Climate Change and Global Warming

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Seminar in Mathematics and Climate
MATH 392-01 Spring 2018
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Lecture Outline

- Evidence that the planet is warming
- Consequences and concerns of global warming
- Climate modeling and the role of mathematics
- Course overview and goals

The 10 hottest years on record (NOAA Global Climate Report)

Rank	Year	Anomaly ^{0}C	Anomaly ^{0}F
1	2016	0.94	1.69
2	2015	0.90	1.62
3	2017	0.84	1.51
4	2014	0.74	1.33
5	2010	0.70	1.26
6	2013	0.67	1.21
7	2005	0.66	1.19
8	2009	0.64	1.15
9	1998	0.63	1.13
10	2012	0.62	1.12

Table: From 1880–2017, the 10 warmest years for the global combined land and ocean annual average temperature. Anomaly is computed against the 20th century average of 13.9°C (57.0°F). 2017 is the warmest year on record without an El Niño present in the Pacific Ocean.

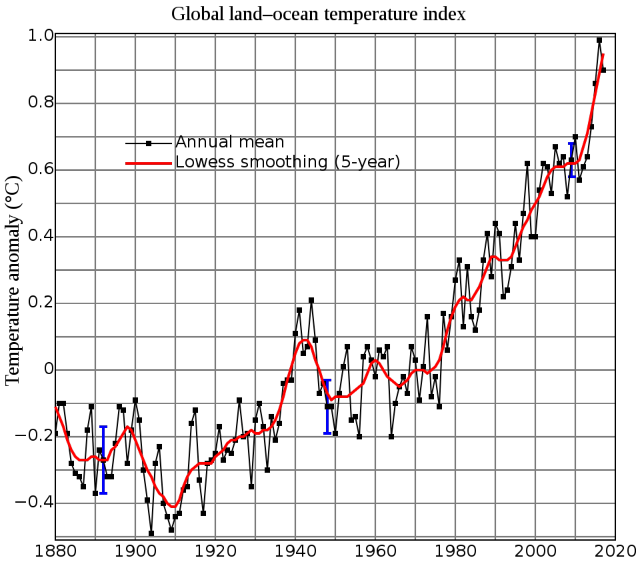


Figure: Global mean surface temperature change since 1880. Source: NASA Goddard Institute for Space Studies

How much warmer was your city in 2016?

Click Here

- AccuWeather database of 5,000 cities
- For 2016, 90% of them recorded annual mean temperatures above average.

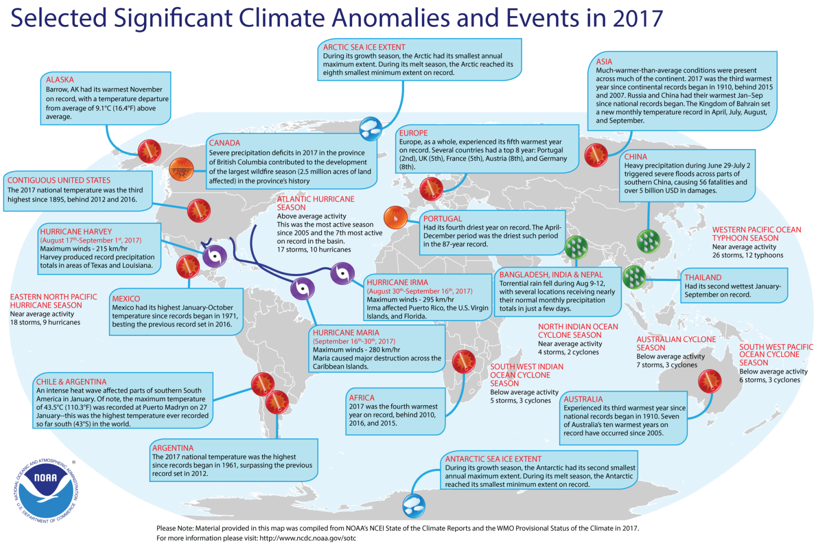
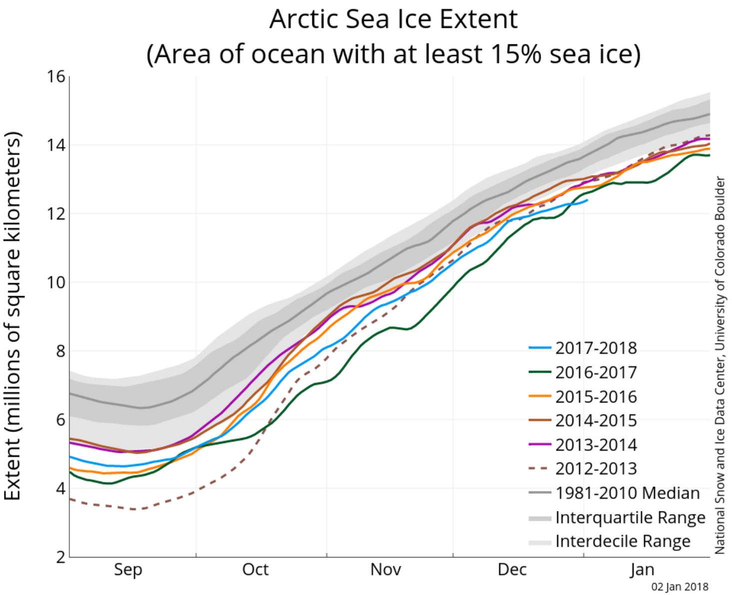


Figure: 2017 Global Significant Weather and Climate Events. Source: NOAA Global Climate Report `https://www.ncdc.noaa.gov/sotc/global/201713`

Loss of Arctic Sea Ice



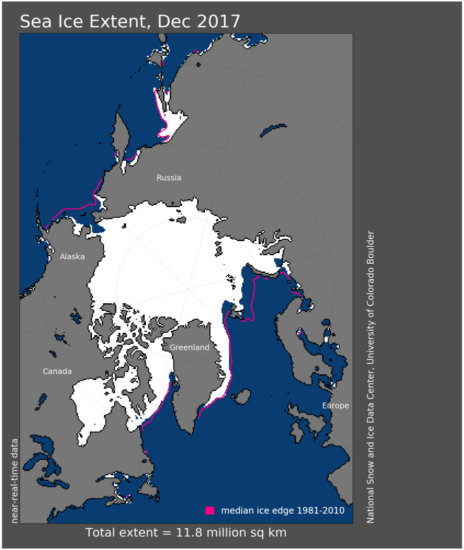


Figure: The Arctic sea ice extent for December 2017 (second lowest on record). The magenta line is average extent for December over 1981–2010 (satellite records).

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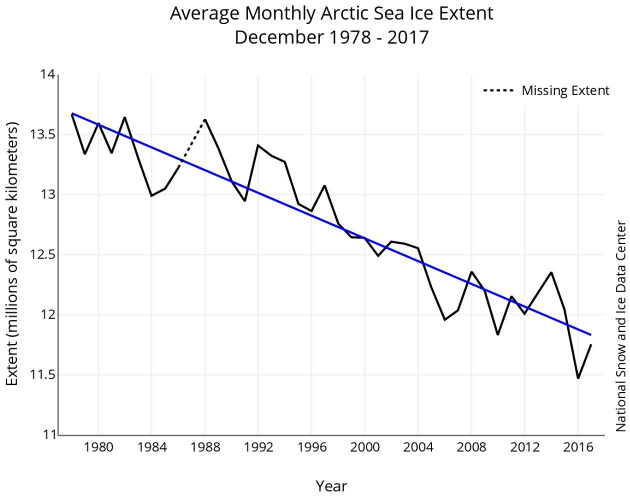

Figure: The monthly December sea ice extent for 1978–2017 shows a 3.7% loss per decade.

Air Temperature Difference December 2017

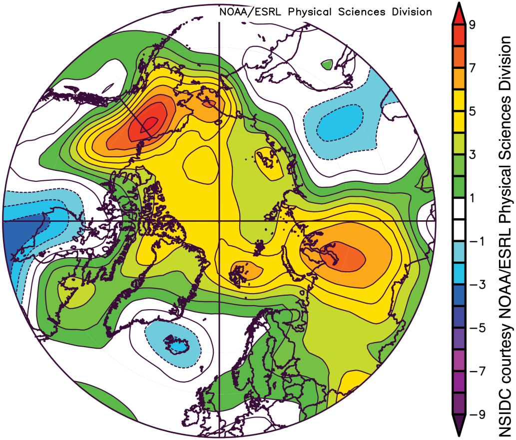

Figure: Differences in December 2017 air temperatures (in °C) from the average, measured about 2,500 feet above sea level. Parts of central Alaska were more than 18°F above average!

The Great Greenland Thaw in July 2012

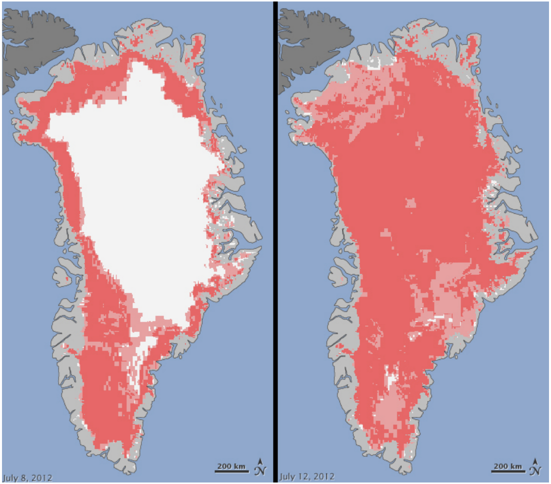

Figure: Around 97% of the Greenland ice sheet experienced melting during the middle of July in 2012 (pink and red), up from a usual average of 50%. Most of the melt water refreezes; however, if the entire sheet were to melt, sea level could rise 24 feet!

Disappearing Glaciers in Greenland

L: DANISH GEODATA AGENCY; HANS HENRIK THOLSTRUP/
R: NAT. HIST. MUS. DENMARK

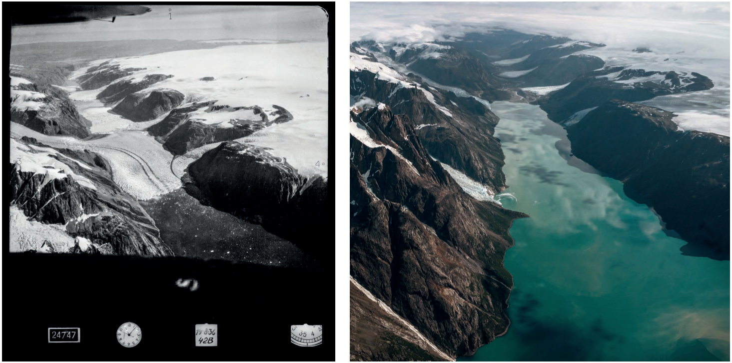

Figure: Aerial photos of the Ujaraannaq Valley (southwest Greenland) taken in the summer of 1936 (left) and in 2013 (right) showing severe glacier loss.
Source: “The ice historians,” Q. Schiermeier, *Nature* **535**, July 28, 2016, pp. 480–483.

Decline of the Greenland Ice Sheet

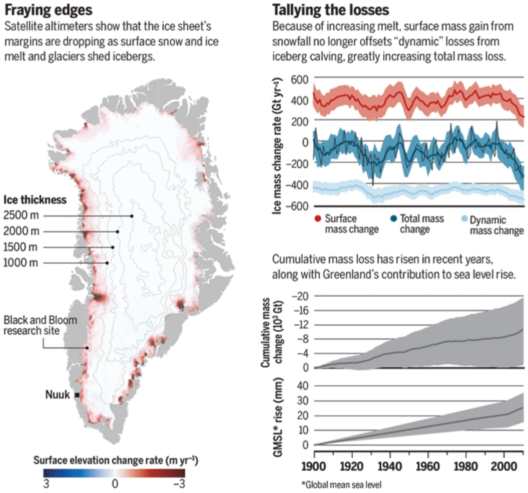

Figure: "Nobody expected the ice sheet to lose so much mass so quickly," Isabella Velicogna, geophysicist at the University of California, Irvine. Source: "The great Greenland meltdown," E. Kintisch, *Science*, Feb. 23, 2017, doi:10.1126/science.aal0810

Impacts of Global Warming

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5. Ocean acidification (higher acidity near surface due to excess carbon dioxide) and long-term damage to coral reefs.

The Destructive 2017 Hurricane Season

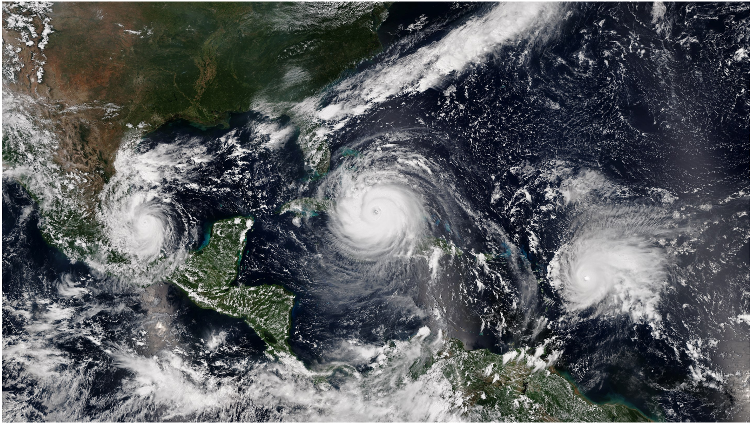

Figure: Three simultaneous hurricanes on Sept. 8, 2017: Katia (left), Irma (center) and Jose (right). The year 2017 saw 17 storms and 10 hurricanes, 6 of which were Category 3 or higher. Image Source: NOAA Suomi NPP satellite

Hurricane Sandy (2012)

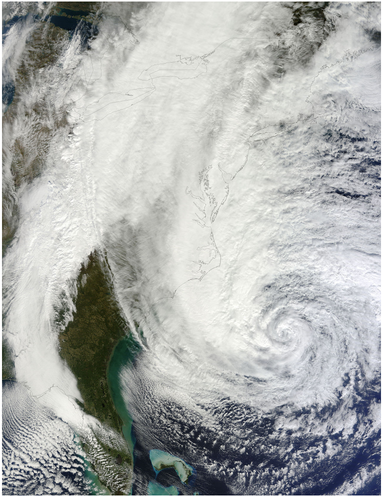

Figure: Before 2017, Sandy was the second-most costly hurricane in US history after Katrina. It is the largest Atlantic storm on record, spanning 1,100 miles in diameter. Source: LANCE MODIS Rapid Response Team at NASA GSFC

Hurricane Sandy (2012)

Figure: A roller coaster off the Jersey shore after Hurricane Sandy.

Vanishing Rivers?!

A view of the ice canyon that now carries meltwater from the Kaskawulsh glacier, seen here on the right, away from the Slims river and toward the Kaskawulsh river. Photograph: Dan Shugar/University of Washington Tacoma

“Receding glacier causes immense Canadian river to vanish in four days,” — headline in The Guardian, April 17, 2017

River Piracy: The Loss of the Slims River

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Reference: “River piracy and drainage basin reorganization led by climate-driven glacier retreat,” Shugar (et. al.), *Nature Geoscience* (May 2017) **10**, pp. 370–376.

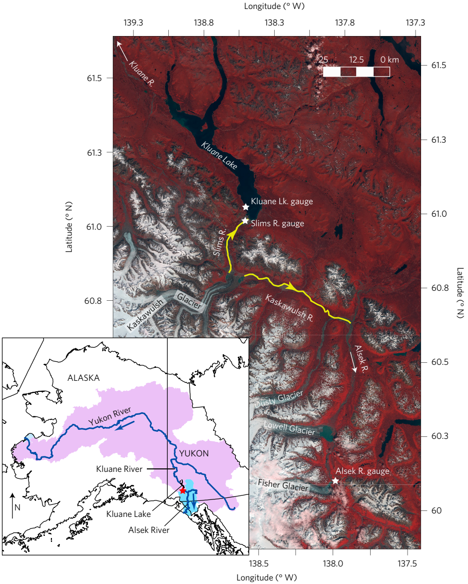
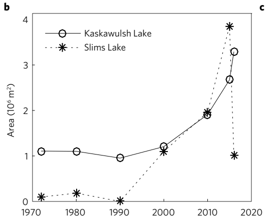


Figure 1 | Satellite image showing the Slims, Kaskawulsh and upper Alsek rivers, and Kluane Lake. Locations of river and lake gauges are shown with white stars. Yellow lines with arrows represent pre-2016 flow paths of the Slims and Kaskawulsh rivers. Inset map of Alaska and Yukon shows the Yukon (pink shading) and Alsek (blue shading) watersheds. Red star indicates study area at the south end of Kluane Lake.

The Loss of the Slims River: Tipping Points



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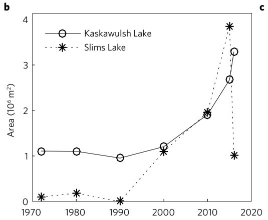

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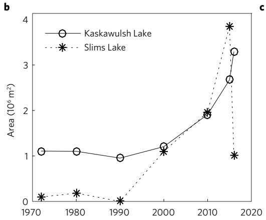

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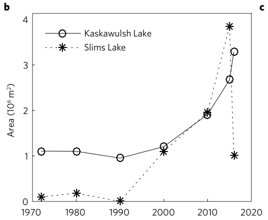

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- “There are definitely thresholds which, once passed in nature, everything abruptly changes.” — Lonnie Thompson (paleoclimatologist, Ohio State University).
- A small change in one quantity (temperature) can cause dramatic changes elsewhere (loss of a river). In dynamical systems theory, this is the butterfly effect. In climate science, this is called a tipping point. We will call such points bifurcations.

The Vital Role of Applied Mathematics

▸ Click Here

Math Behind Sea Ice and Our Changing Planet: Video published by Society for Industrial and Applied Mathematics (SIAM) featuring Emily Shuckburgh (Deputy-Head, Polar Oceans, British Antarctic Survey) and Kenneth M. Golden (Distinguished Professor of Mathematics, University of Utah)

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- “We wouldn’t be able to start understanding climate change if it wasn’t for our understanding of applied math.” — Emily Shuckburgh
- “Over the past 10-20 years we’ve lost over half of the summer Arctic sea ice pack.” — Ken Golden

Course Overview/Goals

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4. We will focus on low-dimensional (conceptual) climate models. Even one-variable models can reveal interesting dynamical behavior. Can't run controlled climate experiments of the planet. Need mathematical models!

Sample Questions of Inquiry

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5. How do changes in the Earth's celestial orbit affect the climate?
6. Why has the Earth cycled through ice ages over the last million years?

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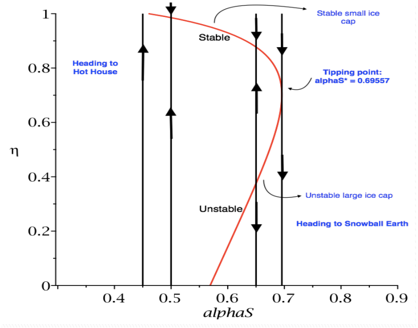
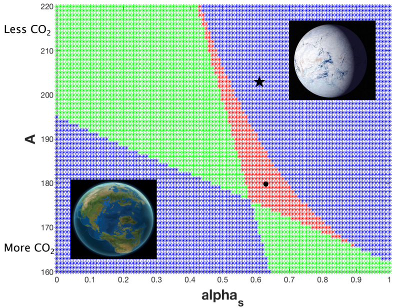
   - Field trip to Harvard Forest (mid-April). Meet climate scientists and learn about their research.
   - Movie night: *The Day After Tomorrow*

Sample Research Project (Cara Donovan)





Left figure: Different phase lines for the ice-line (η) as the albedo for snow-covered ice (α_s) is varied in the Budyko-Widiasih Energy Balance Model (land concentrated near equator).

Right figure: The number of equilibria and the fate of the climate as the parameters A and α_s vary in the model. The star is our current climate conditions while the dot represents the Neoproterozoic era.