The Science of Climate Change in the Arctic and its Impacts

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Coverage of these remarks

- How climate is changing in the Arctic
- Impacts of climate change in the Arctic
  - within the region
  - beyond the region
- The future of Arctic climate change and its impacts
- Meeting the challenge together

How climate is changing in the Arctic

The relation between climate and weather

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

Climate change globally and in the Arctic

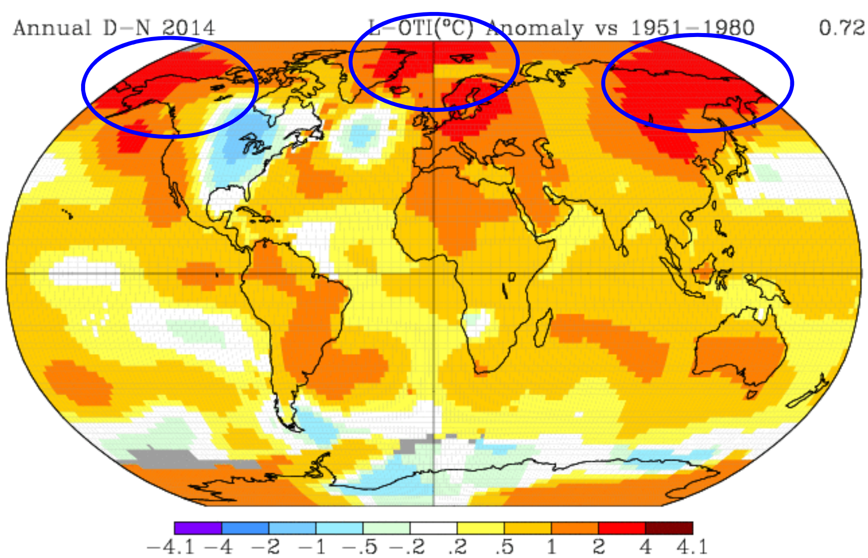
GLOBALLY

- Annual average surface temperature was about 0.9°C (1.6°F) warmer in 2005-2014 than in 1890-1899.
- Extremely hot days became much more frequent and extremely cold days much less frequent.
- Rain and snow increased on the average, but…
  - Now more comes as rain and less as snow
  - A higher fraction of the rain now comes in extreme downpours
  - Higher losses to evaporation and flood runoff—and earlier snowmelt—mean many regions are drier than before.

IN THE ARCTIC

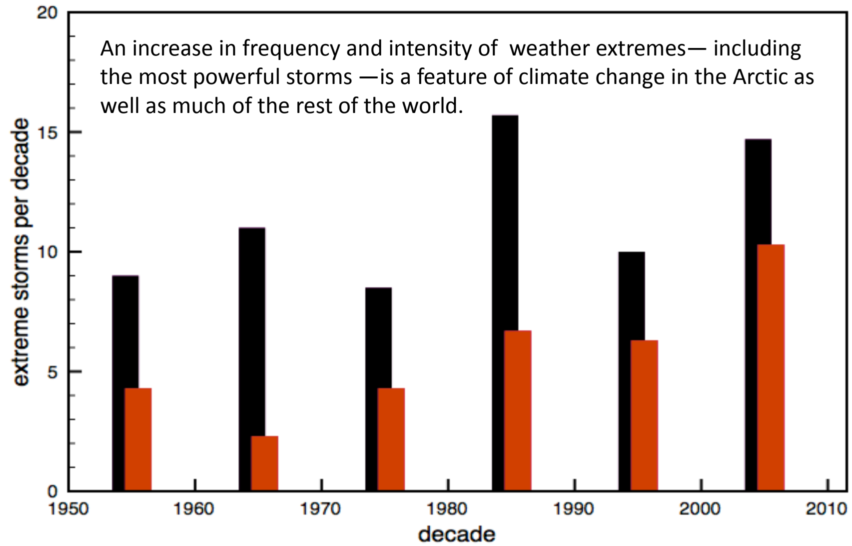
- Temperatures have gone up about 2X the global average (and as much as 4X in some Arctic regions).
- Change in other climate features has also been rapid.

Amplification of T increase in the Arctic



(NASA)

Autumn storms on the NW Alaska coast



(Black = total # of extreme storms; red = those with open water)

Courtesy J. Walsh and W. Chapman, U of Alaska Fairbanks, 2015

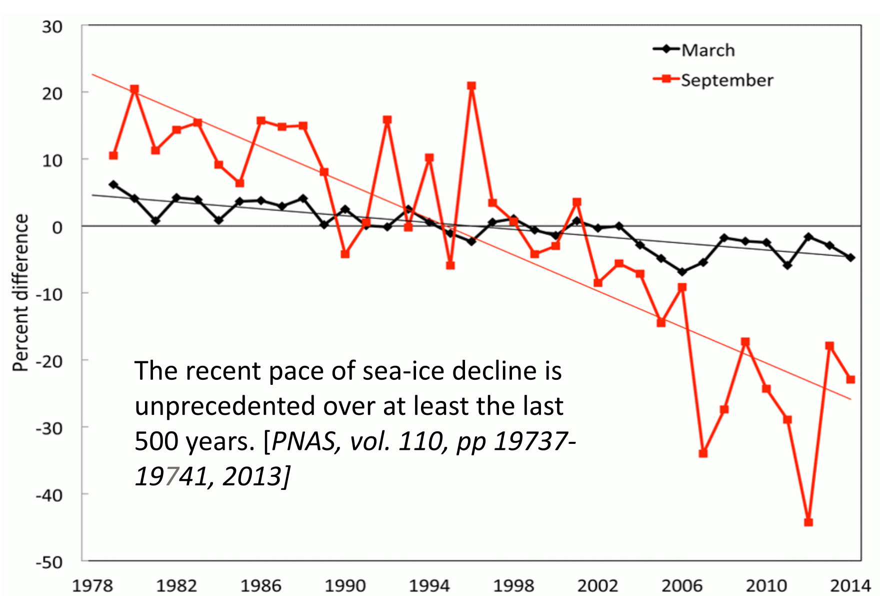
Impacts of climate change in the Arctic:

Within the region

Shrinking sea ice

- Area of Arctic sea ice in late summer is over 40% smaller than in the late 1970s; ice volume is down by even more.
- More open water means increased maritime activity and new fishing and seabed resource development opportunities, with economic benefits but new challenges for oversight, search & rescue, and international interactions.
- Open water instead of ice also means…
  - bigger waves and loss of shoreline protection leading to coastal erosion and damage, even evacuation, for coastal settlements (made worse by sea-level rise);
  - feeding/breeding/survival challenges for seals, walruses, whales, and polar bears, impacting subsistence hunting;
  - more absorption of incident sunlight, thus increased heating and accelerated further temperature increase in the Arctic.

Sea-ice area at winter maximum & summer minimum

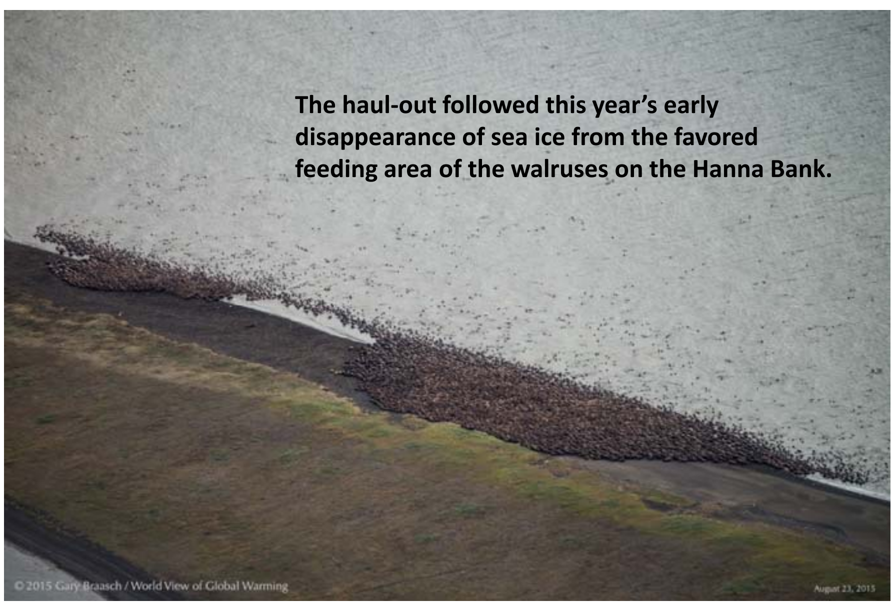


(NOAA, 2014)

Coastal erosion in Shishmaref, Alaska

Courtesy Gary Braasch

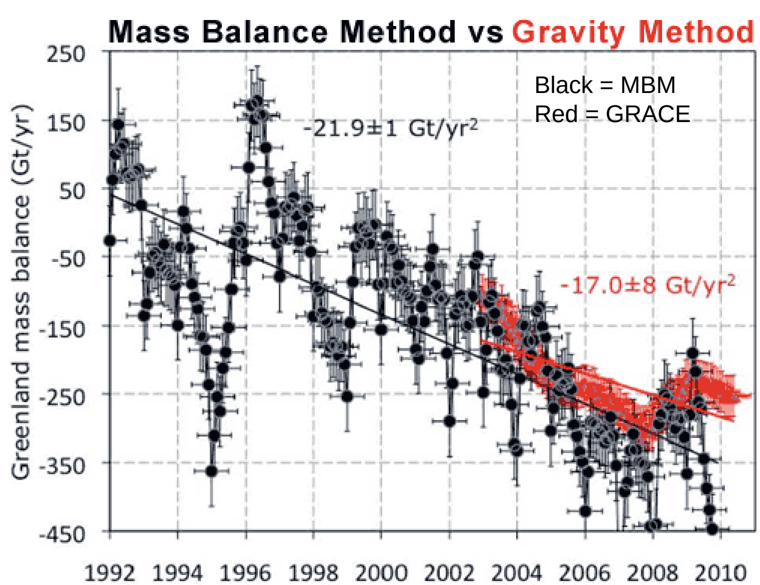
Walruses hauled out on 8-23-15 near Point Lay, NW Arctic cost of Alaska



Shrinking land ice

- Most mountain and coastal glaciers across the Arctic are shrinking, which increases river discharge and turbidity, in turn affecting erosion and, potentially, fisheries in the ocean as well as in the rivers. Alaska's glaciers alone are losing 75 gigatons of ice annually.
- The Greenland Ice Sheet is experiencing extensive surface melting in summer, as well as acceleration of the flow of major coastal glaciers to the sea.
  - Water on the surface of the ice increases absorption of sunlight and thus produces further melting.
  - Total loss of ice from Greenland is averages 250-350 gigatons annually, up 4X in the last 2 decades.

Greenland ice sheet mass balance



Rignot et al., 2011 *Geophys. Res. Lett.* DOI: 10.1029/2011GL046583

Thawing permafrost

- A high proportion of land in the Arctic and sub-Arctic is in the permafrost region. (For the state of Alaska, the proportion is 80 percent.)
- As soil temperature rises along with air temperature, the upper layers of permafrost in the wamer regions start to thaw. This is happening over much of the permafrost region.
- Impacts of thawing permafrost include…
  - land subsidence, threatening buildings, roads, and energy infrastructure;
  - increased vulnerability to coastal erosion & wildfires;
  - exposure of previously frozen soil carbon to release as CO_2 and methane.

Impacts of permafrost melting

Norwegian Polar Institute, 2009

Expanding wildfires

- Higher temperatures, drier landscapes, trees killed by insect infestations, and more lightning (all related to climate change) mean more, bigger, hotter wildfires.
- The combined acreage burned in wildfires in 2015 in Siberia, Canada and Alaska by early August was about 13 million ha (31 million acres).
- In Alaska, the annual number of large wildfires has doubled since the 1980s, and the average annual area burned has quadrupled.
- Wildfires destroy valuable timber and habitat, create massive smoke pollution, directly add large quantities of CO_2 to the atmosphere, expose soil carbon to microbial action (producing more CO_2), and contribute to permafrost thawing.

Bogus Creek fire, near Aniak, Alaska, June 2015

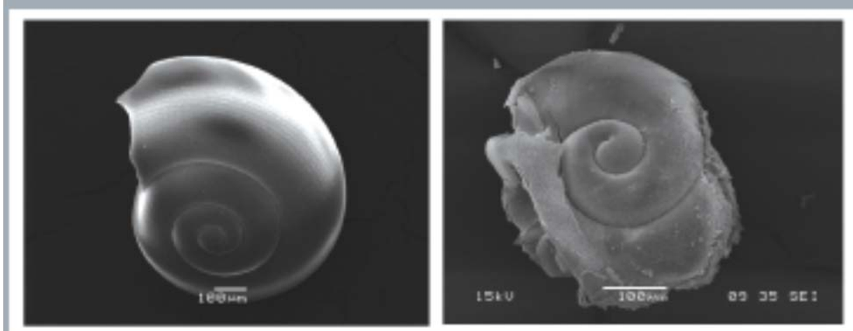
Courtesy of Nicky Sundt, WWFUS. Photo by Matt Snyder, Alaska Division of Forestry.

Changing ocean chemistry

- In addition to reduced salinity and increased turbidity as a result of increased discharge to the ocean of glacial fresh water, the Arctic Ocean (like the rest of the global ocean) is becoming more acidic.
- Ocean acidification is intensified in the Arctic by the low temperature and low salinity of the ocean there.
- The effects of these changes include…
  - impacts of acidification on marine organisms that make their shells or skeletons with calcium carbonate;
  - interaction of salinity changes with changes in temperature to alter ocean circulation;
  - impacts of all of this together on marine fisheries, with consequences still largely unknown but potentially severe.

Effects of ocean acidification

Shells Dissolve in Acidified Ocean Water



Pteropods, or "sea butterflies," are eaten by a variety of marine species ranging from tiny krill to salmon to whales. The photos show what happens to a pteropod's shell in seawater that is too acidic. On the left is a shell from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod in a region where the water is more acidic. (Figure source: (left) Bednaršek et al. 2012[e] (right) Nina Bednaršek).

3rd US National Climate Assessment: Highlights (2014)

Impacts of climate change in the Arctic:

Beyond the region

Wider impacts of Arctic climate change include…

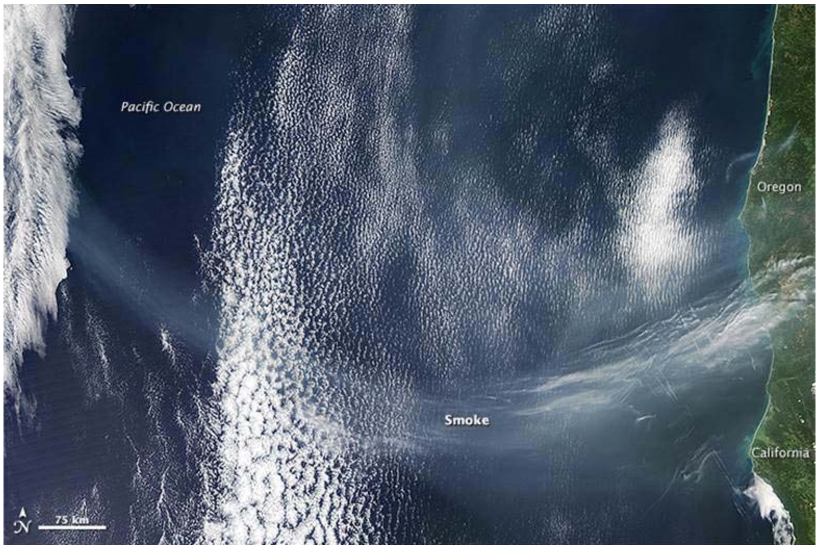
REGIONALLY

- impacts on human health, as well as visibility, sunlight reaching ground, and atmospheric heating from long-distance transport of smoke from Arctic wildfires
- changes in Northern Hemisphere atmospheric circulation patterns (e.g., blocking highs, jet-stream slowdown and waviness bringing "polar vortex" phenomena to mid-latitudes) because of faster warming in Arctic

GLOBALLY

- acceleration of global sea-level rise as glaciers and the Greenland ice sheet lose ice as a result of warming
- increased release of CO_2 & CH_4 from microbial action on organic carbon previously frozen in permafrost, plus CH_4 from thawing methane hydrates soils

Smoke from Siberian fires reaches the North—western United States, April 2015

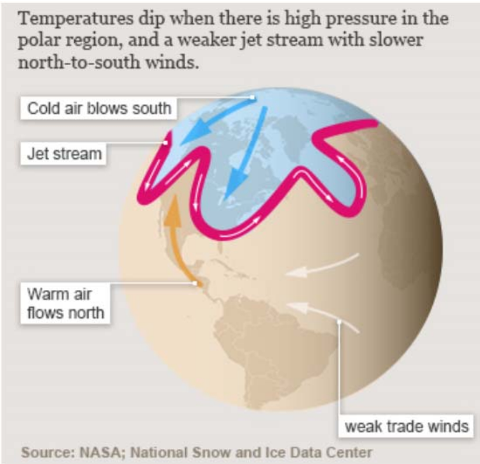


23 http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=85724

Mid-latitude impact of a warming Arctic

<u>The warming Arctic atmosphere was strongly connected to lower latitudes</u> in early 2014 causing cold air outbreaks into the eastern USA and warm air intrusions into Alaska and northern Europe.

NOAA, *Arctic Report Card*, 2015

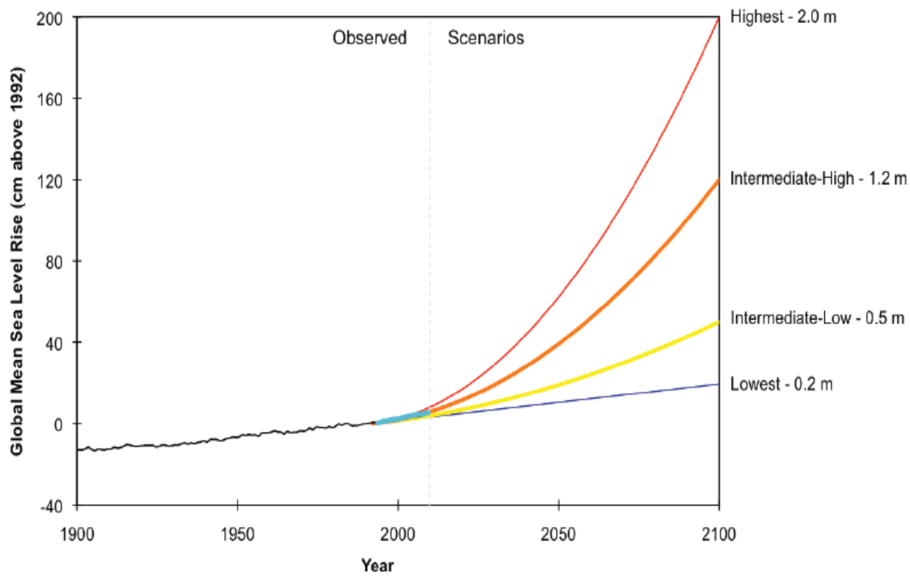


http://www.arctic.noaa.gov/reportcard/

The future of Arctic climate change and its impacts

- Temperature: The most recent IPCC assessment (2013-14) projected that summer temperatures in the Arctic in the last 20 years of this century, under business-as-usual emission growth, would average about 4°C (7°F) higher than the 2005-2015 level.
- Sea ice: Under business-as-usual emissions growth, sea ice in the Arctic ocean in late summer could disappear altogether as early as 2040 and no later than 2100.
- Wildfires: The 2014 U.S. National Climate Assessment projects another doubling in annual area burned in Alaska by mid-century; similar growth in annual area burned is expected across the Arctic under continuing warming.

Projections for global-average sea-level rise



NOAA OAR CPO-1, December 2012

Meeting the Challenge Together:

Mitigation

Preparedness, Resilience, Adaptation

Research

What can we do together?

MITIGATION

- Agree upon and commit to ambitious national targets for emissions reductions.
- Work together across national, state-provincial, local, & tribal governments, the private sector, academia, and civil society to identify & deploy cleaner, more efficient technologies for energy supply & use.

PREPAREDNESS / RESILIENCE / ADAPTATION

- Work together, similarly, to make available the data, infor-mation on best practices, & financing to help communities, businesses, & individuals reduce vulnerability to…
  - Sea-level rise, powerful storms, and coastal erosion
  - Wildfires and thawing permafrost
  - Declines in commercial & subsistence species

What can we do together? (continued)

RESEARCH

- Improve understanding of challenges and oppor-tunities around climate change in the Arctic through data-sharing and cooperative research on…
  - improved technologies for energy supply and end-use for reduced emissions and increased efficiency and resilience;
  - climatic, ecological, and socio-economic processes shaping climate change in the Arctic, its impacts, and society's responses.
- Collaborate on geographically denser, more compre-hensive, more continuous measurement and monitoring of Arctic climate change and its impacts.

Thank you!

http://www.ostp.gov