Why Think About Geoengineering Now?

Time is Much Shorter than Most Think

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———

President Obama's Science and Technology Advisor
(January 2009 – January 2017)

Lunch Address

Workshop on Governance of Solar Geoengineering

Harvard Kennedy School • 27 September 2018

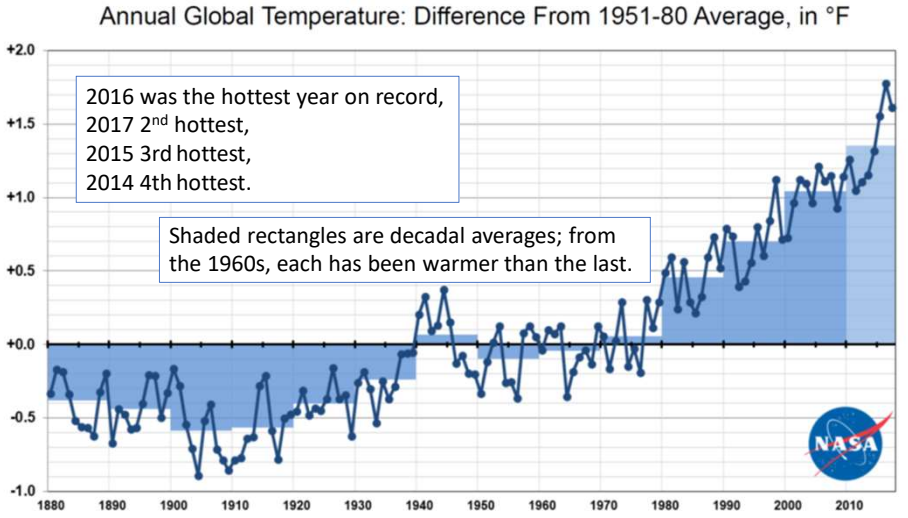
Outline of my main points

- Dangerous climate change is already a reality
- Worse is unavoidable
- Society is far behind on "conventional" mitigation
- A frantic reach for additional measures is likely soon
- When some reach for geoengineering, as they almost certainly will, we'd better be ready with insights…
  - not only about what if any technologies make sense
  - but also about governance.

Dangerous Climate Change Is Already a Reality

Dangerous climate change is already a reality

After a brief slowdown, global T is rising fast again



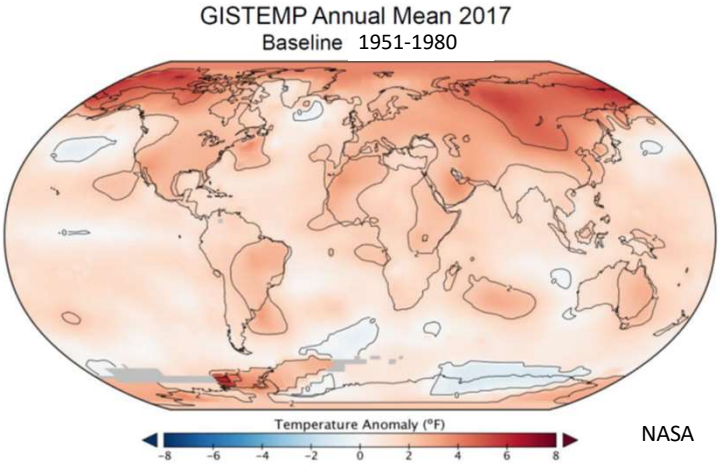
Earth has been warming more or less steadily for the last 100+ years, as the increasing forcing from the human-caused GHG buildup came to dominate natural variability. The 1998-2012 "hiatus" was a slowdown in rate of warming, not a halt.

Dangerous climate change is already a reality

Mid-continents & the poles are warming fastest

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

2nd Warmest year of NASA GISTEMP record



NASA

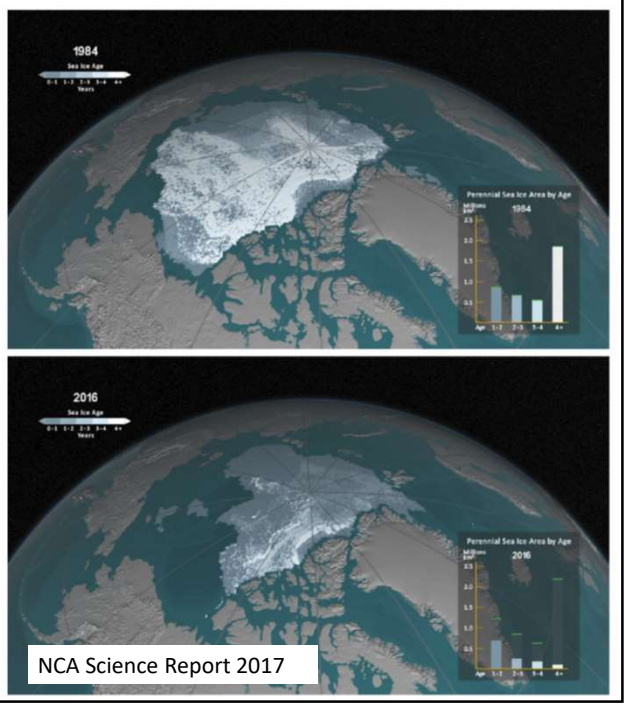
The Arctic on average is warming at >2 times the global rate, and in some parts of the region at 3-4 times the global rate. West Antarctic Ice Sheet is similar.

Dangerous climate change is already a reality

Arctic sea-ice extent & thickness are plummeting

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

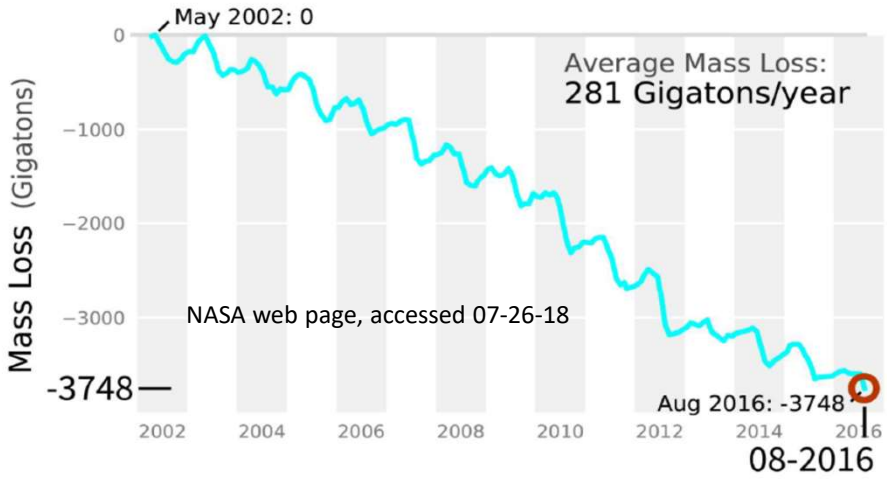
But the change from ice to open water, while offering some economic opportunities, has drastic effects on regional temperatures, winds, storm impacts, and valued species.



NCA Science Report 2017

Dangerous climate change is already a reality

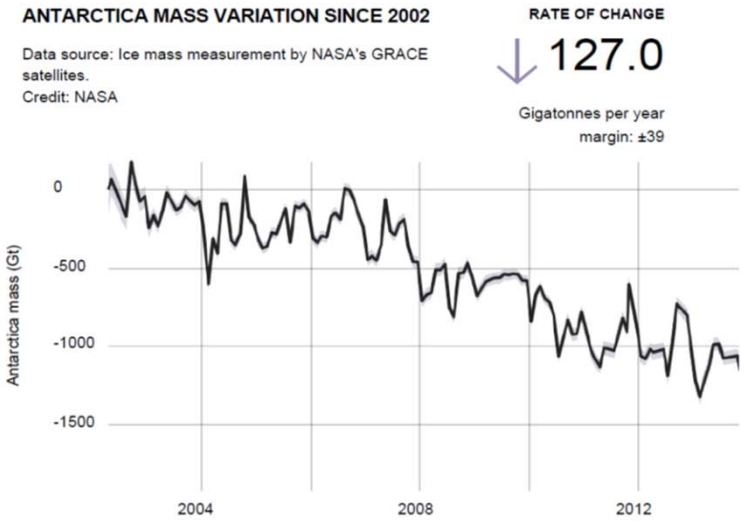
Greenland is steadily losing its land ice



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

Dangerous climate change is already a reality

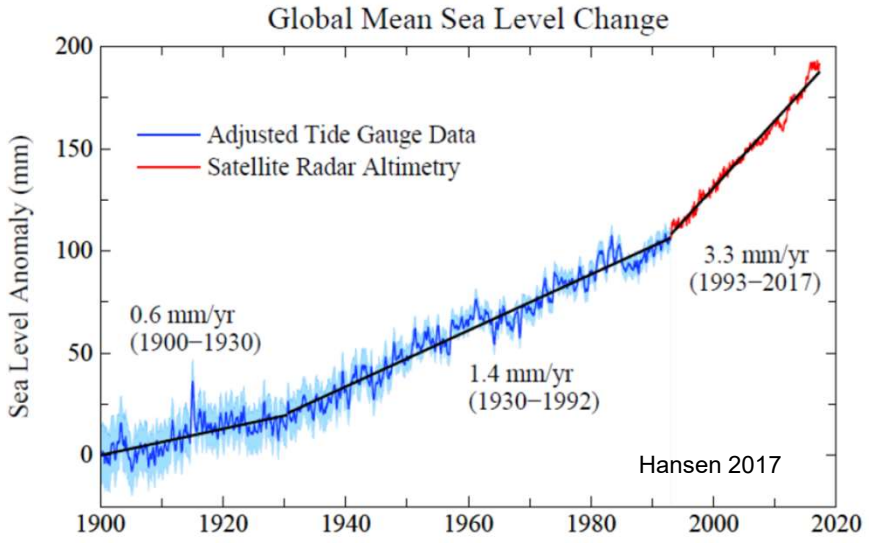
It's now clear Antarctica is also losing ice



NASA web page, accessed 6-18

Dangerous climate change is already a reality

Rate of sea-level increase is accelerating



Post-2010 is actually 5.5 mm/yr!

Dangerous climate change is already a reality

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

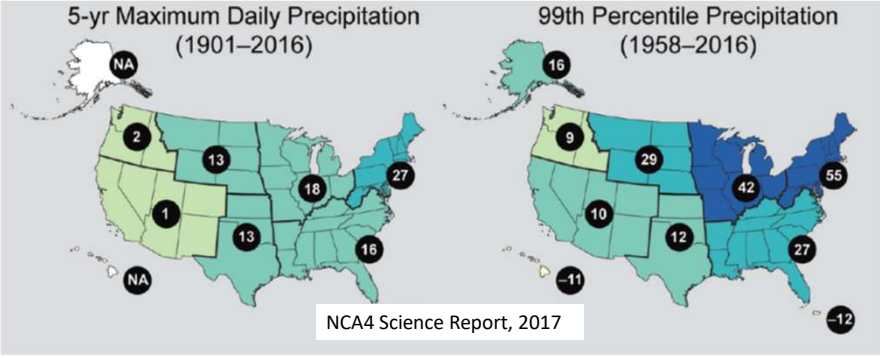
Around the world we're seeing, variously, increases in

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

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

Dangerous climate change is already a reality

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.

Dangerous climate change is already a reality

Downpours and floods (continued)

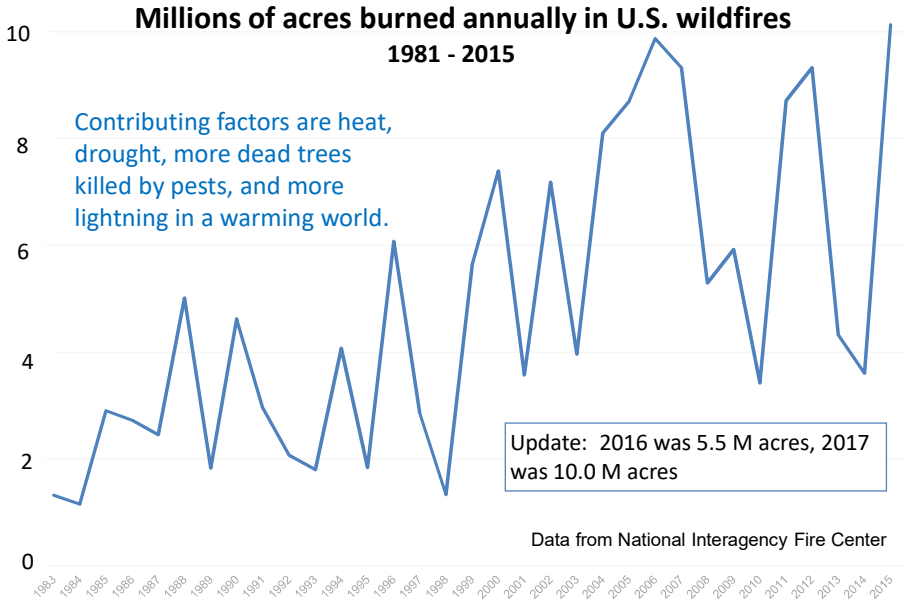
"Hundred-year" floods now occur once a decade or more in many places.
Three "five-hundred-year" floods occurred in Houston in three years.

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.

Dangerous climate change is already a reality

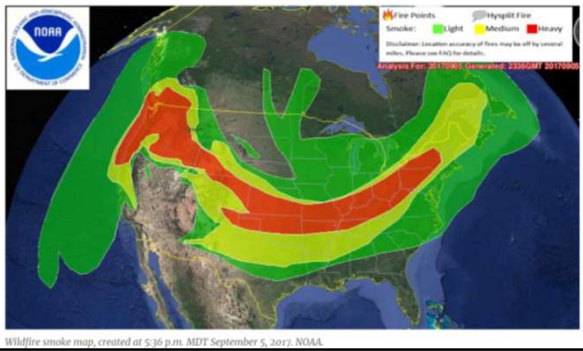
Wildfires are increasing dramatically



Dangerous climate change is already a reality

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).
- Five these were in Alaska, where now even the tundra burns.
- Smoke from today's big fires impacts health 1000s of miles away.

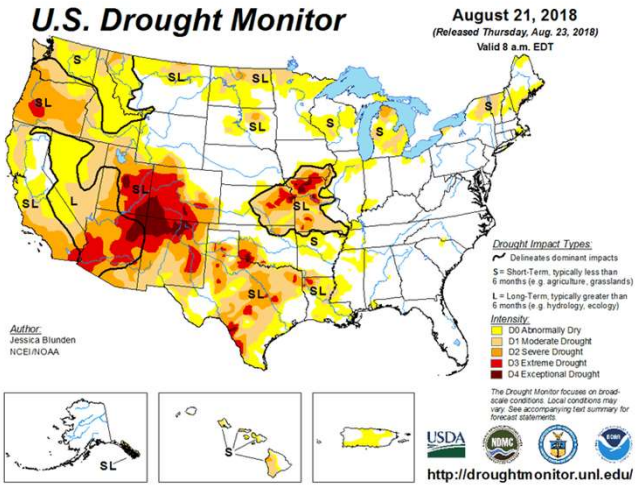


Wildfire smoke map, created at 5:36 p.m. MDT September 5, 2017. NOAA.

Dangerous climate change is already a reality

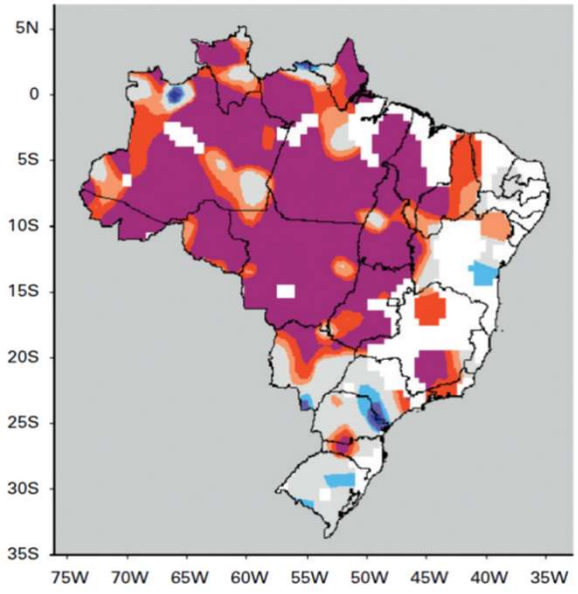
Climate change is exacerbating drought

- 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.

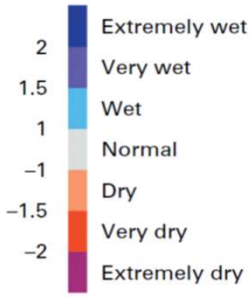


Dangerous climate change is already a reality

Worsening drought is widespread



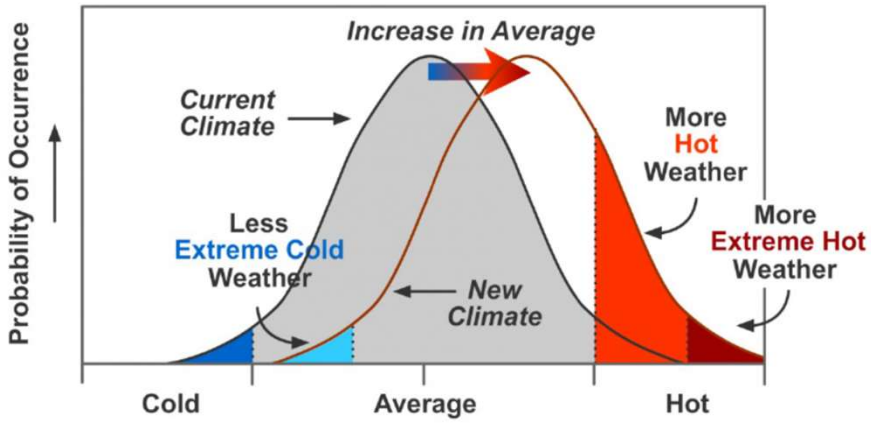
Precipitation index for Brazil, 1/15 – 12/16



WMO 2017

Dangerous climate change is already a reality

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. This disproportionate impact at the extremes applies to any normally distributed climate-related variable.

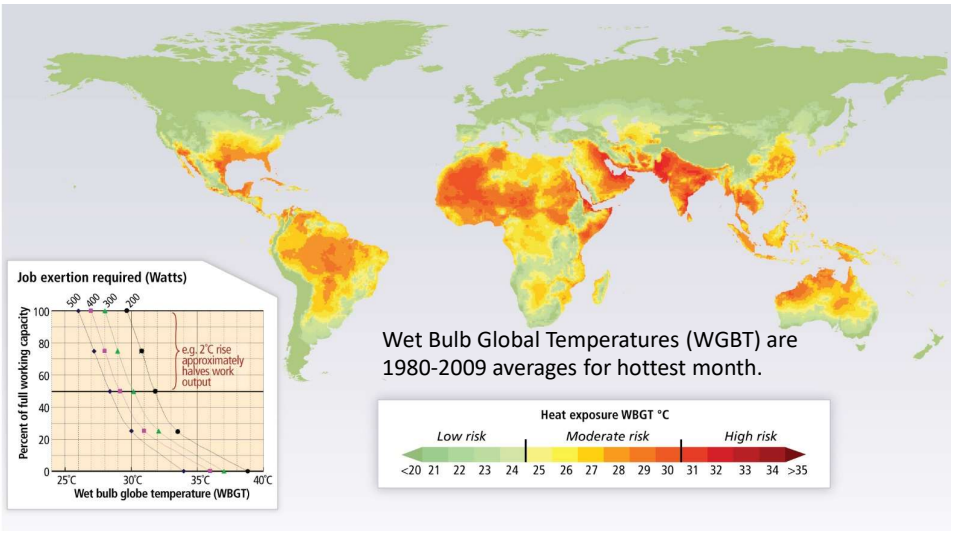
Impacts today

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

Dangerous climate change is already a reality

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



IPCC AR5, WGII, Figure 11-5

Dangerous climate change is already a reality

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

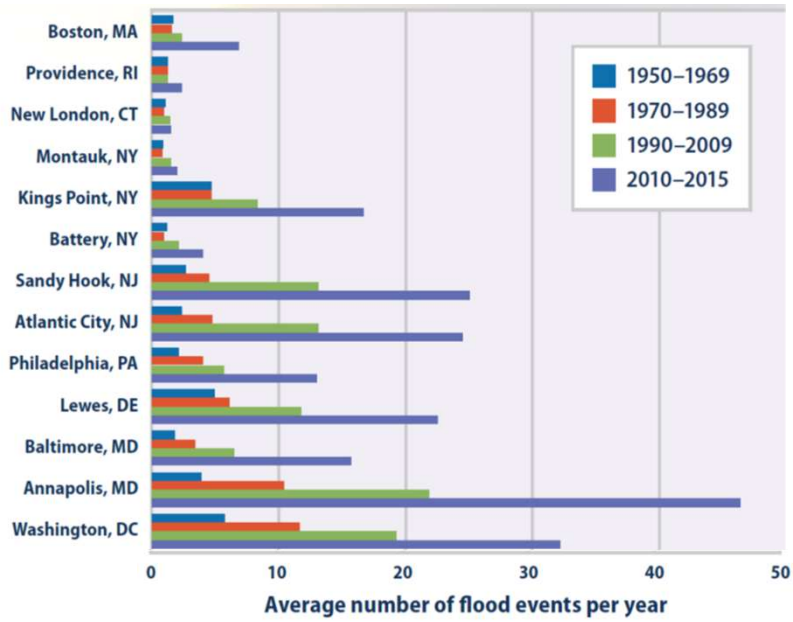
Dangerous climate change is already a reality

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

Dangerous climate change is already a reality

Rising sea → coastal inundation



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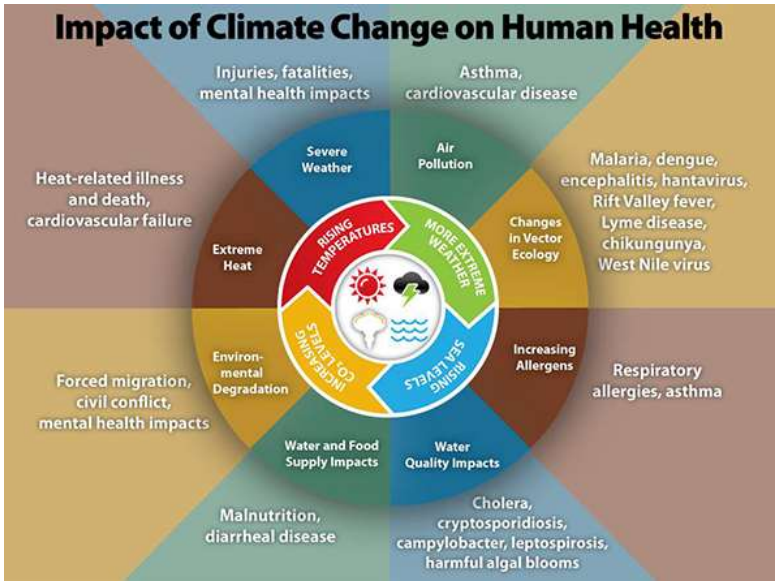
Dangerous climate change is already a reality

Permafrost is thawing & subsiding

Norwegian Polar Institute, 2009

Dangerous climate change is already a reality

Direct impacts on health are serious & diverse



Centers for Disease Control & Prevention 2018

Dangerous climate change is already a reality

Pests are flourishing

Pine bark beetles, with longer breeding season from warming, have killed huge swaths of forest weakened by heat & drought in California, Colorado, & Alaska.

Dangerous climate change is already a reality

Valued species are declining or moving

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]

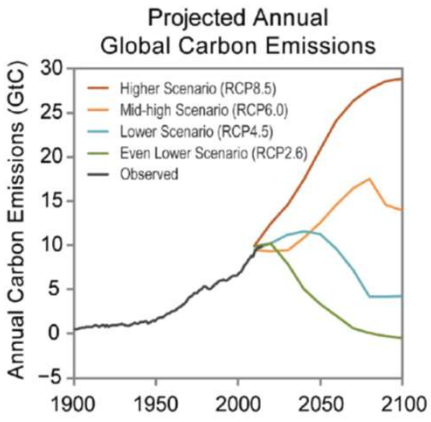
Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Santa Cruz, CA 95060

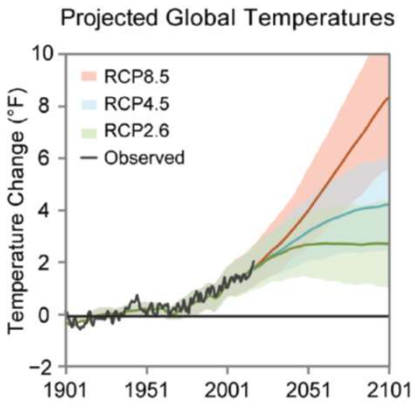
Worse Is Unavoidable

Worse is unavoidable

Temperatures rise under all scenarios

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



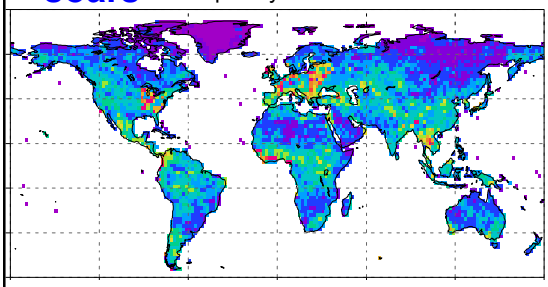


NCA5 Science Report, 2017

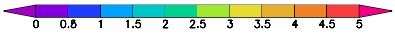
Worse is unavoidable

Absent aggressive mitigation, drought frequency soars

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



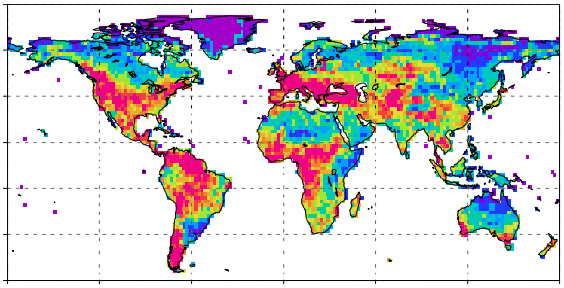
Drought defined as soil moisture below historical 10th percentile value for that calendar month.



events per 30 years

1961-1990

Results shown are the mean of 8 global climate models.



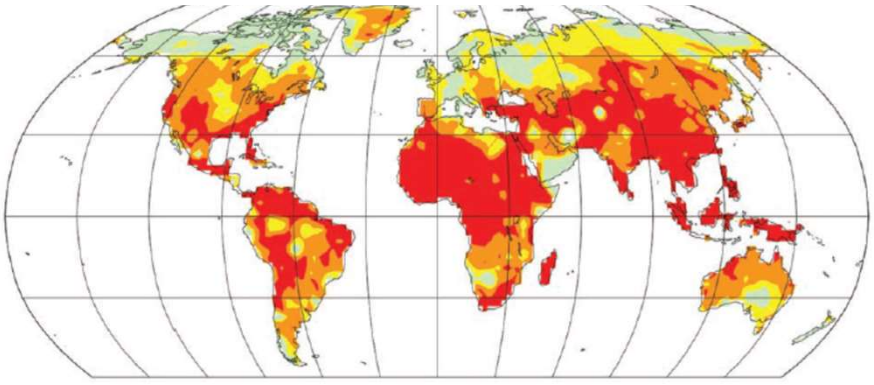
2070-2099, IPCC A2 scenario

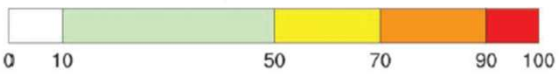
Source: Sheffield and Wood 2008 Climate Dynamics (2008) 31:79–105
DOI 10.1007/s00382-007-0340-z

Worse is unavoidable

Record heat will be the new normal

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





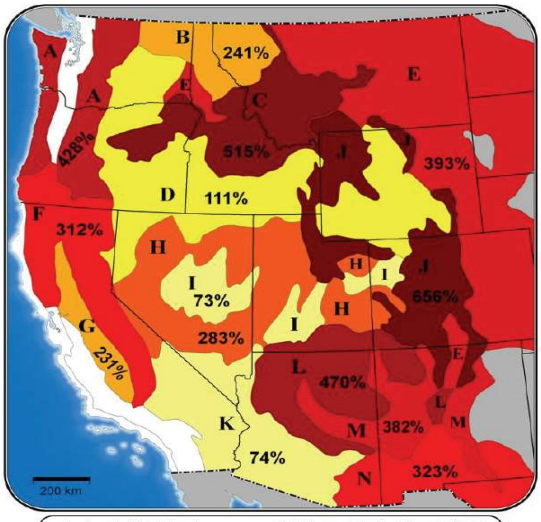
Battisti & Naylor, SCIENCE, 9 January 2009, using IPCC A1B emission scenario

Worse is unavoidable

Even a 2°C increase (low emissions) portends a large worsening of wildfires

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

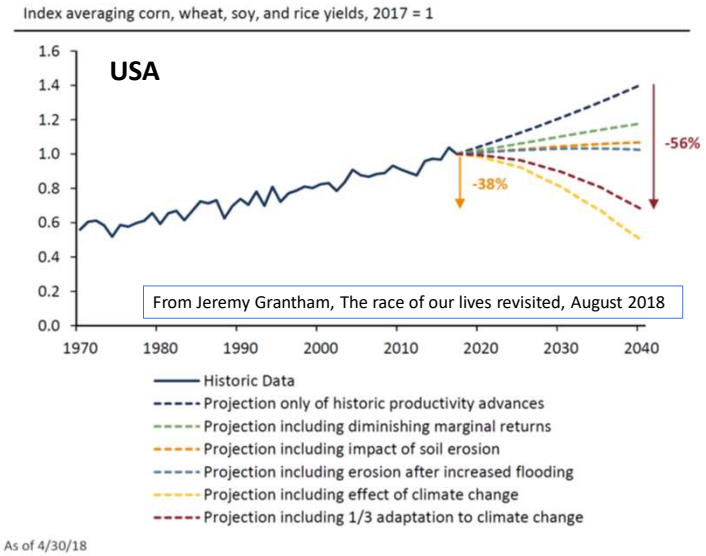
National Academies, Stabilization Targets, 2010



- A - Cascade Mixed Forest
- B - Northern Rocky Mt. Forest
- C - Middle Rocky Mt. Steppe-Forest
- D - Intermountain Semi-Desert
- E - Great Plains-Palouse Dry Steppe
- F - Sierran Steppe-Mixed Forest
- G - California Dry Steppe
- H - Intermountain Semi-Desert / Desert
- I - Nev.-Utah Mountains-Semi-Desert
- J - South. Rocky Mt. Steppe-Forest
- K - American Semi-Desert and Desert
- L - Colorado Plateau Semi-Desert
- M - Ariz.-New Mex. Mts. Semi-Desert
- N - Chihuahuan Semi-Desert

Worse is unavoidable

Agriculture yields could plummet



From Jeremy Grantham, The race of our lives revisited, August 2018

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

Most other countries will do worse.

Worse is unavoidable

Direct impacts on health are expected to grow

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)

Worse is unavoidable

All scenarios bring increased storm dangers

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]

Scientific best estimates under specified future emissions

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).

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

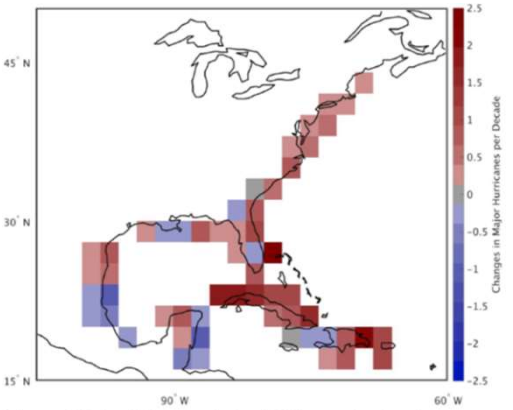


Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

Bhatia and Vechhi, Princeton U, 5 April 2017

Worse is unavoidable

Ocean acidification gets much worse under all scenarios

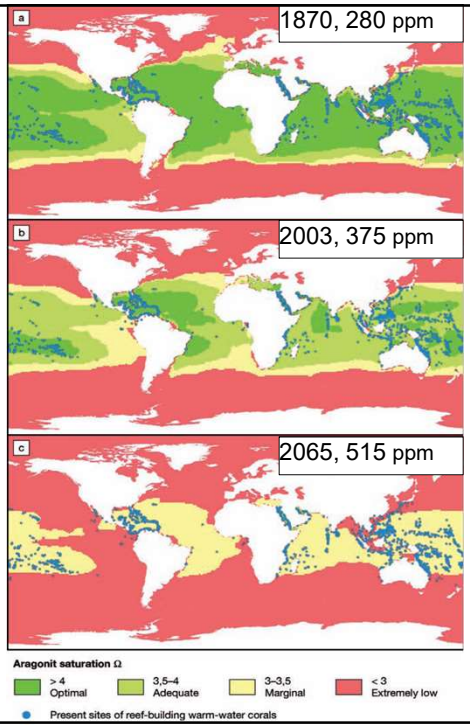
Increased acidity lowers availability of $CaCO_3$ to organisms using it for forming their shells & skeletons (corals, shrimp, clams, oysters…).

Adverse effects already being observed.

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

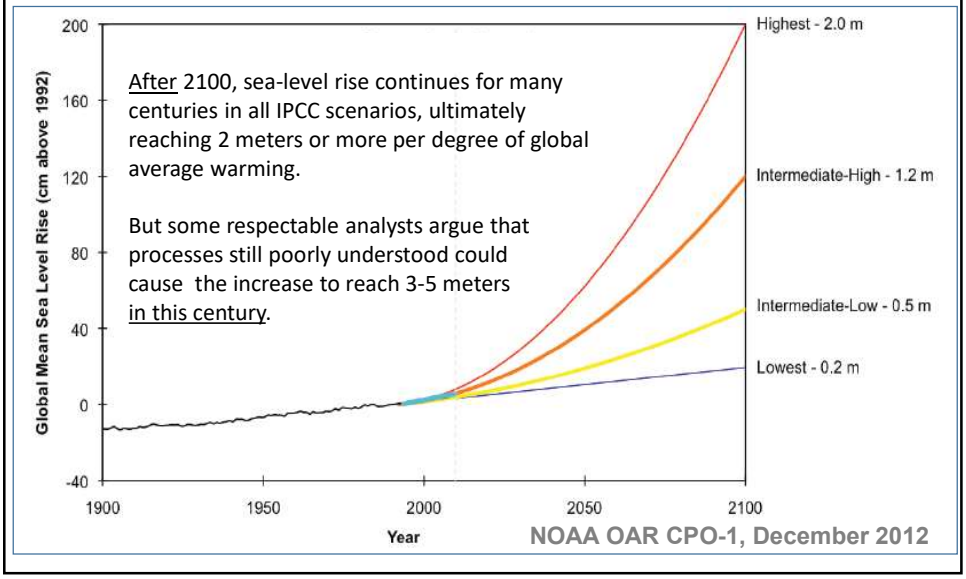
Coral reefs could be dead or in peril over most of their range by mid to late 21st century.

Steffen et al., 2004



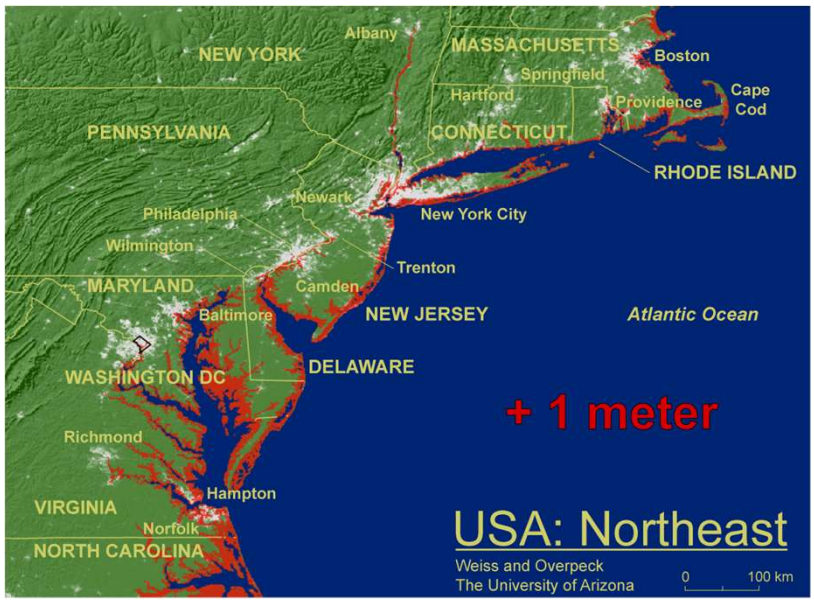
Worse is unavoidable

Sea-level rise continues in all scenarios and accelerates in most



Worse is unavoidable

Area flooded at high tide under 1 meter SLR



Worse is unavoidable

But maybe the following can still be avoided

- 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

These are possible $\Delta T < 2^{\circ}C$ but more likely above that.

Society Is Far Behind on "Conventional" Mitigation

Society is far behind on "conventional" mitigation

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

Under the above (sensible) definition, geoengineering is mitigation (albeit "unconventional" in most current practice).

Society is far behind on "conventional" mitigation

Concerning the three options…

- 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.

Society is far behind on "conventional" mitigation

Mitigation possibilities include…

(CONVENTIONAL)

- 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

(UNCONVENTIONAL)

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

Society is far behind on "conventional" mitigation

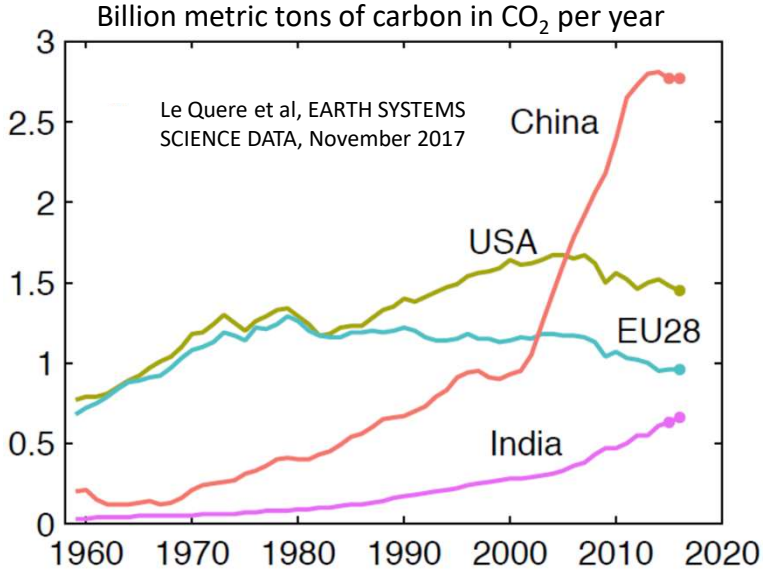
How much mitigation, how soon?

- 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.

Society is far behind on "conventional" mitigation

Yes, emissions in some countries are declining

Billion metric tons of carbon in CO_2 per year

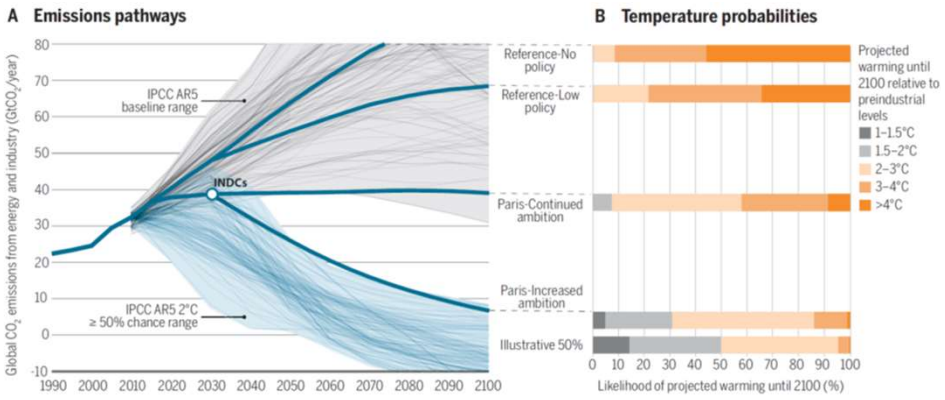


But India's growth offsets all these declines.

Society is far behind on "conventional" mitigation

Paris commitments are not nearly enough…

…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.

Society is far behind on "conventional" mitigation

Trump has turned sharply in the wrong direction

THE OBAMA ADMINISTRATION…

- Boosted climate research & monitoring; invested in clean-energy R&D & incentives; promulgated aggressive efficiency standards; promoted climate-change adaptation
- Launched the "Climate Action Plan" with further mitigation, adaptation, & international initiatives; reached agreement with China leading to Paris accords with 195 countries; initiated Mission Innovation; boosted aid to "countries in need".

THE TRUMP ADMINISTRATION…

- Put climate contrarians in charge at OMB, EPA, & DOI, while leaving most key science positions unfilled; proposed deep budget cuts in climate science & clean energy R&D
- Cancelled Obama's Climate Action Plan & Executive Orders on adaptation; withdrew from Paris accord; cut off international assistance on climate change

The Rest of the Story

The rest of the story

Getting to the last 2 conclusions stated up front

- Public recognition of the challenge & public's sense of urgency are growing rapidly in the USA & worldwide as climate-related extreme events multiply.
- "Young voter" demographics are particularly alarmed & are shifting political reality in a way elected officials cannot long ignore.

That, plus points made in this talk about inevitability of even more obvious harm & likely continuing gross inadequacy of "conventional" mitigation, make clear that, as stated at the outset,

- A frantic reach for additional measures is likely soon.
- When some reach for geoengineering, as they almost certainly will, we'd better be ready with insights…
  - not only about what if any technologies make sense
  - but also about governance.

So…

Thank you for your attention,

and all success in your deliberations!