Climate Change and the Cape & Islands:
What We Know. What We Expect. What We Can Do.

John P. Holdren

Professor of Environmental Science and Policy
Harvard University

Senior Advisor to the Director
Woods Hole Research Center

Former Assistant to President Obama for Science & Technology
and Director, Office of Science & Technology Policy
Executive Office of the President of the United States

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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".

A few basics

The relation between climate and weather

- Climate is the pattern exhibited by weather, for a particular geographic region and season…
  - expressed as average values, typical highs and lows, and extremes of temperature, humidity, rain, snow, and winds,
  - as observed over a period of decades
- How climate is changing over time is expressed most simply as the change in year-round average air temperature for a region or for the globe.
- Small changes in that index typically reflect much larger changes in aspects of weather patterns that matter most to humans and ecosystems.

Most importantly, when average temperature changes a little, the frequency and magnitude of extremes (not only of temperature but also of other weather variables) change a lot.

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 some emphasis on the Cape & Islands)

WHAT WE CAN DO

- 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

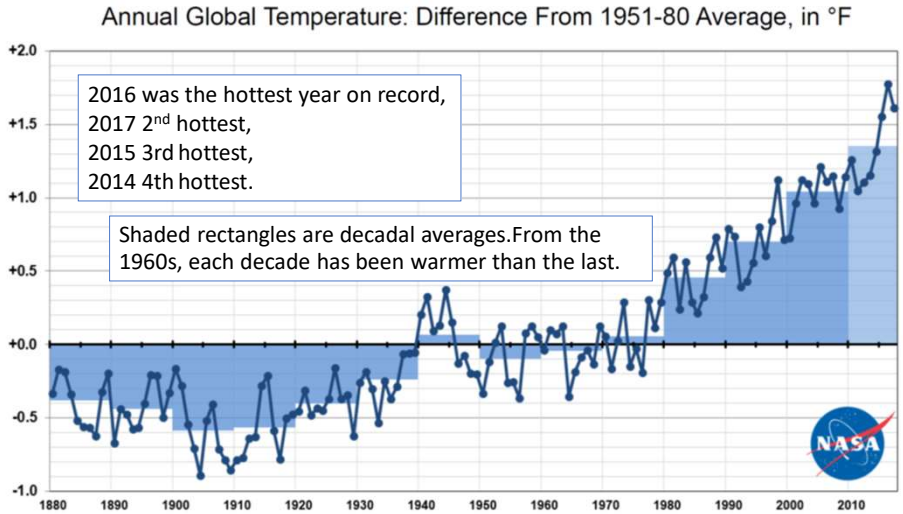
What We Know

"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

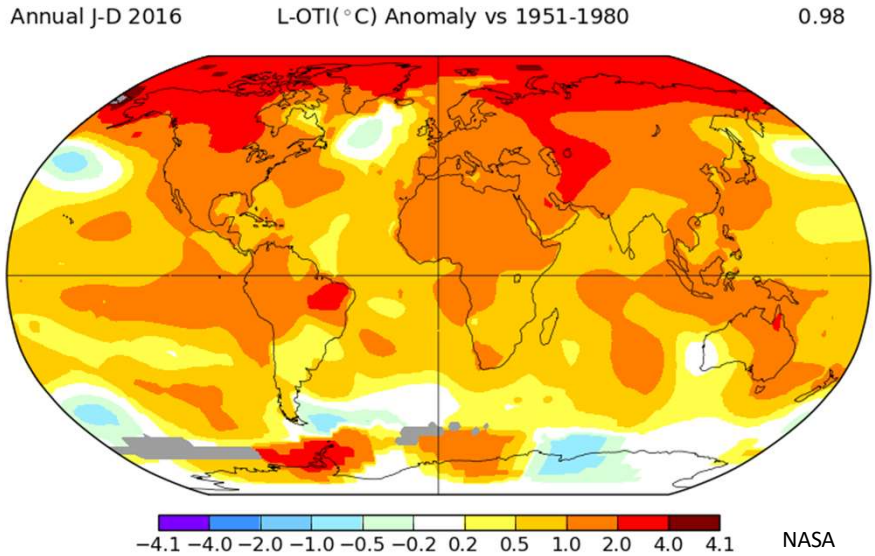
Rapid warming is ongoing



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.

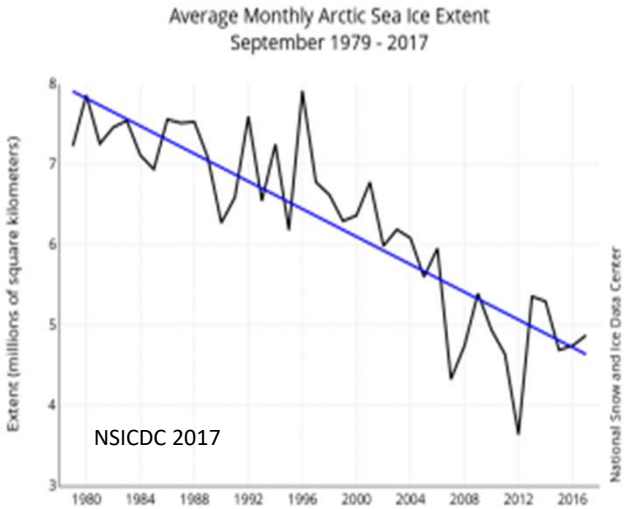
What We Know: The pace, character, and consequences of climate change

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



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

Arctic sea-ice is shrinking rapidly



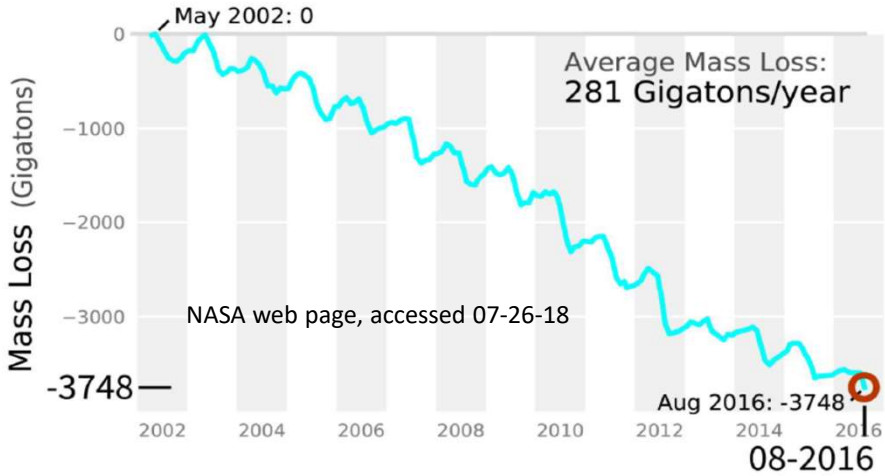
Sea ice floats, so its shrinkage doesn't affect sea level.

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

The recent pace of sea-ice decline is unprecedented for at least the last 500 years.

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

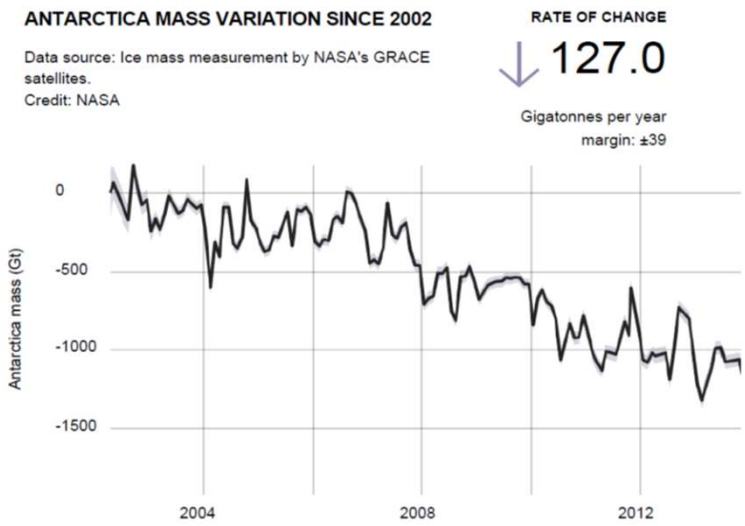
Greenland is steadily losing its land ice



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

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

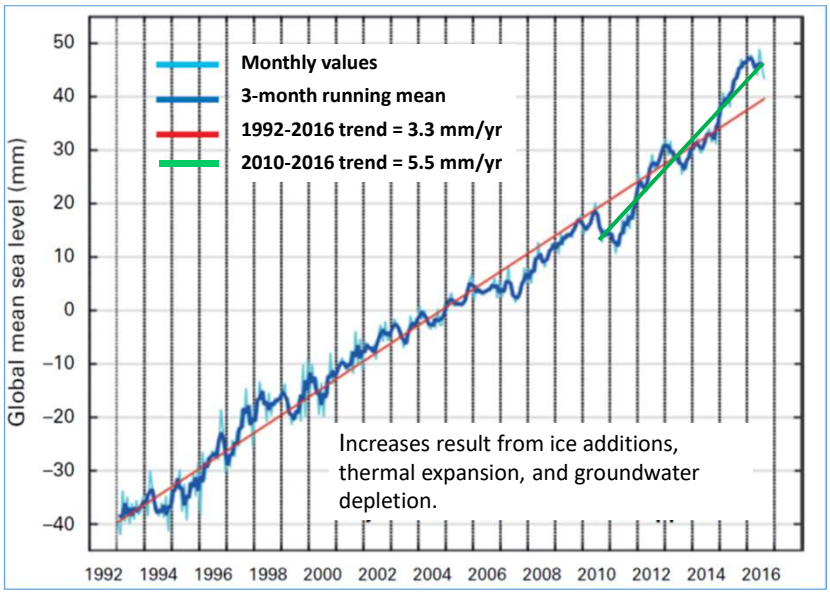
It's now clear Antarctica is also losing ice



NASA web page, accessed 6-18

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

The pace of sea-level rise has increased



WMO 2017

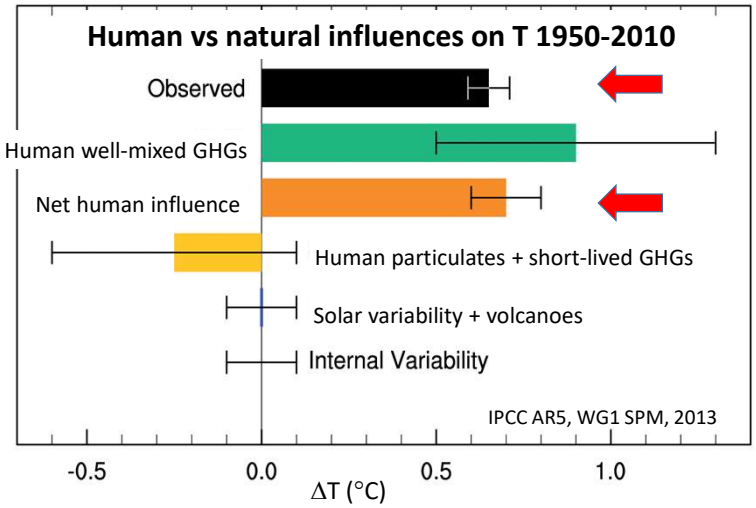
What We Know: The pace, character, and consequences of climate change

Humans are the main cause of current climate change

- 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.
- 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

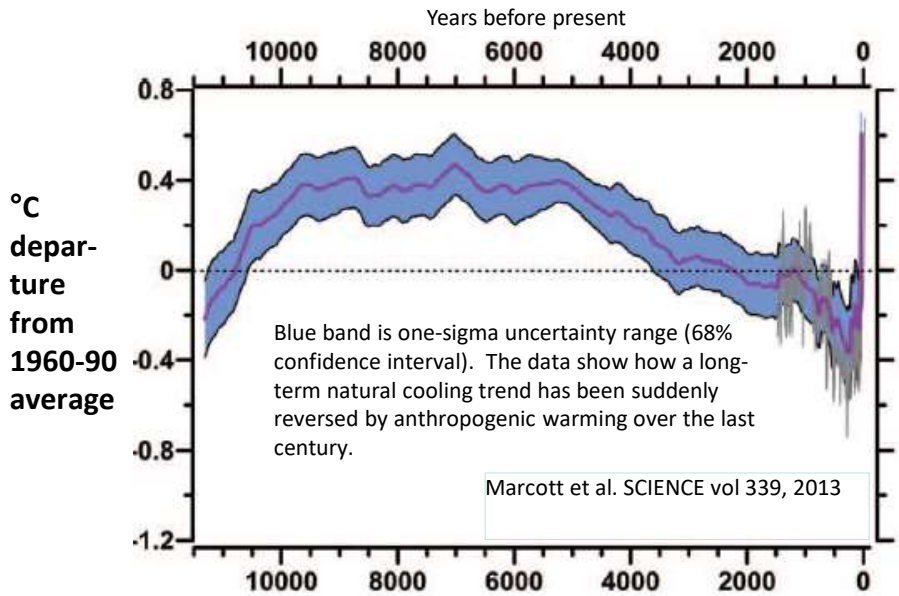
Within measurement & analytical uncertainties, essentially all of the recent observed warming was human-caused.



The contrarians' claim there's a lot of uncertainty about the human role is wrong.

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

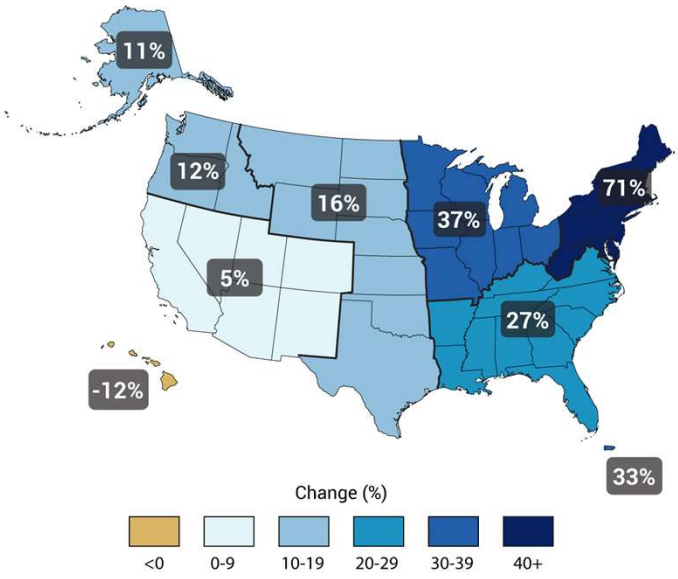
Around the world we're seeing, variously, increases in

- 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

Bigger downpours → More flooding

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

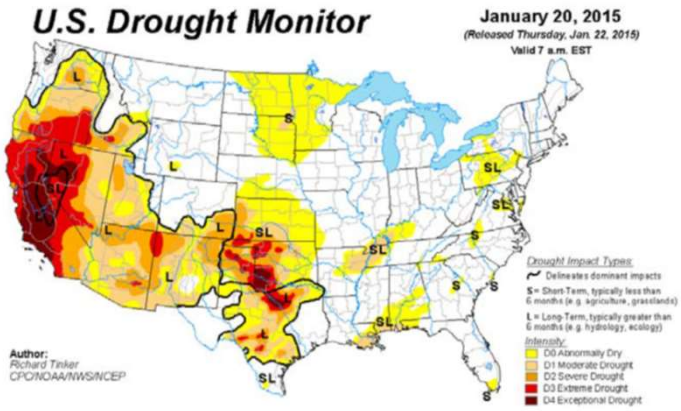
East Baton Rouge, LA, August 2016: Up to 20 inches of rain in 3 days

Hurricane Harvey brought >50 inches of rain over 5 days to parts of Texas in August 2017.

What We Know: The ongoing impacts on people and ecosystems

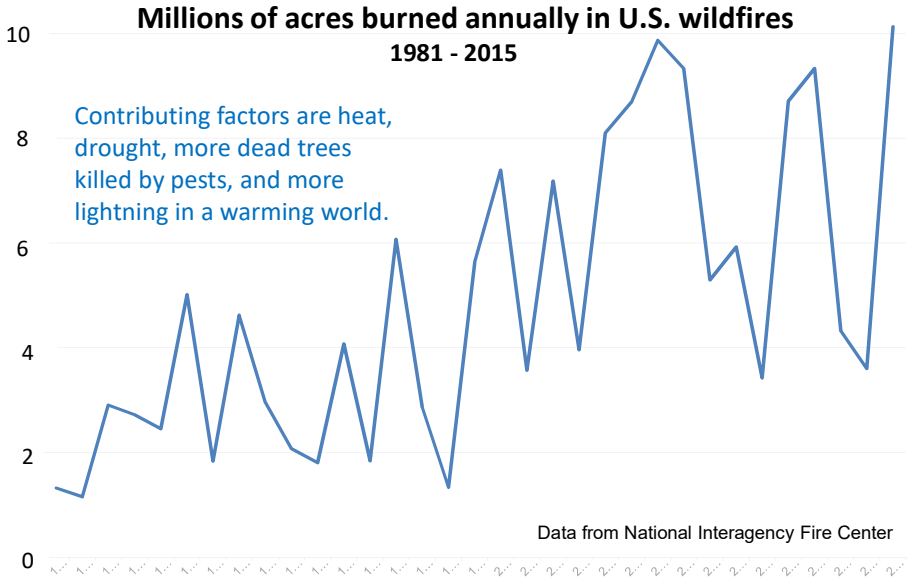
Ongoing harm: drought

- 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



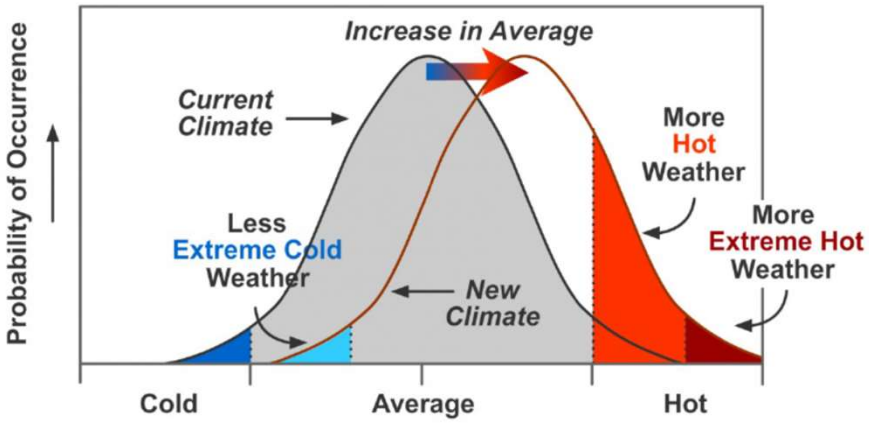
What We Know: The ongoing impacts on people and ecosystems

Wildfires (continued)

- 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, spreading faster & doing far greater damage.
- Nine of the ten biggest U.S. wildfires on record have occurred since 2004. (The other one was in 1997).
- Five of the 10 largest were in Alaska, where now even the tundra is burning.
- The smoke from today's big wildfires can cause health impacts 1000s of miles away.

What We Know: The ongoing impacts on people and ecosystems

Modest change in average temperature are leading to enormous change in heat extremes



As climate warms overall, high-T extremes that previously had probability of occurrence near zero occur with some regularity.

What We Know: The ongoing impacts on people and ecosystems

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
• 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

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

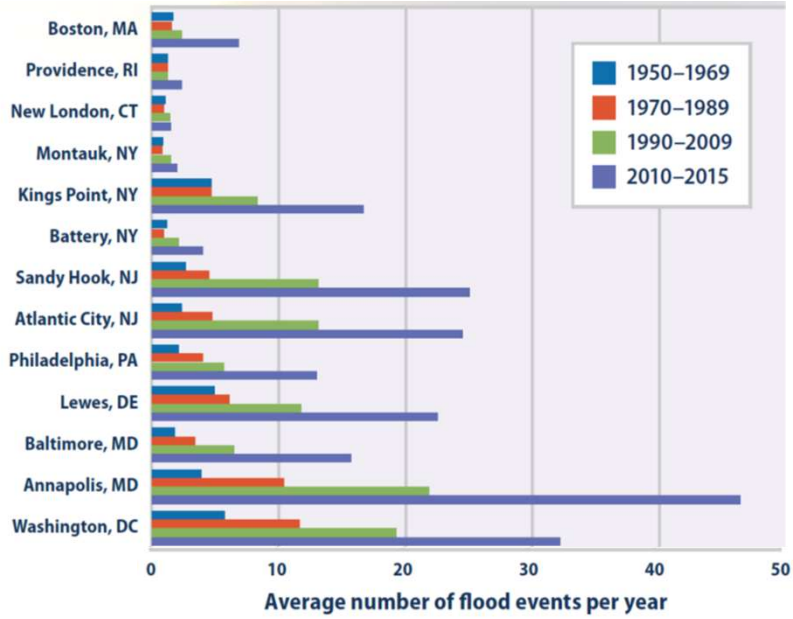
What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: thawing/subsiding permafrost

Norwegian Polar Institute, 2009

What We Know: The ongoing impacts on people and ecosystems

Ongoing harm: rising sea → coastal inundation



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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

Tropical storms are getting stronger

- 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

What We Know: The ongoing impacts on people and ecosystems

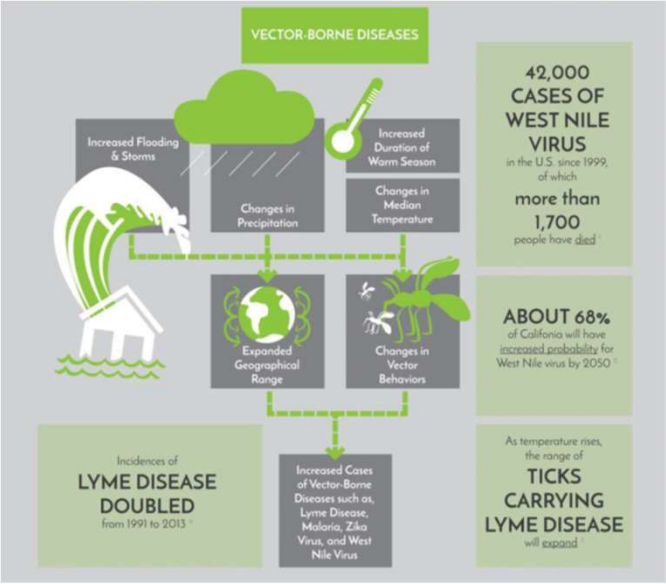
Ongoing harm: Pest outbreaks

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 Expect

The future of climate change and its impacts

"Prediction is difficult…especially about the future."

attributed to Yogi Berra and Neils Bohr

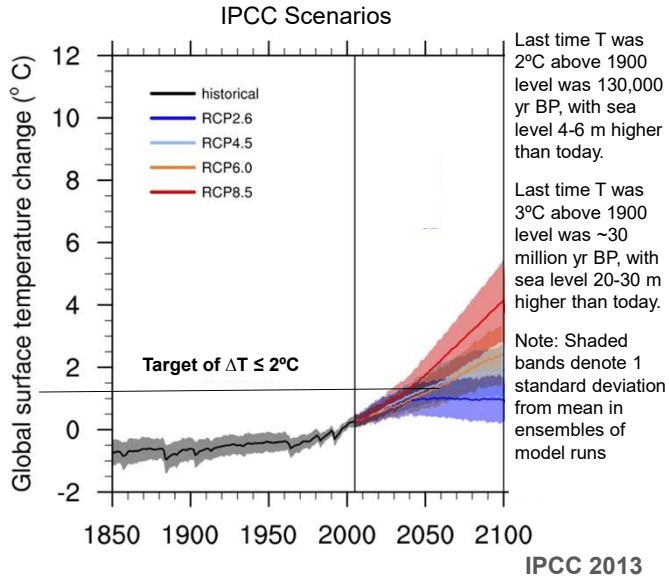
What We Expect: The future of climate change and its impacts

What's coming depends on future emissions

Global average T continues to increase under <u>all</u> plausible scenarios.

Momentum in the climate system means T continues to go up even after at mospheric conditions stabilize.

And sea level continues to go up even after T stabilizes.



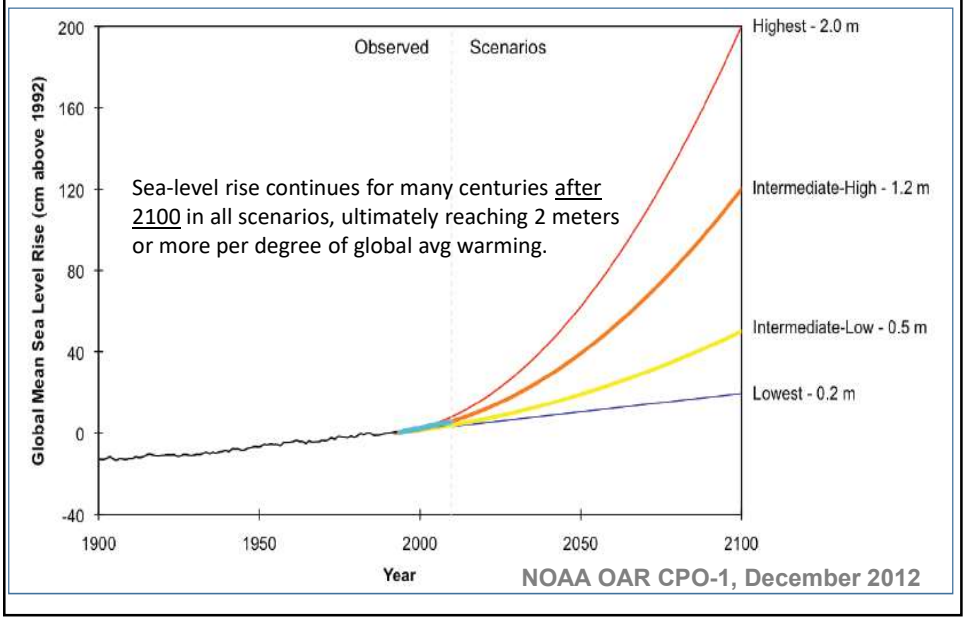
Last time T was 2ºC above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

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

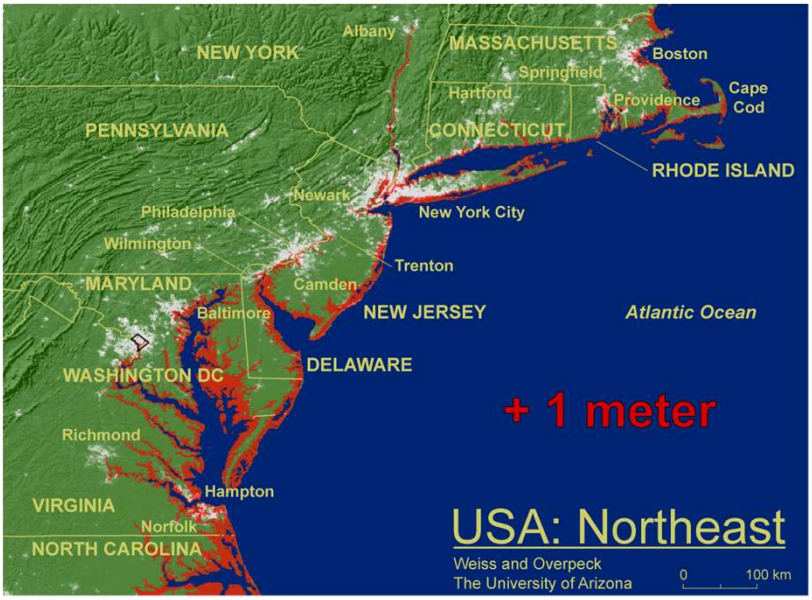
Scientific best estimates under specified future emissions

Sea level likely to rise another 0.5-2 m by 2100



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

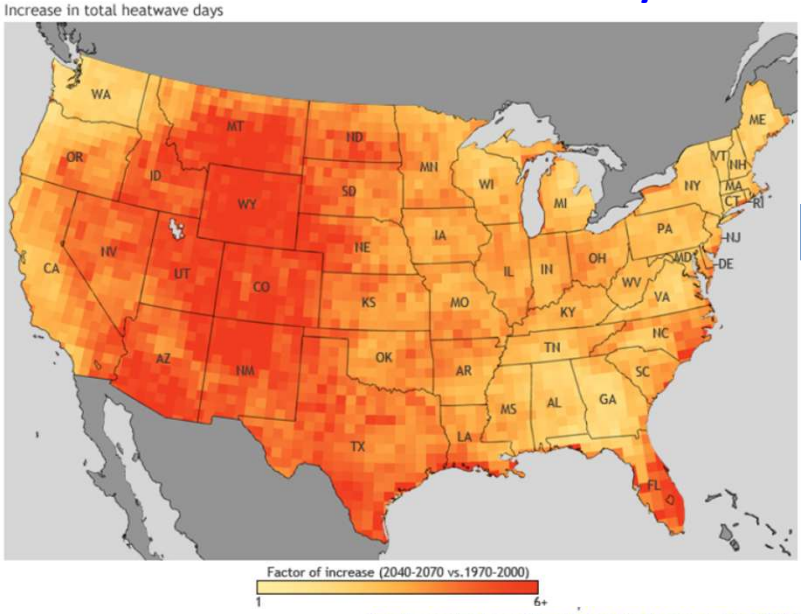
Sea level: Flooded area with 1 meter rise



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

Increase in heatwaves at mid-century under BAU

Increase in total heatwave days



Cape Cod is red!

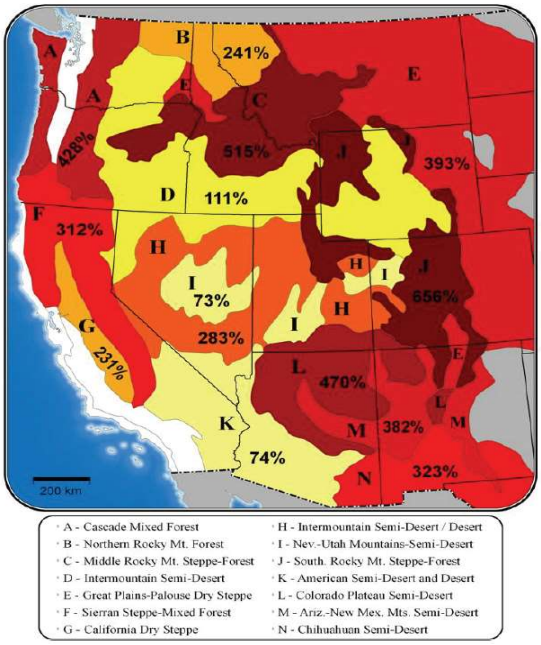
(http://www.climate.gov//sites/default/files/Heatwave_days2040-2070_HR.jpg)

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

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



Scientific best estimates under specified future emissions

Increased storminess in all scenarios

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 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).

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

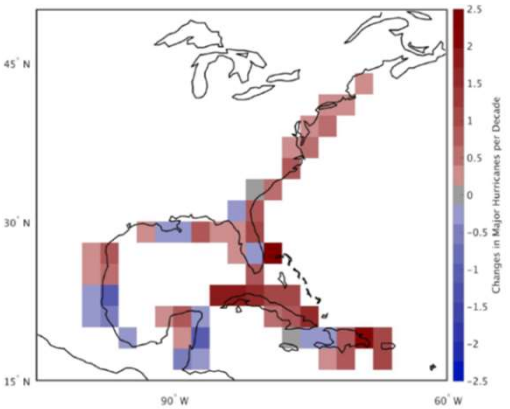


Figure 6. The difference in landfalling major hurricanes per decade between the HIFLOR 2081-2100 experiment and 1986-2005 experiment. Landfall positions are binned in 2° x 2° grid boxes.

Bhatia and Vechhi, Princeton U, 5 April 2017

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

Other impacts likely to affect the Cape & Islands

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

What We Can Do

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

Lao Tzu

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

Is the needed mitigation affordable?

- Detailed analysis by the McKinsey group indicates that a carbon tax increasing over time to $70 per ton of CO_2e by 2030 (in 2015 dollars) would put the world on a 2°C trajectory.
  - The total tax bill (reaching ~$2T per year in 2030) is not society's cost. The average cost to reduce emissions would be << $70 per ton. Gov'ts could rebate the tax on a per-capita basis.
  - GWP in 2030 at 2.5%/yr growth between now and then would be $170 trillion, so even the $2 trillion figure would be ~1%.
- World now spends 2% of GWP on defense; USA spends 3.5% of GDP on defense, 1.7% on env protection. Such costs are not "losses", just choices about resource allocation.
- Most economic models find aggressive mitigation reduces GWP by 2-3% of GWP in 2100, but they underestimate innovation.

Far less affordable would be costs of unmitigated climate change.

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…

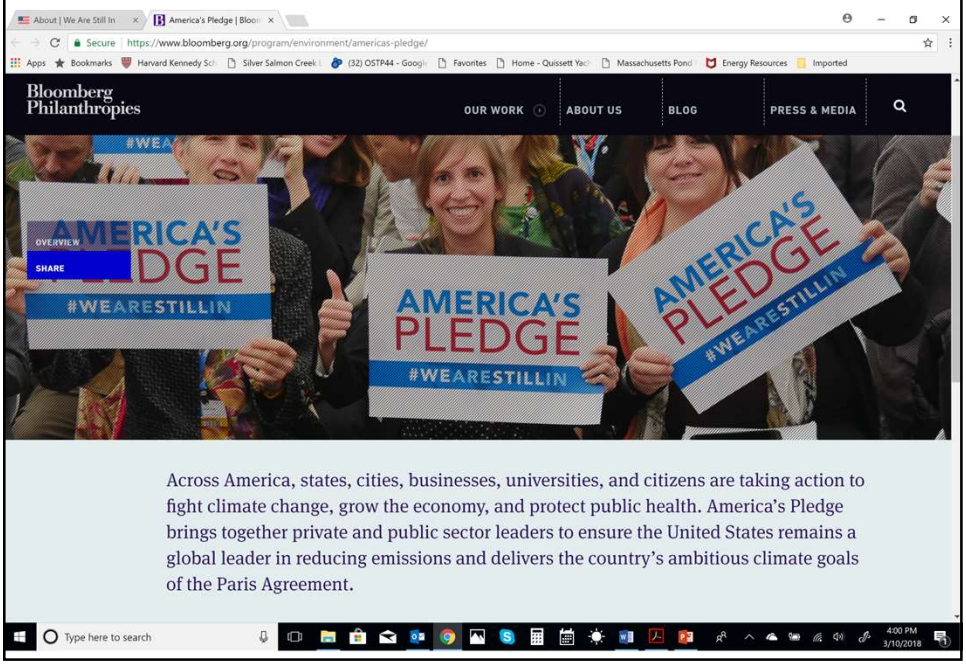
- Put climate contrarians in charge at OMB, EPA, DOI, & DOE while leaving many key science positions unfilled; proposed deep budget cuts in climate science & clean energy R&D
- Cancelled Obama's Climate Action Plan & Executive Orders on adaptation; withdrew from Paris accords

What We Can Do

Damage by recent steps is significant but limited

- USA cannot formally withdraw from Paris accord until 2020, but what Trump has done is halt most of the Federal government's efforts to comply with it.
- The most damaging potential consequences are
  - Loss of U.S. credibility and moral authority in the global community
  - Cuts to government-funded climate research, Earth observation, & energy R&D if Congress accepts Trump's proposals
  - Elimination of Federal government standards affecting U.S. emissions
  - Cuts to U.S. climate-change assistance to other countries
- Nonetheless, many states, cities, companies, universities, civil-society organizations, and individuals are taking positive steps to meet U.S. Paris commitments.

Many Americans are working to counter Trump's retreat from Paris



The U.S. private sector is largely still committed to climate action

One thousand companies and investors have signed the Business Backs Low-Carbon USA statement since November 2016. Companies and investors wishing to add their name to the statement can do so by registering here. For media inquires, please contact: Peyton Fleming fleming@ceres.org or Melanie Gade melanie.gade@wwfus.org.

Dear President Trump, Members of the US Congress, and Global Leaders:

What We Can Do

What individuals should do

- Climate scientists should continue their work to monitor climate change & its impacts; to improve projections of future conditions; and to communicate to decision makers & the public what we know and how we know it.
- Business people should embrace the private-sector movement to reduce their companies' emissions, build their resilience against climate-change impacts, and invest in energy innovation.
- Civil society leaders should use their organizations' influence to propagate understanding of climate-change impacts and the mitigation & adaptation remedies.
- State and local government officials should be creative in advancing those remedies.
- Philanthropists should support all of these efforts, starting with filling gaps left by the federal government's retreat.

What We Can Do

What everybody should do

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

"Trend is not destiny."

Rene Dubos