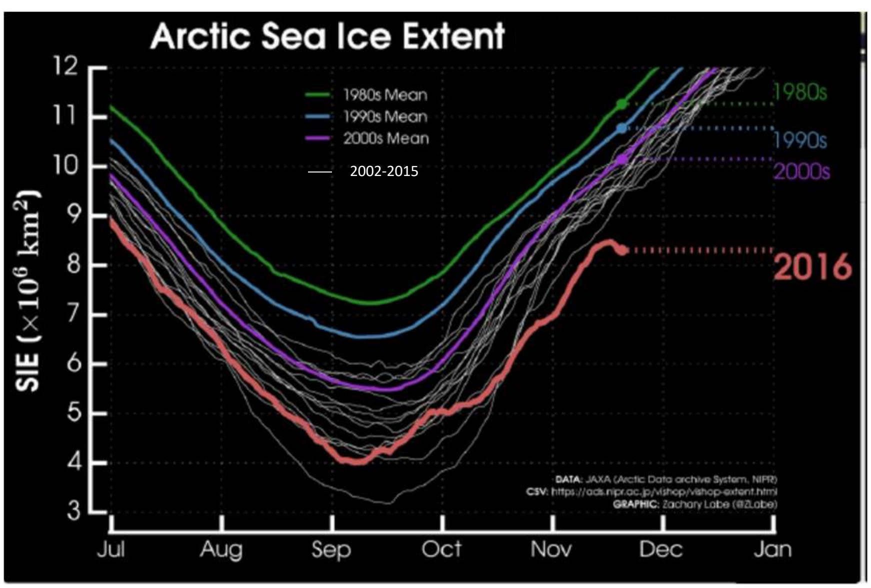


Global ocean heat content, 0-700 m depth

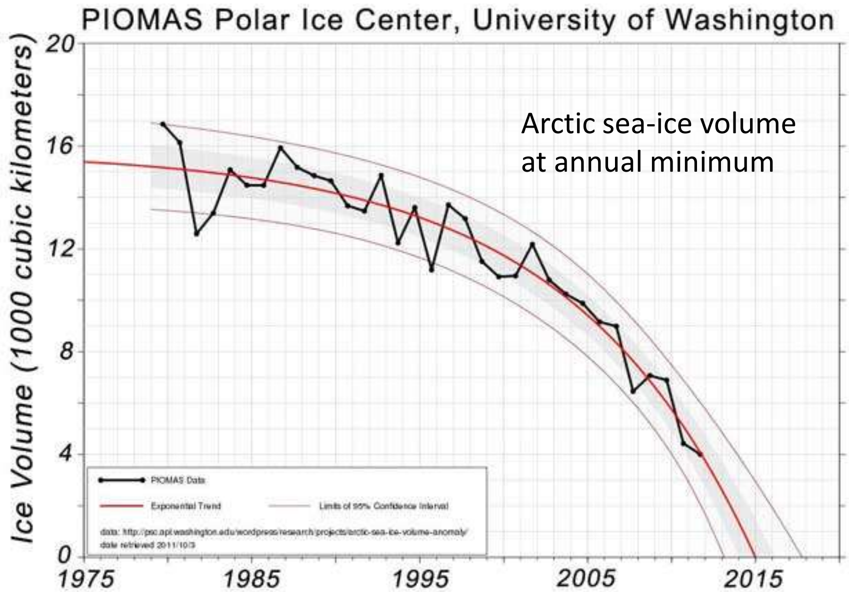


WMO 2017

Arctic sea-ice area: shrinking dramatically



Arctic sea-ice volume is shrinking even faster

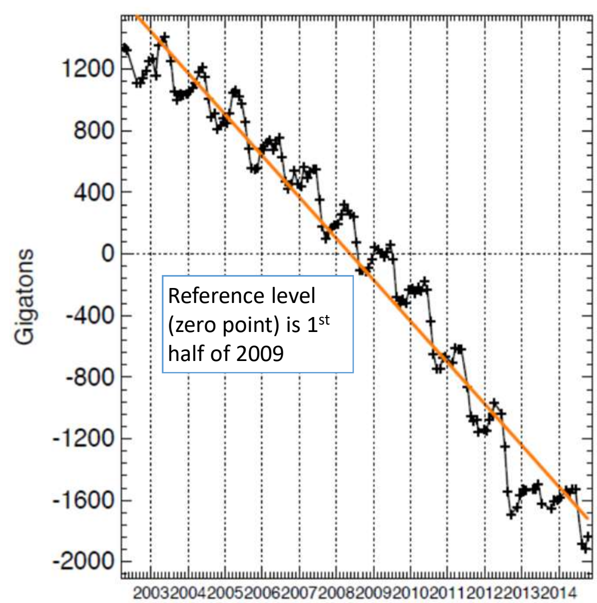


Mass of ice on Greenland: declining steeply

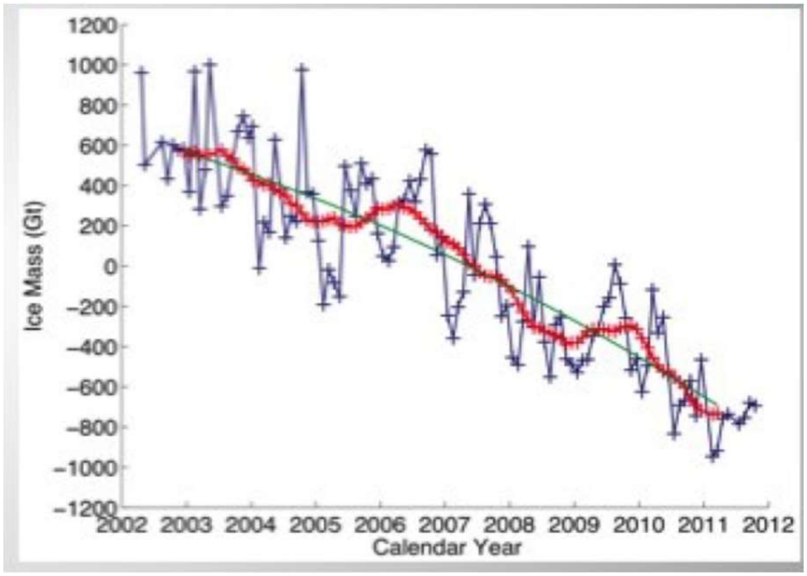
Land-ice loss from melting & accelerated calving of icebergs raises sea level.

Antarctic ice mass is shrinking, too.

Waleed Abdalati, from GRACE, December 2014

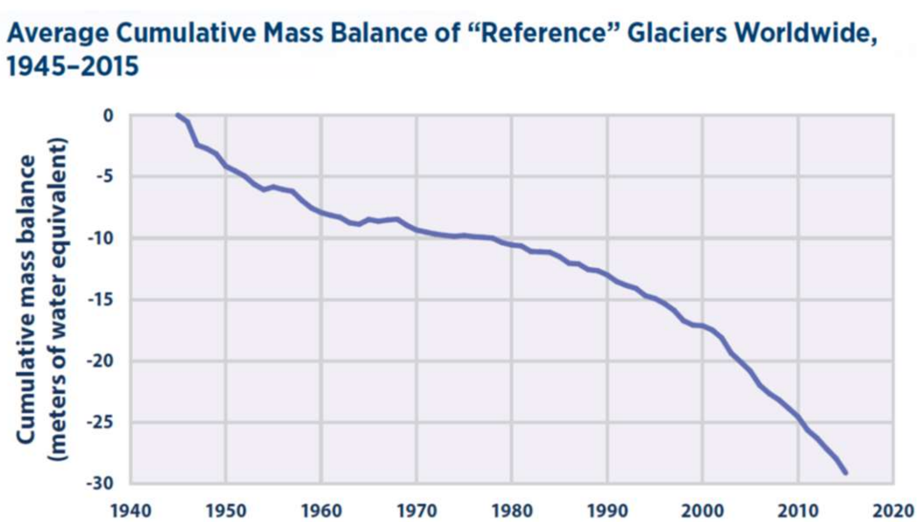


Antarctic ice mass also shrinking



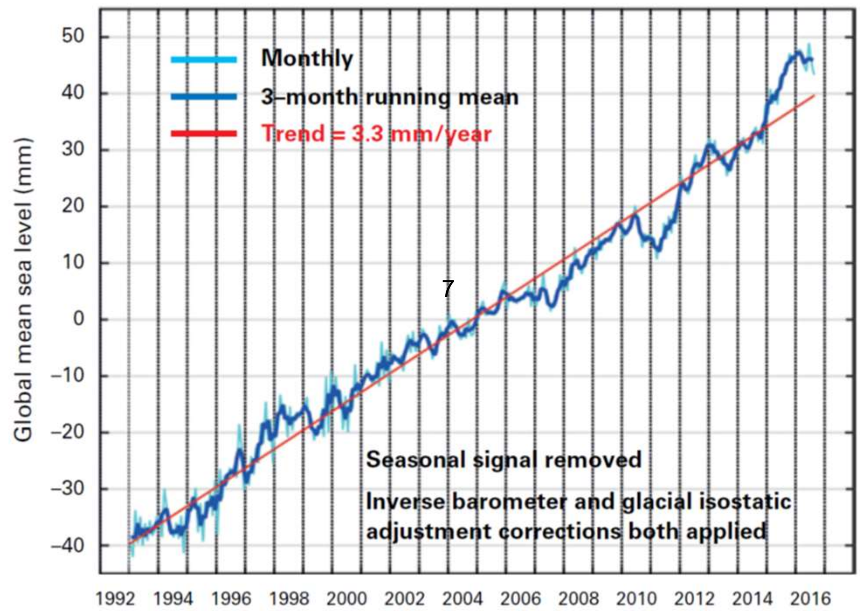
Data from GRACE (Velicogna and Wahr 2013)

Mass of mountain & coastal glaciers shrinking too



EPA 2016

Recent rate of sea-level rise > long-term trend



WMO 2017

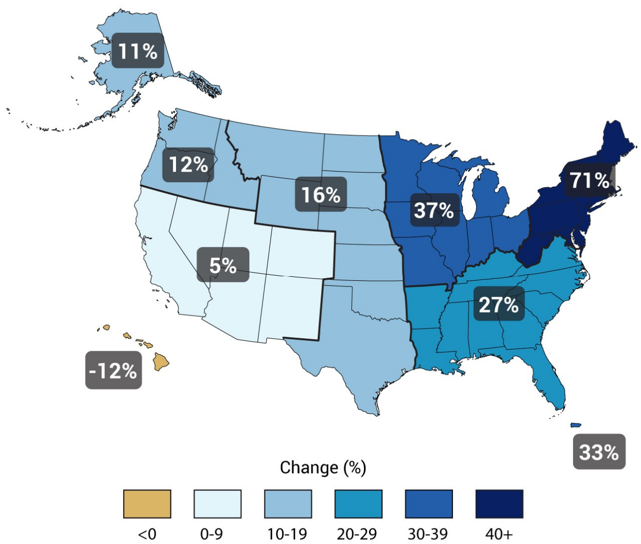
"Dangerous interference"? Already here.

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

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

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

Ongoing danger: heavier downpours → flooding

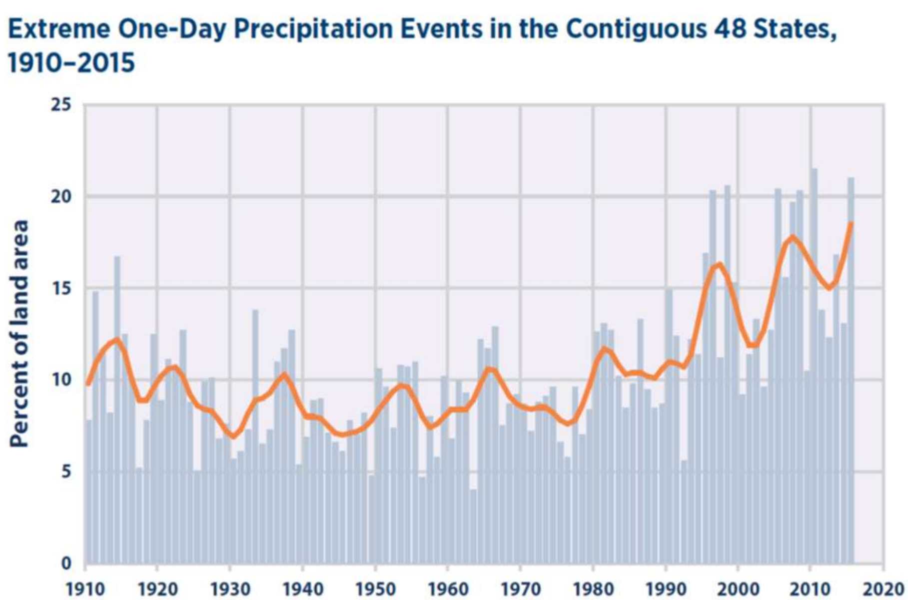


Percentage increase, between 1958 and 2012, in the amount of precipitation falling in the heaviest 1% of precipitation events in each region.

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

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

Downpours → flooding (continued)



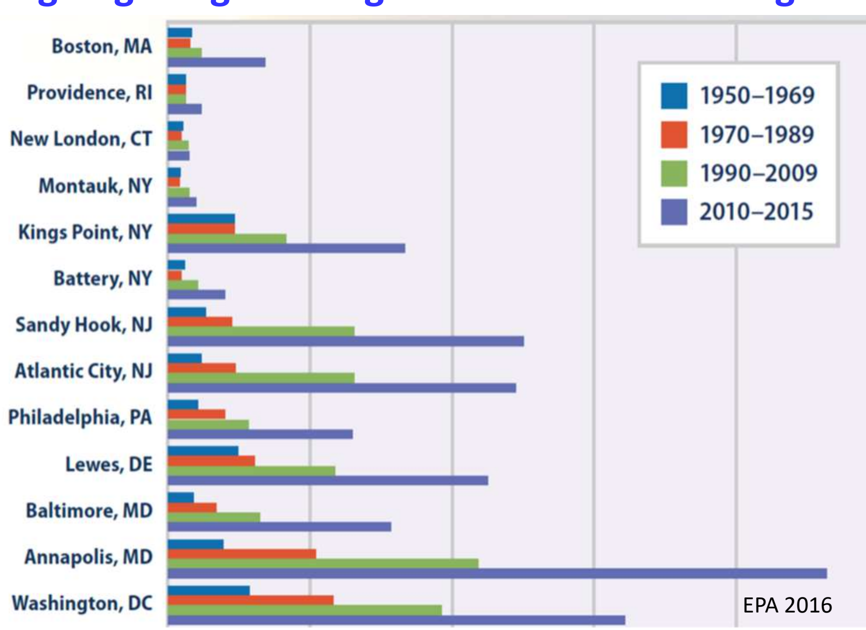
EPA 2016

Downpours → Flooding (continued)

Flooding in downtown Nashville, TN, after a massive rainstorm in May 2010 triggered a "thousand year flood"

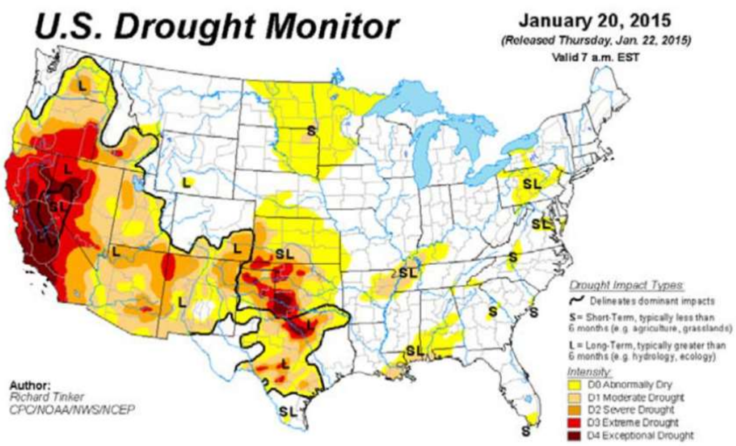
From "When It Rains It Pours", Environment America Research and Policy Center, 2012; photo credit Wayne Hsieh.

Ongoing danger: rising sea → coastal flooding



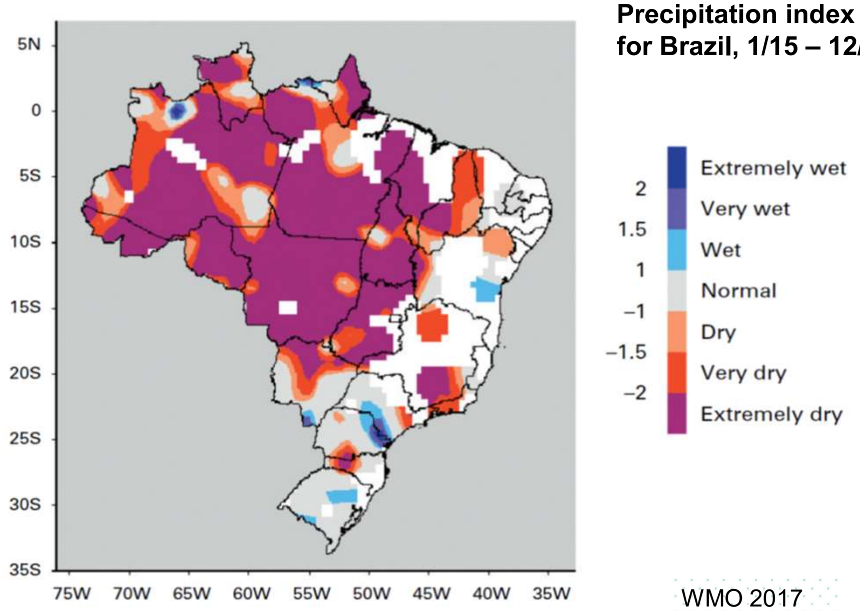
Ongoing danger: drought

- 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.



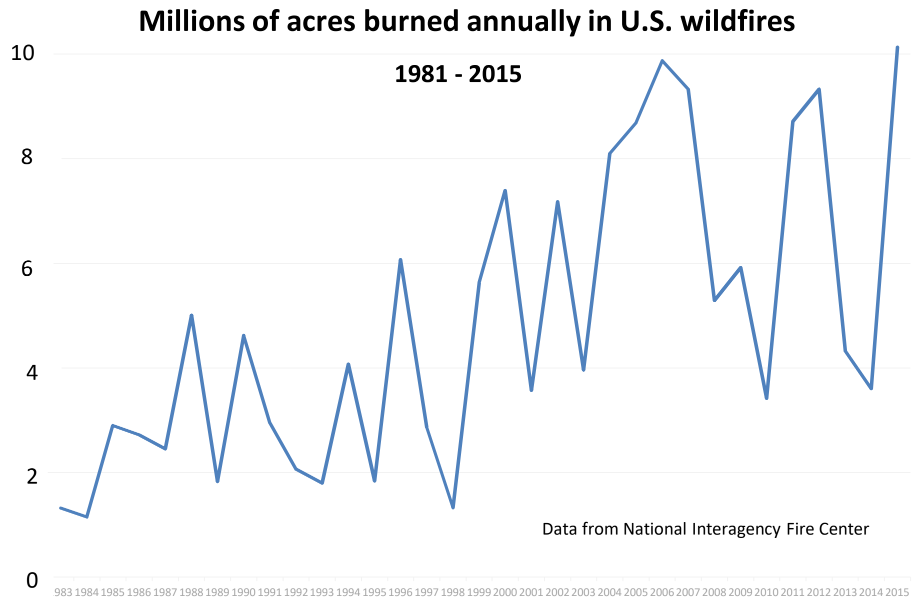
Drought (continued)

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



WMO 2017

Ongoing danger: wildfires



Wildfires (continued)

The most destructive wildfire in Canadian history, 05-16

Burned nearly 1.5 million acres, destroyed 2400 structures, did >$5B damage

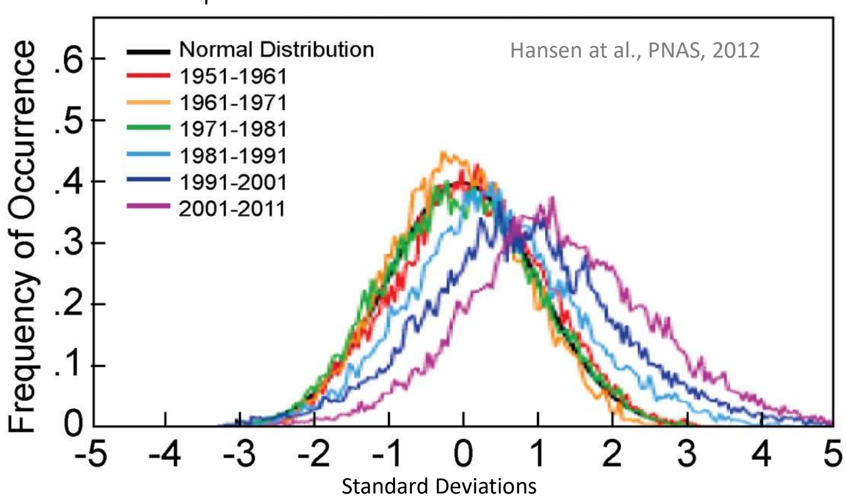
Wildfires (continued)

Bogus Creek fire, near Aniak, Alaska, June 2015

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

Ongoing danger: heat waves

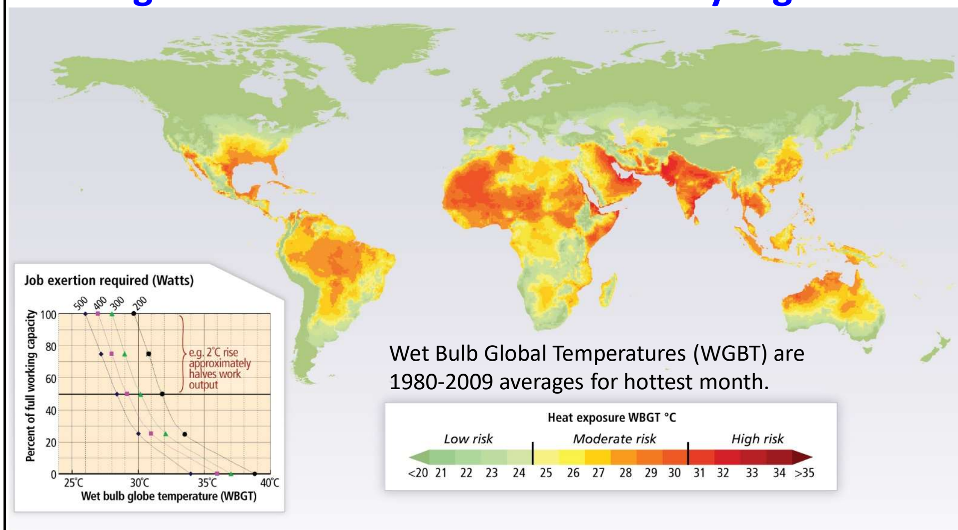
Probability distribution for Jun-Jul-Aug temperature anomaly on land in the Northern Hemisphere. Baseline normal distribution is for 1951-80.



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.

26

Heat (continued): Working outdoors already difficult & dangerous in hottest months in many regions



IPCC AR5, WGII, Figure 11-5

Ongoing danger: Pest outbreaks

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

USGCRP 2009

Ongoing danger: 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

Ongoing danger: coastal erosion

Shishmaref, Alaska

Courtesy Gary Braasch

Ongoing danger: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

Ongoing danger: stronger storms

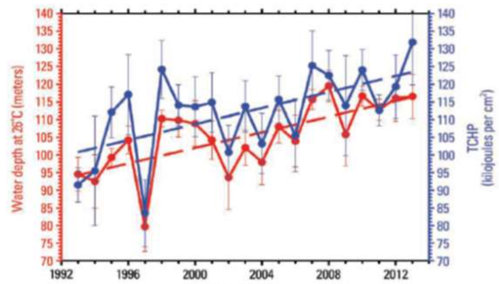
- 10/12: Sandy, largest ever in Atlantic
- 11/13: Haiyan, strongest in N Pacific
- 10/15: Patricia, strongest worldwide
- 10/15: Chapala, strongest to strike Yemen
- 02/16: Winston, strongest in S Pacific
- 04/16: Fantala, strongest in Indian Ocean

Sandy

Winston

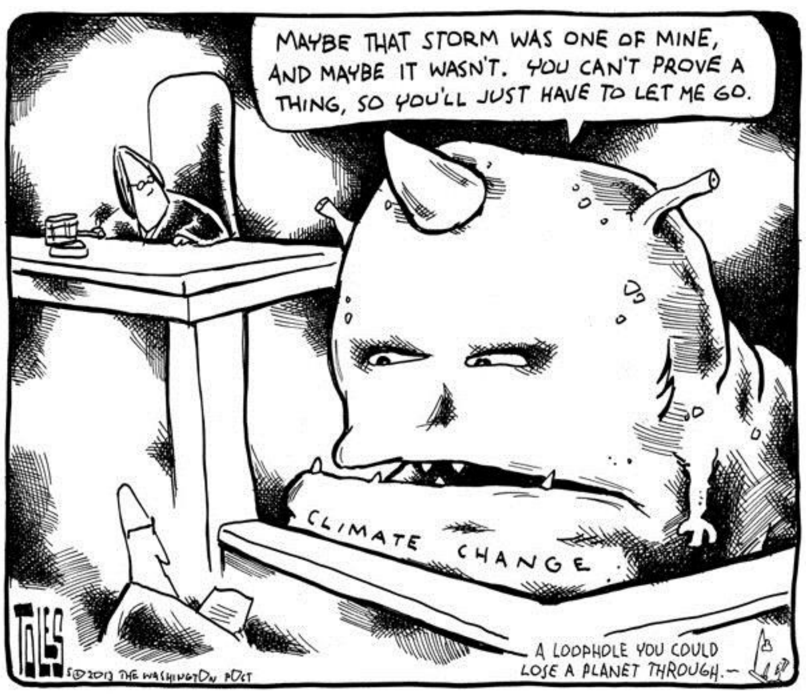
More devastating cyclones are not coincidence

- 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 adds energy to the atmosphere, heating it. The heated air rises, which lowers pressure at the surface, causing air from surrounding areas to flow toward the zone of low pressure.
- The greater the heating, the lower the pressure, the stronger the cyclone.



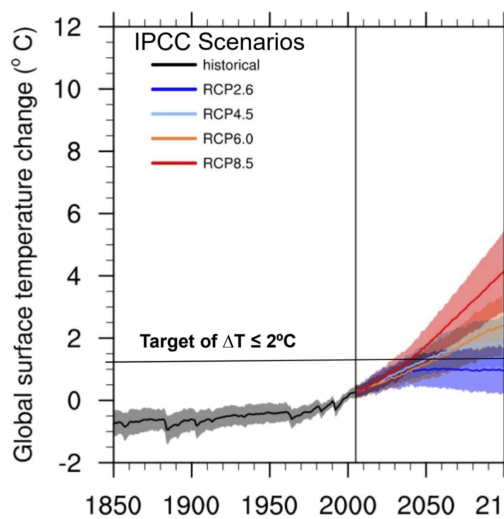
In the region that spawned Cyclone Haiyan, the Tropical Cyclone Heat Potential had gone up 20% since 1990.

- 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 than it would be otherwise. And the higher local sea level is, the worse the storm surge from any given cyclone will be.



Science: Likelihoods

What's expected: T and impacts grow for decades under all scenarios.



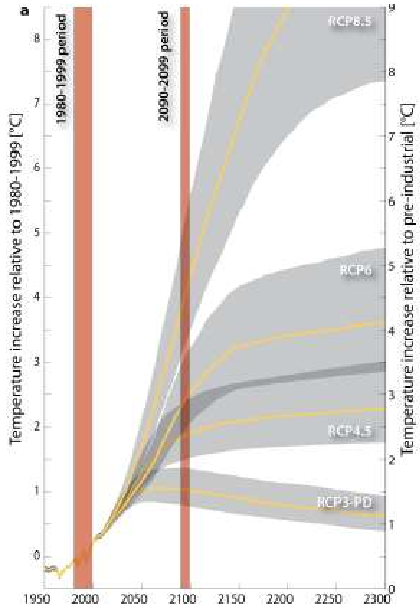
Last time T was 2ºC above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

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

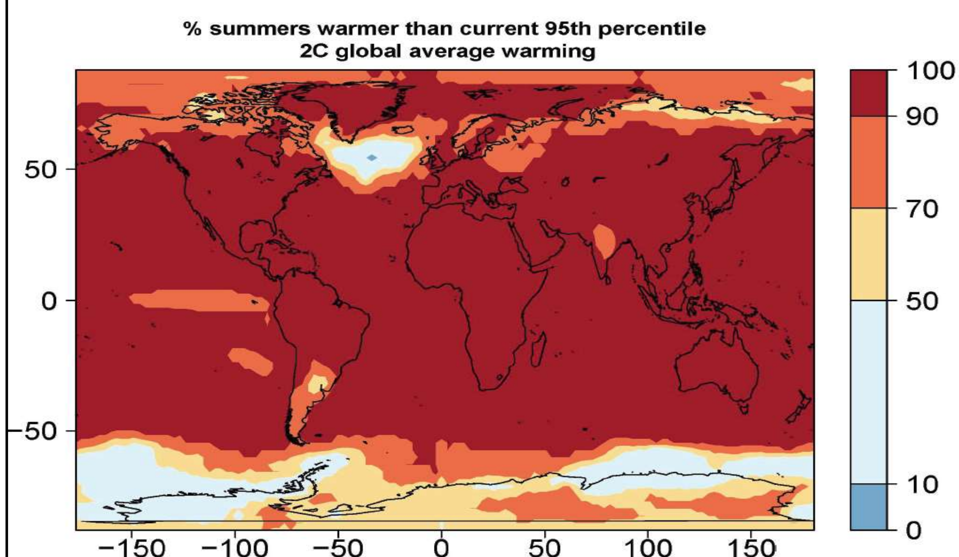
What's expected: Projecting ΔT to 2300



Global-average surface T from 1950 to 2300 according to Representative Concentration Pathway (RCP) scenarios developed for the 5th IPCC Assessment. Yellow lines are medians and gray bands represent 66% probability that the true value, for the given concentration assumption, lies within. RCP8.5 is a no-mitigation scenario. RCP6 assumes modest mitigation policies.

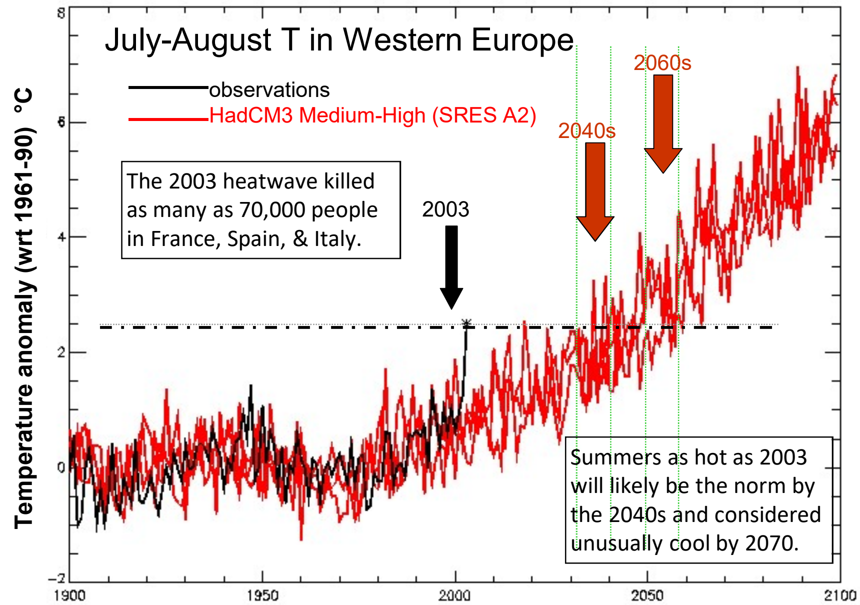
World Bank / Potsdam Institute Nov 2012

What's expected: Hotter summers



National Academies, Stabilization Targets, 2010

Hotter summers (continued)



Hotter summers (continued)

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

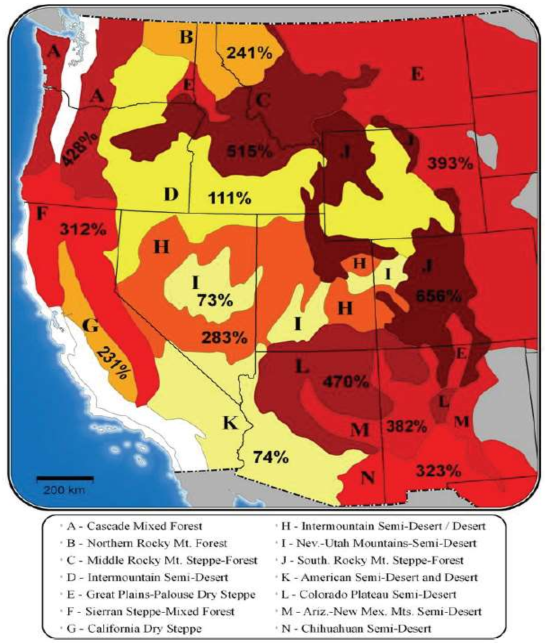
Bryan Jones[1]*, Brian C. O'Neill[2], Larry McDaniel[3], Seth McGinnis[3], Linda O. Mearns[3] and Claudia Tebaldi[2]

What's expected: Worse wildfires

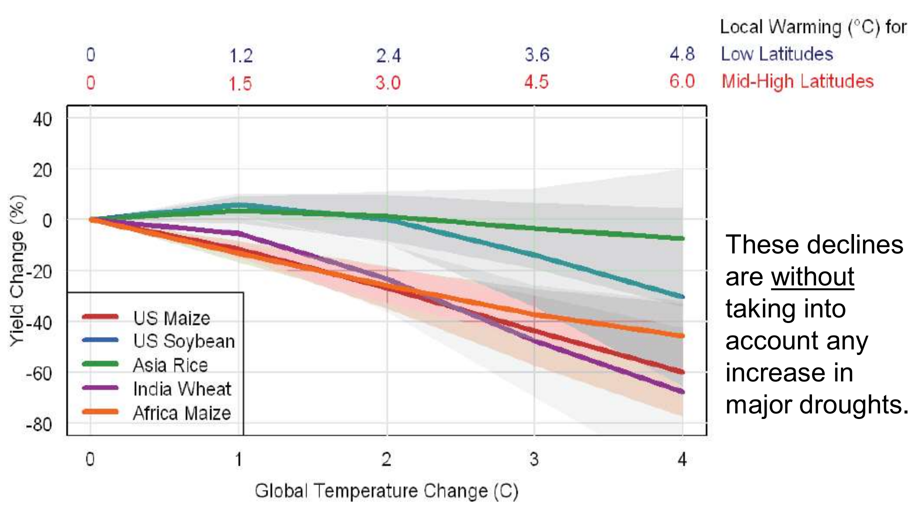
Area burned by wildfires, already up substantially, is destined to go up much more.

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

National Academies, Stabilization Targets, 2010



What's expected: declining crop yields

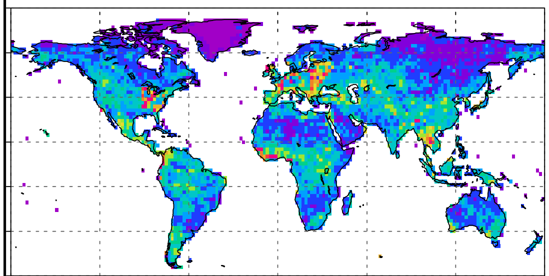


These declines are <u>without</u> taking into account any increase in major droughts.

National Academies, Stabilization Targets, 2010

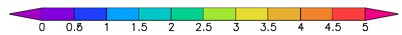
But expected increases in drought are widespread

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

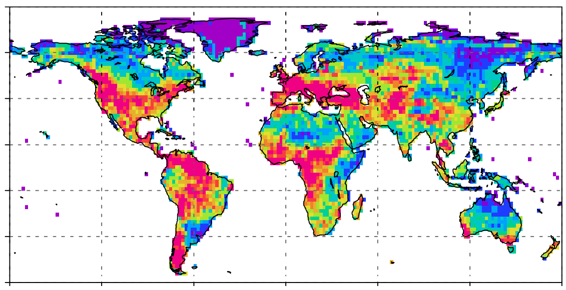


1961-1990

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

What's expected: Worsening storm conditions

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

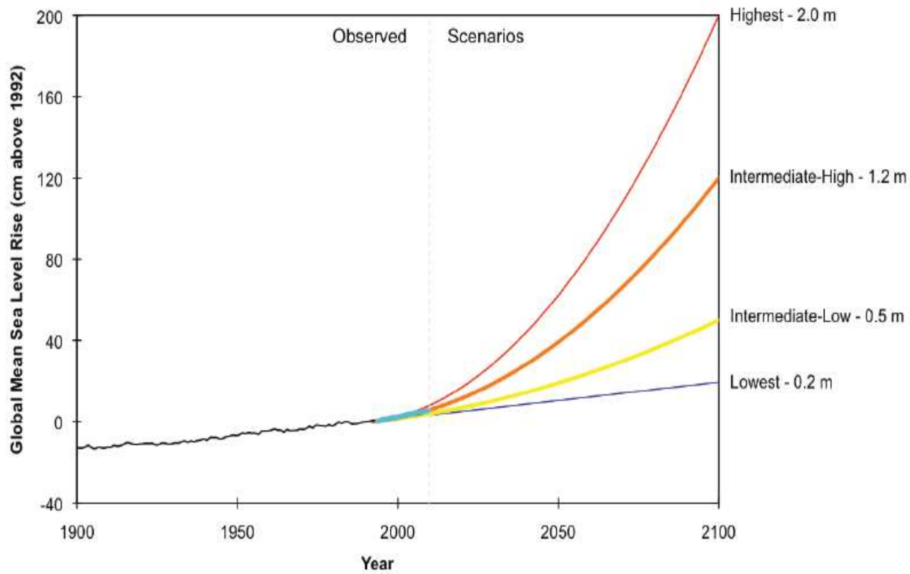
David M. Romps,[1*] Jacob T. Seeley,[1] David Vollaro,[2] John Molinari[2]

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

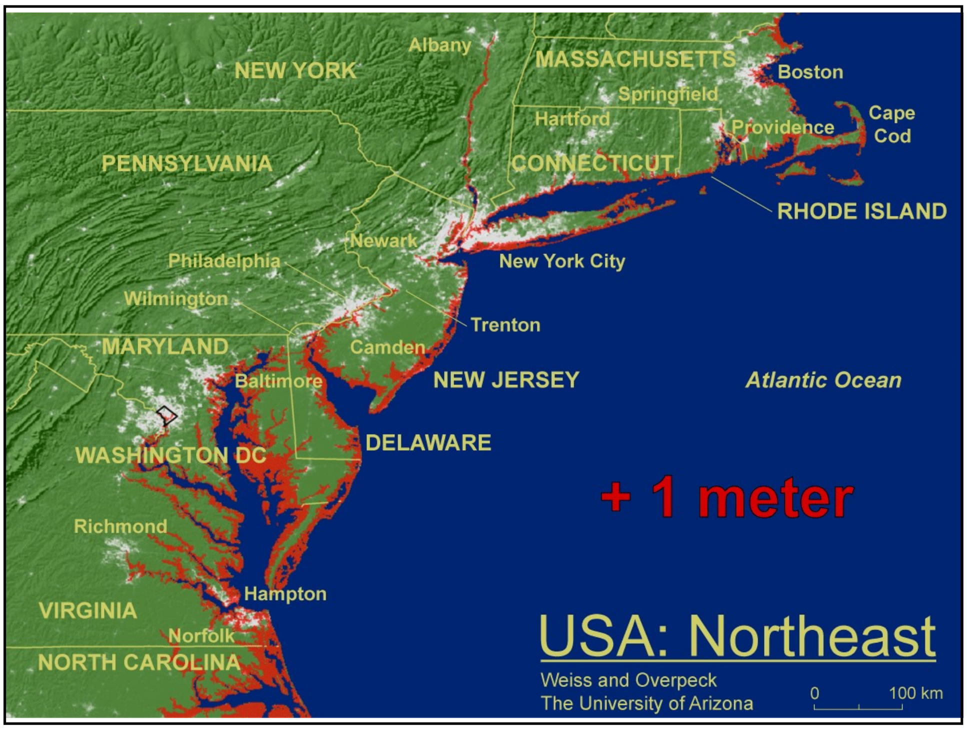
Increased threat of tropical cyclones and coastal flooding to New York City during the anthropogenic era

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]

What's expected: sea-level rise



NOAA OAR CPO-1, December 2012



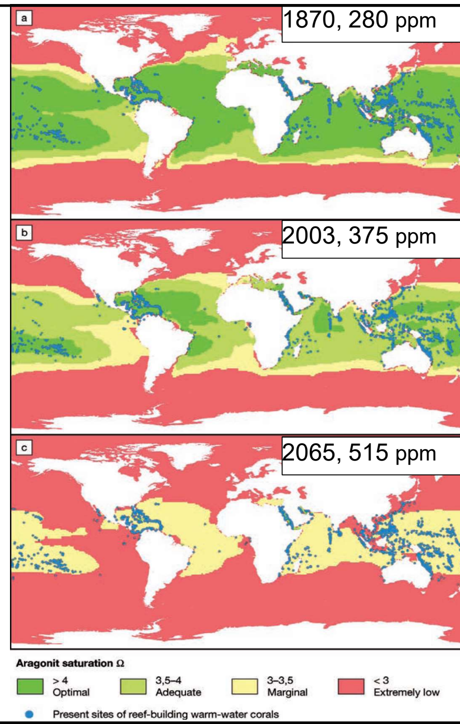
What's expected: continued fall in ocean pH

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

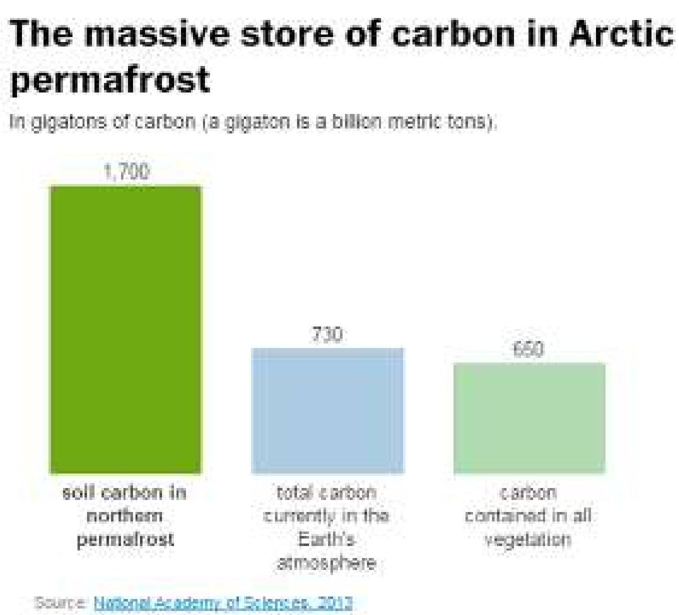


Science: Downside Risks

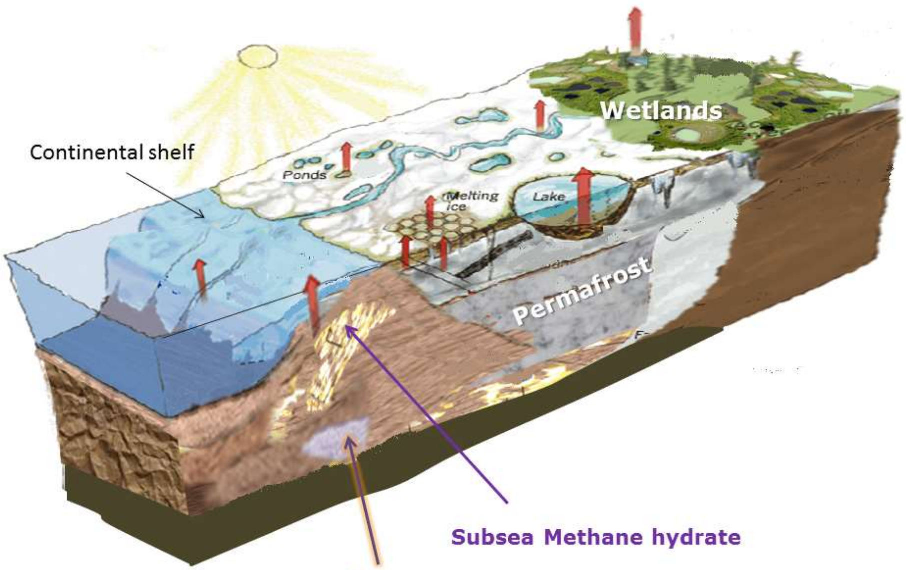
Top tipping-point potentials

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

My top-ranked tipping point: Arctic CH_4 & CO_2



Arctic sources of methane



Arctic methane from 2000
13 June 2015

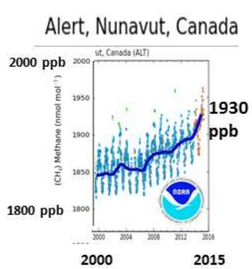
Arctic methane has always been highest, but an Arctic concentration of 1930 ppb compared with Mauna Loa's 1855 ppb is extreme.

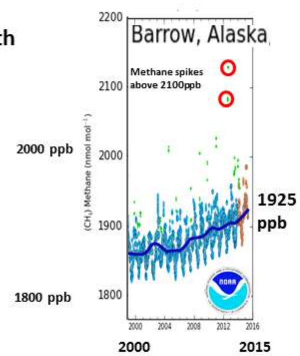
Methane's heating effect is 86X CO2

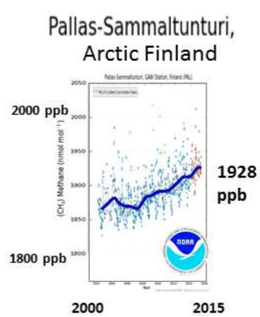
Methane's 800,000 year maximum is 80ppb

NOAA

Highest methane on Earth is the farthest North







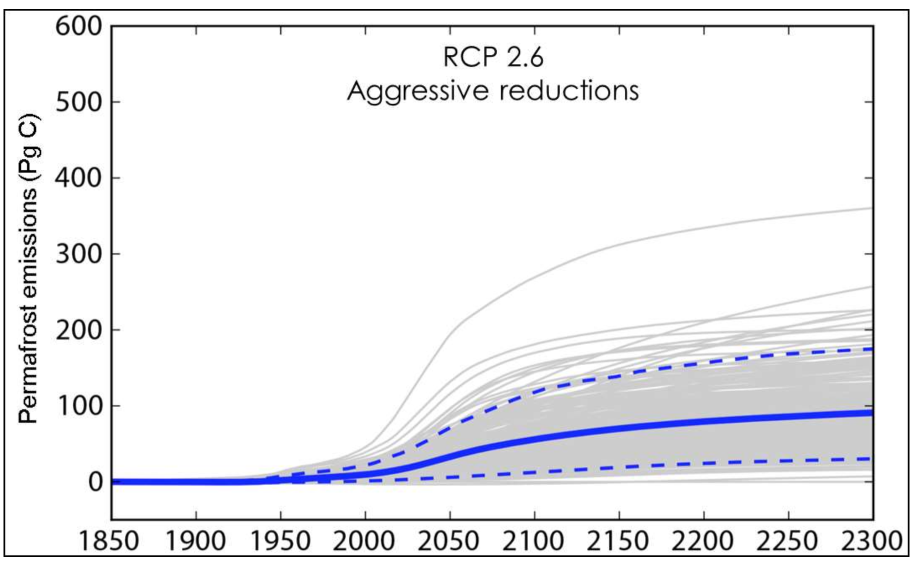
NOAA

Peter Carter

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

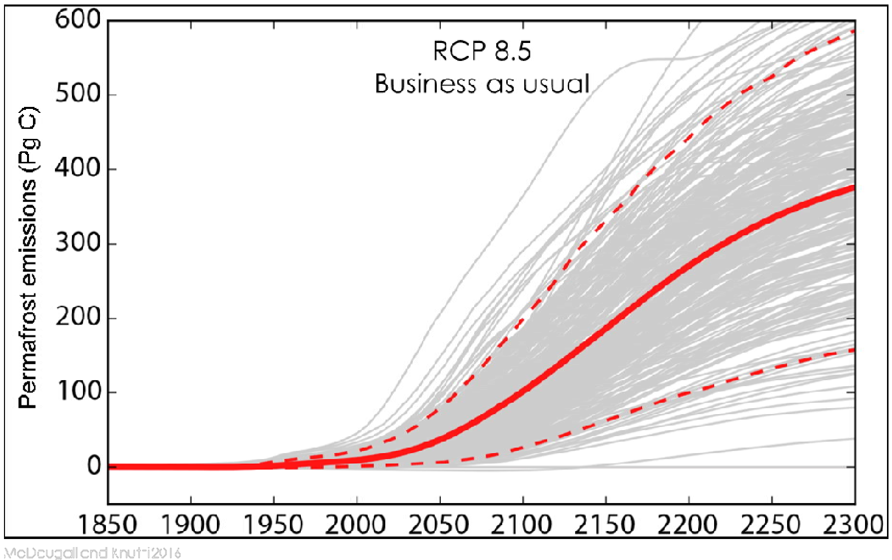
Methane-burst crater in the Siberian tundra

Permafrost C emissions to 2300 under low-emissions scenario



MacDougall & Knutti 2016 via Rogers 2017

Permafrost C emissions to 2300 under high-emissions scenario

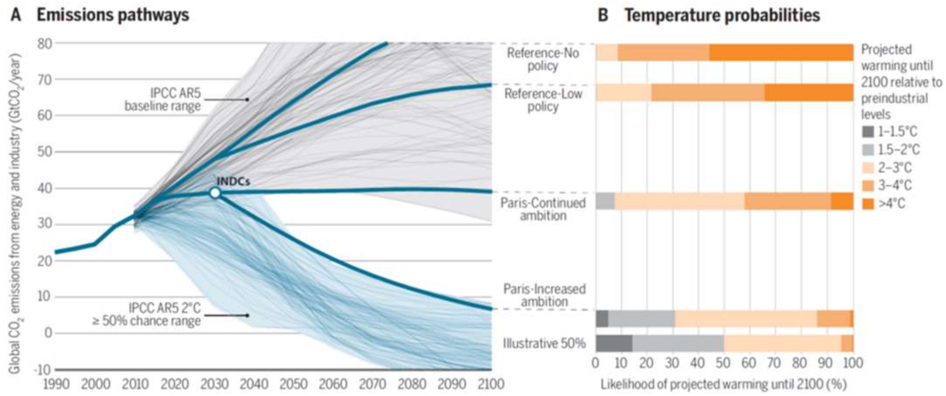


MacDougall & Knutti 2016 via Rogers 2017

Science: The Remedies

The science & technology of emissions reductions

Emissions pathways & ΔT probabilities

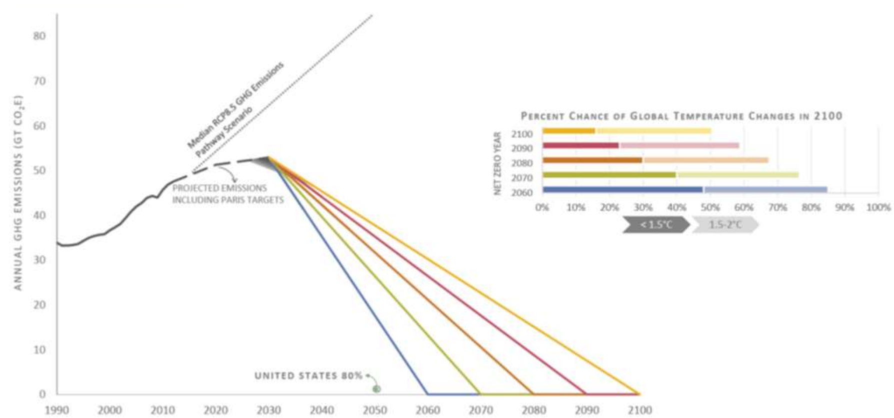


Fawcett et al., SCIENCE, December 4, 2015

The S&T of emissions reductions (continued)

Global net-zero year and chances of ΔT<1.5°C or 2.0°C

FIGURE E11: GLOBAL TRAJECTORIES TO NET-ZERO GHG EMISSIONS AND PROBABILITY OF GLOBAL TEMPERATURE CHANGES

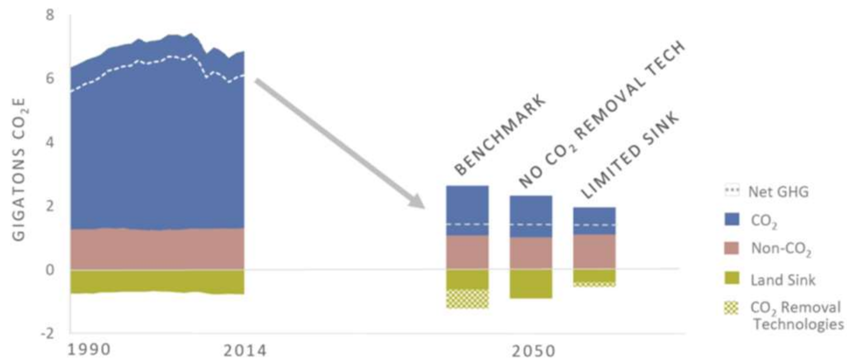


U.S. Mid-Century Strategy for Deep Decarbonization, 11-16

The S&T of emissions reductions (continued)

Pathways to 80% reduction in U.S. GHG emissions by 2050

FIGURE E1: U.S. NET GHG EMISSIONS UNDER THREE MCS SCENARIOS

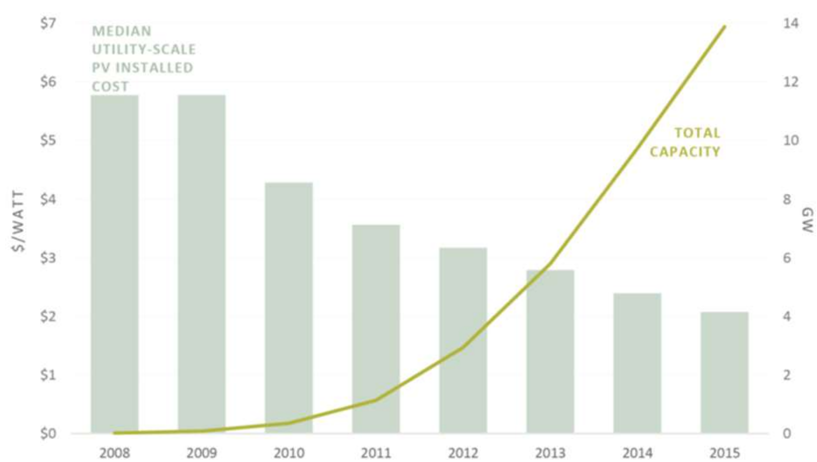


U.S. Mid-Century Strategy for Deep Decarbonization, 11-16

The S&T of emissions reductions (continued)

Economics: Renewables are getting more affordable

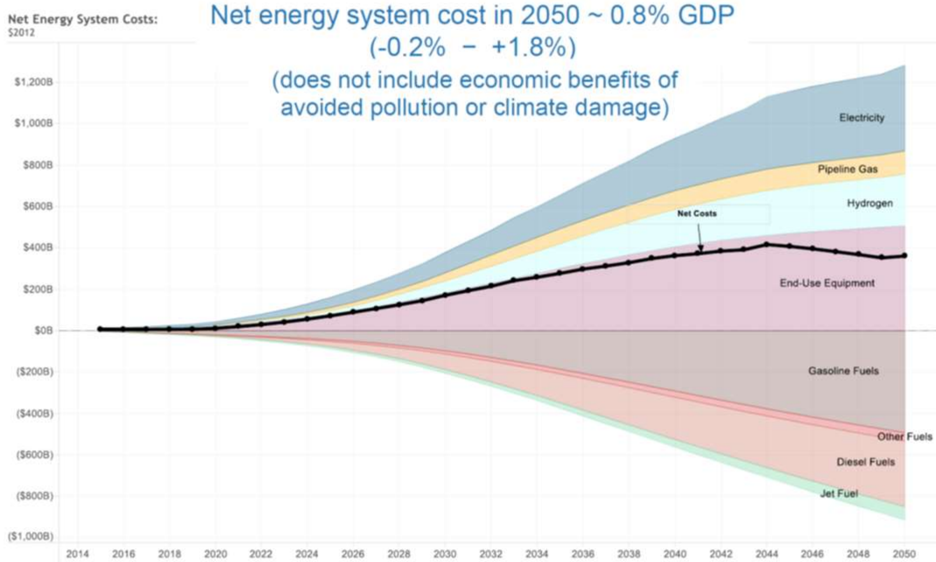
FIGURE E9: SOLAR ENERGY COSTS AND DEPLOYMENT IN THE UNITED STATES



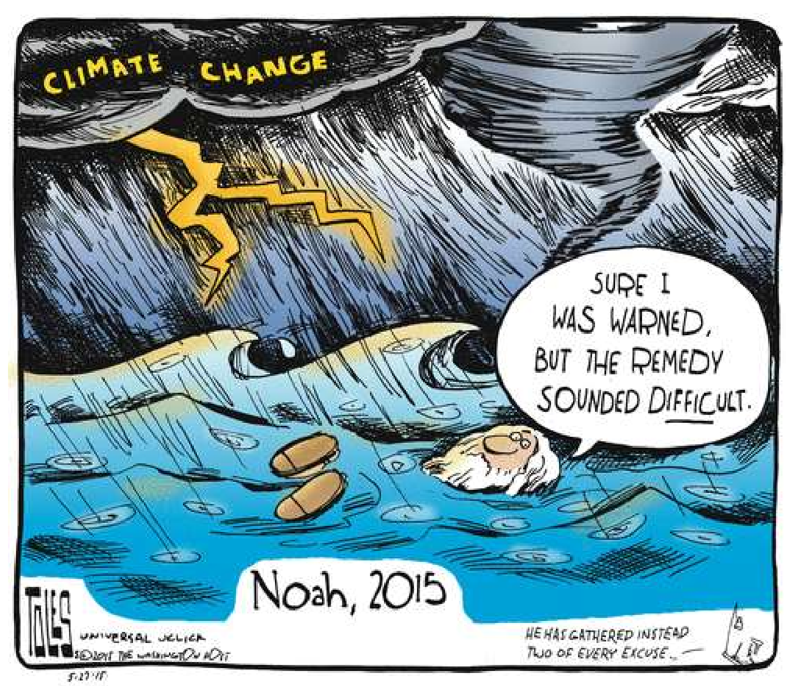
U.S. Mid-Century Strategy for Deep Decarbonization, 11-16

The S&T of emissions reductions (continued)

Economics: Cost of 80% reduction by 2050 for USA is manageable



Deep Decarbonization Pathways Project 2016



Policy

GOOD NEWS

- Smart policies (assisted by technology & economics) have reduced (U.S.) or leveled off (global) emissions over the past several years.
- Obama-Xi leadership (Nov 2014) led to Paris success (Dec 2015) w ~200 countries committing to emissions reductions under nationally determined targets.

BAD NEWS

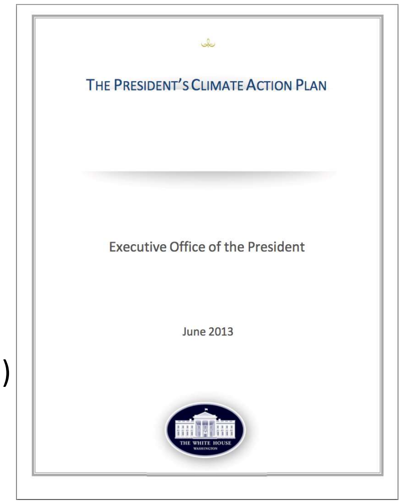
- Meeting Paris commitments to 2025-2030 will be difficult; much deeper reductions thereafter needed for $\Delta T<2°C$ will be more so.
- Trump wants to undo Obama policies, with potential adverse impact on U.S. emissions & maybe others'.

Energy-climate policy under 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 US Global Change Research Program
- 1st govt calculation & use of Social Cost of Carbon

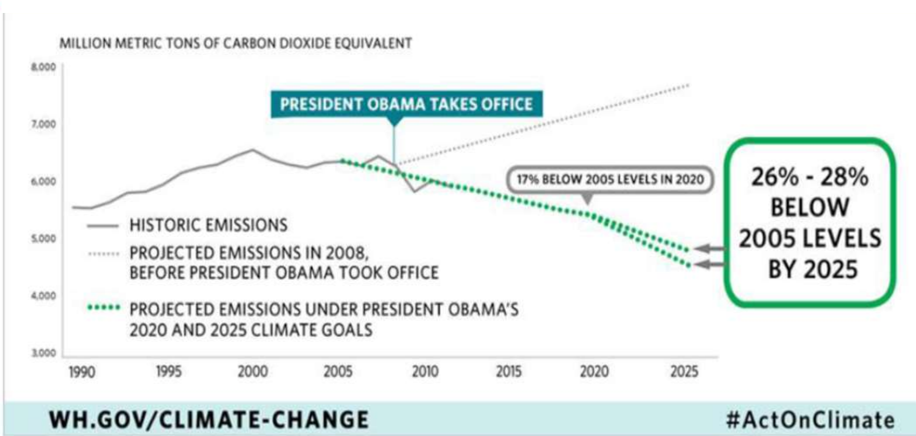
2nd Term: The Obama Climate Action Plan

- Cutting heat-trapping pollution in America (mitigation)
- Preparing the United States for the impacts of climate change (adaptation)
- Leading efforts on mitigation and adaptation globally



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

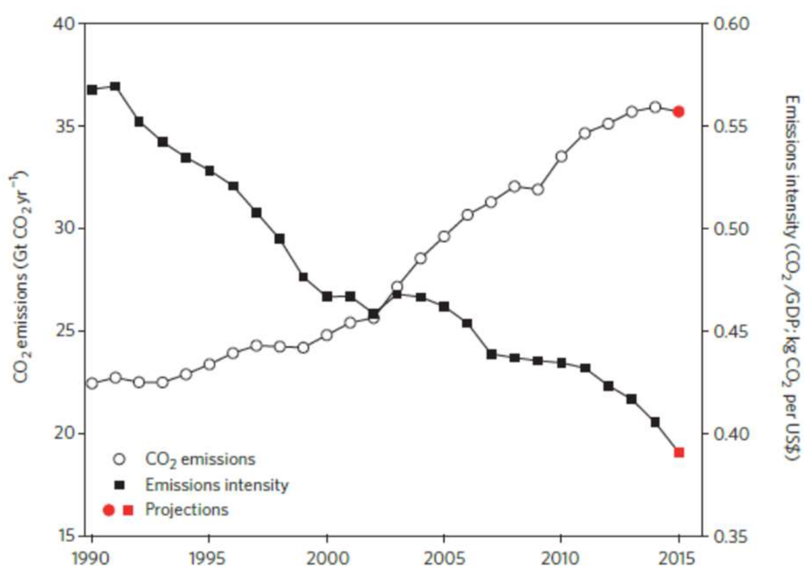


The U.S. energy-climate record under Obama

	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

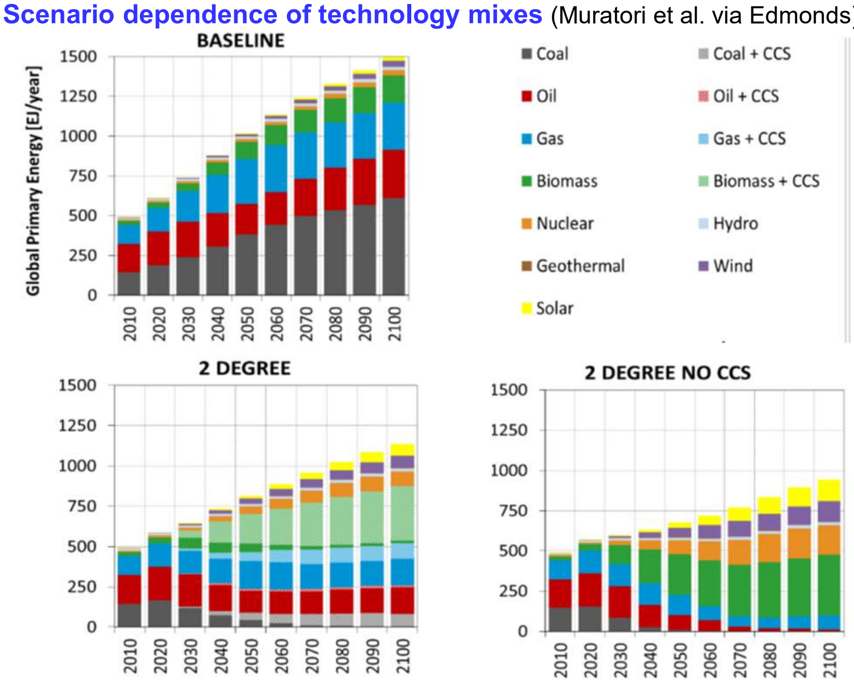
Global industrial CO2 emissions through 2015



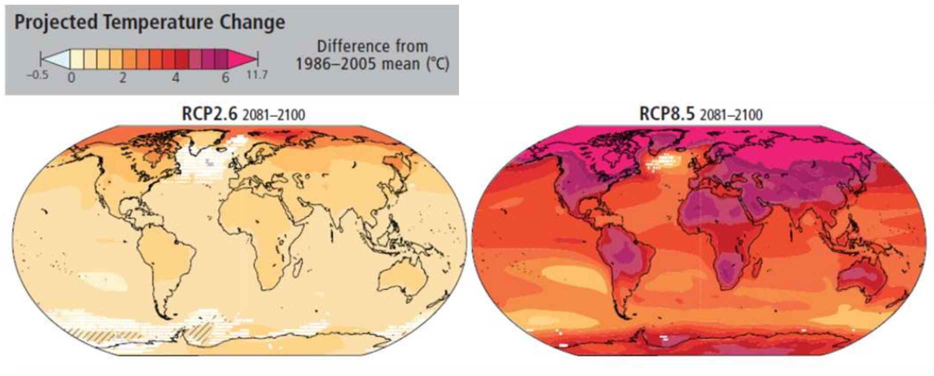
Jackson et al., Nature Climate Change, January 2016

But there's a difficult road ahead if ΔT is to be held even to 2°C, as a comparison of technology contributions under "baseline" and some "2°C" scenarios underscores.

Scenario dependence of technology mixes (Muratori et al. via Edmonds)



An indication of the stakes in deep reductions: A 2°C future is far less severe than BAU

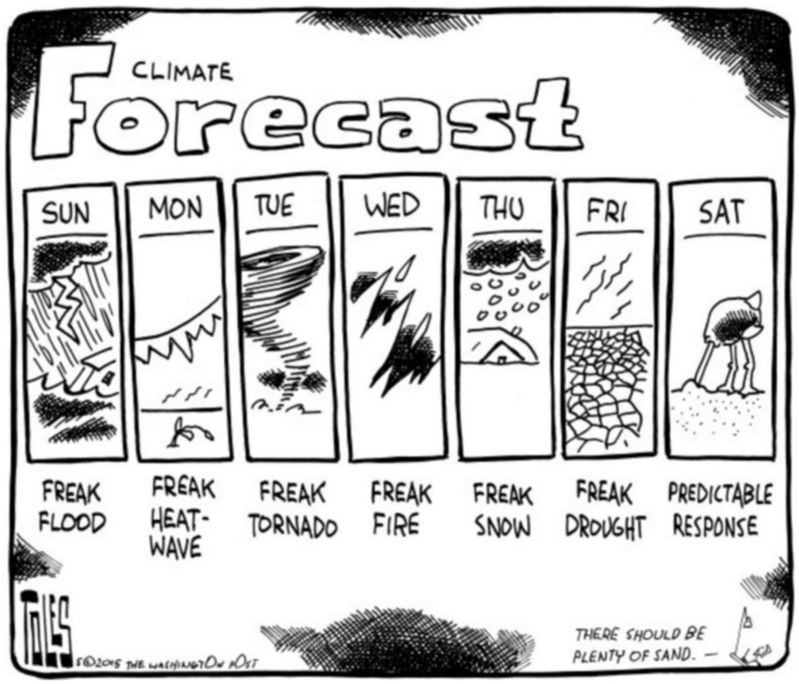


IPCC WGII, 2014

Any significant delay in implementing Obama policies may well prevent the world from keeping $\Delta T < 2°C$.

President Trump's stated climate-change agenda

- Drastic cuts in budget & authority for EPA
- Other cuts in climate-change monitoring & analysis
  - Zeroes Earth-observation functions of DISCOVR (NASA)
  - Zeroes OCO-3, PACE. and CLARREO missions (NASA)
  - Cuts ocean grants & programs by $250M (NOAA)
- Drastic cuts in energy R&D at DOE
  - Zeroes ARPA-E
  - Cuts other energy R&D by $2B
- Roll-back / "re-examination" of Obama climate EOs
  - Clean Power Plan, coal-plant NSPS, methane strategy
  - Social Cost of Carbon, NEPA need to consider climate change
  - Preparedness EOs: USA and international



What should the climate-science community do?

- Keep doing our science
- Keep talking about the results and their implications
- Get better at explaining the science to laypeople, not just what we know, 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