Rapid Climate Change in the Arctic (And Why Everybody Should Care)

John P. Holdren

Professor of Environmental Science & Policy
Kennedy School of Government and Department of Earth & Planetary Sciences
HARVARD UNIVERSITY

Visiting Distinguished Professor
Tsinghua University

Former Science Advisor to President Obama
and Director, Office of Science and Technology Policy
THE WHITE HOUSE
(January 2009 – January 2017)

A Lecture Hosted By
Xue Lan, Dean of Schwarzman Scholars
Tsinghua University • Beijing • 6 June 2019
Topics to be covered

• Human-caused climate change globally
• Human-caused climate change in the Arctic
• Why everybody should care about climate change in the Arctic
• What is being done about...
  — the pace of climate change worldwide
  — impacts in & propagating from the Arctic
• What more is needed
Human-Caused Climate Change Globally

“Science is true whether or not you believe in it.”

Neil deGrasse Tyson
Earth’s temperature depends on the balance between incoming & outgoing energy.

The quantity of “greenhouse gases” in the atmosphere influences this balance.
Some greenhouse gases exist in the atmosphere naturally; some are added by human activities.

• The most important naturally occurring greenhouse gases are water vapor (H₂O) and carbon dioxide (CO₂).

• Without them, the surface of the Earth would be too cold to support life as we know it.

• When humans burn coal, oil, and natural gas (“fossil fuels”) or wood, the combustion products, CO₂ and H₂O, go into the atmosphere.

• The H₂O remains in the atmosphere only briefly and so does not add much to the natural water vapor there.

• But much of the CO₂ remains for centuries, and so its concentration in the atmosphere builds up over time as fossil fuels and forests are burned.
Growth of population & prosperity from 1850 to the present increased world energy use by over 20-fold.

Units are million tonnes of oil equivalent per year.

Most of the increase came from burning fossil fuel.

In 2019, coal, oil, & natural gas still supply about 80% of world energy consumption and two-thirds of electricity generation.
Fundamentals of human-caused climate change

Civilization’s CO$_2$ emissions grew along with deforestation and fossil-fuel use

Global CO$_2$ emissions from human activities

- Fossil fuels, cement and flaring
- Forestry and other land use
Fundamentals of human-caused climate change

The buildup of CO$_2$ and other greenhouse gases changed the energy balance of the Earth.

Methane (CH$_4$) and nitrous oxide (N$_2$O) come from energy, agriculture, & decomposition of dead organic matter

“Radiative forcing” measures how much warming the additions of these gases have added to Earth’s natural greenhouse effect.
The warming from forcing by GHGs is evident

From 1750 to 1900 natural cooling & human-caused warming were in rough balance, so globally and annually averaged temperature stayed roughly constant. The 20th century saw global warming because the human influences had become dominant.
The human warming influence overcame slow natural cooling that started 7,000 years ago.

Natural influences—mainly variations in Earth’s orbit and axis of rotation—were in a long-term cooling phase from 7,000 years ago until around 1750. Cooling would have continued for 1000s of years more, but for the influence of deforestation and fossil-fuel burning.
Climate change is not only about temperature
Climate = weather patterns, meaning averages, extremes, timing, and spatial distribution of...

• not only hot & cold, but also...
• humid & dry
• cloudy & clear
• drizzles, downpours, sleet, hail
• snowfall, snowpack, snowmelt
• breezes, blizzards, tornadoes, hurricanes

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 (much like your body temperature).
Modest increase in average T $\rightarrow$ very large change in extremes

In a warmer climate, extreme high temps that previously were very improbable now occur much more frequently. The accentuation of extremes accompanying small changes in the average occurs with any normally distributed variable.
Some all-time high temperatures reached in 2017-18

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iran</td>
<td>129°F</td>
<td>June 2017</td>
</tr>
<tr>
<td>Pakistan</td>
<td>128°F</td>
<td>May 2017</td>
</tr>
<tr>
<td>South Africa</td>
<td>122°F</td>
<td>Nov 2018</td>
</tr>
<tr>
<td>Spain</td>
<td>117°F</td>
<td>July 2017</td>
</tr>
<tr>
<td>Chile</td>
<td>113°F</td>
<td>Jan 2017</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>111°F</td>
<td>July 2018</td>
</tr>
<tr>
<td>Argentina</td>
<td>110°F</td>
<td>Jan 2017</td>
</tr>
<tr>
<td>Shanghai</td>
<td>106°F</td>
<td>July 2017</td>
</tr>
<tr>
<td>San Francisco</td>
<td>106°F</td>
<td>Sept 2017</td>
</tr>
<tr>
<td>Denver</td>
<td>105°F</td>
<td>June 2018</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>102°F</td>
<td>Aug 2017</td>
</tr>
</tbody>
</table>

Already, working outdoors in the hottest months risks heat stroke in many regions.
Changes in average & extreme weather are producing widespread harm **today**, including increases in...

- severe floods
- intense droughts
- bigger, hotter wildfires
- power of strongest storms
- heat waves and heat stress
- other harm to human health
- coastal erosion and inundation
- impacts of crop and forest pests
- permafrost thawing and subsidence
- ocean impacts of warming and acidification
- distribution and abundance of valued species

**All** are plausibly linked to climate change by theory, models, and observed “fingerprints”; most growing **faster** than projected.
What’s coming is worse: temps will keep rising

But **how much** they rise depends strongly on emissions.

Momentum in the climate system means T continues to go up even after atmospheric conditions stabilize. And sea level continues to go up even after T stabilizes.
Absent big, fast emissions cuts, we can expect...

• Record heat waves as “the new normal”
• Far more torrential downpours & flooding
• Large expansion in area burned by wildfires
• Destruction of most of the world’s coral reefs
• Wider disruption of marine food webs & fisheries
• Big increases in frequency & intensity of droughts
• More Cat 3-5 hurricanes/typhoons making landfall
• More sickness & death from heat stress, tropical diseases
• Falling agricultural yields for maize, wheat, rice, soybeans...
• Sea-level rise reaching $\geq 0.5$ m by 2050, $\geq 1$ m by 2100, 6-10 m eventually
• And, as a result, much bigger flows of environmental refugees
Human-Caused Climate Change
In the Arctic

“No place on Earth is changing faster than the Arctic.”

James J. McCarthy
Dimensions of the Arctic

• Area N of Arctic Circle is $20 \times 10^6$ km$^2$
  – 70% is open & ice-covered ocean
  – Eight nations have land or territorial waters in the Arctic
  – Largest share of Arctic land area is Russian

• Population north of the Arctic Circle
  – Total is 4 million, about half in Russia.
  – Indigenous people make up 10% of the total, spread across two dozen ethnolinguistic groups (e.g., Aleut, Chukchi, Inuit, Inupiat, Sami, Yupik...).
  – Largest city N of the Arctic Circle is Murmansk, Russian Federation (~350,000)
Amplification of T increase in the Arctic

The pace of T increase in the Arctic is 2-4 times the global average.
The recent pace of sea-ice decline is unprecedented over at least the last 500 years. [PNAS, vol. 110, pp 19737-19741, 2013]
Extent & thickness of Arctic sea ice, Sept 1984 and Sept 2016

The recent pace of sea-ice decline is unprecedented in at least the last 1450 years.

NCA Science Report, 2017
Effects of shrinking sea ice

• More open water means increased maritime activity and new fishing and seabed resource development opportunities, with potential economic benefits but new challenges with climate-altering pollution, oil spills, 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.
Sips emit heat-trapping black carbon...

...which will accelerate Arctic warming

Figures are average tons emitted per year

ICCT 2015
Sea-ice loss means more storm damage

Open water lets wind build waves. And without the protection of ice along the shoreline, those waves damage structures & erode beaches.

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

Courtesy J. Walsh and W. Chapman, U of Alaska Fairbanks, 2015
Coastal erosion in Shishmaref, Alaska

Courtesy Gary Braasch
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.

Alaska’s Muir Glacier

August 1941

August 2004
Shrinking land ice (continued)

- 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 averaging 250-350 gigatons annually, up 4X in the last 2 decades.

Change in Greenland ice mass, billions of tons
Melting of Arctic glaciers & the Greenland Ice Sheet accelerates sea-level rise

Post-2010 rate is actually 5.5 mm/yr!

Hansen 2017
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 was about 15 million ha (37 million acres). Now even the tundra is burning.

- In Alaska, the annual number of large wildfires has doubled since the 1980s, and the average annual area burned has quadrupled.

- Wildfires destroy infrastructure, timber, and habitat; create massive smoke pollution; directly add large quantities of CO₂ to the atmosphere; expose soil carbon to microbial action (producing more CO₂); and contribute to permafrost thawing.
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 warmer 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.
Thawing permafrost: Subsidence

Russia

Fairbanks, AK

Norwegian Polar Institute, 2009
Thawing permafrost: Accelerated release of CO$_2$ and methane

Methane is bubbling from “thermokarst” lakes (created or expanded by voids left by melting permafrost).

Some of this methane may be coming from unfrozen fossil fuel rather than from bacterial action.

Chris Mooney 09-22-18
Changing ocean chemistry

• In addition to reduced salinity & 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.

• Pollution by microplastics is also impacting Arctic Ocean life.
Future impacts of Arctic climate change under “business as usual” global GHG emissions

• **Summer temperatures** in the Arctic in 2080-2100 will average 6-8°C above pre-industrial Arctic temps.

• **Sea ice** in the Arctic ocean in late summer could disappear altogether as early as 2040 and no later than 2100.

• **Alaska wildfires**, already burning 2x the area they did 50 years ago, likely to double that area again by 2050; similar growth in area burned is expected across the Arctic.

• **Permafrost thawing** will be widespread, with major impacts on communities & infrastructure and increased releases of CO₂, CH₄, and mercury.

• **Loss of ice** from glaciers & Greenland Ice Sheet will accelerate, making ever bigger contributions to global sea-level rise.
Why Everybody Should Care

“What happens in the Arctic doesn’t stay in the Arctic.”

Judah Cohen
Why care? International security challenges

International security challenges exacerbated by climate change in the Arctic

• Protecting borders, coastal waters, and shipping routes around an increasingly open Arctic Ocean

• Managing tensions around territorial & resource claims and the interests of non-Arctic nations

• Addressing climate-change risks to national-defense infrastructure

• Understanding and coping with Russian military expansion in the region
Security (cont.): Protecting coasts, shipping

Shipping routes around retreating sea ice

= Bottleneck

Thule AB
Bering Strait

(http://NASA.GOV)
Security (continued): Territorial claims

[Map showing territorial claims in the Arctic region]
Security (cont.):
Tensions & risks from access to Arctic oil and gas

Some think these are the largest unexploited oil & gas resources in the world.

Tensions may arise over rights or international impacts of spills.

And extracting and burning this oil & gas would be a huge further boost to global climate change.
“I would ask you to pay special attention to the deployment of infrastructure and military units in the Arctic. ... Russia is actively exploring this promising region, returning to it, and should use all possible channels to protect its security and national interests.”

Speech to Expanded Meeting of the Defense Ministry Board
Why care? Carbon release from a warming Arctic will accelerate climate change worldwide

Estimates of C release from thawing permafrost

1 petagram (Pg) = $10^{15}$ g = 1 billion tons; current global fossil-fuel emissions $\approx 10$ Pg/yr
Why care? Impacts of Arctic climate change on Northern Hemisphere mid-latitudes

• Changes in Northern Hemisphere atmospheric circulation patterns
  — blocking highs, plus jet-stream slowdown and waviness bringing “polar vortex” phenomena to mid-latitudes, because of faster warming in Arctic
  — acceleration of the differential warming by black soot from increasing ship traffic

• Impacts on human health—as well as on visibility, sunlight reaching ground, and atmospheric heating—from long-distance transport of smoke from Arctic wildfires
Why care? Impact of Arctic change on extreme mid-latitude weather

“High confidence” – from observational and modeling studies

“Lesser confidence” – weaker signal-to-noise ratio

Asia: Arctic-Midlatitude Weather Linkages

North America: Warmer Arctic Temperatures Can Reinforce Wavy Jet Stream

Source: J. Overland (NOAA/PMEL) and J. Francis (Rutgers Univ.)
Why care? Smoke from huge Arctic fires pollutes mid-latitudes

http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=85724
After 2100, sea-level rise continues for many centuries in all IPCC scenarios, ultimately reaching 2 meters or more per degree of global average warming.

The ice in the Greenland Sheet is enough to raise sea level by 7 meters.
What Is Being Done

“If you don’t change direction, you’ll end up where you’re heading.”

Lao Tzu
...about the pace of climate change worldwide

• Intergovernmental Panel on Climate Change (IPCC), created in 1988, has produced periodic assessments of climate science that have solidified & propagated understanding of the imminence of major climate-change impacts globally and in the Arctic.

• United Nations Framework Convention on Climate Change (UNFCCC), agreed in 1992, has focused on national commitments to reduce emissions and assist countries in need with technologies for doing so (and with adaptation to changes in climate that can no longer be avoided).

—Obama-Xi announcement in Beijing in 2014 prepared the basis for the Paris Agreement one year later

—In 2015 in Paris, 195 countries agreed to intended nationally determined commitments for emissions reductions by 2025 or 2030

—Also in Paris, a coalition of 20 nations, including USA & China, announced “Mission Innovation”, to double clean-energy R&D funding over 5 years
Action on climate change worldwide (continued)

• Increases in energy end-use efficiency and energy supply from low- and no-carbon sources have reduced carbon emissions in many countries, but few are on track to meet their Paris targets.

• President Trump announced in 2017 that US would withdraw from Paris Agreement, stopped US assistance to countries in need, and rescinded essentially all of the Obama initiatives on both emissions reduction & adaptation.

• Global emissions of CO₂, which had seemed to level off in 2016 and 2017, rose significantly in 2018.
Action on climate change in the Arctic

- The Arctic Council was established 1996 to promote cooperation & coordination among the 8 nations with Arctic territory—with involvement of Arctic Indigenous communities—on sustainable development, environmental protection, shipping, research.
  - Standing working groups focus on sustainable development, emergency prevention & response, protection of marine environment, conservation of Arctic flora & fauna, toxic contaminants, and monitoring & assessment.
  - It has produced agreements on search & rescue, oil-spill response, and cooperation on Arctic monitoring & research; and it is seeking an agreement to stop use of heavy fuel oil in Arctic shipping (to avoid emissions of black carbon)

- The United States and Europe have led international conferences of foreign ministers and science ministers to advance research, monitoring, and action on Arctic climate change.

- Academic & civil-society initiatives in cooperation with Arctic governments are proliferating.
What More Needs to Be Done

“Between fatalism and complacency lies urgency.”

Jake Sullivan
In the Arctic we need...

• National and internationally collaborative efforts to make the monitoring of climate change in the Arctic and its impacts more comprehensive, pervasive, and continuous, in order to better understand ongoing and potential impacts on...
  — the Arctic ocean, its sea ice, and its creatures
  — land ice: coastal & mountain glaciers, the Greenland Ice Sheet
  — permafrost, tundra, and forest ecosystems
  — Arctic communities and infrastructure

• Innovative policies, programs, and projects—regional, national, & international—to find adaptive responses that minimize harm to ecosystems, communities, and infrastructure in the region as climate change continues and development to exploit new opportunities continues
In the Arctic we need...

• Completion of the pending international agreement to ban vessels using black-soot-producing heavy fuel oil from the Arctic

• Increased capacity for patrol and search & rescue in Arctic waters:
  — More icebreakers
  — Enhanced aerial surveillance of Arctic waters
  — Improved ports & supporting infrastructure in Alaska

• Increased security collaboration and communication around Arctic waters and airspace among the 8 Arctic nations and others operating in Arctic waters
Worldwide, deep emissions cuts are needed

Potential future emissions pathways of global greenhouse gas emissions (measured in gigatonnes of carbon dioxide equivalents) in the case of no climate policies, current implemented policies, national pledges within the Paris Agreement, and 2°C and 1.5°C consistent pathways. High, median and low pathways represent ranges for a given scenario. Temperature figures represent the estimated average global temperature increase from pre-industrial, by 2100.

Annual emissions

Based on data from the Climate Action Tracker (CAT). The data visualization is available at OurWorldinData.org. There you find research and more visualizations on this topic. Licensed under CC-BY-SA by the authors Hannah Ritchie and Max Roser.
The deep cuts needed to limit warming to 1.5-2.0°C will likely require...

- A global carbon tax starting **soon** and escalating from around $30/tCO₂e initially to at least $100/tCO₂e by 2030, collected by national governments and rebated on a per-capita basis. This would incentivize using best available low- and no-emission technologies now **and** investing in RD&D to get better ones.

- A massive program of technological innovation on clean energy and energy efficiency, advanced through partnerships among government, industry, & universities, and including...
  - CO₂ capture & sequestration for fossil & biomass power plants
  - Sustainable biomass production for power plants & aviation fuel
  - Cheaper wind & solar power and better electricity storage
  - Innovation to make nuclear-energy expansion safe & affordable
  - Pursuit of practical fusion power
The world will also need...

• A similarly massive set of public-private-university partnerships focused on developing & implementing adaptation measures to limit the harm from the changes in climate that can no longer be prevented.

*     *     *     *     *

The political will to get all this done could materialize faster than many think, as the combination of rapidly increasing damages from climate change and declining costs of remedial action (as a result of innovation) makes ever clearer that action is much cheaper than inaction.
Thank You!