Arctic Change and Possible Influence on Mid-latitude Climate and Weather

Judah Cohen (AER) and Xiangdong Zhang (UAF) co-chairs
June 23, 2015
'Possibly catastrophic': Texas braces for even more flooding

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

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

How climate change may be producing more blockbuster snowstorms

What the massive snowfall in Boston tells us about global warming

Food Grows Where Water Flows
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.
Sea Ice and Snow Cover Decline

Sep SIE and June SCE 1979–2014

$r = .74$

Year

Standardized Anomaly

Sep Sea Ice
June Snow
Arctic Amplification

(a) DJF Area-Averaged Temperature Anomalies

(b) DJF Area-Averaged Temperature Anomalies

(c) DJF Surface Temperature Trends (1990-2013)

Cohen et al. 2014
Northern Hemisphere Land Temperatures 1987-2014

DJF
Trend = -0.50°C/10 yr**
Trend = -0.01°C/10 yr

MAM
Trend = 0.10°C/10 yr
Trend = 0.30°C/10 yr**

JJA
Trend = 0.23°C/10 yr**
Trend = 0.35°C/10 yr**

SON
Trend = 0.28°C/10 yr
Trend = 0.43°C/10 yr**

**p < 0.01

Cohen et al. 2012
Extreme Weather

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

b) Very wet day precipitation

-8 -6 -4 -2 0 2 4 6 8


mm

-18 -16 -14 -12 -10 -8


Tn (°C)

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

d) Coldest daily minimum temperature

-6 -4 -2 0 2 4 6


-20 -18 -16 -14


f) Number of icing days

days

-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4

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

30 35 40


g) Warm summer months [% of land]

20 30 40 50 60


% of Land

h) Cold winter months [% of land]

10 20 30


% of Land

Cohen et al. 2014
Extreme Snowfall

Top 10 Snowstorms for Northeast US Cities

Total Storm Snowfall - [in.]

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

Year


0 10 20 30 40 50
Extreme Rainfall

(a) Zonal wave-5 regime of the May 2015 streamfunction anomalies at 250 hPa overlaid with the climatological jet stream (hatched; |V| > 25 m/s); the yellow-red mark indicates the Texas floods. (b) Linear trend (slope) during the 1981-2014 period of the wave-5 regime streamfunction (unit: 10^6 m² s⁻¹) with the 95% confidence interval shaded. Notice the phase coincidence between (a) and (b).
Trends in Extremes

Source: MunichRe
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).
PCH
Oct-Mar
PCH
Oct-Mar

Winter 2012-2013 PCH (Contribution from SeaIce)

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

01Oct 15Oct 01Nov 15Nov 01Dec 15Dec 01Jan 15Jan 01Feb 15Feb 01Mar 15Mar

Pressure - [hPa]

10 50 100 150 200 250 300 350 400 450 500 550

1.0 0.8 0.6 0.4 0.2 0.0 0.0 -0.2 -0.4 -0.6 -0.8 -1.0

1.6 1.2 0.8 0.4 0.0 0.0 -0.4 -0.8 -1.2 -1.6 -2.0

01Oct 15Oct 01Nov 15Nov 01Dec 15Dec 01Jan 15Jan 01Feb 15Feb 01Mar 15Mar

Pressure - [hPa]

10 50 100 150 200 250 300 350 400 450 500 550

Sandy
Early Nor'easter
Cold/snow in Asia, Europe
Blizzards in the US
Major Stratospheric Warming
Blizzard 2013
Blizzard New England
Late season snow/Arctic outbreaks US & Europe
Snow in the UK/Arctic outbreak US
Midwest-East Coast snowstorm
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.
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
Asia: Arctic-Midlatitude Weather Linkages

Low Sea Ice

Strong Siberian High

Cold Storms

Outten and Esau 2012
Kim et al. 2014

James Overland
North America: Warmer Arctic Temperatures Can Reinforce Wavy Jet Stream

“Warmer Arctic”

Wavier Jet Stream

Cold

Francis and Vavrus 2015
Hartmann 2015

GEFS 6-10 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 06/23/15  FCST: 06/29/15 to 07/03/15

http://www.aer.com/science-research/climate-weather/arctic-oscillation

James Overland
High Snow Forced Cold Signal

- Stratospheric Polar Vortex Weakens

1. Increased Eurasian snow cover
   - Sept
   - Oct
   - Nov
   - Dec
   - Jan
   - Feb

2. Regional Perturbation over Siberia
3. Upward Energy Flux
4. Warming
5. Downward propagation of High pressure and southward displacement of jet.
6. Negative Arctic Oscillation
7. High Pressure over the Arctic and frequent cold air outbreaks

Cohen et al. 2007
Low Sea Ice Forced Cold Signal

(a) ΔSAT for ND, Composite
(b) ΔZ500 for ND, Composite

(c) ΔPCH, Composite

(d) Δ[νT], Composite

Kim et al. 2014
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
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
Arctic Amplification - Jet Stream

Figure 3:
Schematic of a typical jet stream trajectory (solid line) over North America and the expected elongation of ridge peaks northward (dashed line) in response to Arctic Amplification.

Francis 2013
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.
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

- Arctic Amplification

- Changes in:
  - Storm Tracks
  - Jet Stream
  - Planetary Waves

- Global Climate Change

- NH Mid-Latitude Weather

- Polar Vortex

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

Cohen et al. 2014
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
Woollings et al. (2014; QJRMS)
Inverse AMV/NAO relationship in the 20CR reanalysis over 1901-2010

Composite of DJFM SLP based on AMV polarity over 1901-2010 (shading, anomalies significant at the 95% confidence level). Contours represent the NAM mode in surface. Adapted from Peings and Magnusdottir (2014).
Atmospheric model forced with warm SSTs in tropical Eastern Pacific responds with Arctic warming and mid-latitude cooling

Lee et al. 2015
Increased tropical Pacific SST causes a southward shift of the jet stream, enhancing low troposphere baroclinicity and storm activity in US.

Vertical cross section of zonally averaged (between 180°-310° longitude) u-wind (contours: climatology; shading: increased tropical Pacific SST)

Basu et al., 2013
Challenges with Data and Models

- Short time series in observations
- Model deficiencies
- Uncoordinated modeling studies
- Biases and uncertainties in matrices for quantitative analysis
Will Arctic changes lead to mid-latitude weather extremes in the coming decades?

Attribution is Controversial:
Length of data series (<10-20 Years) is short and weather is chaotic.
Large natural variability in the system makes detecting a signal difficult.
There are many forcings of the system making attribution to just one forcing a challenge.
Observational network in the Arctic is sparse.
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)
# Working Group Members

<table>
<thead>
<tr>
<th>Scientist</th>
<th>Affiliation</th>
<th>Expertise</th>
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<tbody>
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Previous Workshops (not all listed)

• National Academy of Sciences – September 2013
  – Large gaps in our understanding
  – short observations
  – conflicting modeling studies

• Reykjavik Iceland – November 2013
  – Topic is controversial
  – There is little agreement on mechanisms
  – Is a major science challenge & may benefit long-range forecasts

• Barcelona Spain – December 2014
  – Attribution is controversial
  – Linkages will be regional
  – Potential for improving seasonal forecasts
New Consensus

Most studies on AA-midlatitude linkages favor early winter linkages that are regional and based on amplification of existing weather patterns *in some years*. 

Linkages are a combination of internal variability, two-way mid-latitude teleconnections, and lower-tropospheric Arctic temperature anomalies. *All are important*. 

Way forward: Investigate multiple dynamic processes often buried in noise; Need a Grand Science Challenge. 

Worth further investigation for potential of improving seasonal forecasts, especially with continued Arctic external forcing. 

James Overland
Proposed Tasks

• Extend observational time series
• Recommend new observations
• Recommend standardized modeling studies
• Coordinate modeling studies-large ensembles and case studies for identifying physical processes
• Coordinate with other Arctic groups (SEARCH, CliC, IASC)
• A synthesis/review project
  a. Review article and/or
  b. Journal special issue (early favorite)
Meetings

• Bi-monthly teleconferences

• Annual meeting – first is likely to be held at fall AGU

• Workshop -TBD
Contributions from WG Efforts

• Better understanding of knowledge gaps
• Better use of the observations
• Standardized modeling studies
• Better understanding of the modeled response to AA
• Improved climate prediction
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 and inconclusive and ambiguous modeling studies.
- The gathering of leading scientists to advance this complex but important challenge is timely.
Arctic Oscillation (AO)/Polar Vortex

- Also known as the North Atlantic Oscillation.

- Can be thought of as a metric of how much mixing of atmospheric masses is occurring in the atmosphere.

- Positive AO/strong polar vortex – little mixing with strong low pressure/cold air sitting over the pole and higher pressure/warmer air to the south.

- Negative AO/weak polar vortex – strong mixing causes warm air to rush the Pole and Arctic south spills equatorward
Melting sea and ice and increasing snow cover are contributing to a weakening of the polar vortex (and more extreme weather).

- Warming Arctic
- Less sea ice
- More atmospheric moisture
- Increasing snow cover
- Decreasing Arctic Oscillation trend/weakening of the polar vortex

Cohen et al. 2012b
Arctic Amplification – Mid-latitude Weather

Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms

3. Lee et al 2015
5. Coumou et al 2015
6. TBD
7. Coumou et al 2014
8. Francis and Vavrus 2015
10. Screen and Simmonds 2014
Slower moving more persistent waves has resulted in greater frequency of heat waves in the era of Arctic Amplification (2000 to present)

7-2011 Heat wave in the United States
7/8-2010 Russian heat wave and Pakistan flood
7-2006 European heat wave
8-2004 Winter like temperatures in Northern Europe
8-2003 European summer 2003 heat wave
8-2002 Elbe and Danube floods in Europe
7-2000 Floods in northern Italy and the Tisza basin, heat wave in the southern U.S.
7/8-1997 Great European Flood, floods in Pakistan and western U.S.
7-1994 Heat wave in southern Europe
7-1993 Unprecedented flood in the U.S.
7-1989 Widespread drought in U.S.
8-1987 Severe drought in the southeastern U.S.
8-1984 Severe heat and drought in the U.S.
7/8-1983 Severe heat and drought in U.S. mid-west

Source: Coumou et al. 2015
Internal atmospheric variability is large

- Decadal variability of blocking frequency is very large, like jet-stream variability (the two are dynamically linked)

- Behavior over the past decade does not appear exceptional compared to the long-term variability

Barnes et al. (2014); GRL
Recent Trends in NH Circulation Resemble AO Variability

Cohen et al. 2014
ARP drives warmer Arctic but cold Eurasian midlatitude, and extreme cold winter occurred when ARP went extremely negative phase.

**ARP amplitude time series**

**ARP driven surface air temperature Anomalies**

**Surface air temperature anomalies** Dec 2009 – Feb 2010

*Zhang et al., 2010*
October 2014 Eurasian snow cover is highest since 1979 and so is Boston snowfall for winter 2014/15.