Arctic Climate Change

Glen Lesins
Department of Physics and Atmospheric Science
Dalhousie University
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The Arctic seems to be warming up. Reports from fishermen, seal hunters, and explorers who sail the seas about Spitzbergen and the eastern Arctic, all point to a radical change in climatic conditions, and hitherto unheard-of high temperatures in that part of the earth's surface.

When was this published?
Deviations from the normal course Algué explains as usually due to the presence not far away of another typhoon. However, there is record of a hurricane in Fiji which recurved so sharply on its course that its center passed twice over the city of Levuka, and yet no other disturbance was known to be anywhere near. Furthermore, this hurricane traveled northwest from Levuka after its first passage over that city, the opposite direction from that which tropical cyclones normally take in that latitude in the southern hemisphere.

**Bifurcation of cyclones.**—Sometimes it happens that a well-developed cyclone apparently divides into two independent, comparable storms, each of which henceforth follows an independent course. Algué suggests that topographic barriers may be the cause, but the cases he considers do not make this explanation altogether satisfactory.

Secondary whirls sometimes develop within a cyclone, producing destructive winds far from the center of the main cyclone. Algué has repeatedly observed such secondary centers in the Philippines. Doctor Okada reports that two or three secondary centers sometimes occur within a typhoon.

**Typhoons and mountains.**—It is stated in some standard meteorologies that tropical cyclones cannot cross a mountain range 3,000 feet high. This is often disproven in the Far East, for typhoons sometimes cross mountains of greater height than this in Taiwan (Formosa), in the Philippines, in Japan, and elsewhere. Mountainous Formosa often appears to deflect typhoons which approach it at a small angle, and sometimes cuts the typhoon in two, according to Froc, but, on the other hand, other storms seem to pass without serious deflection from its mountains, the highest of which reach over 13,000 feet. Doctor Okada reports that studies made on lofty Fiji, near Yokohama, and on the higher mountains of Formosa indicate the depth of most typhoons to be approximately 5 or 6 kilometers (16,000 to 20,000 feet).

Although it is commonly stated that typhoons weaken decidedly as soon as they come upon the land, both Froc and Okada have observed many cases where this was not true in southeast China, the typhoons maintaining most of their force until encountering lofty mountains.

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**The Changing Arctic.**

By George Nicolas Iff.

The Arctic seems to be warming up. Reports from fishermen, seal hunters, and explorers who sail the seas about Spitzbergen and the eastern Arctic, all point to unusual and climatic conditions. The air temperature over the mountains, the highest of which reach over 13,000 feet, has risen sharply. This year, the temperature at the top of Mount Everest, which is over 25,000 feet high, has been recorded as high as 10°C. The Arctic is also experiencing more frequent and severe storms, which are causing significant damage to the infrastructure and economy of the region.

**BIRDS STORM-SWEEP OVER THE NORTH ATLANTIC.**

With the disappearance of white fish and seals comes another life in these waters. This year herring in great shoals were found along the west coast of Spitzbergen, all the way from the Barents Sea to the Greenland Sea, over the North Atlantic. Shools of smelt were also met with.
Observational Evidence for Arctic Amplification

GISS Surface Temperature Anomalies: Zonal Mean versus Time.
(Note: using station data only – 1200 km smoothing)

http://data.giss.nasa.gov/cgi-bin/cdrar/do_LTmapE.py
Warming from 1955 to 2009

Note the Arctic amplification when warming (from 1955 to 2009) is plotted as a function of latitude

http://data.giss.nasa.gov/gistemp/
Location of the radiosonde stations used in this study.

22 Canadian stations were used

Triangle symbol denotes station near sea ice.
Trend in the annual mean surface air temperature averaged over 22 stations covering most of Canada.

Global Trend (1971-2010) = 0.17 °C / decade  (Amplification 4x)
Global Trend (1991-2010) = 0.21 °C / decade  (Amplification 5x)

Annual Average All Stations
Global Warming Trend 1971-2010: 0.17°C/decade
Global Trend (1971-2010) = 0.69 +/- 0.13 °C/decade
Global Trend (1991-2010) = 1.06 +/- 0.35 °C/decade

Canadian Arctic Amplification is a factor of 5 for 1991-2010

Lesins et al, 2012, J. Climate
Line plot of global mean land-ocean temperature index, 1880 to present, with the base period 1951-1980. The dotted black line is the annual mean and the solid red line is the five-year mean. The green bars show uncertainty estimates. [This is an update of Fig. 1A in Hansen et al. (2006).]

http://data.giss.nasa.gov/gistemp/graphs_v3/
Sea ice extent continues to decline rapidly. Even worse, sea ice is getting thinner.
Question

How much of the Arctic warming can be attributed to an amplification of the global greenhouse gas radiative forcing?

vs.

How much can be attributed to inherent sensitivity in the Arctic to natural variability?
Radiative Forcing from Doubling CO₂

Radiative forcing is +4 W m⁻²: Positive means warming

(a) Initial TOA balance

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(b) Instantaneously double CO₂

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Energy imbalance results in warming until a new balance is achieved

(c) CO₂ x 2

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Enhanced in the Arctic?

(d) CO₂ x 2 + feedbacks

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Earth's surface

$T_s=15^\circ$C

$T_s=15^\circ$C

$T_s=15+1.2^\circ$C

$T_s=15+3^\circ$C

Houghton, Fig 2.9
Amplification is greatest in the autumn and winter months.
Arctic Winter Energy Balance

- **Infrared Down (Temp and Greenhouse Gases)**
- **Infrared Up (Skin Temp)**
- **Sensible and Latent Heat (Surface Winds)**
- **Atmospheric Meridional Heat and Moisture Flux**
- **Net Surface Heat Flux**
- **Oceanic Meridional Heat Flux**

- **Outgoing Long-Wave at Top of Atmosphere**
  - 160 W m\(^{-2}\)
- **Heat Conduction & Freezing**
- **No sun**
- **Atmosphere**
- **Clouds (Optical Depth)**
- **Aerosols**
- **Sea Ice**
- **Ocean**
Possible Feedback Explanations for Winter Arctic Amplification

Ice/Snow Albedo - Temperature Feedback
- No direct influence since it is dark in the Arctic winter.

Water Vapour Feedback
- No winter trend in precipitable water.

Cloud Feedback
- Open question.

Thinning Sea Ice Feedback
- Yes, enhanced heat flux from ocean through the sea ice.

Dynamical Feedback
- Yes, enhanced meridional energy transport.
Seasonally Averaged Vertical Temperature Profiles at Eureka

Winter Mean 1961–2007

Spring Mean 1961–2007

Summer Mean 1961–2007

Autumn Mean 1961–2007

Strong winter inversion

Spring

Summer

Autumn
Scatter plot of inversion strength with the time of year.

Note the large variability in inversion strength.
Sounding – plotted on a SkewT-LogP Diagram

Strong surface based temperature inversion

00Z 25 Feb 2010

University of Wyoming
INVERSION ENHANCEMENT OF AMPLIFICATION

Strong temperature inversion inhibits vertical mixing.

Hence an increase in the surface heating will not spread throughout the troposphere.

This results in enhanced warming at the surface compared to more southerly latitudes.
Arctic Winter Surface Energy Balance

\[ I_u = I_d + F' + C \]

Winter Amplification when:
1. More downward longwave.
2. Less upward sensible and latent heat flux.
4. Colder surface temperature.
Effect of Surface Inversion Strength

Effect of Mean Surface Temperature

Lesins et al., 2012: J. Climate
Similar result when plotting the monthly averages over all stations.

Largest warming trends are associated with the strongest inversions and coldest temperatures.

Effect of Surface Inversion Strength

Effect of Mean Surface Temperature
Much of Arctic Amplification is a consequence of a suppressed latent and sensible heat response due to the stable boundary layer.

Change in surface radiative forcing ($\Delta R_s$) caused by changes in temperature, greenhouse gases, clouds and/or aerosols.

The length of the bold black arrow ($\Delta I_u$) gives the amount of surface warming.

\[ \Delta I_u = \Delta R_s + \Delta F_{sh} + \Delta F_{lt} + \Delta C \]
Trend in winter sea ice thickness

2004  2005  2006  2007  2008

Ice thickness

0  5 m

Thickness (m)

Trend = -0.17 m/yr

http://rst.gsfc.nasa.gov/Sect16/365869main_earth2-20090707-full.jpg
Heat Conduction Through the Sea Ice

\[ F_{\text{conduction}} = \lambda_{\text{seaice}} \frac{\Delta T}{\Delta z}_{\text{seaice}} \sim 2.0 \cdot \frac{30}{2} \sim 30 \text{Wm}^{-2} \]
Latent Heat Released by Sea Ice Formation

Assume the whole Arctic ocean grows a fixed amount of sea ice thickness during the winter.

The latent heat is released at the bottom of the sea ice layer.

\[ F_{\text{freeze}} = \frac{f_ol_f\rho_i\Delta z}{\Delta t} \sim \frac{0.9 \times 3.3 \times 10^5 \times 900 \times 2}{6 \text{ months}} \sim 30 \text{ Wm}^{-2} \]

This value is consistent with the conductive flux upward through the sea ice.
Atlantic Multidecadal Oscillation (AMO)

Temporal variation in the average North Atlantic sea surface temperature.

There is evidence of a correlation between the AMO and multidecadal temperature variations in the Arctic.

The AMO index is defined as the SST anomaly for the basin-wide detrended smoothed time series.
AMO Index

Monthly values for the AMO index, 1856 - 2009

Notice the roughly 60-70 year period

Warm phase is associated with more Atlantic hurricanes, more rain in Florida and more drought in the south-west USA

http://www.cdc.noaa.gov/Correlation/amon.us.long.data
The Arctic temperature trend is amplified compared to the global trend.

Chylek et al., 2009

Note the different temperature scales.
Compare the warming of 1910-1940 to that of 1970-2008. Amplification was even greater during 1910-1940.

Chylek et al., 2009

Table 1. Arctic Air Temperature Trends (deg C per decade)

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Chylek et al., 2009
There appears to be a strong AMO connection to the Arctic temperature trend.

Will the Arctic begin to cool if the AMO shifts back to a cool phase?

Figure 3. 11 year running average of the Arctic temperature (combined low and high Arctic stations with long term temperature records) anomaly (thin red line) with respect to 1910 2008 average, detrended anomaly (thick red line), and the AMO index anomaly. The NOAA (blue) and the [Parker et al [2007] (black) AMO index anomaly have been normalized to a peak value of 0.7 within 1930 1940s.
Thank you
This typical model feedback analysis is not applicable to the Arctic winter.
Figure 1: Upper left: Five year moving average of the observed Arctic temperature (NASA GISTEMP) in red and regression reconstruction (in red) using known 20th century forcings as predictors. Upper right: The residue (difference between the observed and reconstructed temperature (black) and AMO index (red). Both sets normalized to zero mean and unit variance. Lower left: Same as upper left, however, with the AGHG, volcanic aerosol, and AMO as predictors. Lower right: Contribution of individual predictors to the reconstructed Arctic temperature.
Significant increases in precipitable water in all seasons except winter.
Warming in winter is not a water vapour feedback.

Lesins et al, 2009, Submitted to AO
Arctic warming occurs when the surface inversion is the strongest (from October to April).

Warming is greatest when the sun is low or absent. So ice albedo feedback is not the direct cause of the winter warming.
Significant increases in precipitable water in all seasons except winter. So the warming in winter is not a water vapour feedback.

Lesins et al, 2010, AO
Mean spring ice thickness for
(a) 1982–1987,
(b) 1988–1995,
(c) 1996–2000,
(d) 2001–2007.

The area of ice exceeding 5 years in age decreased by 56% between 1982 and 2007 [Maslanik et al., 2007].

Within the central Arctic Ocean, the coverage of old ice over this period declined by 88% and ice that is at least 9 years old essentially disappeared.

This change toward younger ice translates to a decrease in mean thickness of ice over the Arctic Ocean from 2.6 meters in March 1987 to 2.0 meters in 2007