Farewell to Ice: Arctic climate feedbacks and their global effects

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San Sebastian, July 2017
The Earth has been warming rapidly since the mid-19th Century…
Fossil fuel & cement CO₂ emissions by country/region

CO₂ emissions (PgC/yr)

Time (yr)

Source: Peters et al. Nature Climate Change submitted, based on CDIAC data and BP energy statistics
Arctic amplification
Figure 6: Arctic-wide and annual averaged surface air temperature anomalies (60°–90°N) over land for the 20th century based on the CRU TEM2V monthly data set.
The average increase in surface temperature since the 1951–1980 reference period is greatest in the Arctic.
Global heating continues

NASA

GISS Surface Temperature Analysis
Zonal Means vs. Time
Zonal average temperature change from 1915 to 2012

Presenting the global average surface temperature change as a colour change allows us to see that the heating of the biosphere has not stopped - it is sustained at the same large increase.

The temperature increase has been the same since 2006. This temperature anomaly above the average past normal - indicates constant heating.

The zonal presentation shows that the NH heats up faster than the SH, and the difference increases over time of heating.

The Arctic is heating by far the fastest which is starting to affect the normally temperate NH

http://data.giss.nasa.gov/cgi-bin/cdrar/rod_LTM apt.cgi

P. Carter Aug 2013
PROJECTIONS OF SURFACE TEMPERATURES

Global Average Surface Temperature Change (°C)

Relative Probability

2020-2029
2090-2099

2020 - 2029

2090 - 2099

°C
Observed seasonal Arctic sea-ice extent (1900-2003)

(million km²)
Record minimum ice extent in Sept. 2007

Current Ice Extent
09/16/2007

Total extent = 4.1 million sq km

National Snow and Ice Data Center, Boulder, CO
September 16, 2012 (summer minimum)

- Median mid-September extent (1979-2000)
- Previous record low (2007)

Sea ice concentration (%)
Reducing MY fraction (Kwok et al, 2009)

- Makes ice cover thinner, weaker, more dynamic
Arctic
September Sea Ice Extent: Observations and Model Runs

Sea Ice Extent (10^6 km^2)

Year

1900 1950 2000 2050 2100

You are here 2012
Fitting multibeam to a submarine - HMS “Tireless” March 2007, Arctic Ocean transect

EM3002 multibeam sonar in forward sonar dome

Mean drafts from April 2004 (Initial Processing)
Example of multiyear ridge intersected by refrozen lead - note poorer resolution than AUV due to greater depth (120 m) and speed of vehicle. But longer range (2000 km of data).
Submarine track
First use of a through-ice AUV - Gavia plus Geoswath sonar from APLIS 2007 ice camp in Beaufort Sea. Vehicle operated under first-year ridge (foreground) from black and red hut (background)
High-resolution multibeam of the first-year ridge. Detail in red is genuine resolution of small broken ice blocks (see diver photo)
A nearby multiyear ridge (left back) showing very solid smoothed ice blocks intersected by leads. Isolated pinnacles in first year ice in foreground.
Min Arctic sea ice volume, 1979 through 8/31/2011

Minimum 1-day volume, thousand km$^3$

graph: L Hamilton
data: PIOMAS
Impacts of Arctic warming

1. Acceleration of sea ice retreat due to thinning and composition changes, leading to albedo feedback.
2. Accelerated melt from Greenland ice sheet leading to enhanced rate of global sea level rise
3. Snowline retreat, also leading to enhanced albedo feedback
4. The threat from offshore Arctic methane
5. Extreme weather affecting food production
6. Decline in strength of the Atlantic thermohaline circulation
Arctic Region Ice Albedo Change, 1979-2011

52% to 48%, 6.4 W/m2 since 1979
Averaged over globe, ¼ Greenhouse gas forcing over past 30 years

K. Pistone, I. Eisenman, and V. Ramanathan, PNAS, Feb. 18, 2014
A consequence for science

- The Arctic is no longer a safe place to have an ice camp
Oil exploration will be easier
Snowline retreat and enhanced albedo feedback
Accelerated melt of Greenland ice sheet
2012 Greenland surface melt
Accelerating melt from Greenland ice sheet
(Isabella Velicogna, GRL 2009, from GRACE data)
(present rate about 300 cu km/yr)
Global sea level

Metres

in the past

in the future

New estimate

IPCC 2007

Source: Cazenave and Llovel, 2009.
Sea level rise: the threat of the normal distribution. Disproportionate effect of a change in mean sea level on the probability of a flooding event.
The threat from offshore Arctic methane

- Over shallow continental shelves (water depth 50-100 m) in summer the warming of ice-free water extends to the bottom.
- The warmer water melts seabed permafrost, releasing methane trapped as methane hydrates in the frozen sediment.
- This has been seen bubbling up to the surface in large (1 km diameter) plumes, in areas close to shore north of Siberia.
- The people who work on this phenomenon estimate that 50 Gt (50 billion tons) of methane could be released in 10 years.
- We calculated the cost of the extra warming to the planet. Using the Stern Review model we got 50 trillion dollars over a century.
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Methane global mean mixing ratios, surface (NOAA) and AIRS (400 mb)
Methane emission from the Arctic shelf?
AIRS v5 and IASI low troposphere data
Leonid Yurganov, JCET/UMBC  Shawn Xiong, NOAA
NASA Sounder Science Team Meeting, November 14, 2012, Greenbelt, MD

Satellite data images

September, 2008

IASI CH4, low troposphere, mean below 600 hPa

November, 2008

Siberia
September, 2011

November, 2011

East Siberian shelf

Locations of hydrates

Batimetry

CAMBRIDGE
Effect of methane outbreak on global temperatures

Emission of 50Gt 2015-2025, three scenarios
Cost of methane outbreak per decade - total over 100 years 60 trillion dollars
Permafrost on land: the “ticking Arctic time bomb” (Science, 2012)

Permafrost at Deadhorse, Alaska
Temperatures at 20 metres depth (°C)

Extreme weather and food production

Is this an effect of Arctic sea ice retreat? Jury still out.
Simulation of jet stream (NASA)
Crops
National Research Council Climate Stabilization Targets 2011 5.1 p. 261-262 Food production

Loss of Crop Yields per Degree Warming

Above 1.0°C yields of all crops in all regions are tipped into decline - except for IPCC mid-high latitude wheat assumed large CO2 benefit declining at 1.5°C.

These plots are model projections that do not capture a large number of large adverse effects... several processes have not been adequately quantified. These include weeds, insects, pathogens; changes in water resources for irrigation; surface ozone levels; flood frequencies; and response to extremely high temperatures. changes in sustained droughts (which are likely to increase in many regions), or potential changes in year-to-year variability of yields. NRC 2010
Decline in strength of the Atlantic thermohaline circulation

..... The “Great Conveyor Belt”
Thermohaline circulation is weakening

The large marine conveyor belt with cold deep flow and warm surface current. (Source: DKRZ/MPI-Hamburg).

Annual mean surface temperature anomalies, from NCAR data, relative to zonal averages. There is a 5-10°C warm anomaly over NW Europe and the Nordic Seas (Rahmstorf, S. A., Ganapolski, 1999).
Greenland Sea in a severe winter

Convective chimneys form in the Odden ice tongue
A convective chimney in the Greenland Sea

Discovered by “Jan Mayen” 2001, 75N 0W, 10 km diameter (Wadhams et al, 2004)
What can we do?

• WARMING can be slowed by reducing carbon emissions, i.e. switching to renewable energy (which includes nuclear), but can’t be slowed to less than 2°C by end of this century (Paris Agreement).

• Only real solution is taking CO2 out of atmosphere (Direct Air Capture).

• METHANE OUTBREAKS can only be stopped by restoring the Arctic sea ice; applying a yet-to-be-invented technique to dispose of seabed methane; or GEOENGINEERING.
Geoengineering

Geoengineering Proposals from the New York Times

Peter Fairly UEA
Direct air capture (DAC)

- This is the only ultimate solution.
- CO2 levels are already too high and emission reductions by themselves cannot be enough to keep warming below 2°C.
- Other carbon reduction methods have drawbacks
  - Crushed olivine rocks – too slow
  - BECCS (bioenergy with carbon capture and storage) – uses too much land (40-50% of arable land on planet)
  - Afforestation – difficult to achieve when forests are disappearing
- Techniques so far are too expensive (100s of dollars per ton). Need a method costing less than $40 per ton. A new Manhattan Project?
Conclusions

• So long as carbon emissions continue to increase, global warming will continue to develop.
• Even if carbon emissions were to stop entirely, there would still be some continued warming for several decades.
• If present trends continue, average warming at low latitudes will be about 4°C by end of 21st Century.
• Multiply this by 2-4 for high latitudes.
• This will be accompanied by GLOBAL SEA LEVEL RISE (about 1 m in century); LOWER PRECIPITATION in key tropical regions leading to desertification, reduced food production, and loss of rain forest.
• Possible surprises: methane boost from permafrost melt causing short term acceleration of warming, other effects not yet recognised (cf. ocean acidification).
Renewed methane increase for five years (2007–2011) observed by solar FTIR spectrometry (SCIAMACHY satellite) R. Sussmann et al 2012

Fig. 1. (a) Time series of methane column-averaged mole fractions above Zugspitze and Garmisch (monthly means). Shaded bars indicate the statistical error of the monthly means calculated from the individual measurements ($\pm 3 \sigma/\sqrt{n}$), where $n$ is the number of FTIR measurements per month. (b) De-seasonalized time series and linear trends (red lines). See Table 2 for trend magnitudes and significance.
Temperature of Planet Earth

![Graph showing temperature changes over millions of years](image)

- **Cm, O, S, D, C, P, Tr, J, K, Pal, Eocene, OI, Miocene**
- **Pliocene**
- **Pleistocene**
- **Holocene**

- **PETM** (Pleistocene Excursion Thermal Maximum)
- **K-T** (K-T boundary)
- **Permian glaciations**

- **Rao et al. (2004)**
- **CO2 from observations (5-2.5 kyr B.P.)**
- **Zachos et al. (2003)**

- **Millions of years before present**
- **Thousands of years before present (2015 CE)**

- **°C vs 1961-1990 average**
- **°F vs 1961-1990 average**

**Source:** Image from the University of Cambridge

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This graph represents the temperature changes of Planet Earth over millions of years, highlighting key events such as the PETM and Permian glaciations. The data is sourced from various studies and observations, providing a comprehensive view of Earth's temperature history.