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

Judah Cohen (AER) and Xiangdong Zhang (UAF) co-chairs

June 23, 2015

Capital Weather Gang

How climate change may be producing more blockbuster snowstorms

The Washington Post

Energy and Environment

What the massive snowfall in Boston tells us about global warming

CNN

'Possibly catastrophic': Texas braces for even more flooding

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

The Weather Channel

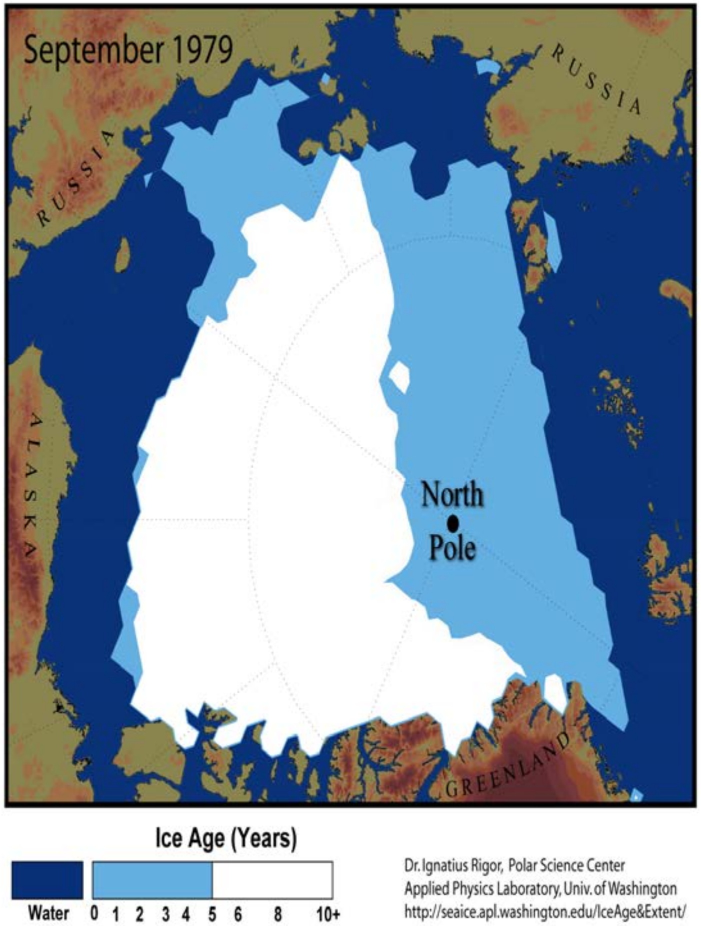
As California Drought Enters 4th Year, Conservation Efforts and Worries Increase

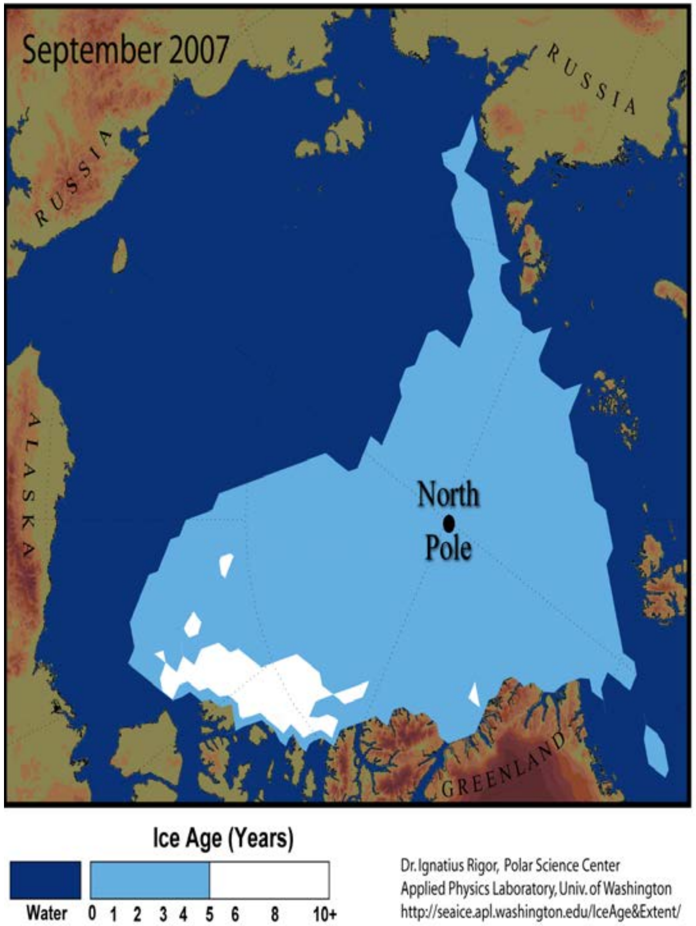
The New York Times

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.

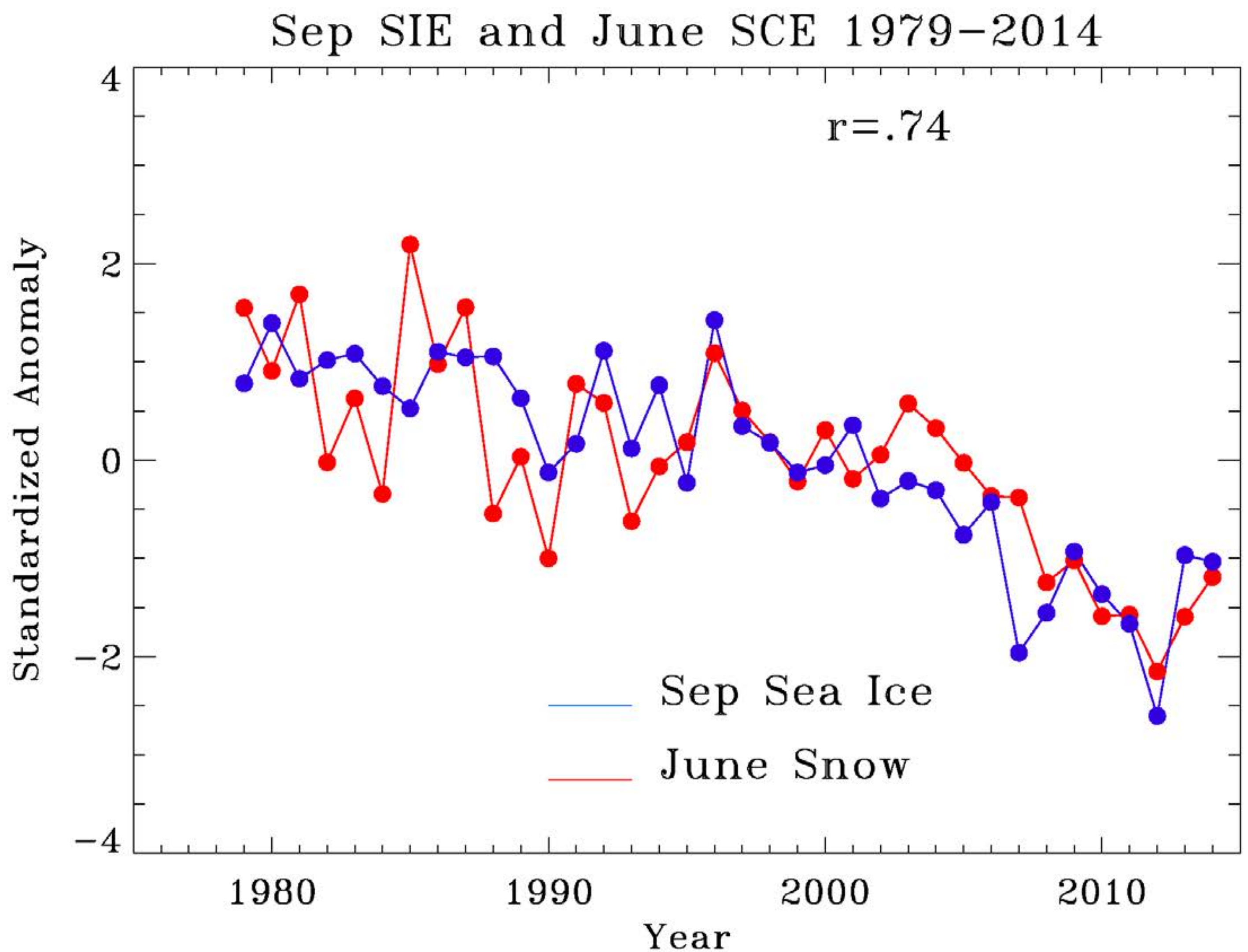
Sea Ice Melt



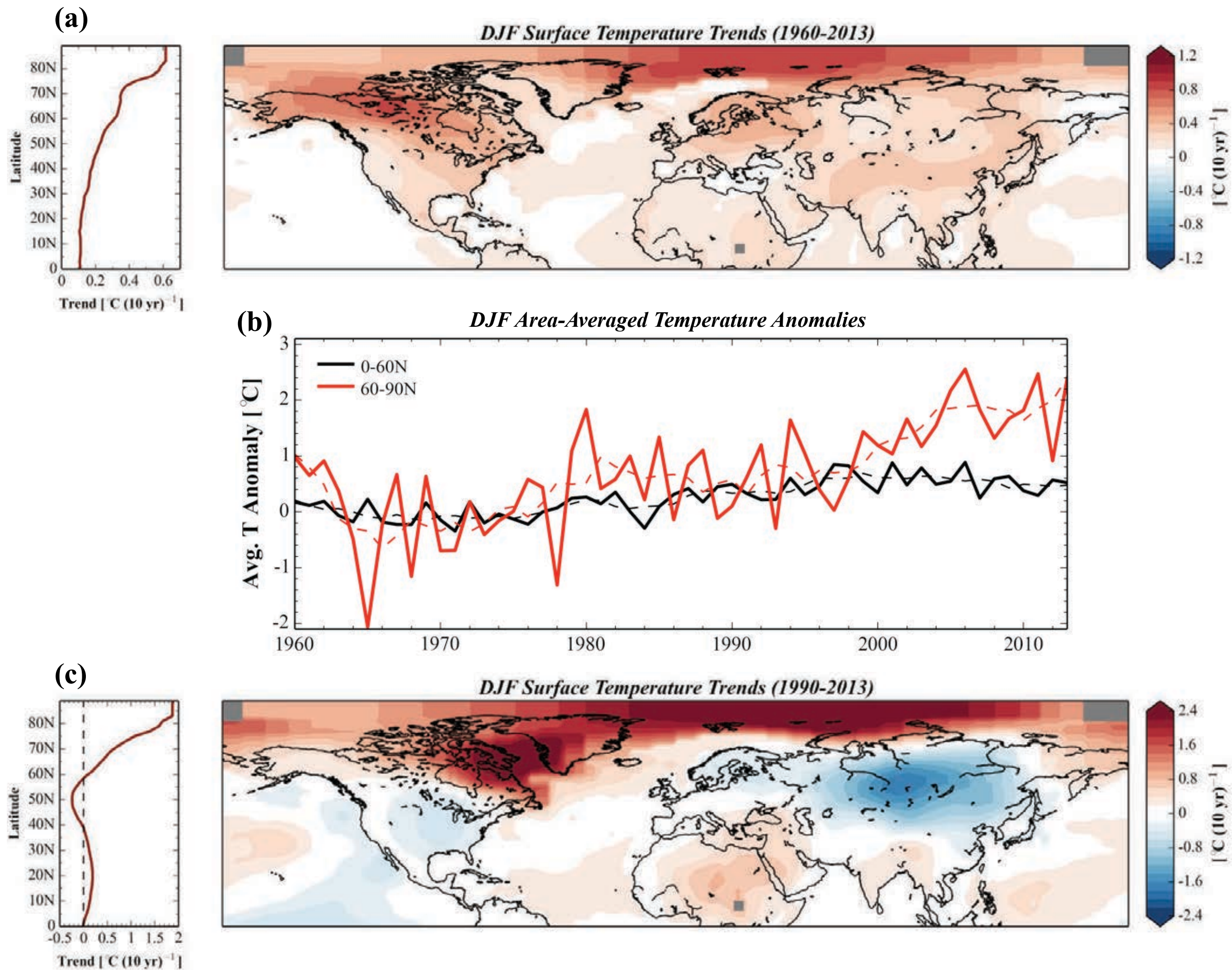


Ignatius Rigor

Sea Ice and Snow Cover Decline

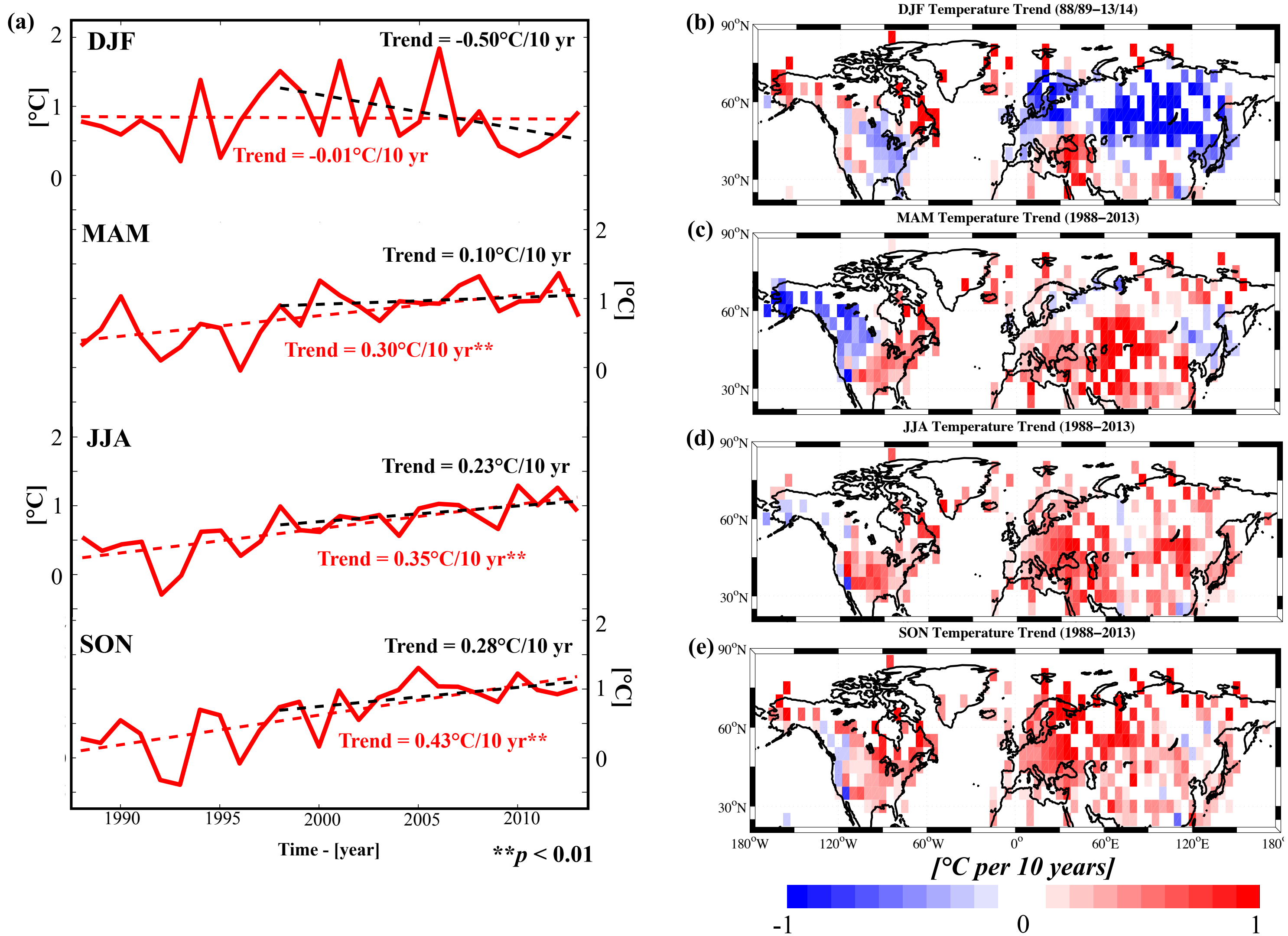


Arctic Amplification



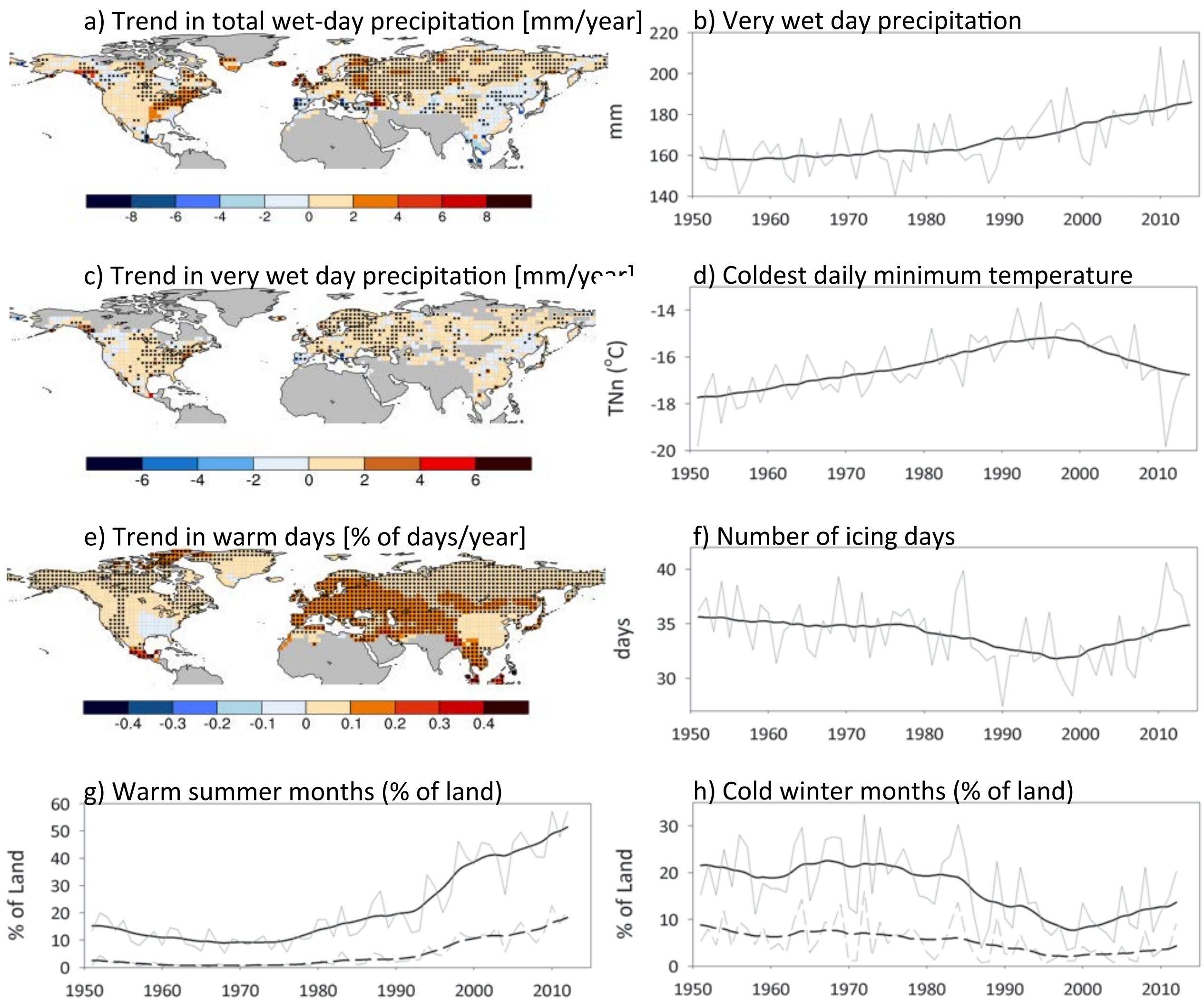
Cohen et al. 2014

Northern Hemisphere Land Temperatures 1987-2014



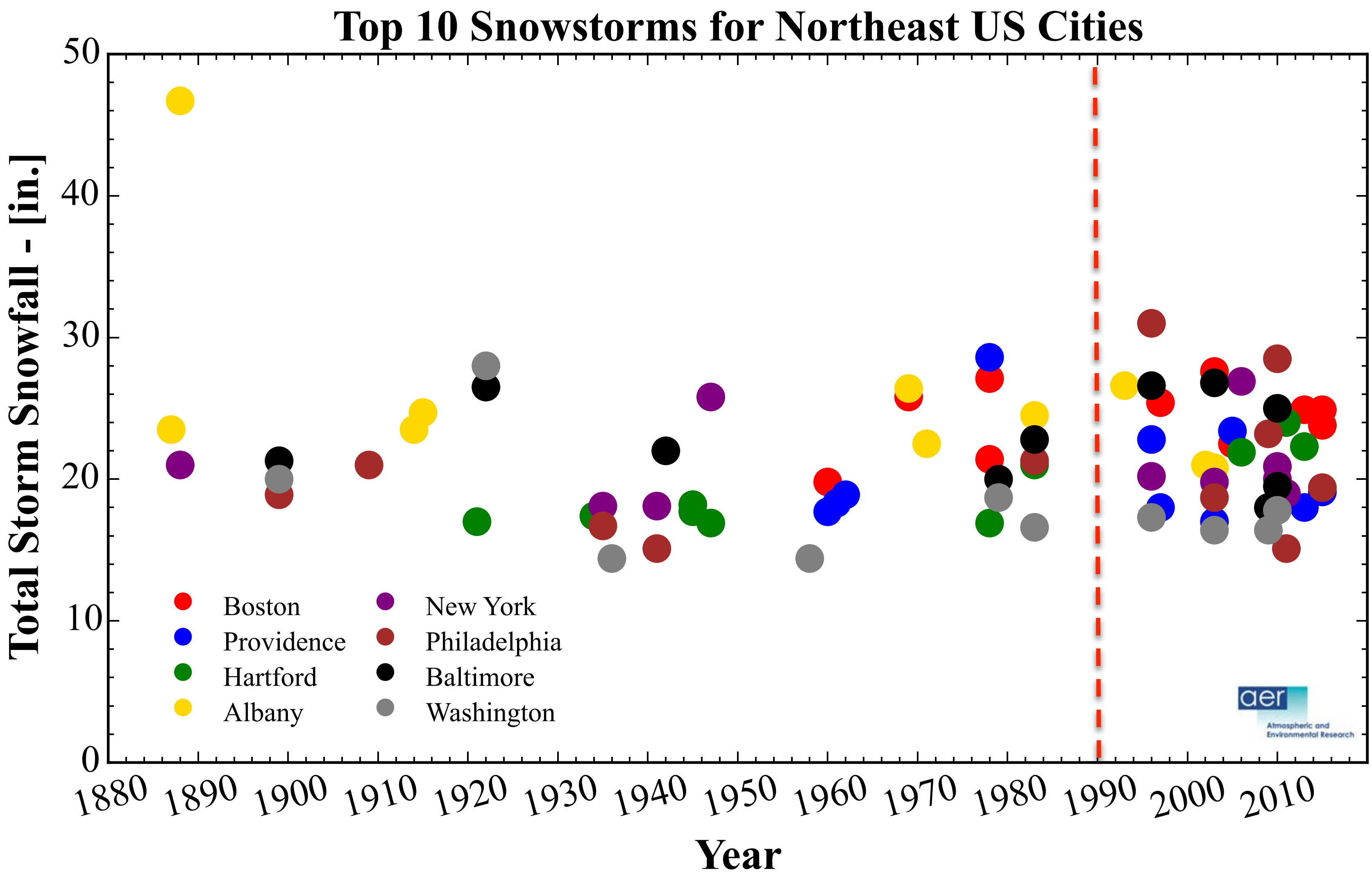
Cohen et al. 2012

Extreme Weather

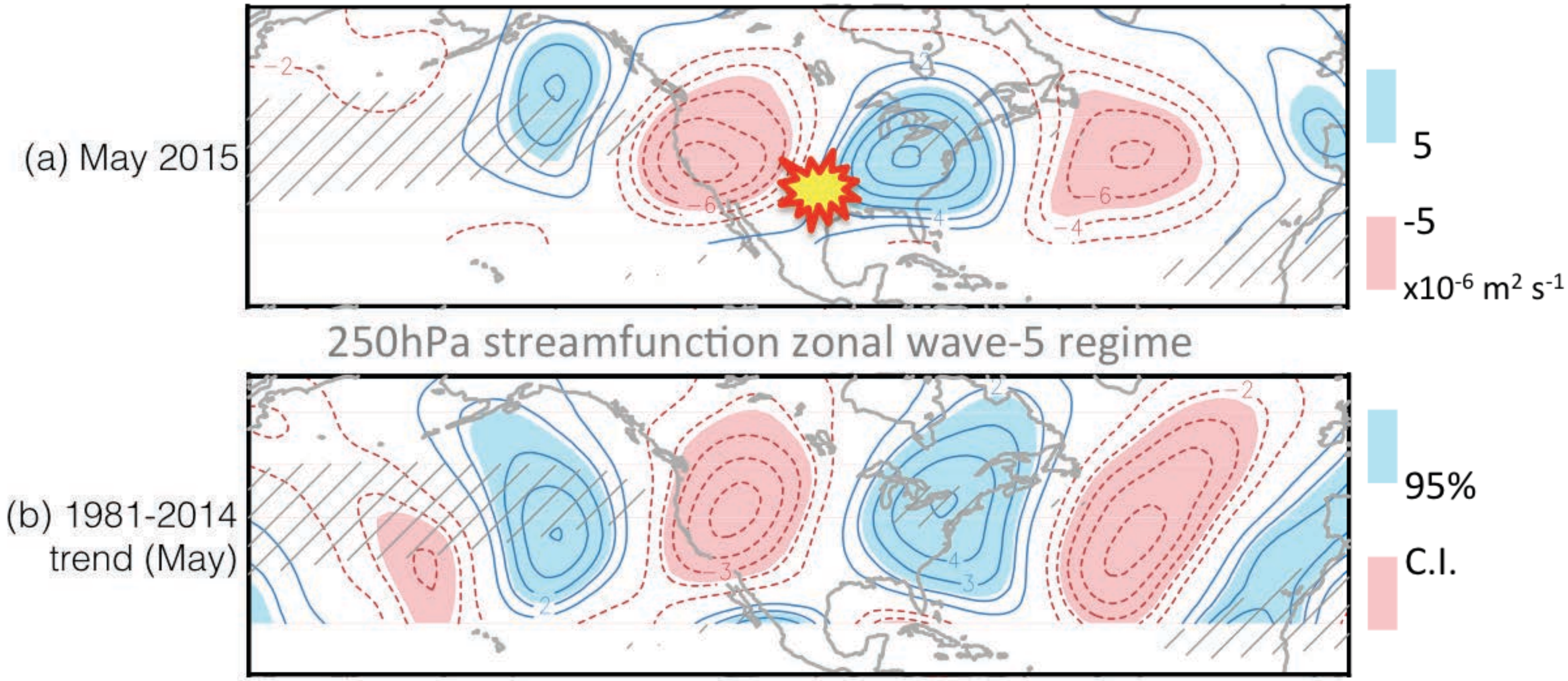


Cohen et al. 2014

Extreme Snowfall

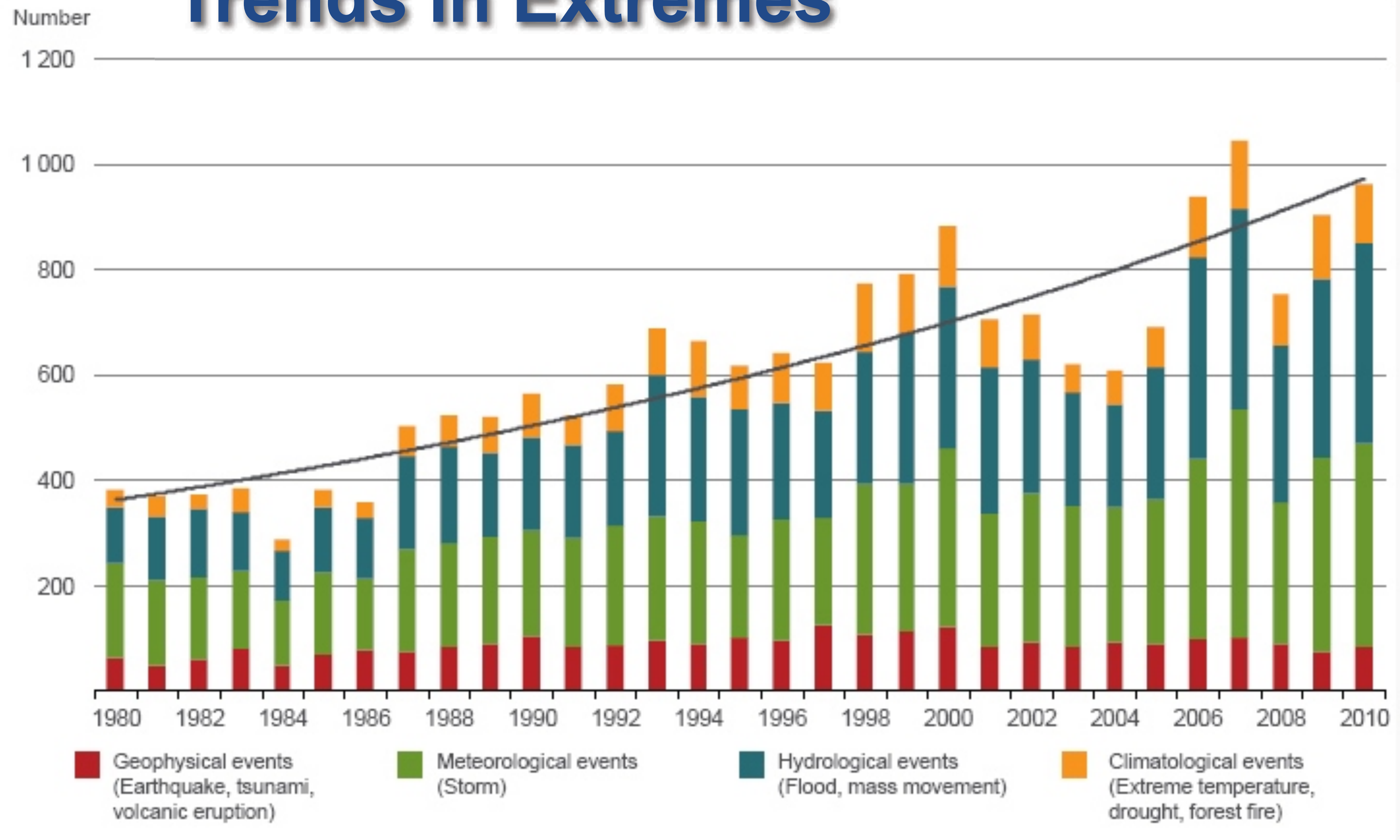


Extreme Rainfall



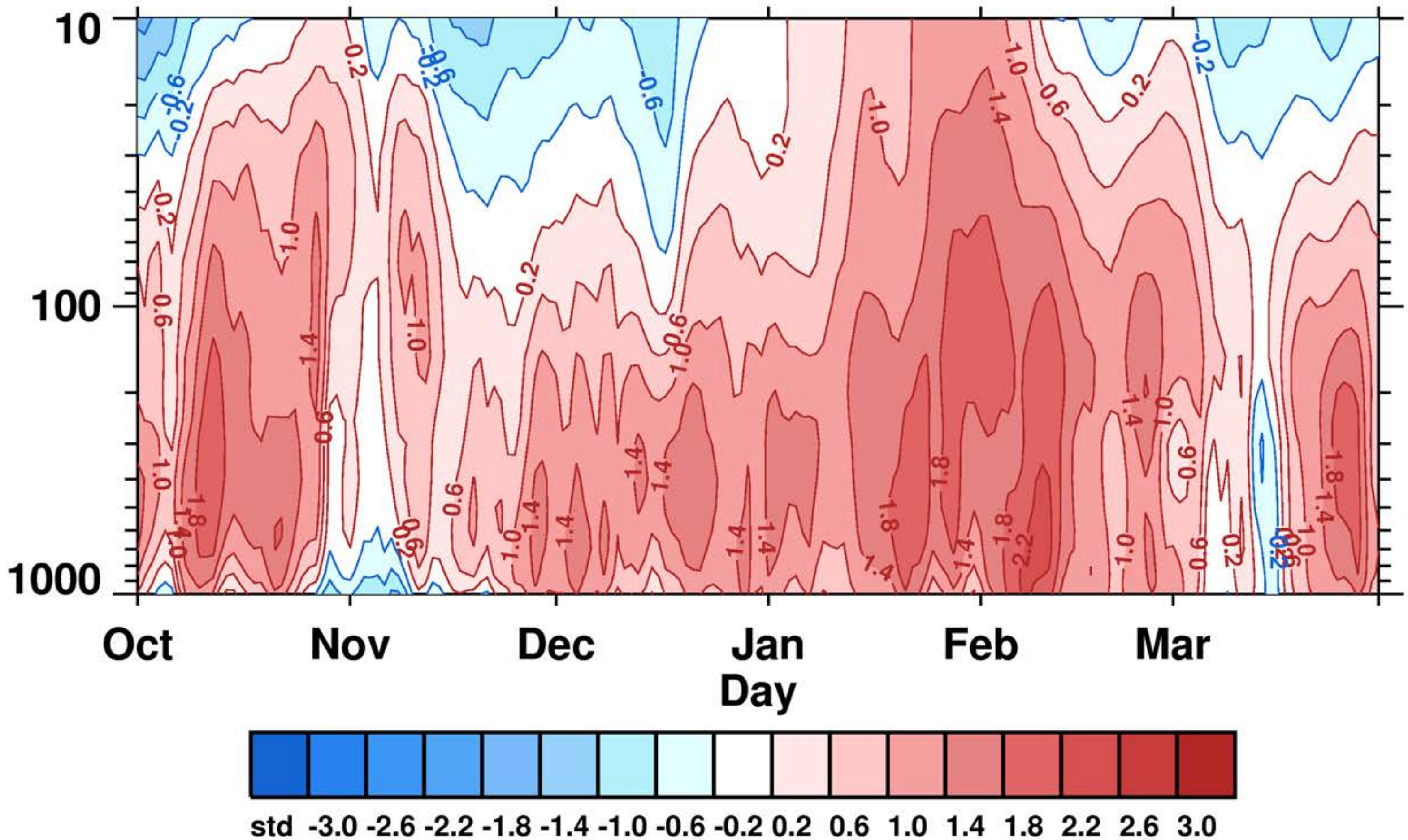
(a) Zonal wave-5 regime of the May 2015 streamfunction anomalies at 250 hPa overlaid with the climatological jet stream (hatched; $|V| > 25$ m/s); the yellow-red mark indicates the Texas floods. (b) Linear trend (slope) during the1981-2014 period of the wave-5 regime streamfunction (unit: 10^6 m^2 s^{-1}) with the 95% confidence interval shaded. Notice the phase coincidence between (a) and (b).

Trends in Extremes



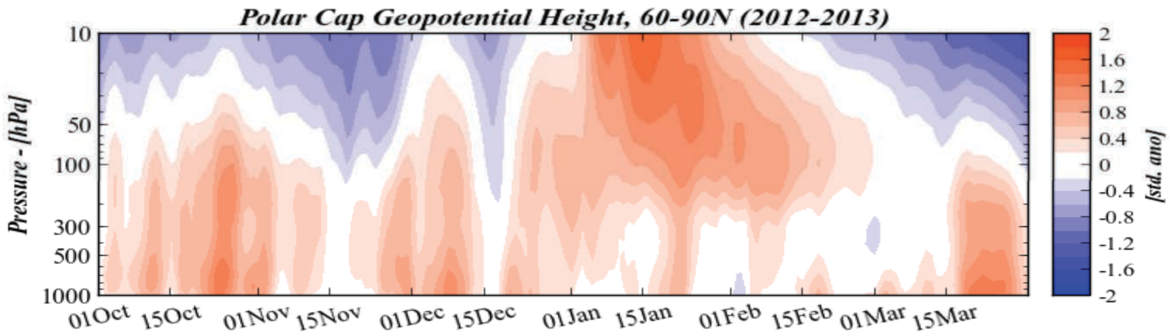
Source: MunichRe

Trend in Polar Cap Geopotential Height 1988/89-2013/14



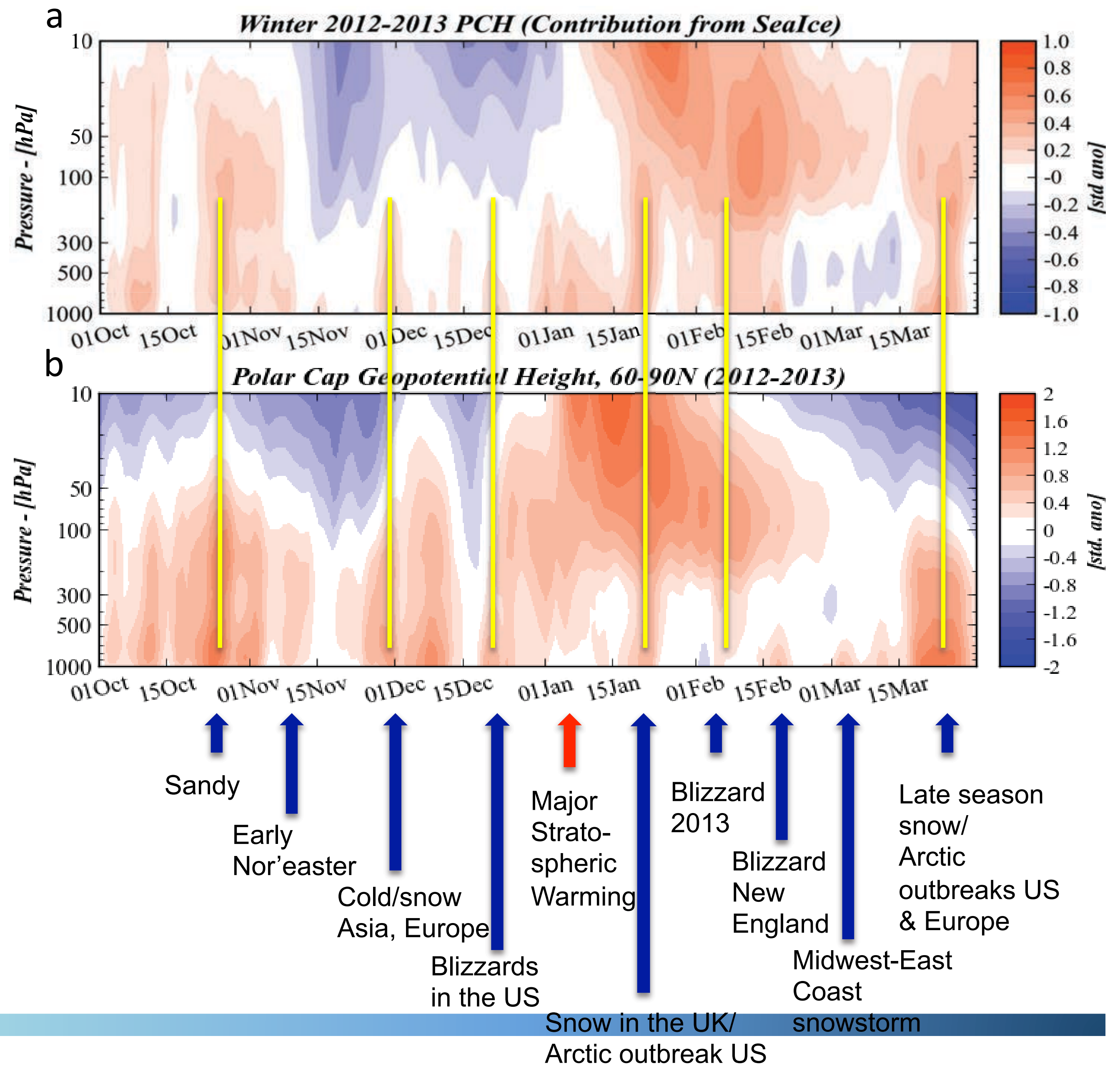
Increase in stratosphere-troposphere coupling mid-late winter that favors a warmer polar stratosphere and higher heights in the Arctic troposphere (negative AO/weak polar vortex).

PCH
Oct-Mar



Polar Cap Geopotential Height, 60-90N (2012-2013)
Pressure - [hPa]
10
50
100
300
500
1000
01Oct
15Oct
01Nov
15Nov
01Dec
15Dec
01Jan
15Jan
01Feb
15Feb
01Mar
15Mar
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
[std. ano]

PCH Oct-Mar



a
Winter 2012-2013 PCH (Contribution from SeaIce)
Pressure - [hPa]
10
50
100
300
500
1000
01Oct
15Oct
01Nov
15Nov
01Dec
15Dec
01Jan
15Jan
01Feb
15Feb
01Mar
15Mar
1.0
0.8
0.6
0.4
0.2
-0
-0.2
-0.4
-0.6
-0.8
-1.0
[std ano]
b
Polar Cap Geopotential Height, 60-90N (2012-2013)
Pressure - [hPa]
10
50
100
300
500
1000
01Oct
15Oct
01Nov
15Nov
01Dec
15Dec
01Jan
15Jan
01Feb
15Feb
01Mar
15Mar
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
-1.6
-2
[std. ano]
Sandy
Early Nor'easter
Cold/snow Asia, Europe
Blizzards in the US
Major Strato-spheric Warming
Snow in the UK/ Arctic outbreak US
Blizzard 2013
Blizzard New England
Midwest-East Coast snowstorm
Late season snow/ Arctic outbreaks US & Europe

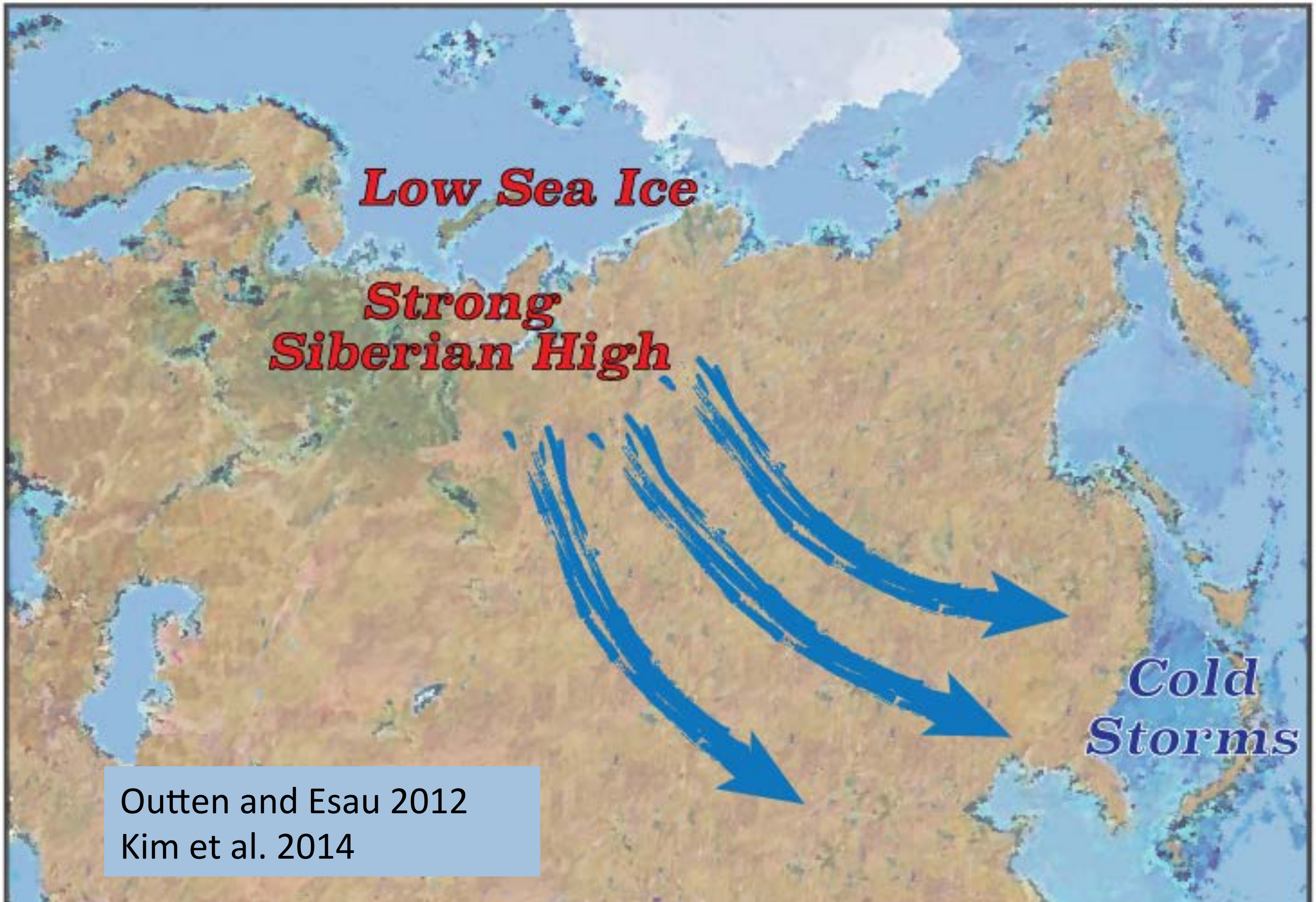
Extreme Weather

- 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.

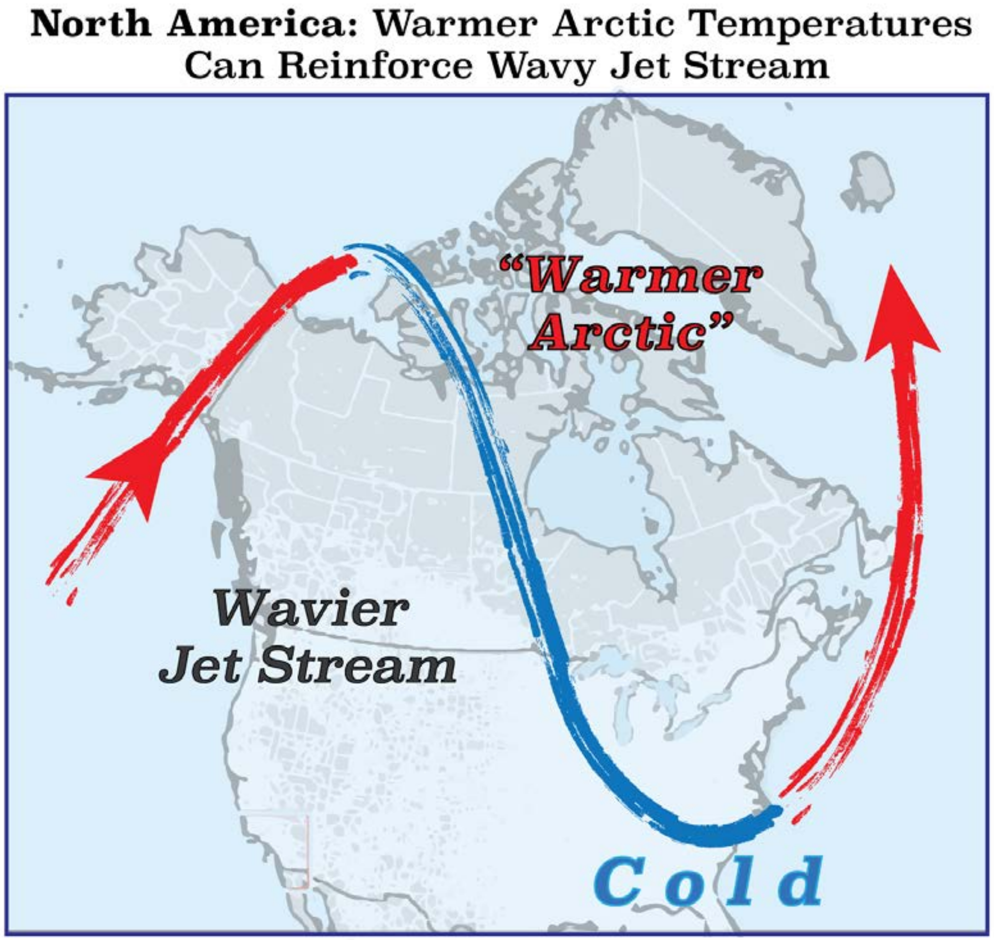
Theories linking AA to Mid-latitude Weather

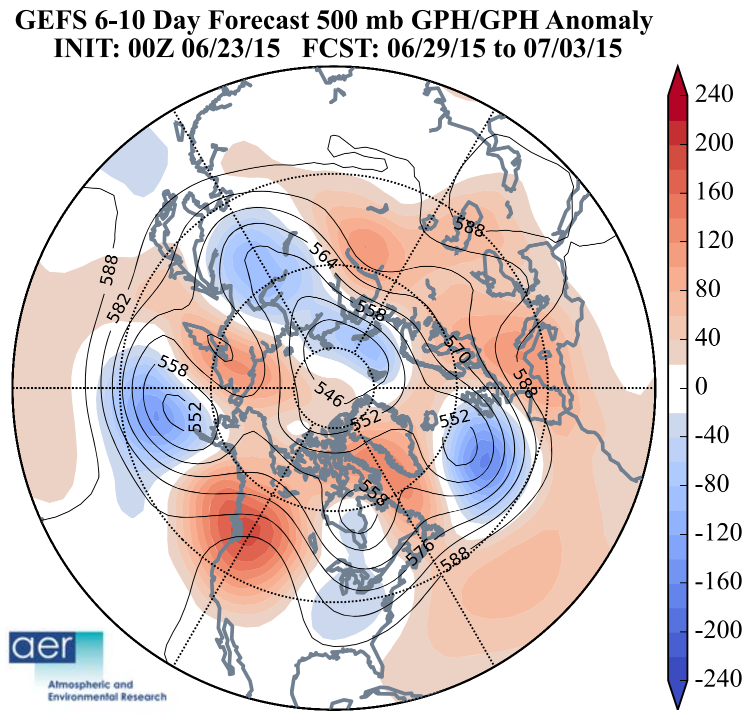
- Changes to latitudinal temperature gradient
- Changes to the Jet Stream/blocking/wave speed
- Changes to atmospheric waves:
  - Planetary waves (winter)
  - Synoptic scale waves (summer)
- Changes to troposphere-stratosphere coupling
- Support of these theories are conditional and challenged by imperfect observations and models

Asia: Arctic-Midlatitude Weather Linkages



James Overland



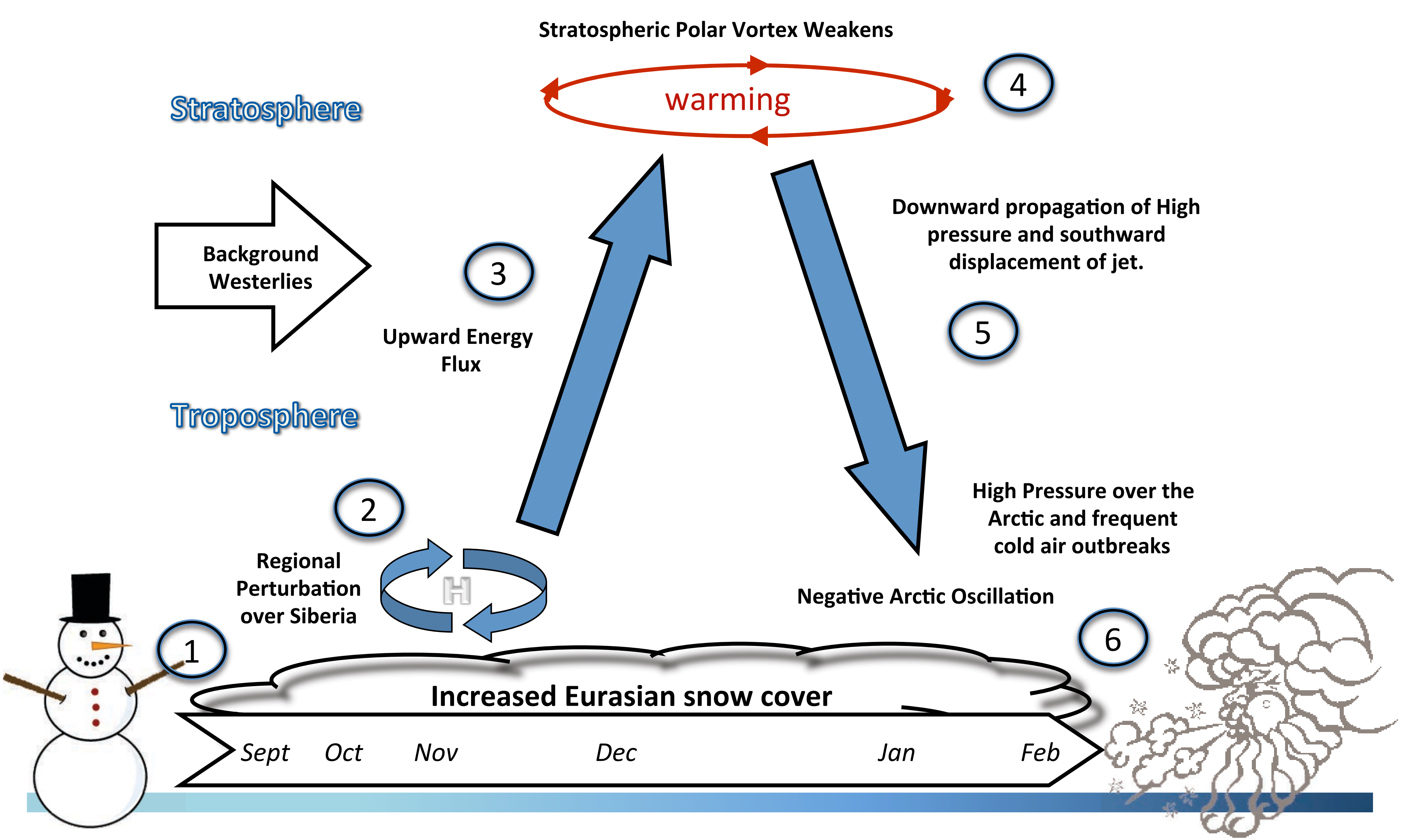


Francis and Vavrus 2015
Hartmann 2015

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

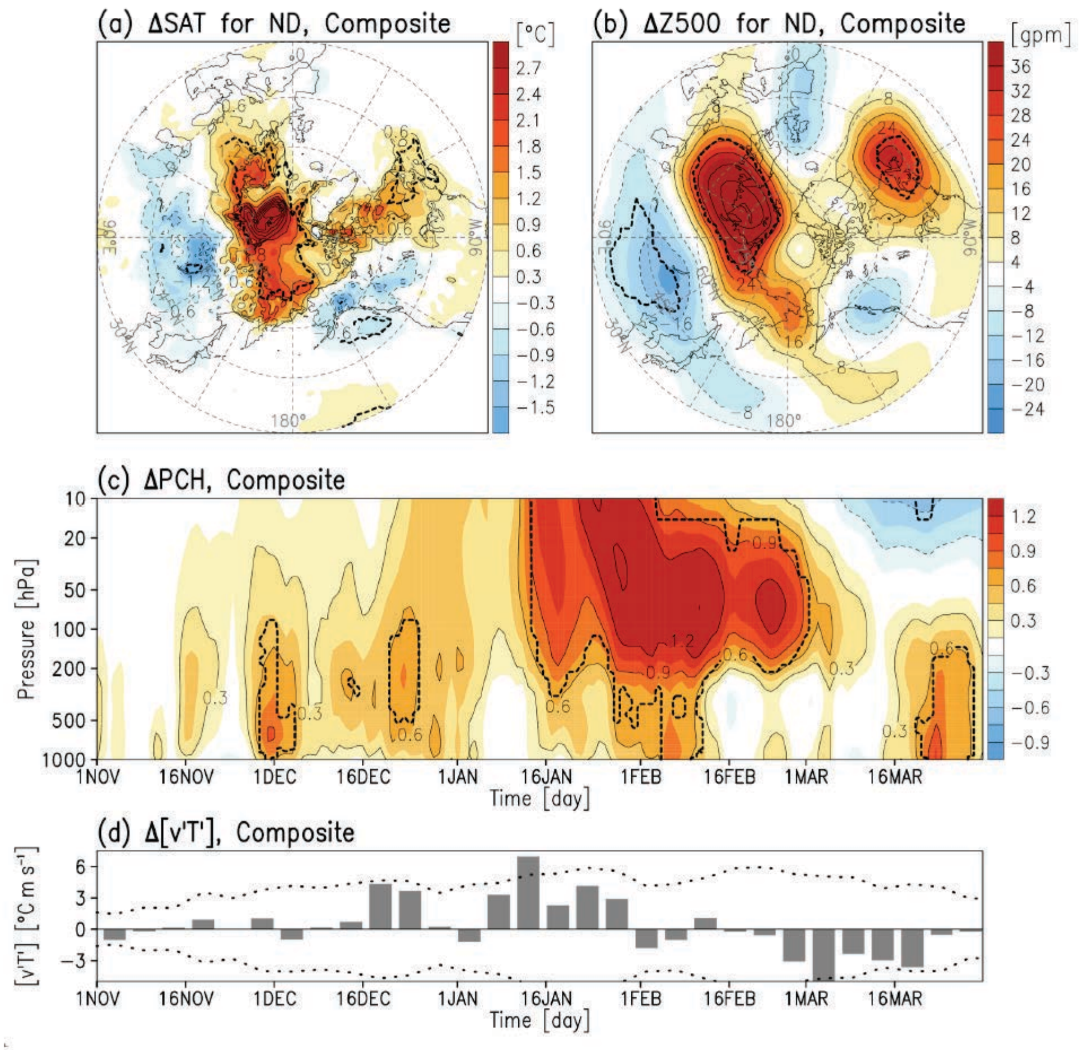
James Overland

High Snow Forced Cold Signal



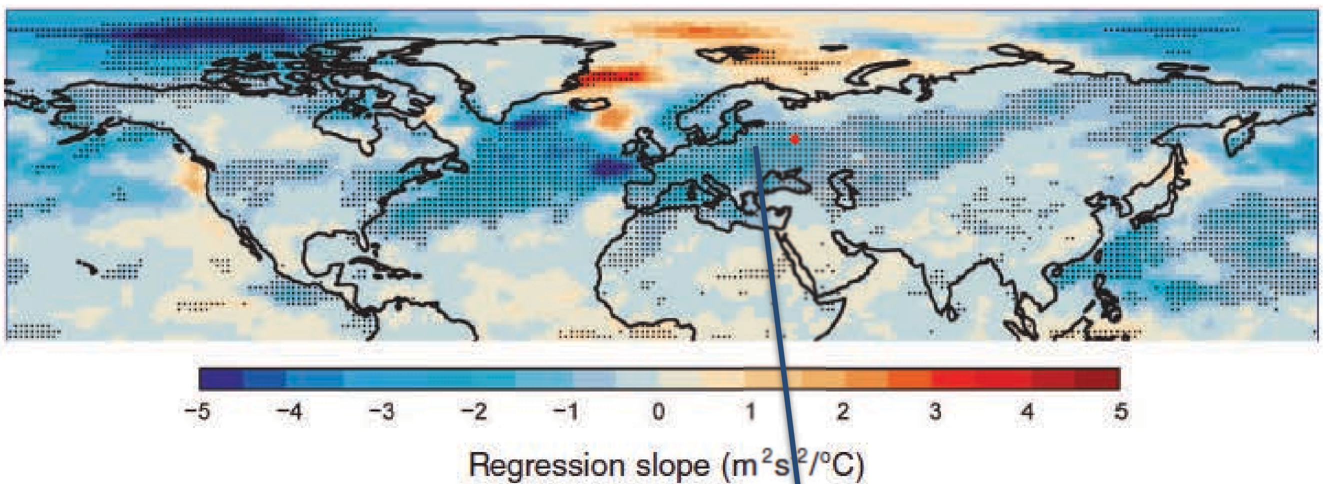
Cohen et al. 2007

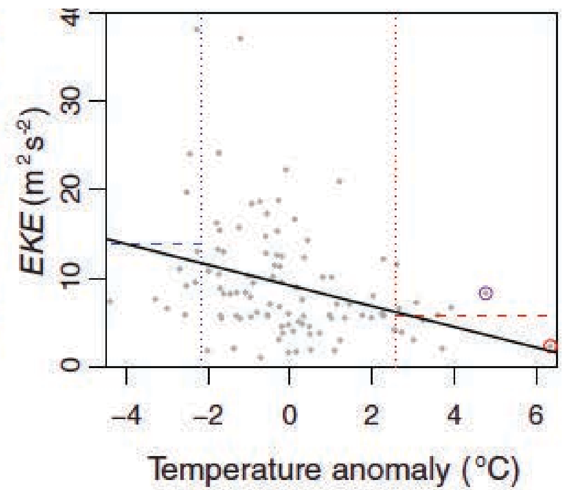
Low Sea Ice Forced Cold Signal



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

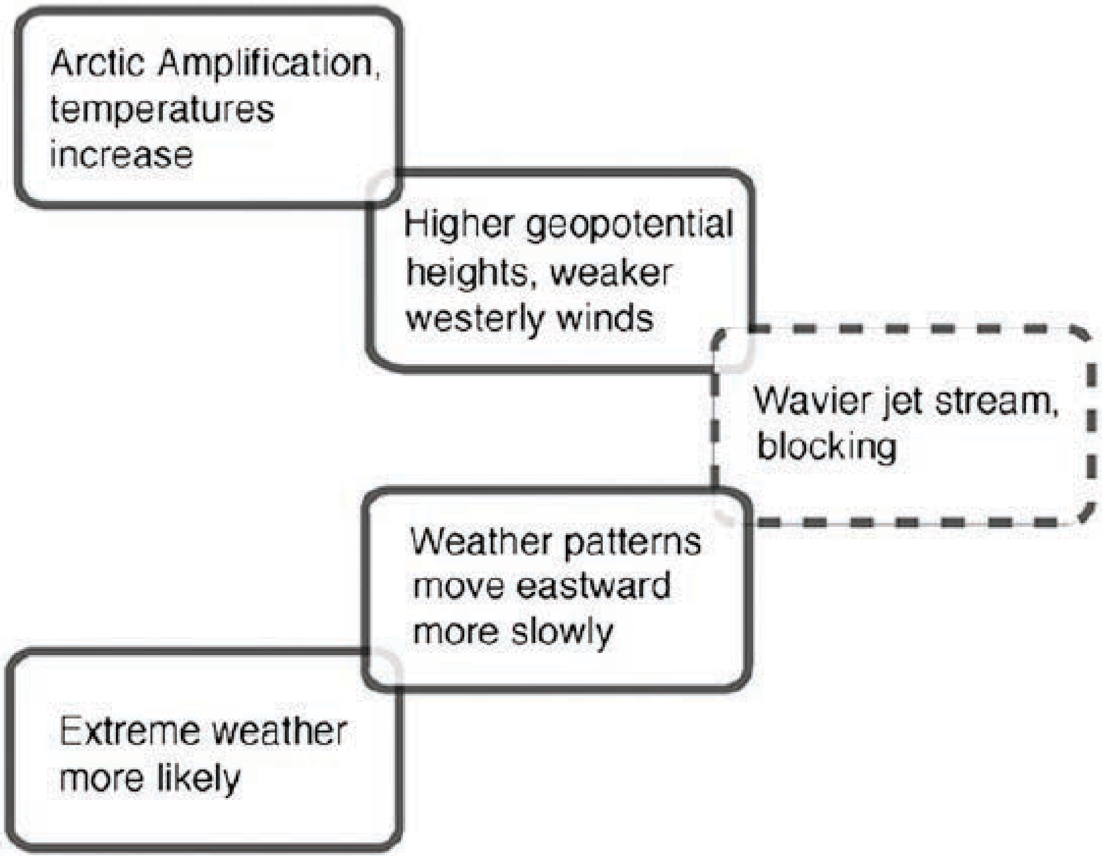


FIG. 2. Hypothesized steps linking Arctic amplification with extreme weather events in Northern Hemisphere midlatitudes.

Overland et al. 2015

Arctic Amplification - Jet Stream

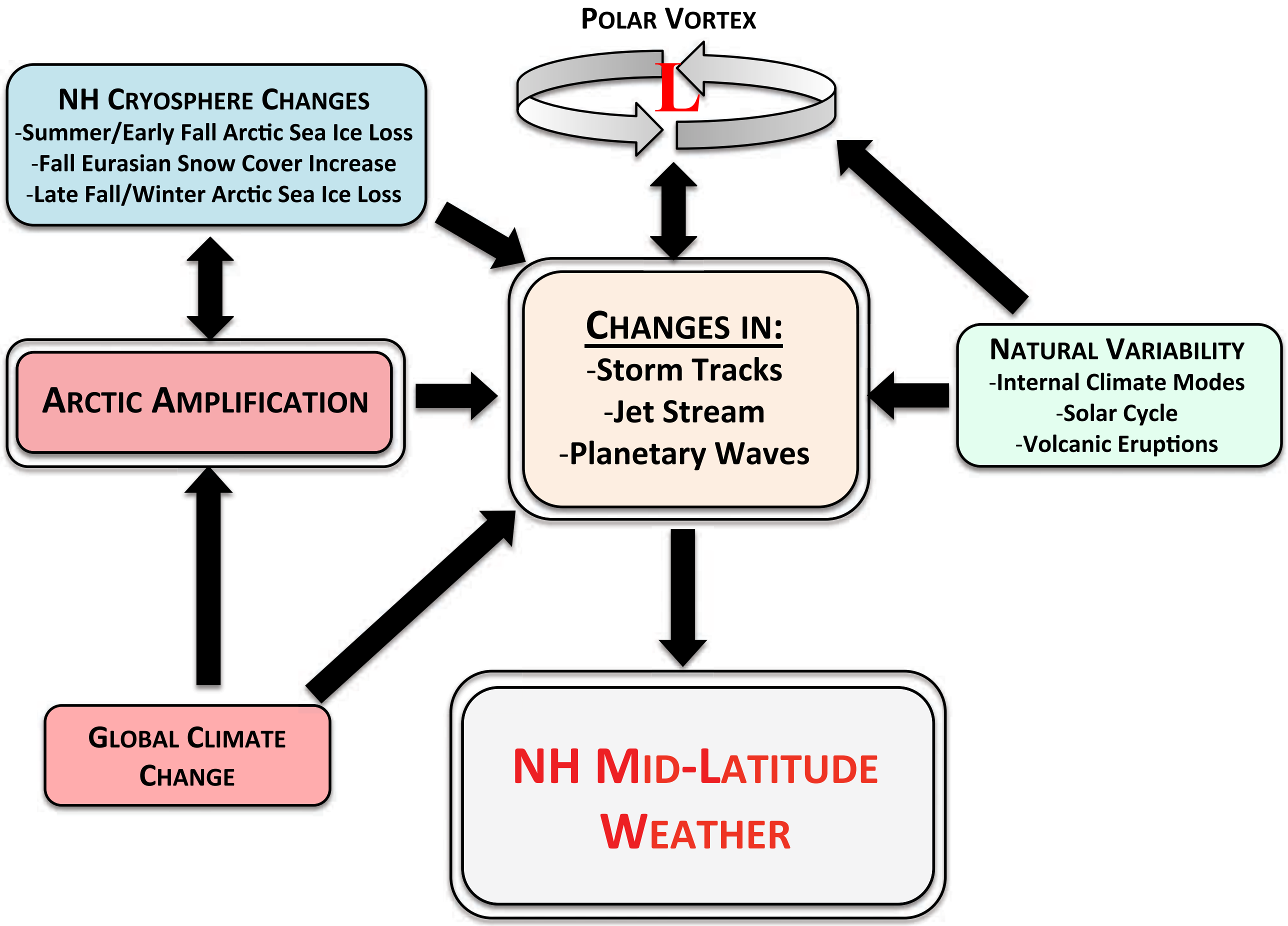
Figure 3:
Schematic of a typical jet stream trajectory (solid line) over North America and the expected elongation of ridge peaks northward (dashed line) in response to Arctic Amplification.

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 my be more societal based than metric based.

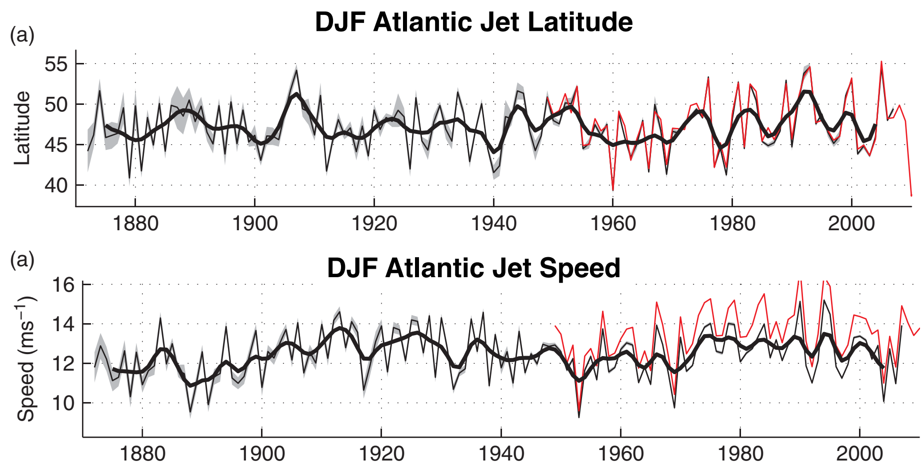
Mid-latitude Weather is Complicated



Cohen et al. 2014

Natural Variability in the Mid-latitudes

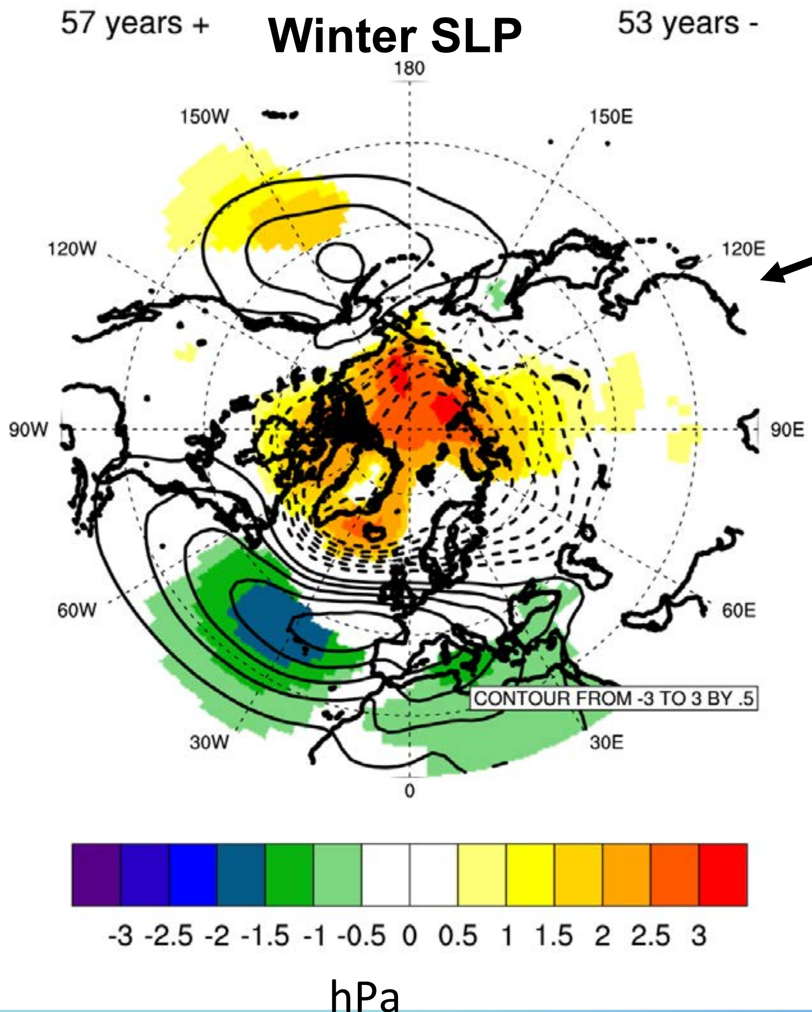
Internal atmospheric variability is large

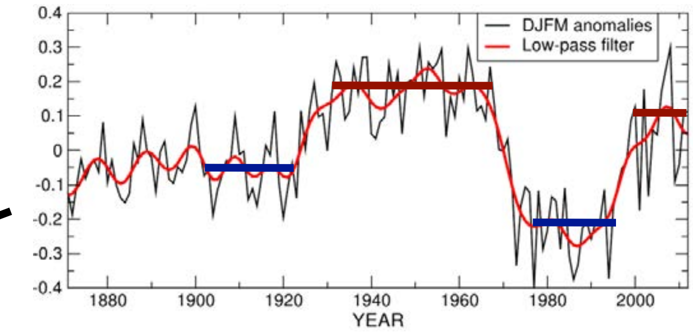


20th Century Reanalysis jet latitude and speed
red line denote NCEP-NCAR Reanalysis
Woollings et al. (2014; QJRMS)

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

Inverse AMV/NAO relationship in the 20CR reanalysis over 1901-2010

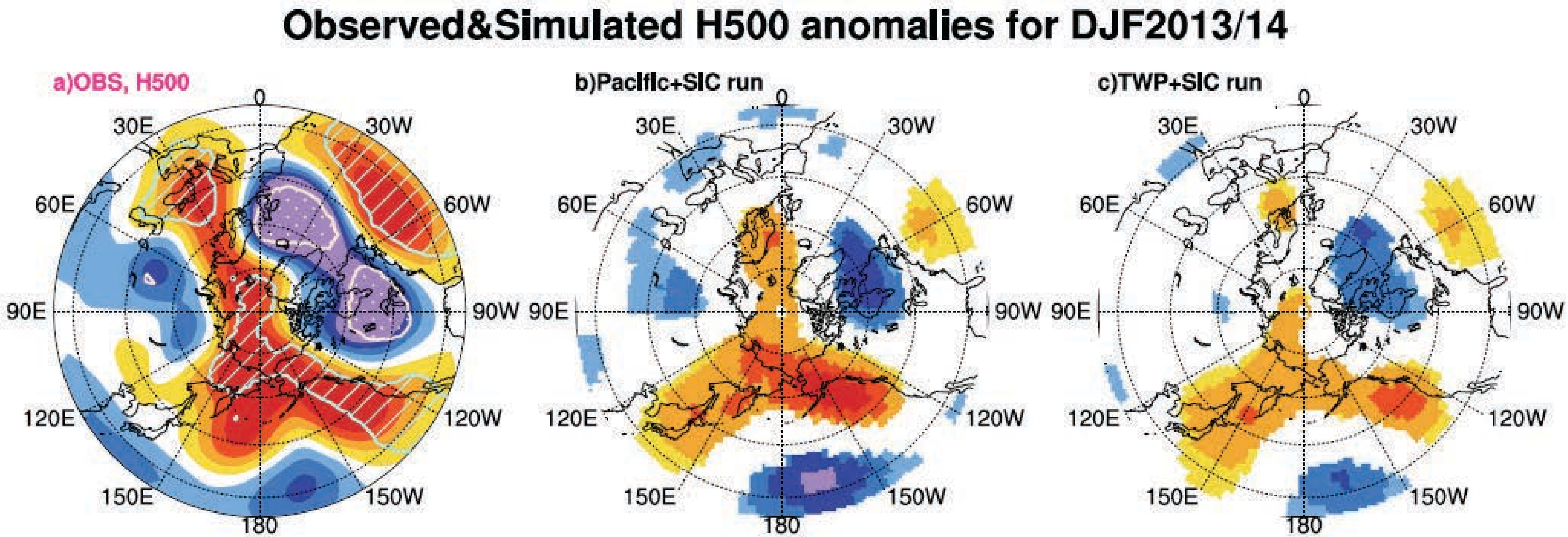




Composite of DJFM SLP based on AMV polarity over 1901-2010 (shading, anomalies significant at the 95% confidence level). Contours represent the NAM mode in surface. Adapted from Peings and Magnusdottir (2014).

Yannick Peings

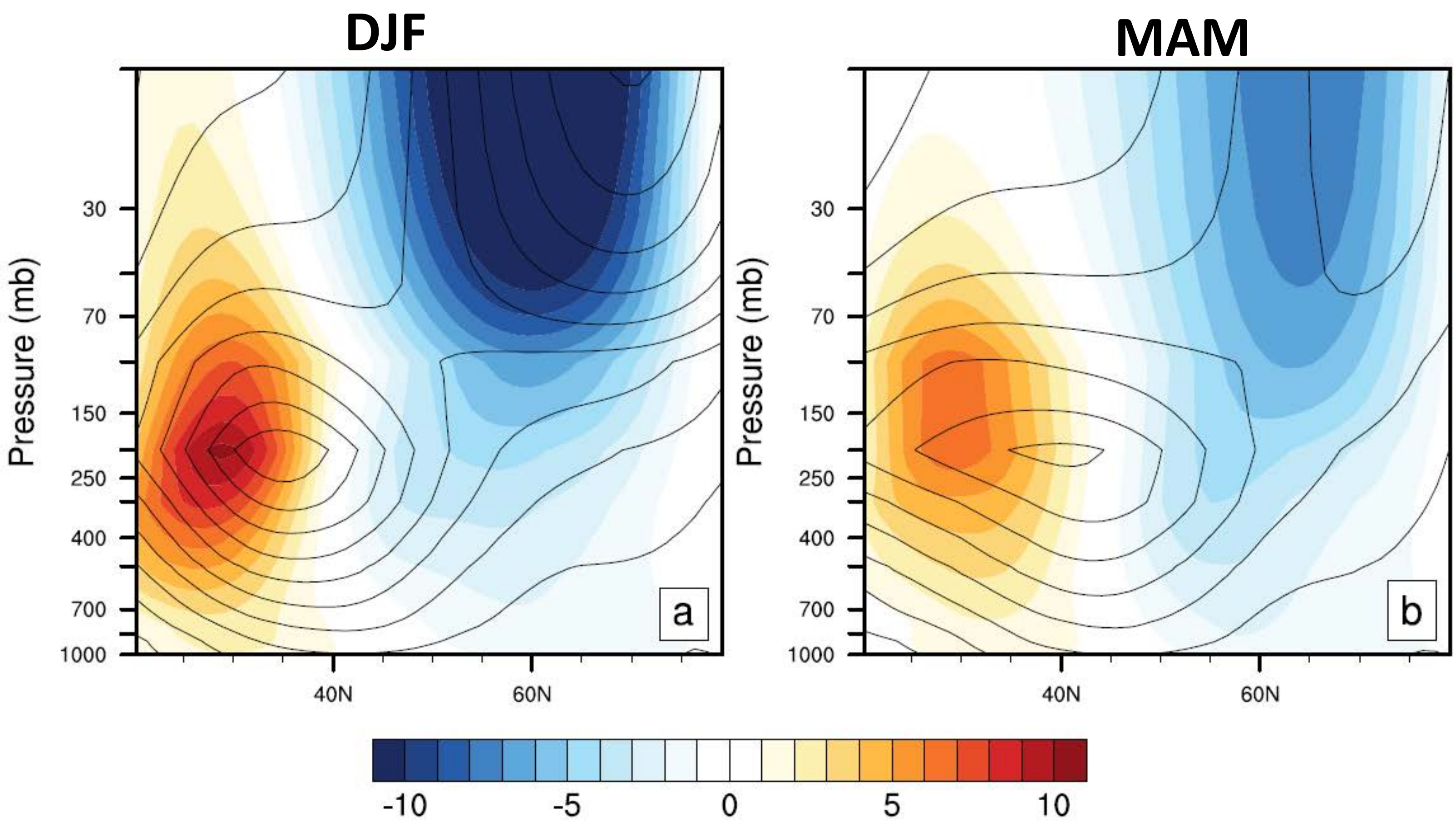
Tropical Forcing



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.

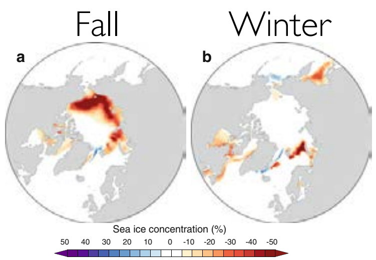
Large natural variability in the system makes detecting a signal difficult.

There are many forcings of the system making attribution to just one forcing a challenge.

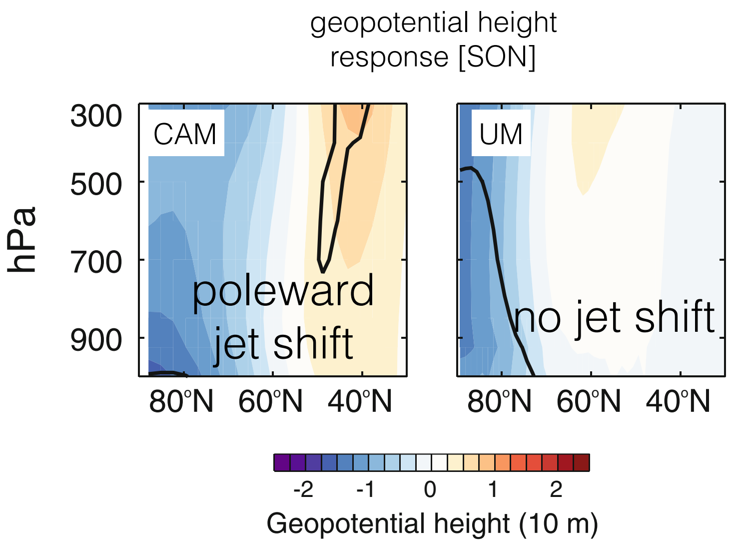
Observational network in the Arctic is sparse.

Same sea ice forcing – different model response

Internal atmospheric variability is large



perturbed sea ice minus control (similar to 2009-1979)



- 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)

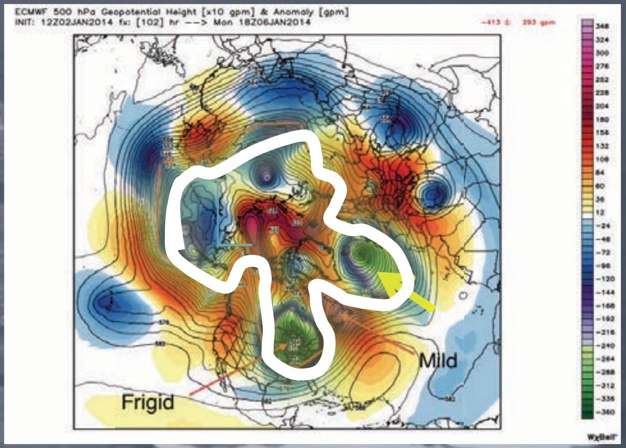
Working Group Members

Scientist	Affiliation	Expertise
Elizabeth Barnes (ECS)	Colorado State University	Atmospheric dynamics - B
Uma Bhatt (SEARCH)	University of Alaska	Arctic climate - O
Dim Coumou	PIK	Climate impacts/extremes - O
Clara Deser	NCAR	Climate modeling - M
Steven Feldstein	Penn State University	Large Scale dynamics - B
Jennifer Francis (SEARCH)	Rutgers University	Arctic climate - O
Dorothy Hall	NASA/GSFC	Cryosphere/Climate - O
Arun Kumar	NOAA CPC	Climate prediction - M
Ron Kwok	NASA/JPL	Remote sensing/Arctic climate - O
Gudrun Magnusdottir	University of California	Atmospheric dynamics -M
Wieslaw Maslowski	Naval Postgraduate School	Arctic Oceanography - M
James Overland	NOAA/PMEL	Arctic - O
Yannick Peings (ECS)	University of California	Atmospheric dynamics -M
Emily Riddle (ECS)	University of Massachusetts	Climate variability - M
Ignatius Rigor	University of Washington/APL	Coordinator IAPB program - O
James Screen IM	University of Exeter	Climate variability and change - B
Julienne Stroeve	NSIDC	Sea ice -O
Stephen Vavrus (SEARCH)	University of Wisconsin	Arctic climate - M
Timo Vihma IM	Finnish Meteorological Inst.	Arctic boundary dynamics - O
Simon Wang	Utah State University	Atmospheric Dynamics - M

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

Wavy Jet Stream



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

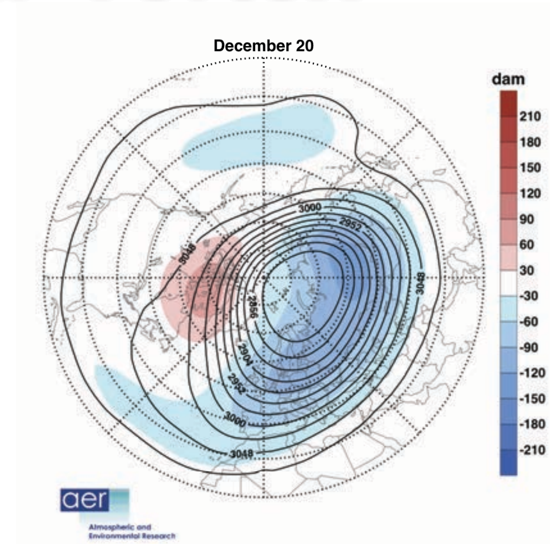
Contributions from WG Efforts

- 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).

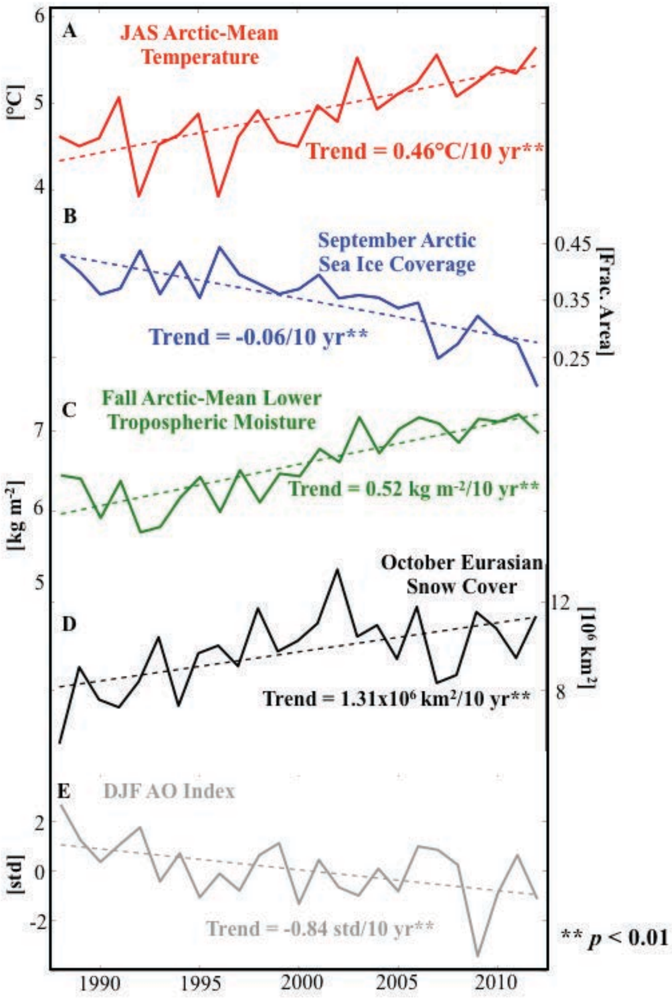
✓Warming Arctic

✓Less sea ice

✓More atmospheric moisture

✓Increasing snow cover

✓Decreasing Arctic Oscillation trend/weakening of the polar vortex

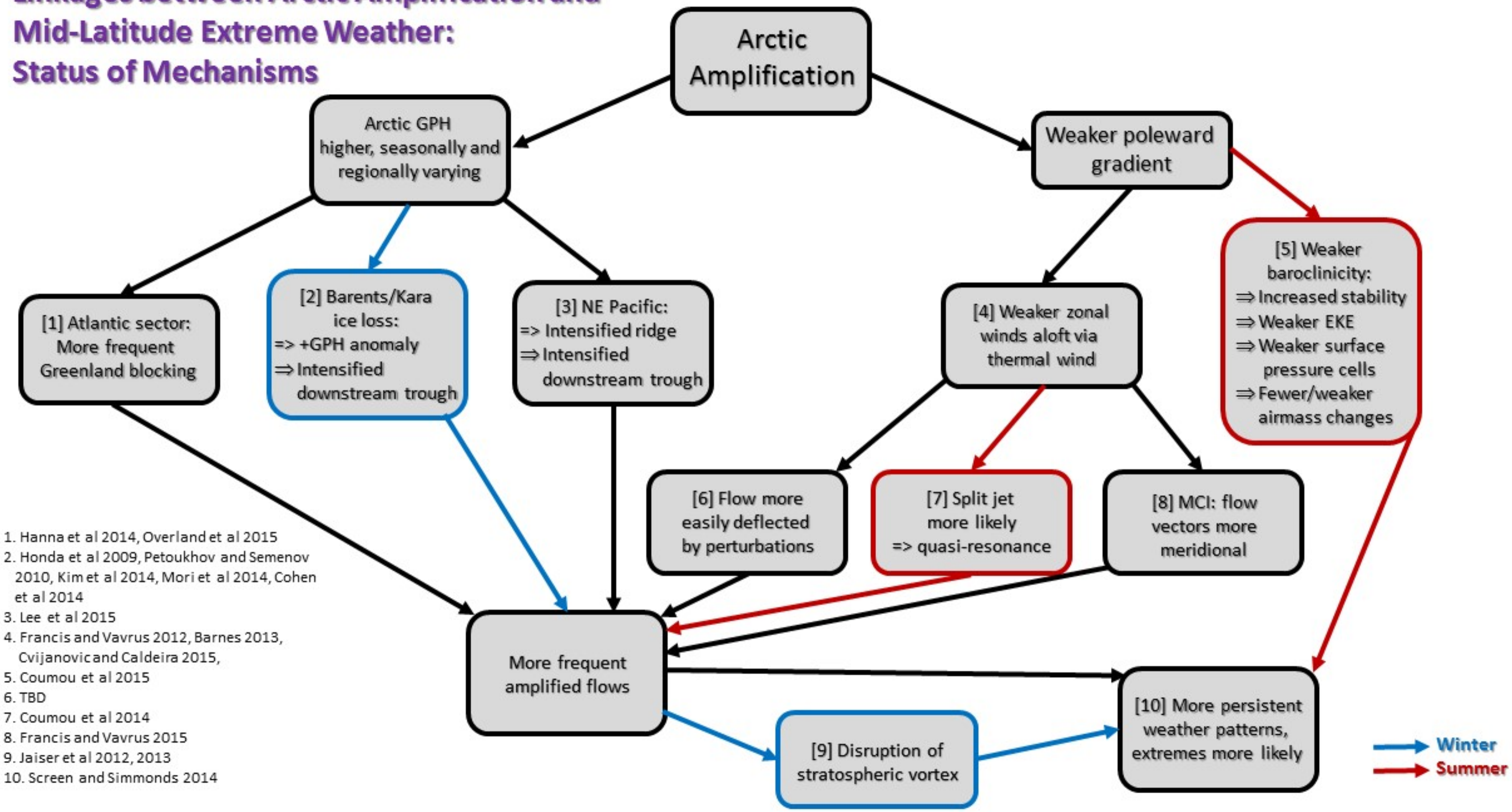


Cohen et al. 2012b

Arctic Amplification – Mid-latitude Weather

J. Francis, 6 May 2015

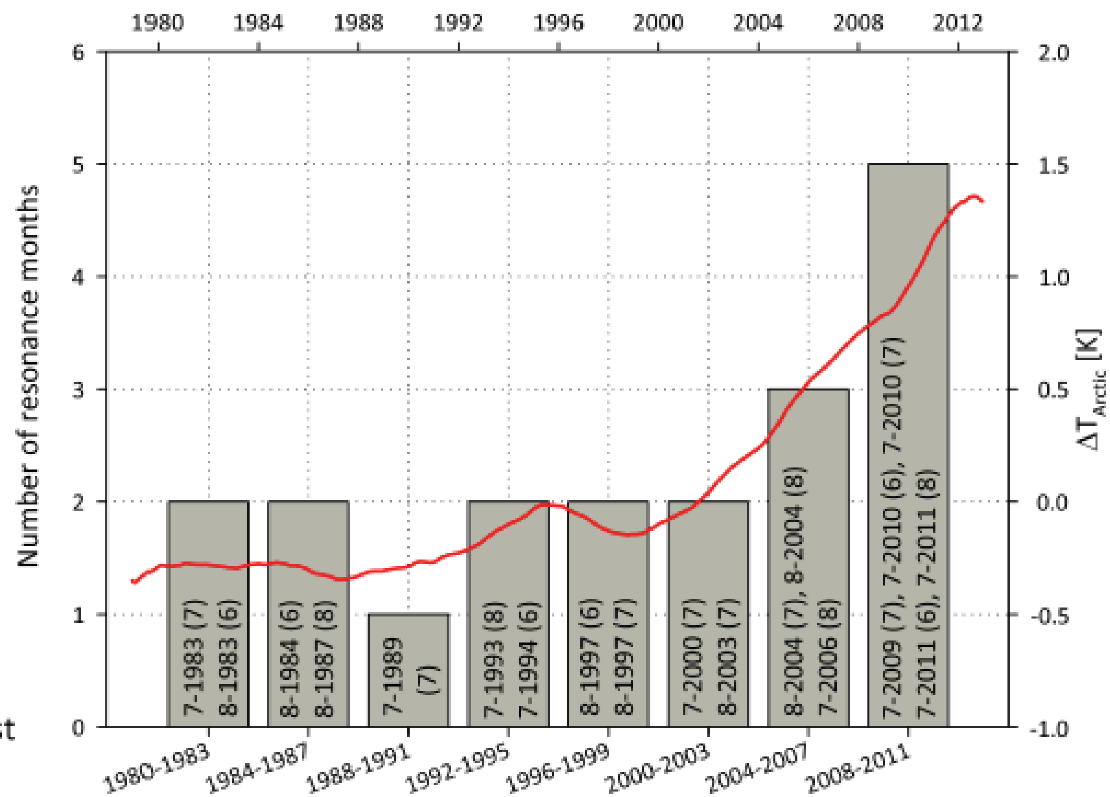
Linkages between Arctic Amplification and Mid-Latitude Extreme Weather: Status of Mechanisms



1. Hanna et al 2014, Overland et al 2015
2. Honda et al 2009, Petoukhov and Semenov 2010, Kim et al 2014, Mori et al 2014, Cohen et al 2014
3. Lee et al 2015
4. Francis and Vavrus 2012, Barnes 2013, Cvijanovic and Caldeira 2015,
5. Coumou et al 2015
6. TBD
7. Coumou et al 2014
8. Francis and Vavrus 2015
9. Jaiser et al 2012, 2013
10. Screen and Simmonds 2014

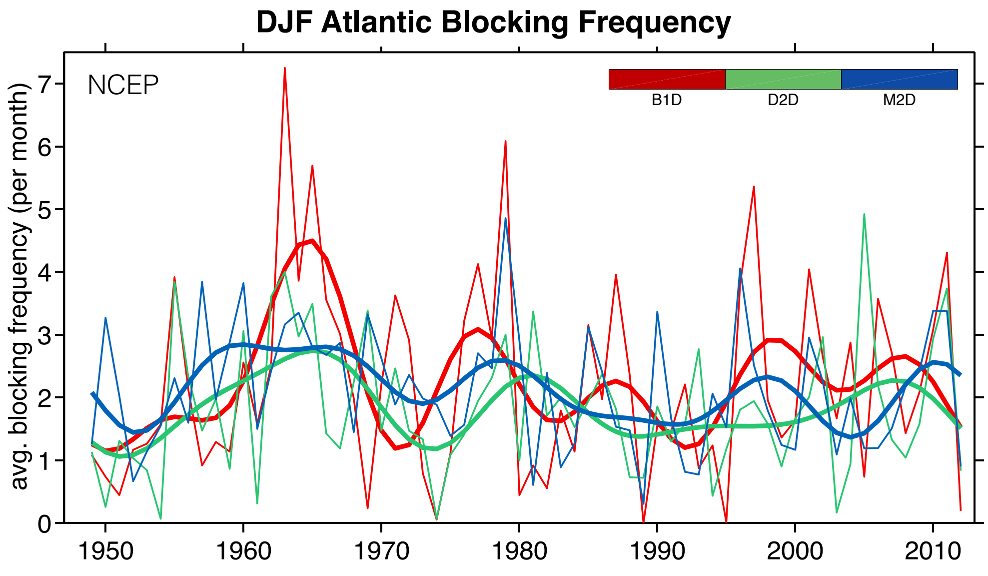
Slower moving more persistent waves has resulted in greater frequency of heat waves in the era of Arctic Amplification (2000 to present)

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



Coumou et al. 2015

Internal atmospheric variability is large

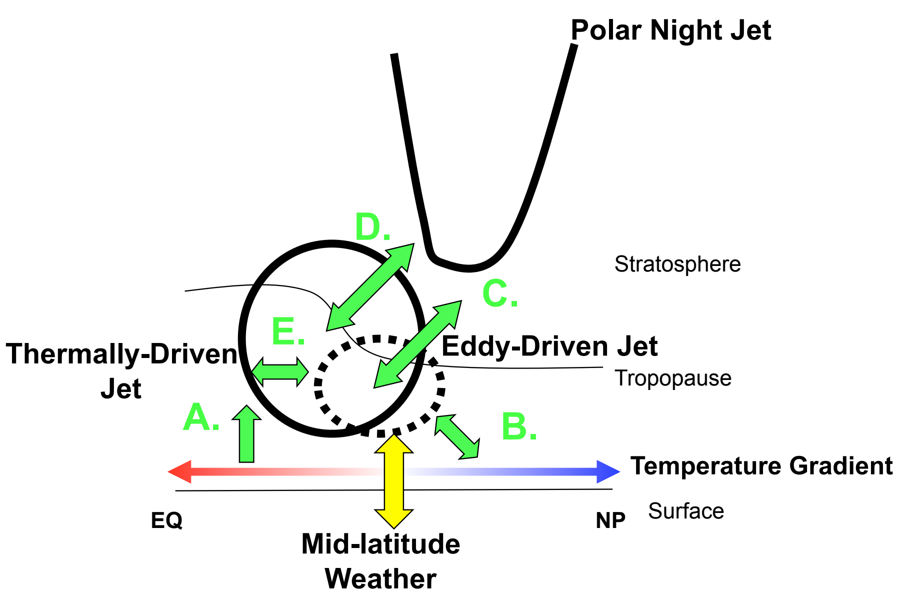


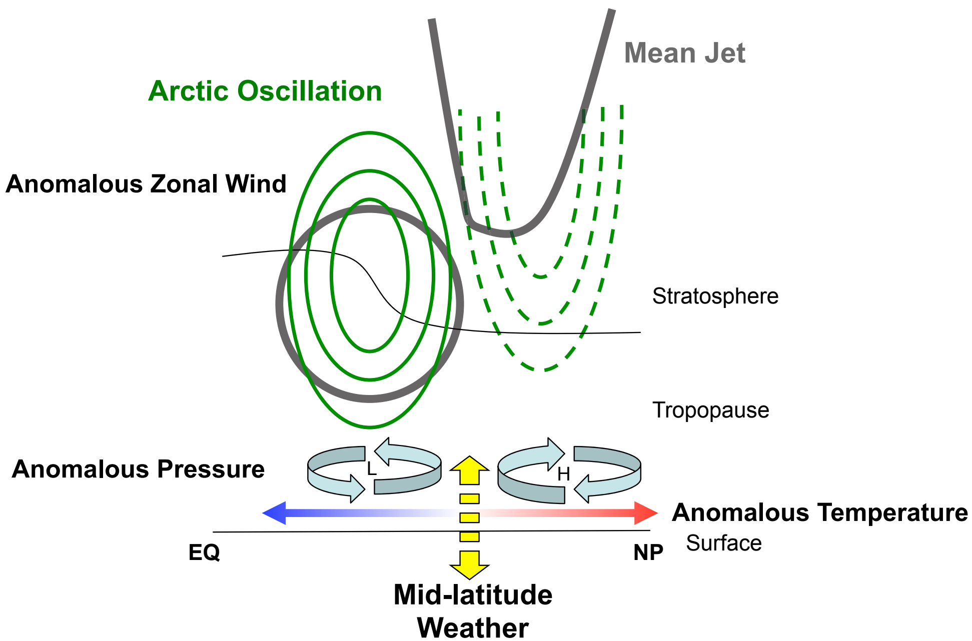
- 3 blocking identification methods
- 4 seasons
- 4 reanalyses
- 3 different time periods

- 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

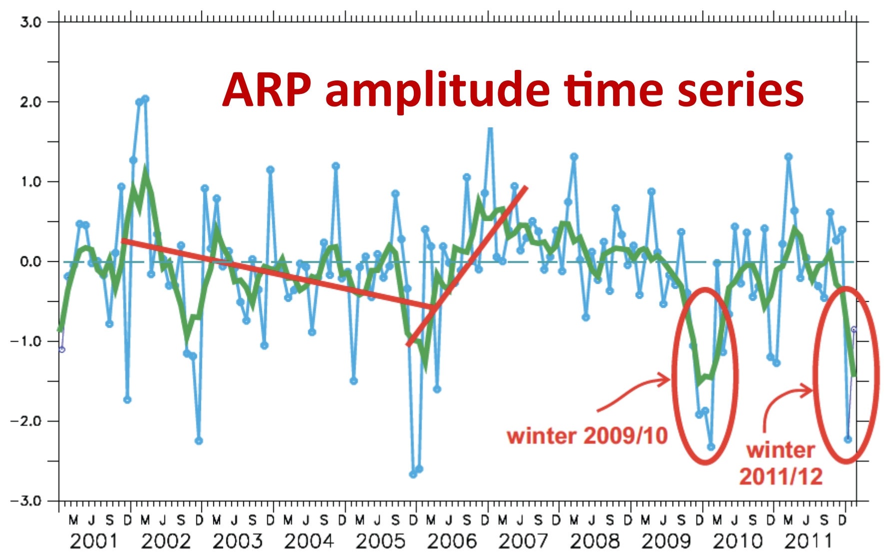
Recent Trends in NH Circulation Resemble AO Variability

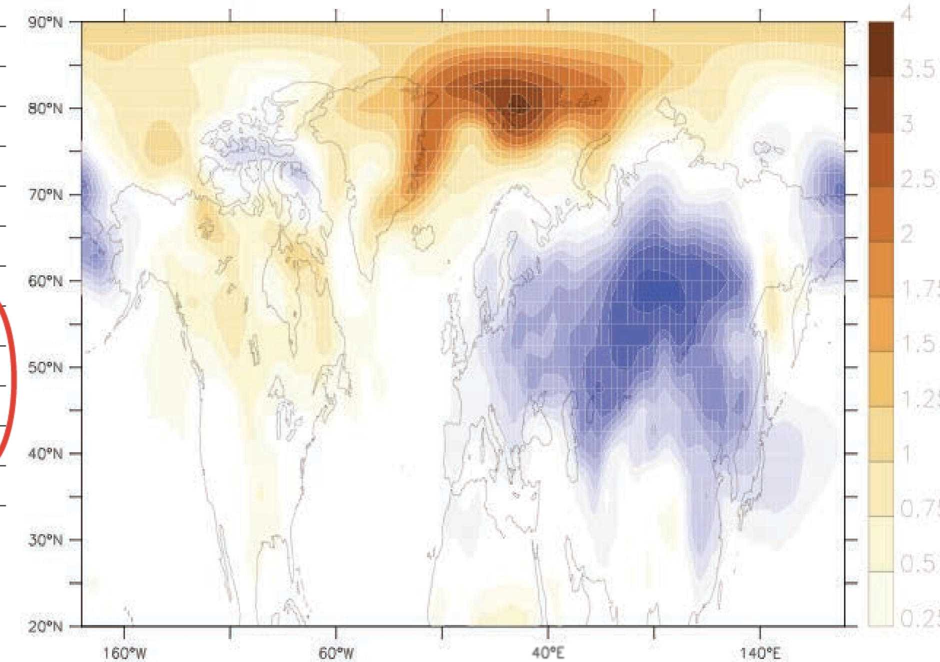




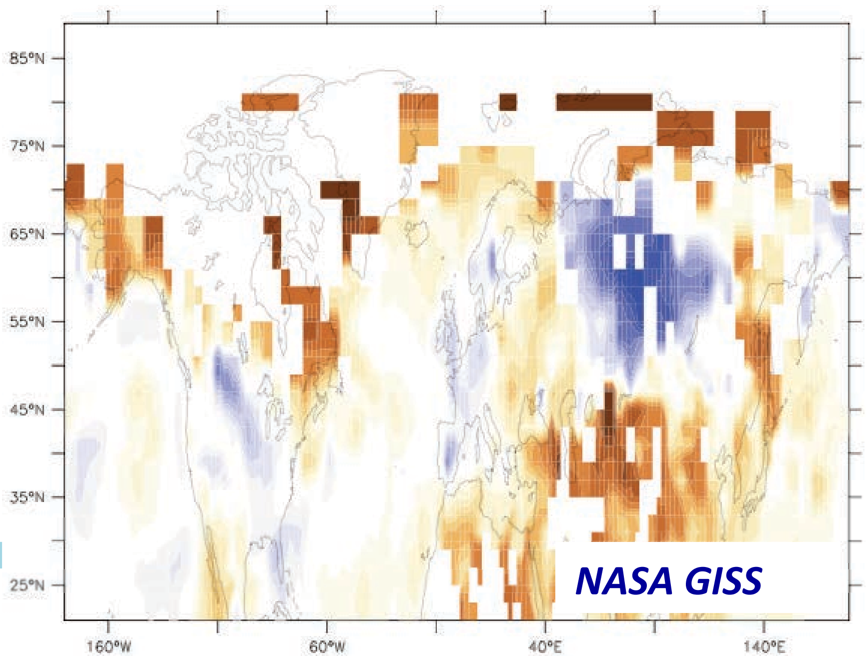
Cohen et al. 2014

- **ARP drives warmer Arctic but cold Eurasian midlatitude, and extreme cold winter occurred when ARP went extremely negative phase.**





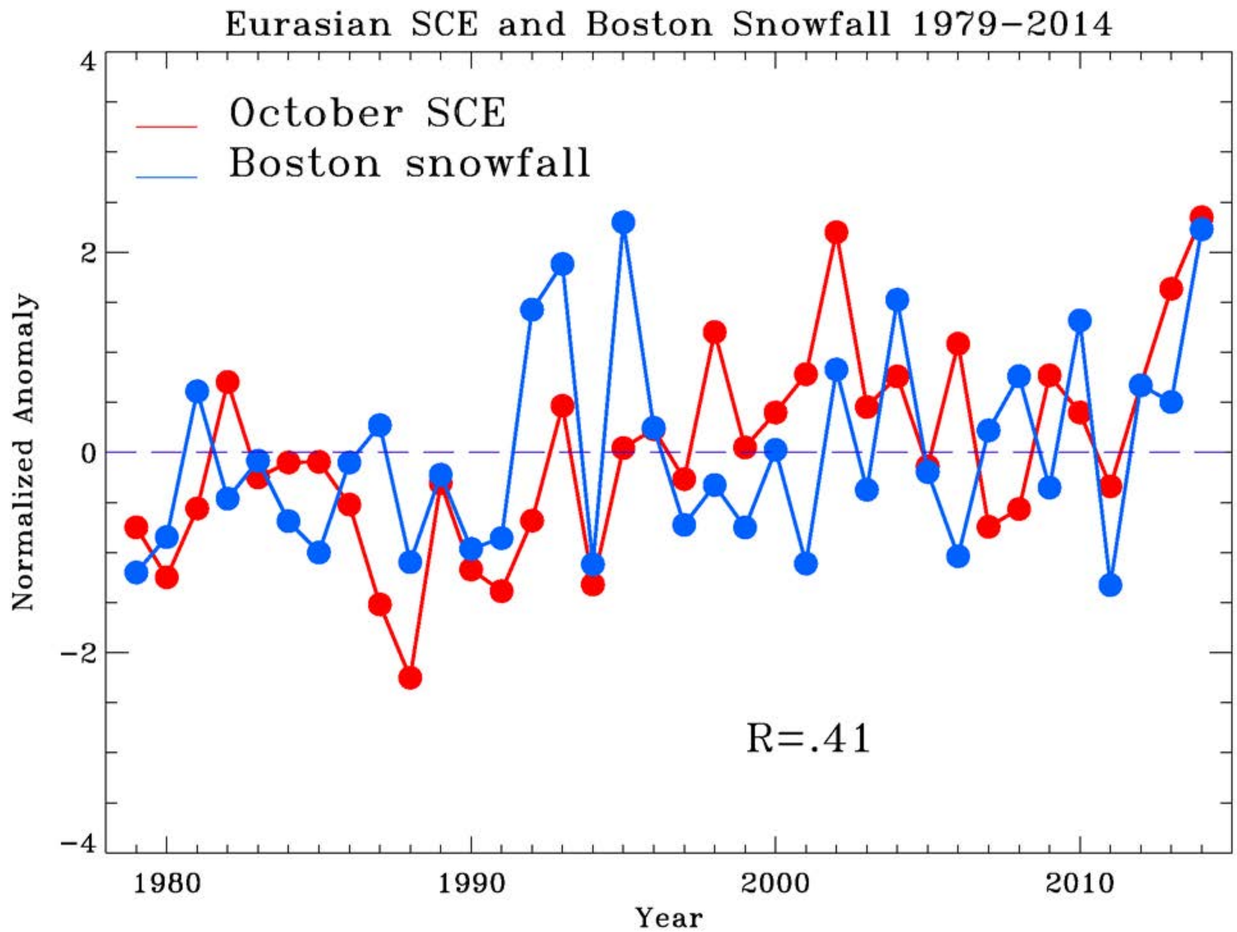
ARP driven surface air temperature Anomalies



Surface air temperature anomalies Dec 2009 – Feb 2010

Zhang et al., 2010

Boston Annual Snow Fall



October 2014 Eurasian snow cover is highest since 1979 and so is Boston snowfall for winter 2014/15.