Arctic Amplification and its Possible Influence on Mid-latitude Extreme Weather

Judah Cohen (AER)
November 10, 2015
How climate change may be producing more blockbuster snowstorms

South Carolina governor calls deadly rain a 'thousand-year' event

'Possibly catastrophic': Texas braces for even more flooding

India Heat Wave, Now 5th Deadliest on Record, Kills More Than 2,300

Heat Records Shattered in Germany, France, The Netherlands in June/July 2015 Europe Heat Wave

As California Drought Enters 4th Year, Conservation Efforts and Worries Increase
Extreme Weather

a) Trend in total wet-day precipitation [mm/year]

b) Very wet day precipitation

c) Trend in very wet day precipitation [mm/year]

d) Coldest daily minimum temperature

e) Trend in warm days [% of days/year]

f) Number of icing days

g) Warm summer months (% of land)

h) Cold winter months (% of land)

Cohen et al. 2014
Extreme Snowfall

Top 10 Snowstorms for Northeast US Cities

Year

Total Storm Snowfall - [in.]


- Boston
- Providence
- New York
- Philadelphia
- Hartford
- Baltimore
- Albany
- Washington

Attached image: A graph showing the total storm snowfall in inches for the top 10 snowstorms for Northeast US cities, with data points scattered across years from 1880 to 2010.
Theories linking AA to Mid-latitude Weather

• Changes to latitudinal temperature gradient

• Changes to the Jet Stream/blocking/wave speed

• Changes to atmospheric waves:
  – Planetary waves (winter)
  – Synoptic scale waves (summer)

• Changes to troposphere-stratosphere coupling

• Support of these theories are conditional and challenged by imperfect observations and models
Sea Ice Melt

Dr. Ignatius Rigor, Polar Science Center
Applied Physics Laboratory, Univ. of Washington
http://sealke.apl.washington.edu/IceAgeExtent/

Ignatius Rigor
Sea Ice and Snow Cover Decline

Sep SIE and June SCE 1979–2014

$r = .74$

Standardized Anomaly

Year

1980  1990  2000  2010

Sep Sea Ice
June Snow
WAVE SPEED AMPLITUDE AND SUMMER WEATHER
Surface temperature anomalies are inversely proportional to the speed of the wind.

This relationship is especially strong for Europe where the penetration of maritime air is needed to keep temperatures moderate. Weakening of the westerly winds will result in warmer temperatures.

Coumou et al. 2015
Precipitation anomalies are proportional to the speed of the wind (all year).

Coumou et al. 2015
For wave numbers 6-8 we have observed an increase in the frequency of high-amplitude quasi-stationary waves. This has coincided with an increase in summer extreme weather events.
STRENGTH OF POLAR VORTEX
AND WINTER WEATHER
Arctic Amplification

Cohen et al. 2014
Snow cover has been increasing since 1988 and sea ice decreasing, especially since 1998.
Trends in NH Fall Snow Cover Extent

Last year was highest on record!
Correlations of AO with Zonal Wind (North Atlantic only)

ENSO

AO
Increase in stratosphere-troposphere coupling mid-late winter that favors a warmer polar stratosphere and higher heights in the Arctic troposphere (negative AO/weak polar vortex).
Polar Cap Geopotential Height, 60-90°N (2012-2013)

Correlation of Daily PCH with the
October Eurasian Snow Index

Correlation of Daily PCH with Inverted
Detrended Sept Arctic SIE Index

Correlation of Daily PCH with the DJF AO Index

Pressure - [hPa]
PCH
Oct-Mar

Winter 2012-2013 PCH (Contribution from SeaIce)

Polar Cap Geopotential Height, 60°-90°N (2012-2013)

Sandy
Early Nor’easter
Cold/snow Asia, Europe
Blizzards in the US
Major Stratospheric Warming
Blizzard 2013
Blizzard New England
Midwest-East Coast
Late season snow/Arctic outbreaks US & Europe
Snow in the snowstorm
UK/Arctic outbreak US
Snow Forced Cold Signal

**Stratosphere**

1. Regional Perturbation over Siberia
2. Upward Energy Flux
3. Stratospheric Polar Vortex Weakens
4. Warming

**Troposphere**

5. Downward propagation of High pressure and southward displacement of jet.
6. High Pressure over the Arctic and frequent cold air outbreaks

Increased Eurasian snow cover

Sept Oct Nov Dec Jan Feb
Tropospheric precursor November 2014

Regression of Nov SLPa onto the Oct. Eurasian SCE Index (Contours) and the Dec 100 hPa [\(\sqrt{v^* T^*}\)] Index (Shading)

Pattern correlation = 0.93 between 40-80°N
Stratospheric Warming/PV Split

10 hPa Geopotential Height Anomaly: Jan 6 - Jan 7 2015
Synthesis of Sea Ice and Snow Cover

Cohen et al. 2014
Atmospheric Circulation

10 hPa Geopotential Height Anomaly: Jan 1 - Jan 10 2015

500 hPa Geopotential Height Anomaly: Jan 19 - Feb 28 2015
Low Sea Ice Forced Cold Signal

Some model runs forced with low sea ice have been able to simulate atmospheric response as observed.

Kim et al. 2014
Relationship between Sea Ice, Snow Cover and the AO

cEOF (Oct Snow / Nov Arctic Sea Ice / DJF SLP)

(a) Snow Mode 1 (15.1%)

(b) Sea Ice Mode 1 (15.1%)

(c) SLP Mode 1 (15.1%)

(d) Leading PC from cEOF & DJF 1000 hPa NAM Index

Furtado et al. in preparation
Relationship between Sea Ice, Snow Cover and Surface Temperatures

cEOF (Oct Snow / Nov Arctic Sea Ice / Surface Temperature)

(a) Snow Mode 1

(b) Sea Ice Mode 1

(c) DJF Surface Temperature Mode 1 (13.4%)

(d) Dec Surface Temperature Mode 1 (11.2%)

(e) Jan Surface Temperature Mode 1 (12.4%)

(f) Feb Surface Temperature Mode 1 (12%)

Furtado et al. in preparation
Relationship between Sea Ice, Snow Cover and Surface Temperatures

Furtado et al. in preparation

Dec

(a) Snow Only

(b) Sea Ice Only

(c) Snow & Sea Ice

Jan

(d)

(e)

(f)

Feb

(g)

(h)

(i)

Anomaly Correlation Coefficient

0.6

0.5

0.4

0.3

0.2

0.1

0

Furtado et al. in preparation
Synthesis of Sea Ice and Snow Cover

Cohen et al. 2014
Dynamical Winter Forecasts 2010/11-15/16
Challenges with Data and Models

- Short time series in observations
- Model deficiencies
- Uncoordinated modeling studies
- Biases and uncertainties in matrices for quantitative analysis
- Still more and more observational and modeling studies argue that a changing Arctic is influencing mid-latitude weather
Mid-latitude Weather is Complicated

- **NH Cryosphere Changes**
  - Summer/Early Fall Arctic Sea Ice Loss
  - Fall Eurasian Snow Cover Increase
  - Late Fall/Winter Arctic Sea Ice Loss

- **Polar Vortex**

- **Changes In:**
  - Storm Tracks
  - Jet Stream
  - Planetary Waves

- **Natural Variability**
  - Internal Climate Modes
  - Solar Cycle
  - Volcanic Eruptions

- **Global Climate Change**
Winter MSLP response to sea-ice loss

- **a)** NCAR CAM3
  - Liu et al. 2012
- **b)** HadGEM2
  - Screen et al. 2015
- **c)** NCAR CAM3
  - Screen et al. 2014
- **d)** HadGEM3
  - Petrie et al. 2015

Contact: j.screen@exeter.ac.uk
All multi-model averages suggest that Niño 3.4 will be above +1.5°C (a “strong” El Niño) during late 2015 into early 2016.

NOAA Climate Prediction Center
Models are confident in regions with high skill from ENSO or sea ice is melting in the Arctic
September Sea Ice Anomalies

Sea Ice Concentration Anomalies
Oct 2014

Sea Ice Concentration Anomalies
Oct 2015

Total anomaly = -1.2 million sq km
Total anomaly = -1.4 million sq km
October Snow Cover Extent

Snow Extent, mln km²

Automated Multisensor Snow/Ice Mapping System
NORTHERN HEMISPHERE

Last update: Nov 4, 2015
Snow area extent: 26.27 10⁶ km²
Arctic Oscillation Blog

GEFS 6-10 Day Forecast T2m Anomaly
INIT: 00Z 05/12/15  FCST: 05/18/15 to 05/22/15

Average 500 hPa Heights and Height Anomalies
02/16/2015 to 02/19/2015

SST Anomaly - Week Ending 10 May 2015

Average 10 hPa Heights and Height Anomalies
01/03/2015 to 01/08/2015

http://www.aer.com/science-research/climate-weather/arctic-oscillation
Expert: Ramp-up in Siberian snow cover hints at cold winter for eastern U.S.

Based on the snow cover behavior, Cohen forecast a colder than normal winter for the eastern U.S. He was not only right that the winter would be a cold one, but also accurately forecast that the second half of winter would be significantly colder than the first half.

Cohen shared his 2014-2015 winter temperature forecast (below right) compared to what actually happened (below left) and the match is remarkable. “As far as seasonal forecasts go, that is incredibly accurate with the gross features correct and differences only in the details,” Cohen said.

Winter Temperature Forecast

(Judah Cohen)
Summary

• Over the past two decades the Arctic has undergone rapid and dramatic changes.
• Strong warming and large variability in sea ice and snow cover could be influencing mid-latitude weather.
• Many theories/studies argue/show that Arctic variability influences mid-latitude weather through wave interference and/or Jet Stream characteristics.
• Skepticism remains high due to large natural variability, short observational record, inconclusive and ambiguous modeling studies and modeling deficiencies.
• The need for advance is significant and appreciated and efforts are underway to improve observational and modeling studies.
Summer Circulation

Observed Sea Level Pressure Anomaly: Jul 1 - Aug 31 2015
Same sea ice forcing – different model response

Internal atmospheric variability is large

- AMIP experiments with high and low sea-ice concentrations based on observed trends (1979-2009)
- same forcing…different response!

100 years of Unified Model
60 years of CAM
Screen, Deser et al. (2013; CDYN)

CSU Elizabeth A. Barnes
Arctic Amplification – Mid-latitude Weather

Arctic Amplification, temperatures increase

Higher geopotential heights, weaker westerly winds

Wavier jet stream, blocking

Weather patterns move eastward more slowly

Extreme weather more likely

FIG. 2. Hypothesized steps linking Arctic amplification with extreme weather events in Northern Hemisphere midlatitudes.

Overland et al. 2015
Natural Variability

- The role of natural variability on mid latitude weather is large and it is always a challenge to separate the signal from the noise.

- There are many factors influencing mid-latitude weather and isolating one factor is difficult.

- We know that the tropics and mid-latitudes influence the Arctic, therefore AA may be more of a response than a cause.

- This is further complicated when studying extreme events which are infrequent, may be poorly observed and definitions are subjective and may be more societal based than metric based.
Natural Variability in the Mid-latitudes

Internal atmospheric variability is large

- Decadal variability of jet position and speed is large
- Behavior over the past decade does not appear exceptional compared to the long-term variability

20th Century Reanalysis jet latitude and speed
red line denote NCEP-NCAR Reanalysis
Woolings et al. (2014; QJRMS)
Extreme Weather

• Extreme weather is subjective and not well defined.

• Extreme weather is predicted to increase under climate change and AA is not needed to explain an increase in extreme weather.

• A challenge for the group is to identify which extremes may or may not be influenced by AA.

• We are not simply focusing on extreme weather but rather AA and linkages to changes in the atmospheric circulation. However extreme weather is what the public is most concerned about.
Outline

• Over the past two decades the Arctic has been warming more than twice as fast as the rest of the globe and is referred to as “Arctic Amplification” (AA)
• Concurrent with AA, extreme weather has been observed to be increasing.
• There have been numerous theories linking AA to more frequent and extreme weather/climate events, though testing these theories is challenging due to large natural variability, short observational record and model shortcomings and conflicting results.
• We have assembled the leading scientists studying this topic to move the science forward through meetings, coordinated studies and future publications.
Trends in Extremes

Source: MunichRe
Correlations of AO with Zonal Wind and Temperature

Corr ENSO and Zonal Wind/Temp Dec-Feb 1980-2015

Corr AO and Zonal Wind/Temp Dec-Feb 1980-2015

ENSO

AO
Summer Circulation

Observed Sea Level Pressure Anomaly: Jul 1 - Aug 31 2015
Summer and Winter AO

![Graph showing normalized anomaly of Jull&Aug AO and DJF AO over the years 1950 to 2010. The graph indicates a correlation (R=0.30).](image)
Warm Arctic Forced Cold Signal

Shown are both observations and models

Kug et al. 2015