Climate Change and Cape Cod

What We Know. What We Expect. What We Can Do.

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Quissett Harbor Preservation Trust

The 11th Annual Wheeler Lecture

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A few basics

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.

A few basics

Terminology: "global warming" is 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".

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.

Outline of the rest of the presentation

WHAT WE KNOW (and how we know it) ABOUT…

- the pace, character, & causes of climate change
- the ongoing impacts on people & ecosystems

WHAT WE EXPECT

- the future of climate change & its impacts (with particular emphasis on Cape Cod)

WHAT WE CAN DO (and who "we" are)

- reducing emissions (how much, how fast, by whom)
- adapting to unavoidable change (acting locally)
- the need for (and current lack of) federal leadership
- what states, cities, businesses, NGOs, & citizens can do

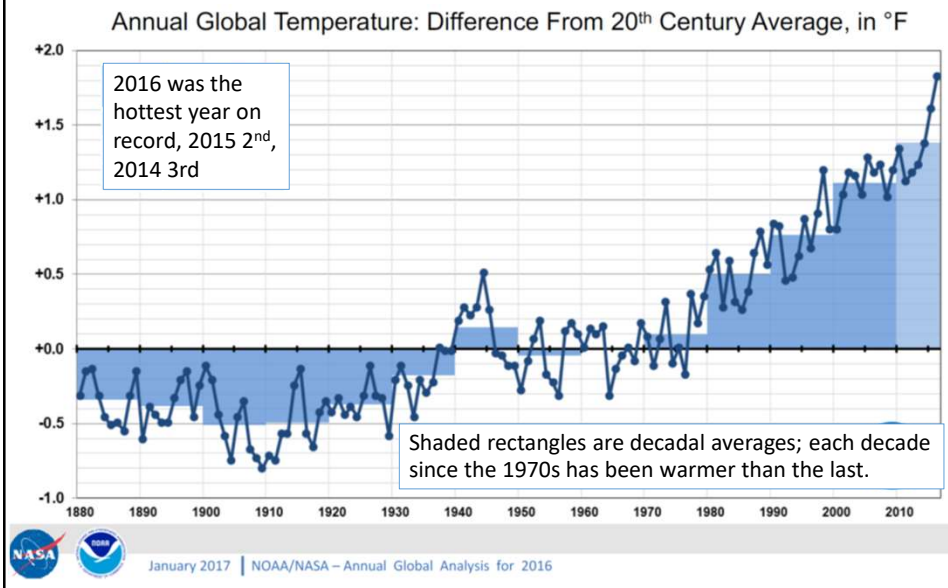
What We Know

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

Daniel Patrick Moynihan

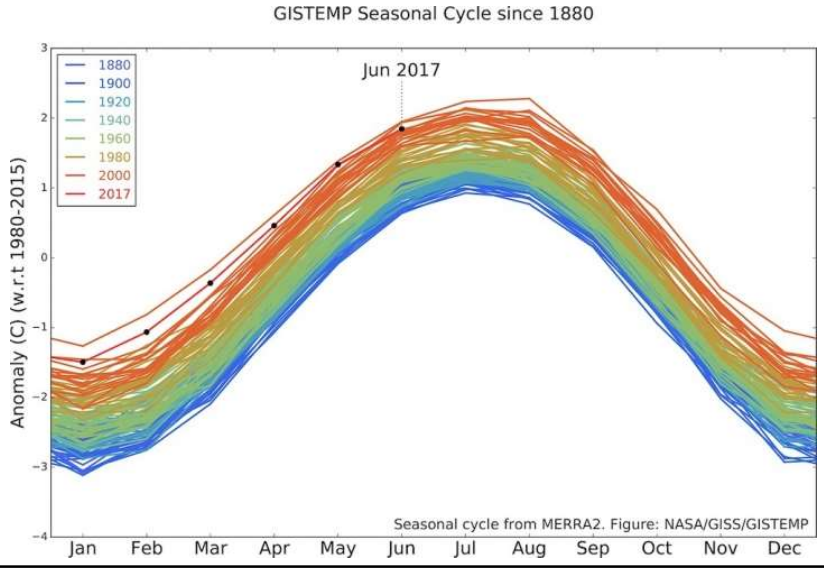
What We Know: The pace, character, and consequences of climate change

Rapid warming is ongoing



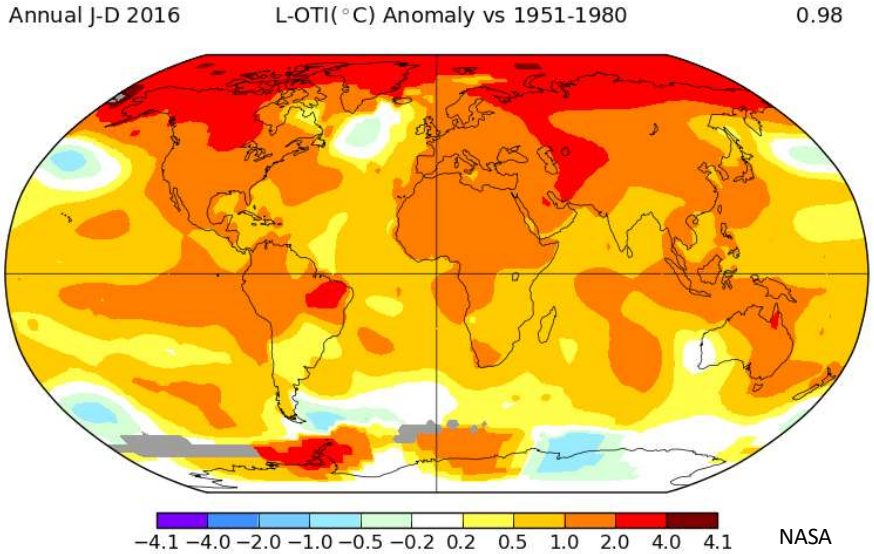
What We Know: The pace, character, and consequences of climate change

First half of 2017 was the 2nd hottest Jan-Jun on record despite absence of El Niño



What We Know: The pace, character, and consequences of climate change

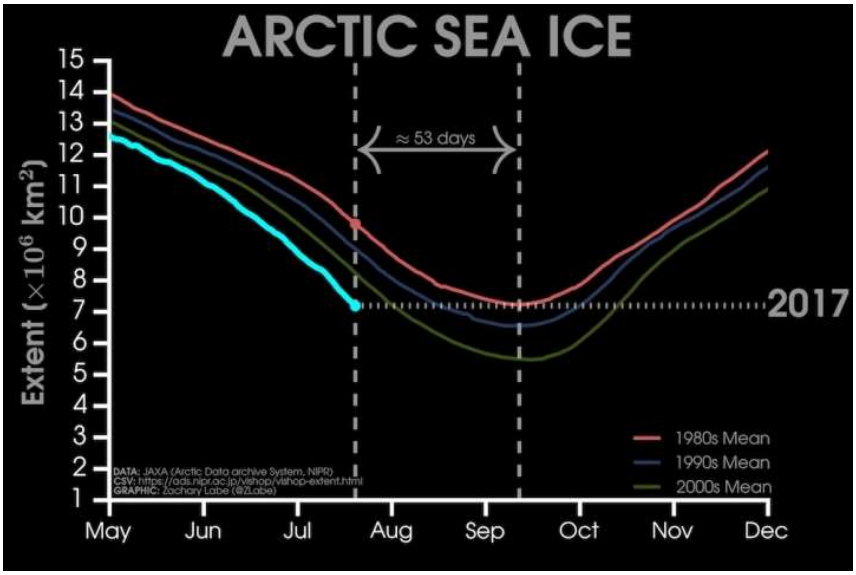
The Arctic, West Antarctic Peninsula, and mid-continents are warming much faster than the global average



NASA

What We Know: The pace, character, and consequences of climate change

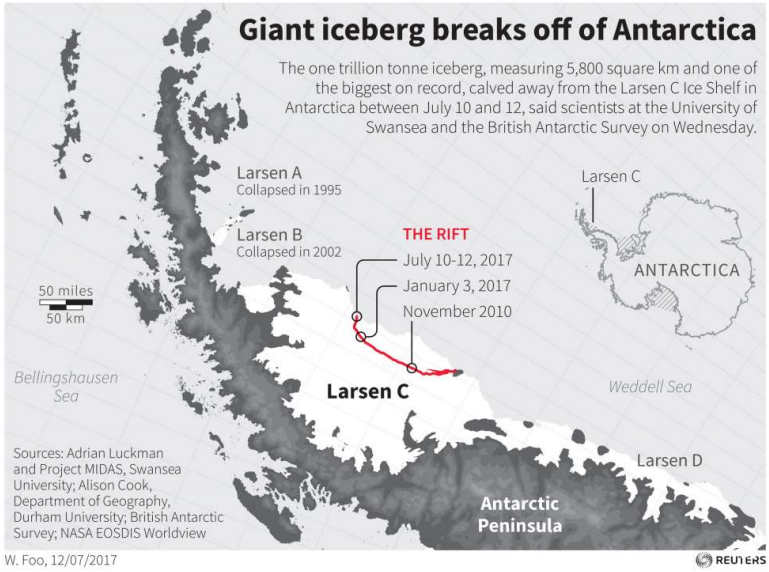
Arctic sea-ice shrinkage is setting new records



Sea-ice loss doesn't raise sea level, but it does accelerate Arctic warming.

What We Know: The pace, character, and consequences of climate change

Antarctic sea-ice is in trouble, too



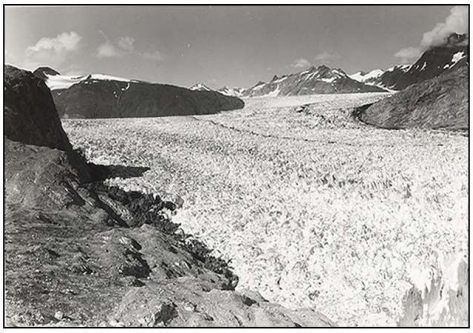
Sea-ice loss in Antarctic allows the land ice to flow into the sea.

What We Know: The pace, character, and consequences of climate change

Glaciers worldwide have been shrinking for decades

Muir Glacier, Alaska, 1941-2004

August 1941



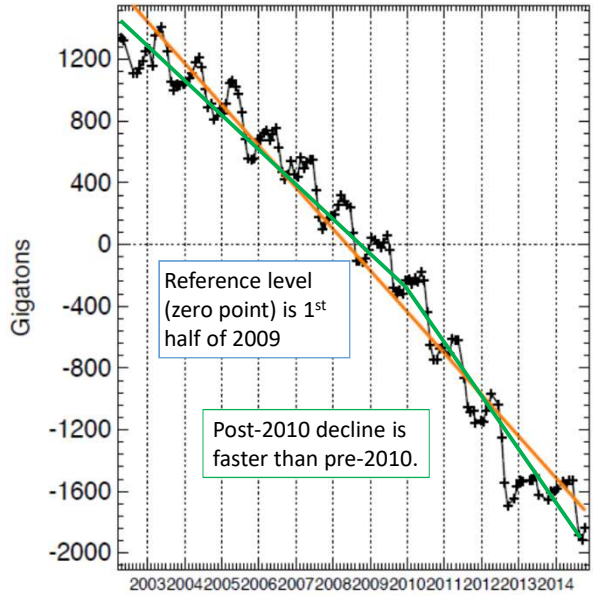
August 2004

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

What We Know: The pace, character, and consequences of climate change

Loss of ice from Greenland is accelerating

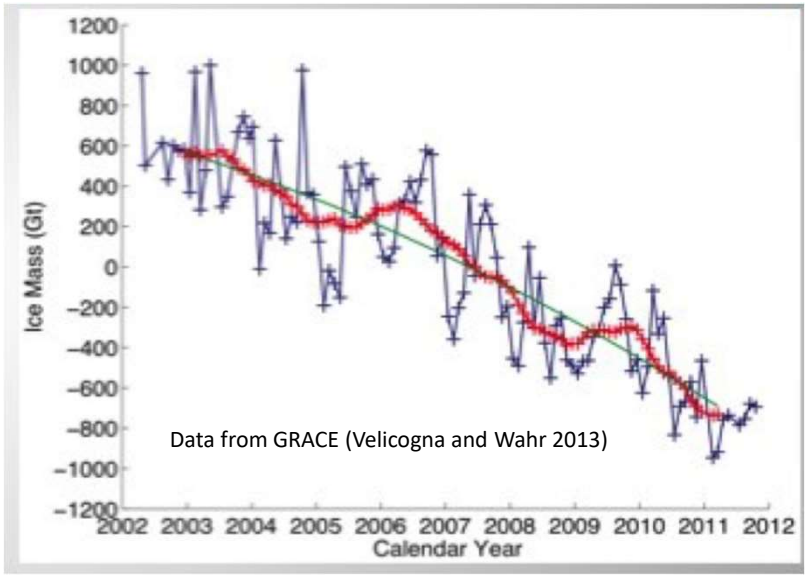
Land-ice loss from melting & accelerated calving of icebergs raises sea level.



Waleed Abdalati, from GRACE, December 2014

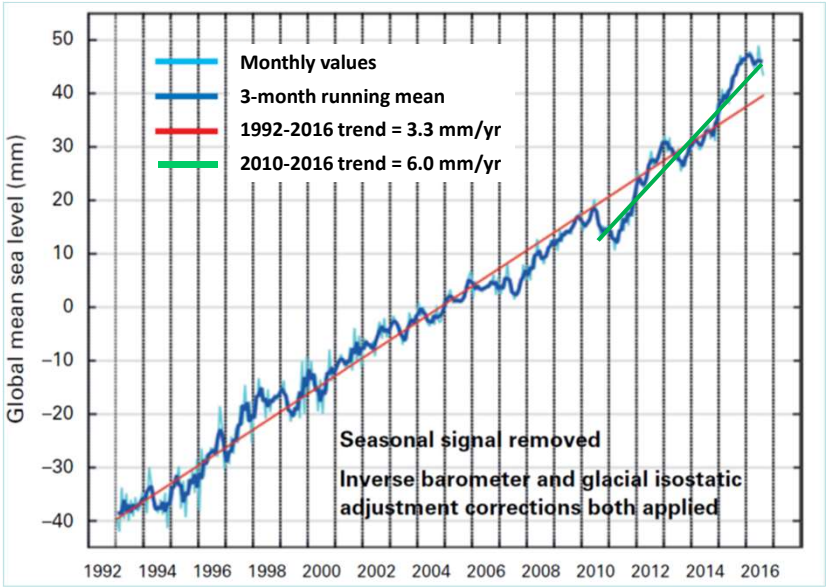
What We Know: The pace, character, and consequences of climate change

Antarctica as a whole is losing ice, too



What We Know: The pace, character, and consequences of climate change

No surprise, then, that sea-level rise is speeding up



WMO 2017

What We Know: The pace, character, and consequences of climate change

That humans are the cause is irrefutable

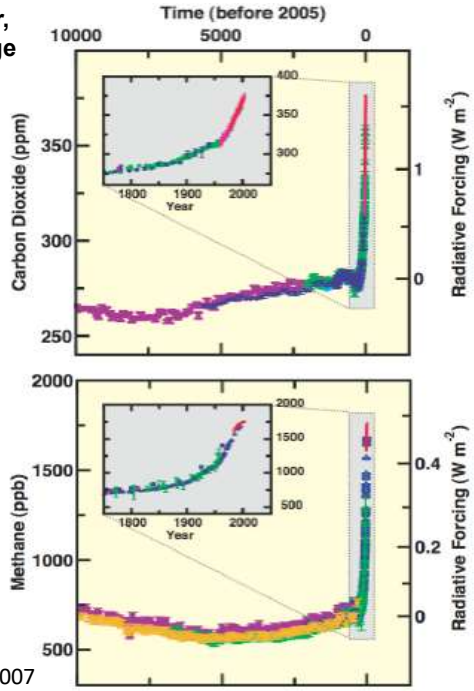
- The rapidly rising use of fossil fuels after 1750, augmented by land-use change, produced a pace of increase in atmospheric concentrations of CO_2, CH_4, and N_2O unprecedented in Earth's history. The attribution to humans is scientifically ironclad.
- When the effects of the concurrent buildup of atmospheric particles are accounted for, these human-caused increases in CO_2, CH_4, N_2O, and industrial HFCs explain essentially all of the observed increase in global-average temperature over this period.
- Not just the magnitude but the spatial and temporal patterns of the warming match what basic physics and climate models say should be the result of the observed GHG buildups.
- Under the natural influences on Earth's climate, Earth had been cooling for 6500 years up to 1750--and would have continued to cool if human-caused warming had not dominated after that.

What We Know: The pace, character, and consequences of climate change

Humans caused the big greenhouse-gas increases since 1750.

Compared to natural changes over the millenia, the spike in concentrations of CO_2 & CH_4 in the past 250 years is extraordinary.

It's clear humans caused the CO_2 spike because fossil CO_2 lacks carbon-14, and the drop in atmospheric C-14 fraction resulting from the fossil-CO_2 additions is measurable.



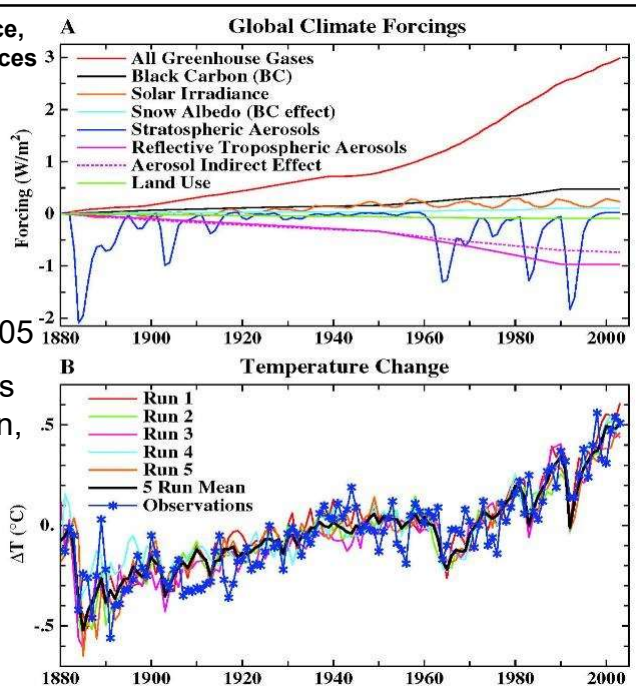
IPCC AR4, WG1 SPM, 2007

What We Know: The pace, character, & consequences of climate change

Human "finger-print" on recent climate change

Top panel shows human & natural influences 1880-2005

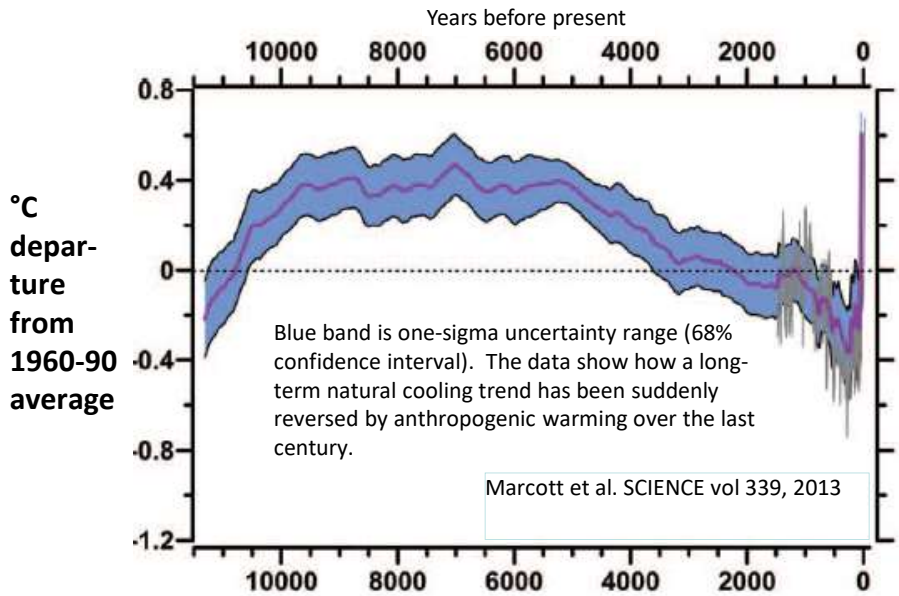
Bottom panel shows computer simulation, when fed these influences, repro-duces the temps that were observed



Source: Hansen et al., *Science 308*, 1431, 2005.

What We Know: The pace, character, and consequences of climate change

Humans reversed 6,500 years of natural cooling



What We Know: The ongoing impacts on people and ecosystems

Climate change is <u>already</u> causing harm

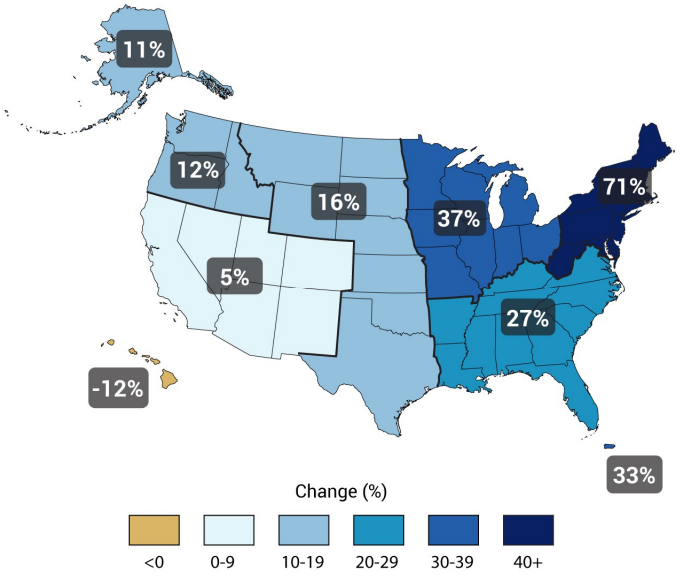
Around the world we're seeing, variously, increases in

- floods
- drought
- wildfires
- heat waves
- coral bleaching
- coastal erosion & inundation
- power of the strongest storms
- permafrost thawing & subsidence
- expanding impacts of pests & pathogens
- altered distribution/abundance of valued species

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

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: Heavier downpours → more floods



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

By far the biggest increase was in the Northeast.

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

What We Know: The ongoing impacts on people and ecosystems

Downpours → Floods (continued)

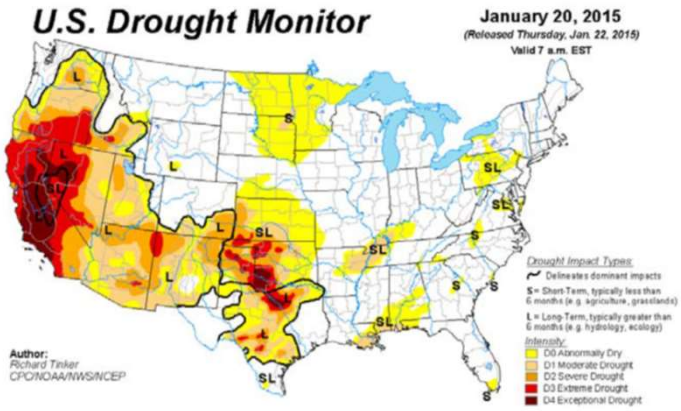
"Hundred-year" floods now occur once a decade in some places.

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

What We Know: The ongoing impacts on people and ecosystems

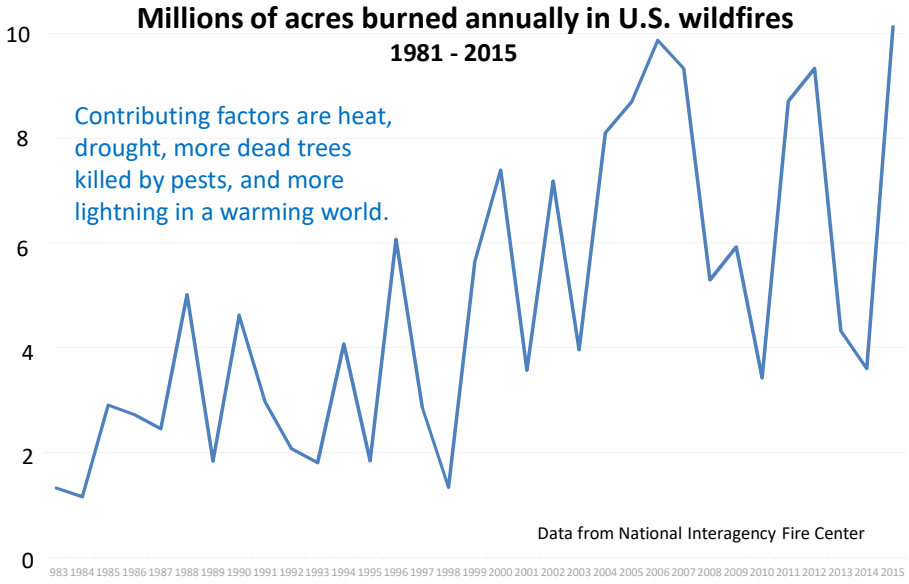
Ongoing harm: drought

- 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.



What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: wildfires



What we know: Impacts

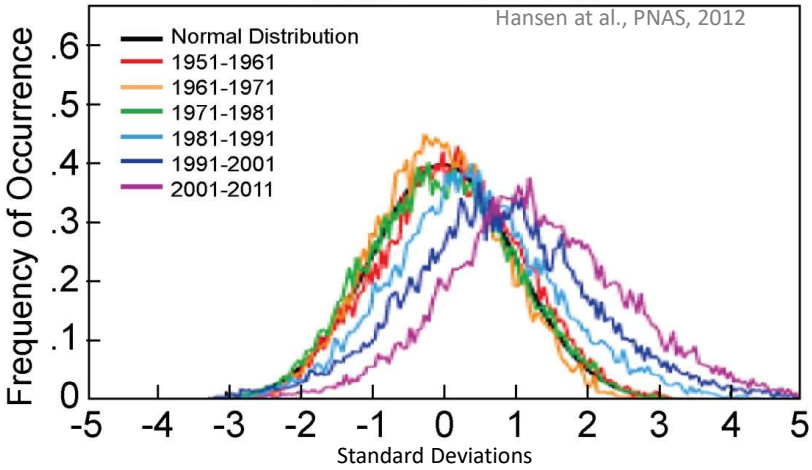
Ongoing harm: Wildfires

- 3.4 million acres had already burned in the USA in 2017 by the beginning of July.
- The fire season in the USA is about 3 months longer than it was 40 years ago.
- The average fire is much bigger & hotter than before. Small wildfires burn at 1300-1400°F; big ones can burn at 2000°F or more, spreading faster, with far greater risks for firefighters.
- In Alaska, even the tundra has experienced wildfires in recent years.

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: huge increase in 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.

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What We Know: The ongoing impacts on people and ecosystems

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

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: Death of coral reefs in Florida Keys

Florida's coral reefs are being devastated by multiple stresses, of which warming water is the most important.

Less than 10% of the reef system is now covered by living coral. (Red circles show percentage declines since 1996.)

Diving, snorkeling, fishing, & eating seafood are threatened mainstays of the Florida Keys economy.

NASA Aqua satellite imagery. Washington Post, 26 June 2017

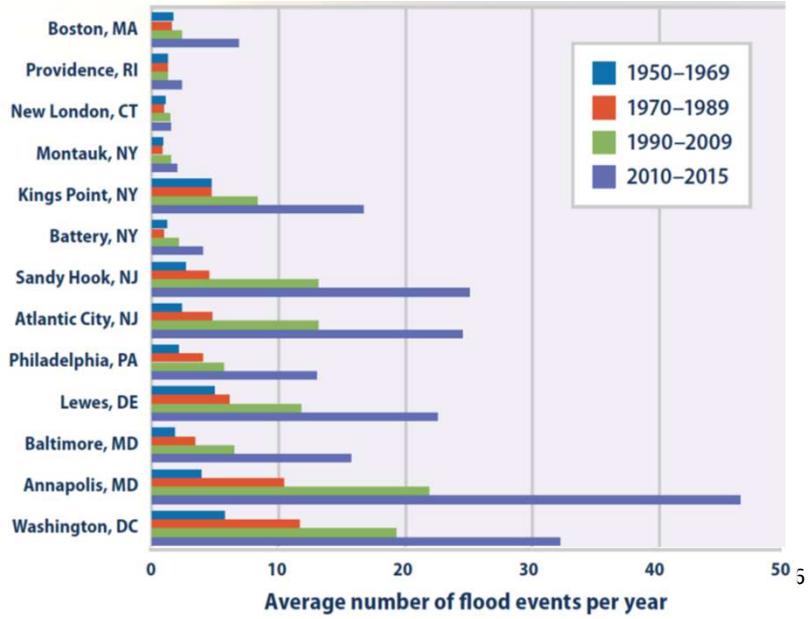
What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: rising sea → coastal inundation



What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: rising sea → coastal erosion

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

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: 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

What We Know: The ongoing impacts on people and ecosystems

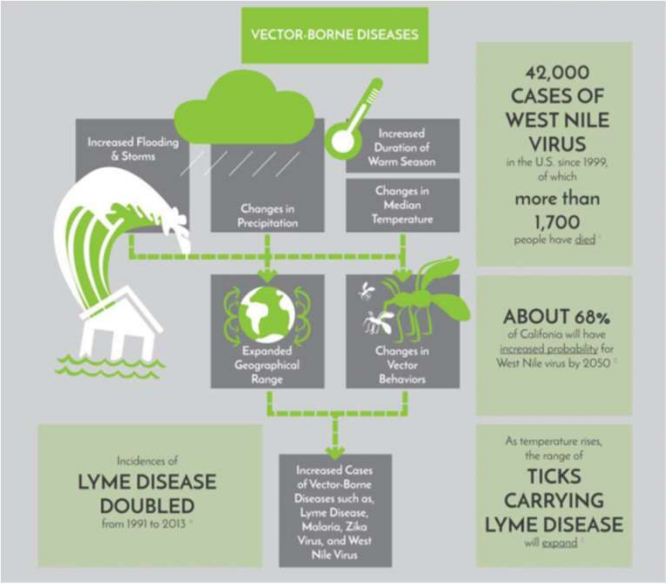
Ongoing harm: Pest outbreaks

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

USGCRP 2009

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: Increased vector-borne disease



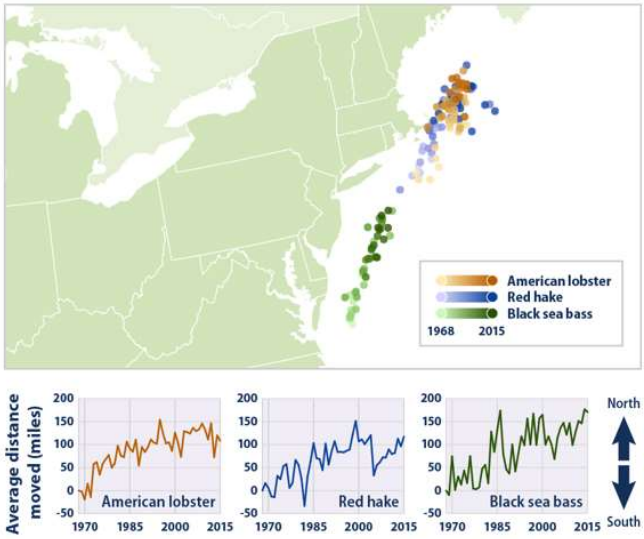
Climate Nexus

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: impacts on valued species

Average Location of Three Fish and Shellfish Species in the Northeast, 1968–2015

US EPA



What We Expect

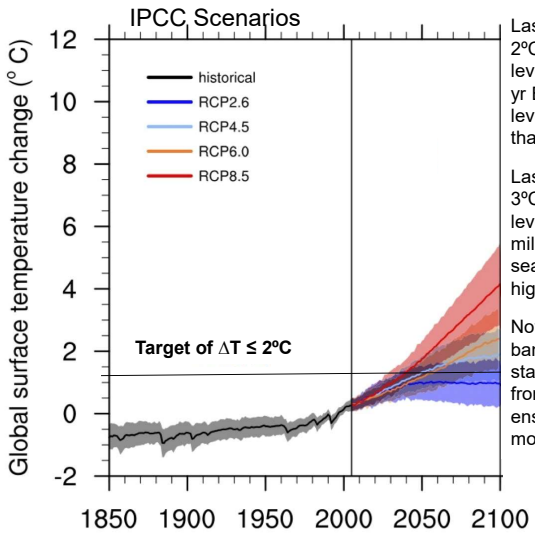
The future of climate change and its impacts

"Prediction is difficult…especially about the future."

attributed to Yogi Berra and Neils Bohr

What We Expect: The future of climate change and its impacts

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 We Expect: The future of climate change and its impacts

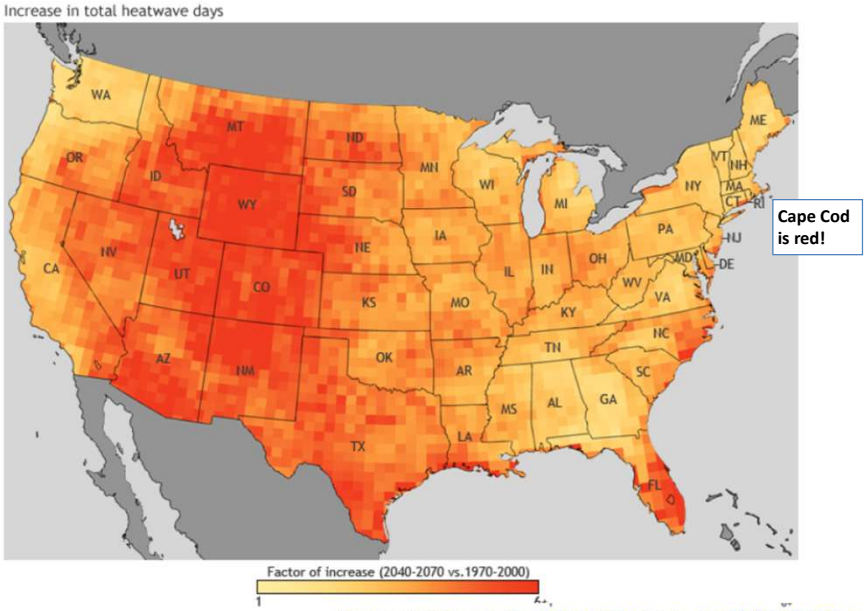
The most worrying recent & emerging insights about future impacts involve…

- Impacts of climate change on human health: heat stress, smog intensity, allergies, pathogens & vectors
- Growing extremes of wet & dry: droughts, wildfires, hailstorms/downpours/floods
- Impacts on the coastal zone from the combination of sea-level rise and increasingly powerful storms
- Impacts of ocean heating & acidification on marine food webs and commercial & subsistence fisheries
- Impacts of rapid climate change in the Arctic outside the region, e.g., Arctic methane release accelerating climate change everywhere; winter extreme weather from weakened polar vortex

Nearly all of these phenomena are germane to Cape Cod.

What We Expect: The future of climate change and its impacts

Increase in heatwaves at mid-century under BAU

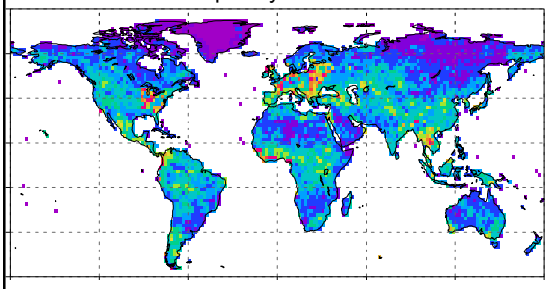


(http://www.climate.gov//sites/default/files/Heatwave_days2040-2070_HR.jpg)

What We Expect: The future of climate change and its impacts

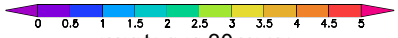
Droughts to increase over much of the globe

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

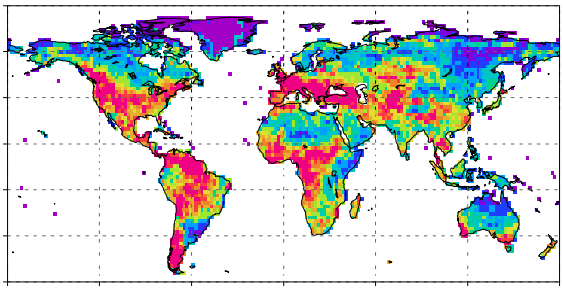


1961-1990

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



events per 30 years



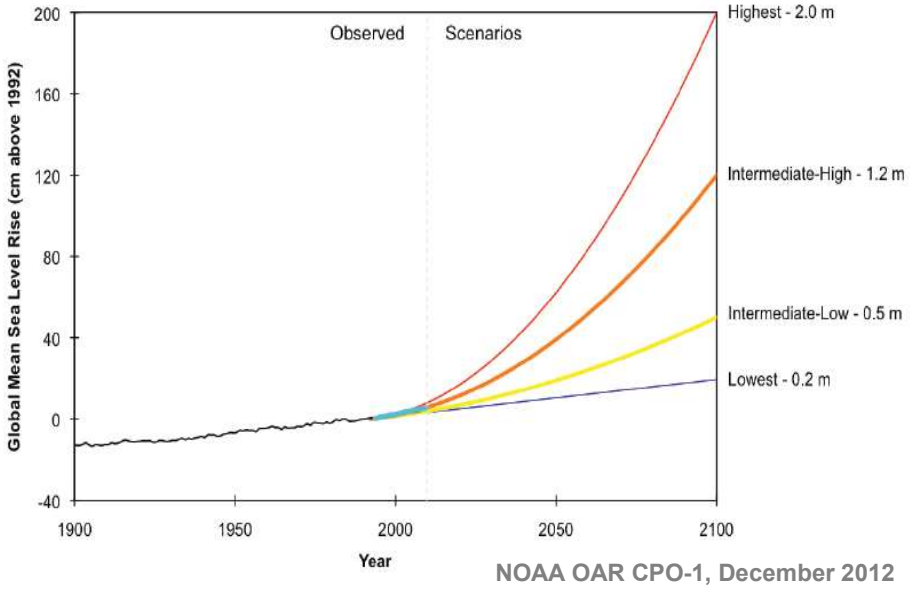
2070-2099, IPCC A2 scenario

Results shown are the mean of 8 global climate models. **Cape Cod drought frequency reaches 5x historical value.**

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

What We Expect: The future of climate change and its impacts

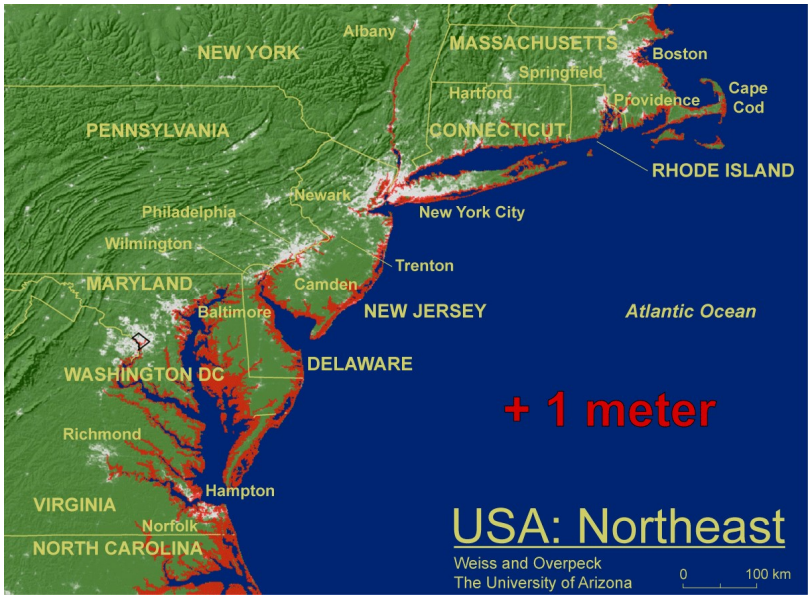
Mean sea level could rise 1-2 meters 2000- 2100



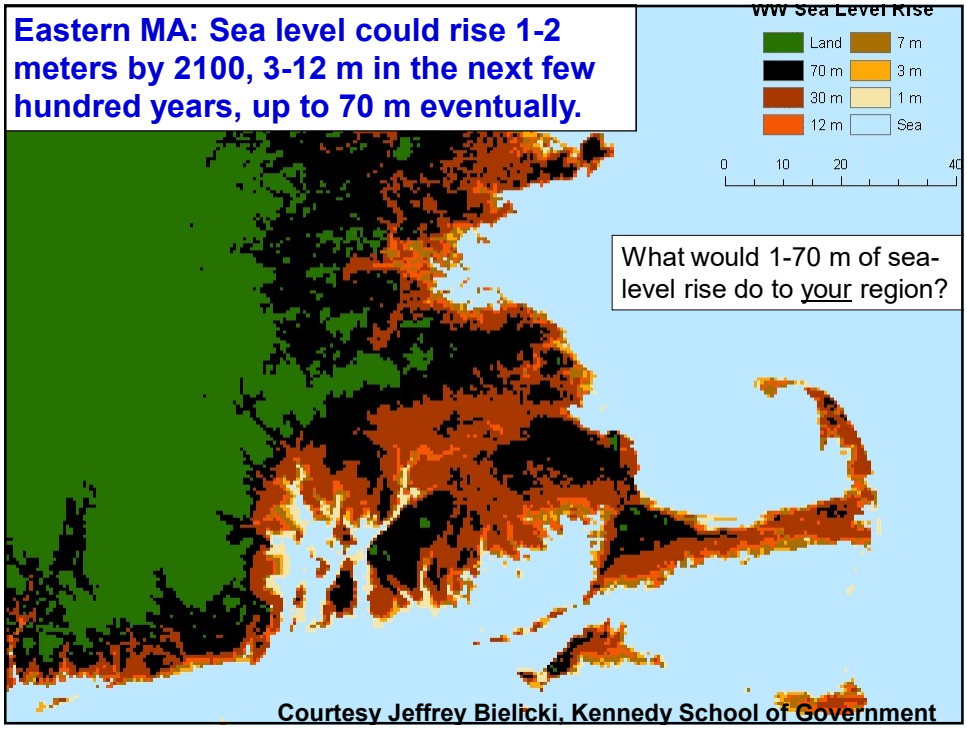
NOAA OAR CPO-1, December 2012

What We Expect: The future of climate change and its impacts

Sea level: Flooded area with 1 meter rise



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.



What would 1-70 m of sea-level rise do to your region?

Courtesy Jeffrey Bielicki, Kennedy School of Government

What We Expect: The future of climate change and its impacts

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).

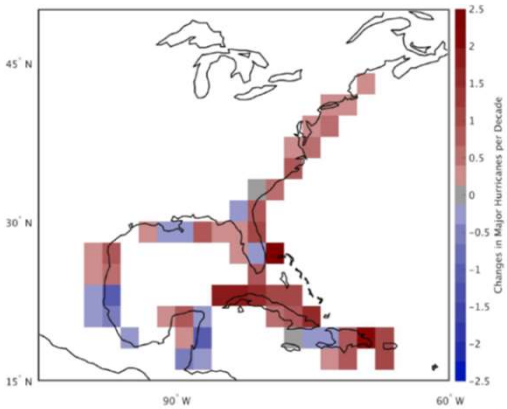


Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

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

What We Expect: The future of climate change and its impacts

Impacts on Northeast fisheries

ICES Journal of Marine Science

ICES Journal of Marine Science (2015), 72(Supplement 1), i69–i78, doi:10.1093/icesjms/fsv093

American lobster nurseries of southern New England receding in the face of climate change

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

PLOS | ONE

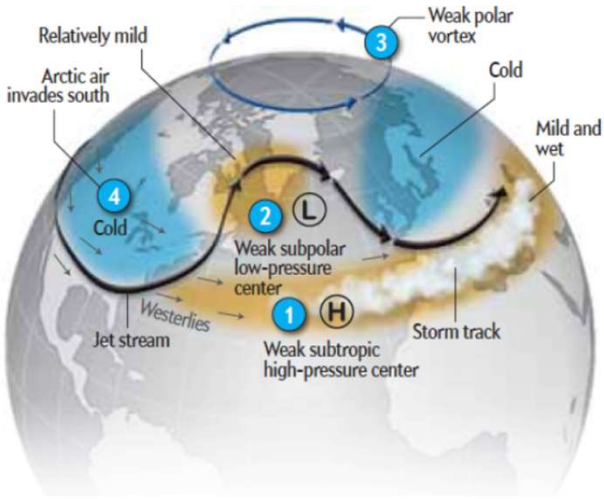
A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf

Published: February 3, 2016 • https://doi.org/10.1371/journal.pone.0146756

"We find that the overall climate vulnerability is high to very high for approximately half of the species assessed."

What We Expect: The future of climate change and its impacts

More NE winter extremes from weak polar vortex



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.

Graphic by XNR Productions

Scientific American blog, January 2014

What We Expect: The future of climate change and its impacts

Other impacts likely to affect Cape Cod

- Saltwater intrusion into freshwater wetlands and the Cape's freshwater aquifer (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
- More thunderstorms and more lightning
- Diminution of cranberry production

What We Can Do

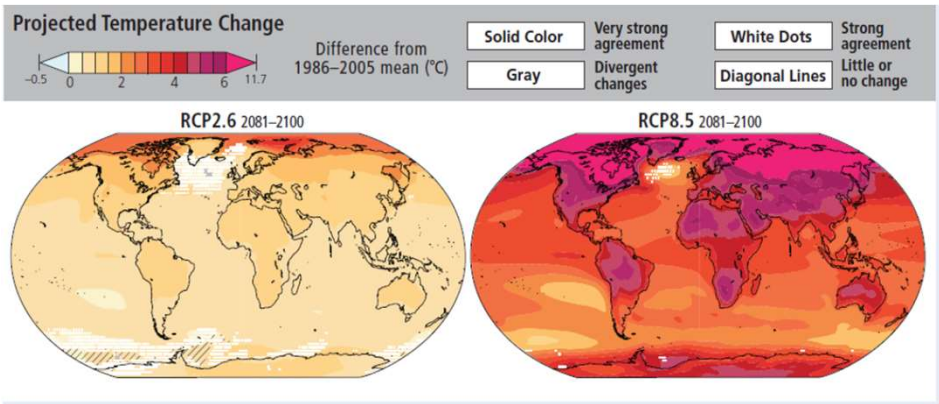
And who "we" are

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

Lao Tzu

What We Can Do

There's a huge difference in expected harm depending on the action society takes

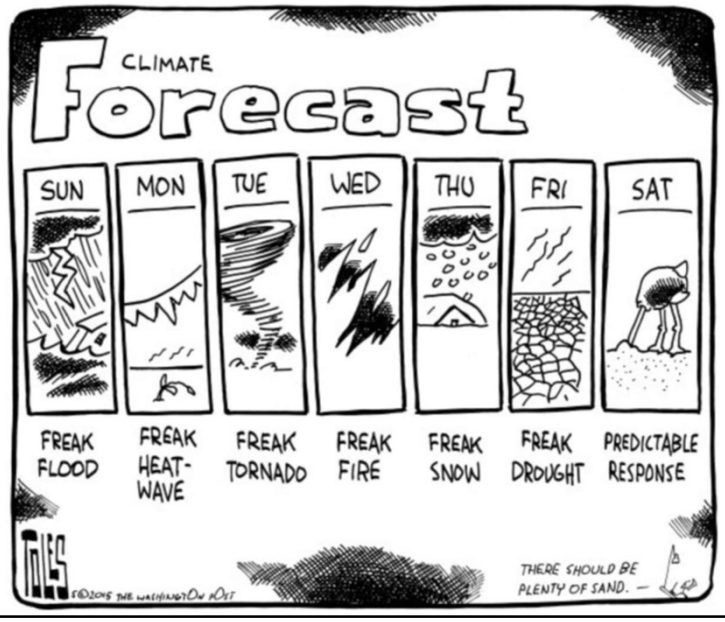


IPCC WGII, 2014

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

What We Can Do

So hiding our heads in the sand is not smart



What We Can Do

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.

What We Can Do

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.

What We Can Do

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

What We Can Do

How much mitigation, how soon?

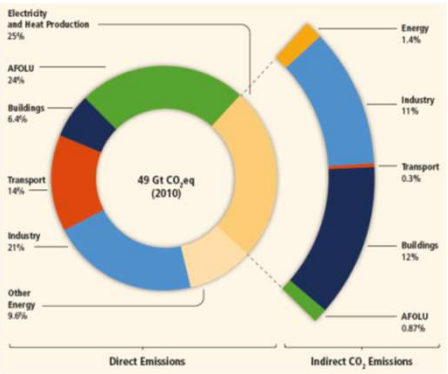
- Limiting ΔT_{avg} to ≤2ºC is now considered by many the most prudent target that still may be attainable.
  - EU embraced this target in 2002, G-8 & G-20 in 2009
  - Paris added 1.5°C as "aspirational goal" in 2015
- To have a >50% chance of staying below 2ºC:
  - atmospheric concentration of heat-trapping 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 We Can Do

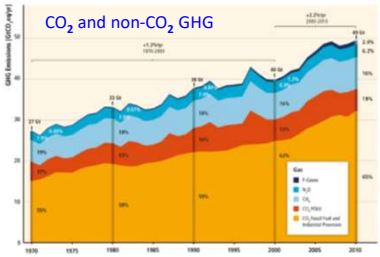
Mitigation: Everybody must get on board

Adequate mitigation will require addressing most heat-trapping substances across most emitting sectors in most countries.

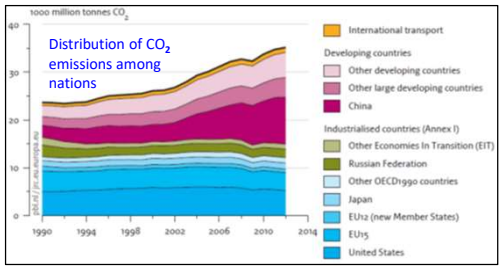
Sectoral sources of global GHG emissions



CO_2 and non-CO_2 GHG



Distribution of CO_2 emissions among nations



What We Can Do

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.

What We Can Do

The need for (& current lack of) Federal leadership

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

THE TRUMP ADMINISTRATION…

- Put climate contrarians in charge at OMB, EPA, DOI, & DOE 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 accords

What We Can Do

What states, communities, businesses, scientists, philanthropists, & opinion leaders can do

- States, communities, & businesses should devise and implement their own mitigation & adaptation plans (as many already have been doing).
- Scientists should continue to…
  - monitor & analyze climate change and improve projections;
  - explain to every available audience what we know, how we know it, how it affects that audience, how we can fix it.
- Philanthropists should seek to fill gaps in climate research & education created by Federal government's cutbacks.
- Opinion leaders should refine their ability to explain climate change impacts & remedies and rebut contrarian errors.
- All should let Congress & President Trump know that abdicating U.S. government leadership on climate change is folly.

What We Can Do

What else individuals can do

REDUCE YOUR OWN CARBON FOOTPRINT

- Get an energy audit of your home & shrink its energy waste
- Replace incandescent (and even fluorescent) lights with LEDs
- Put solar cells on your roof
- Walk, bike, or take public transportation rather than driving
- For needed driving, get a hybrid, all-electric, or other high-fuel-economy car
- Recycle, and, better yet, re-use (shopping bags, utensils, drink containers…)
- Eat less meat
- Invest in companies that are taking action on climate (and disinvest and those that aren't)
- And, for the biggest impact available to young people, have one fewer kid!

"Trend is not destiny."

Rene Dubos