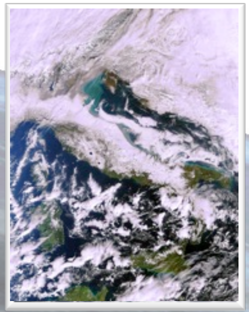
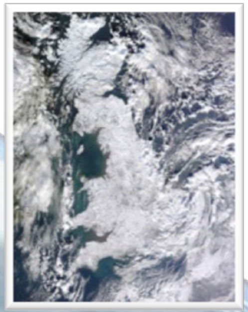
Arctic mid-latitude linkages and reasons for skepticism, previous workshops, questions, workshop outcomes

J. Cohen, X. Zhang, J. Francis, T. Jung, R. Kwok and J. Overland

February 1, 2017





Topics

Provide motivation for why we are all here

- Arctic amplification (AA)
- Extreme weather
- Overview of theories on AA-midlatitude weather
- Challenges – theories, observations and models
- Natural variability
- Goals/review paper
- Summary

WARM ARCTIC/COLD CONTINENTS IN THE HEADLINES

Italy weather: Heavy snow grips earthquake region

The Arctic is showing stunning winter warmth, and these scientists think they know why

Meet the 'Warm Arctic, Cold Continents' hypothesis.

Biting cold below minus 60C brings out the best in Siberian face fashion

Freakishly warm weather hits North Pole days before Christmas

Capital Weather Gang

While the North Pole warms beyond the melting point, it's freakishly cold in Siberia

Stockholm had its snowiest November day in 111 years

Record snow and rain stretches across parched U.S. west

Tokyo sees first November snow in 54 years

Freak weather leaves Sahara Desert covered in one metre of snow

Dozens killed by Europe's coldest weather in years

Siberian cold front sweeps across Europe, bringing record low temperatures

Snow is on the ground in 49 of 50 states

UK snow: Severe weather sweeps across country

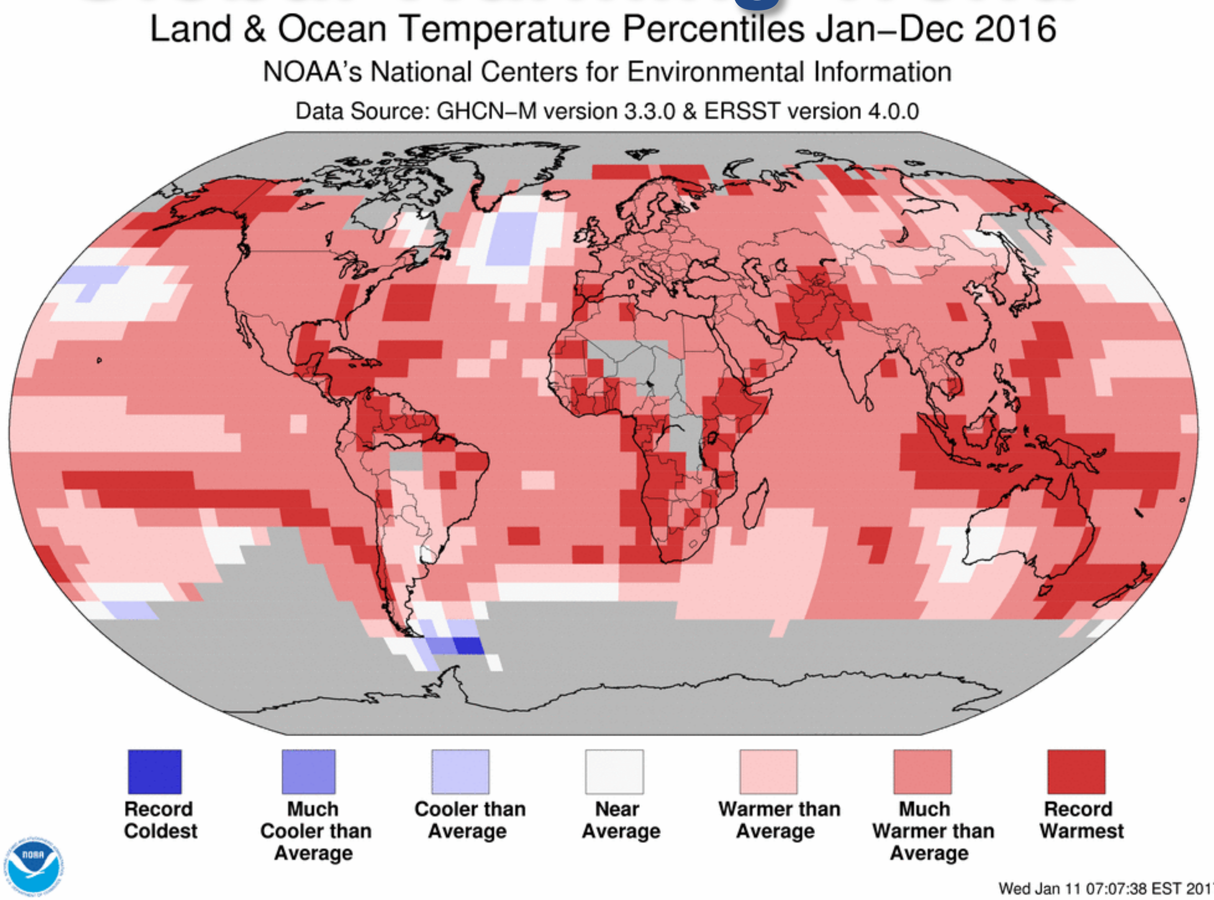
Bitter Cold Arctic Air Sets Dozens of Record Lows in the Midwest and Plains

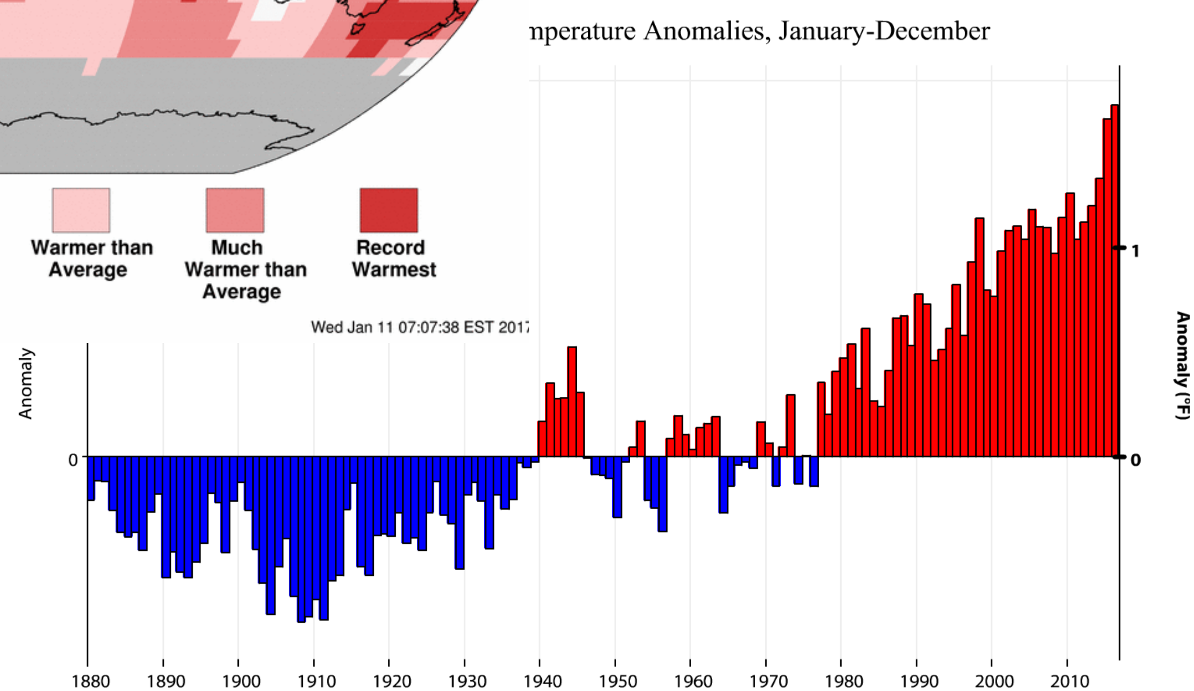
Death toll rises to six in unrelenting ice storms

U.S. preps for 'dangerously' cold temperatures

Snow falls in parts of Spain for the first time in over a century

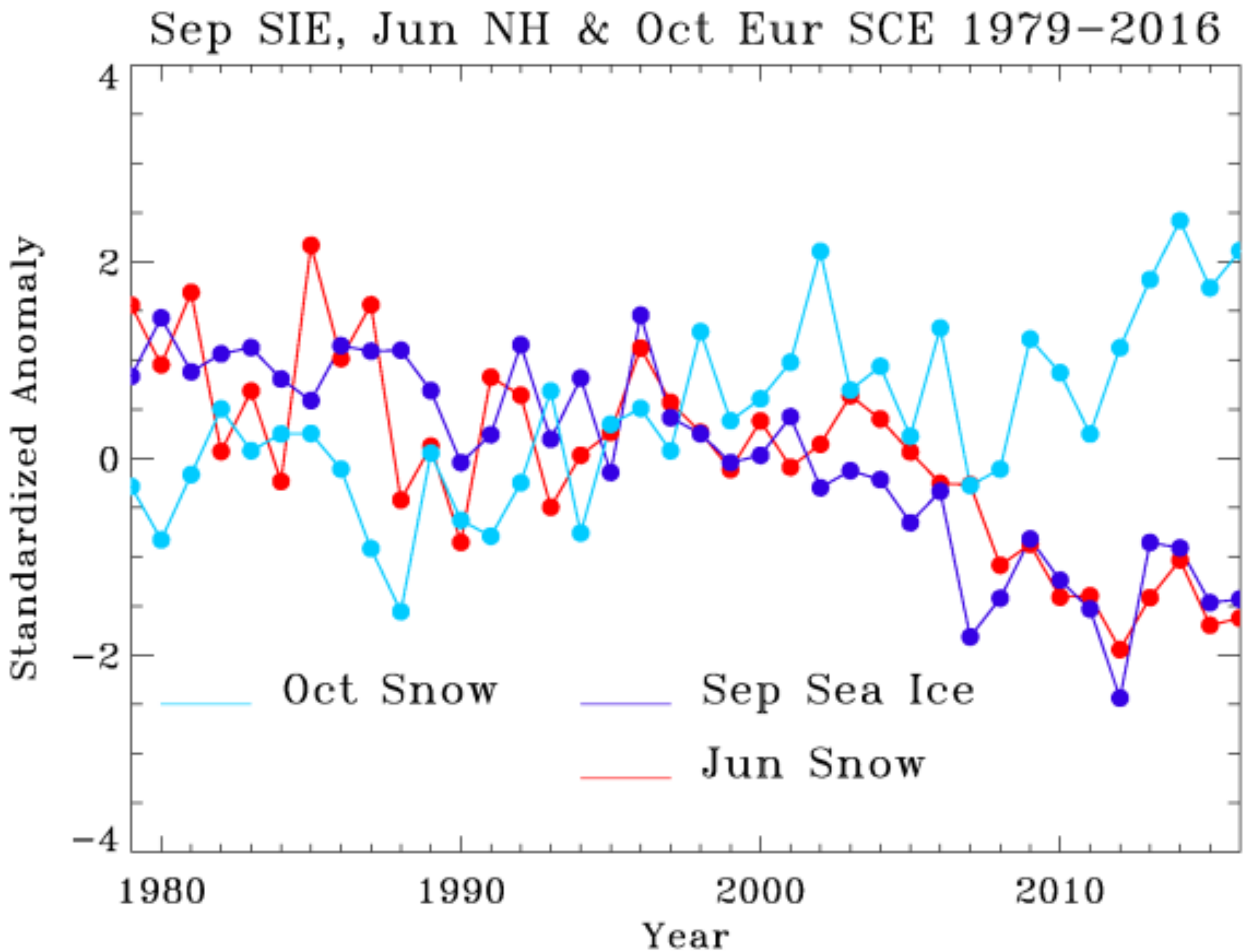
Global Warming Trend



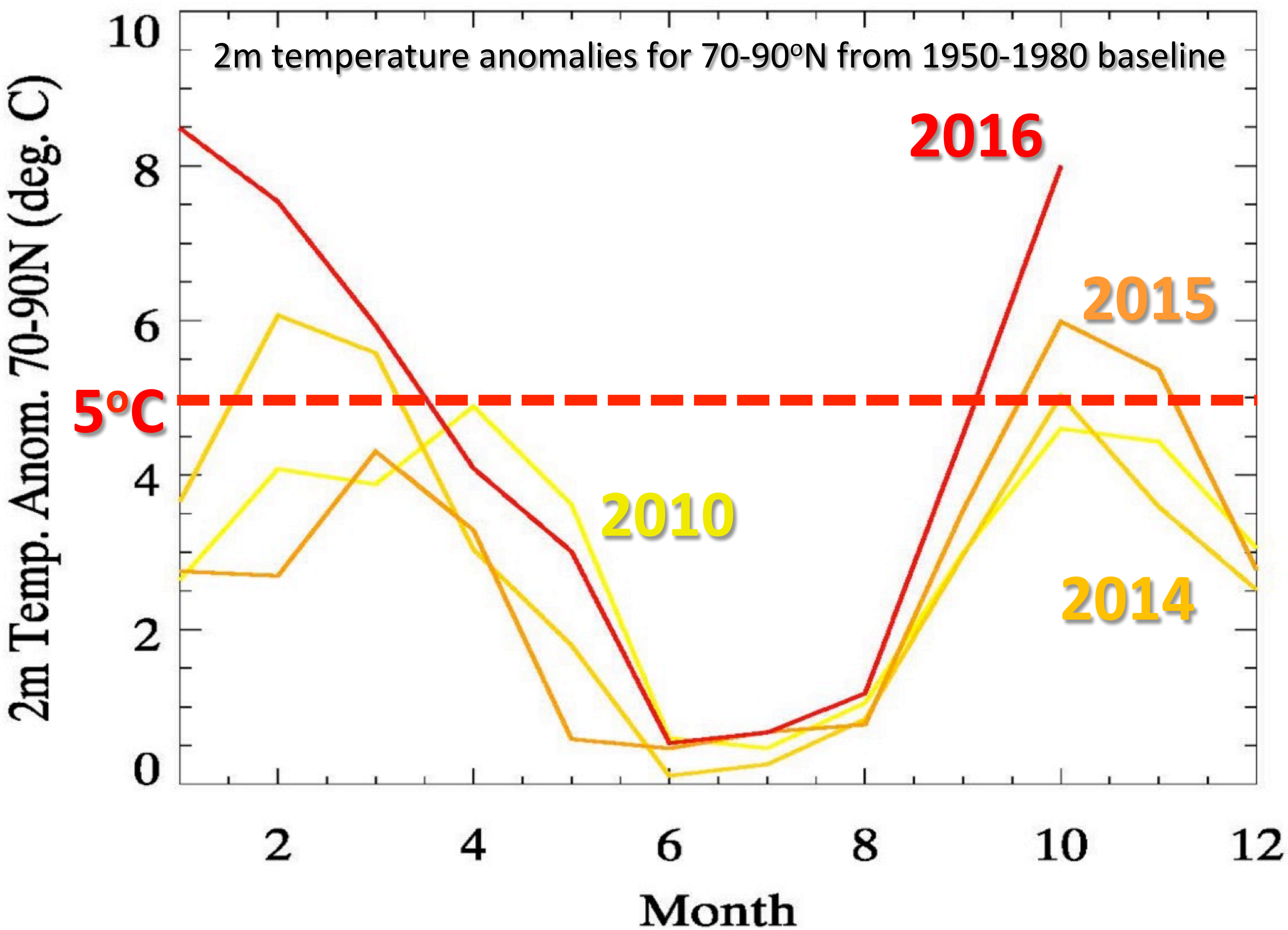


ARCTIC AMPLIFICATION

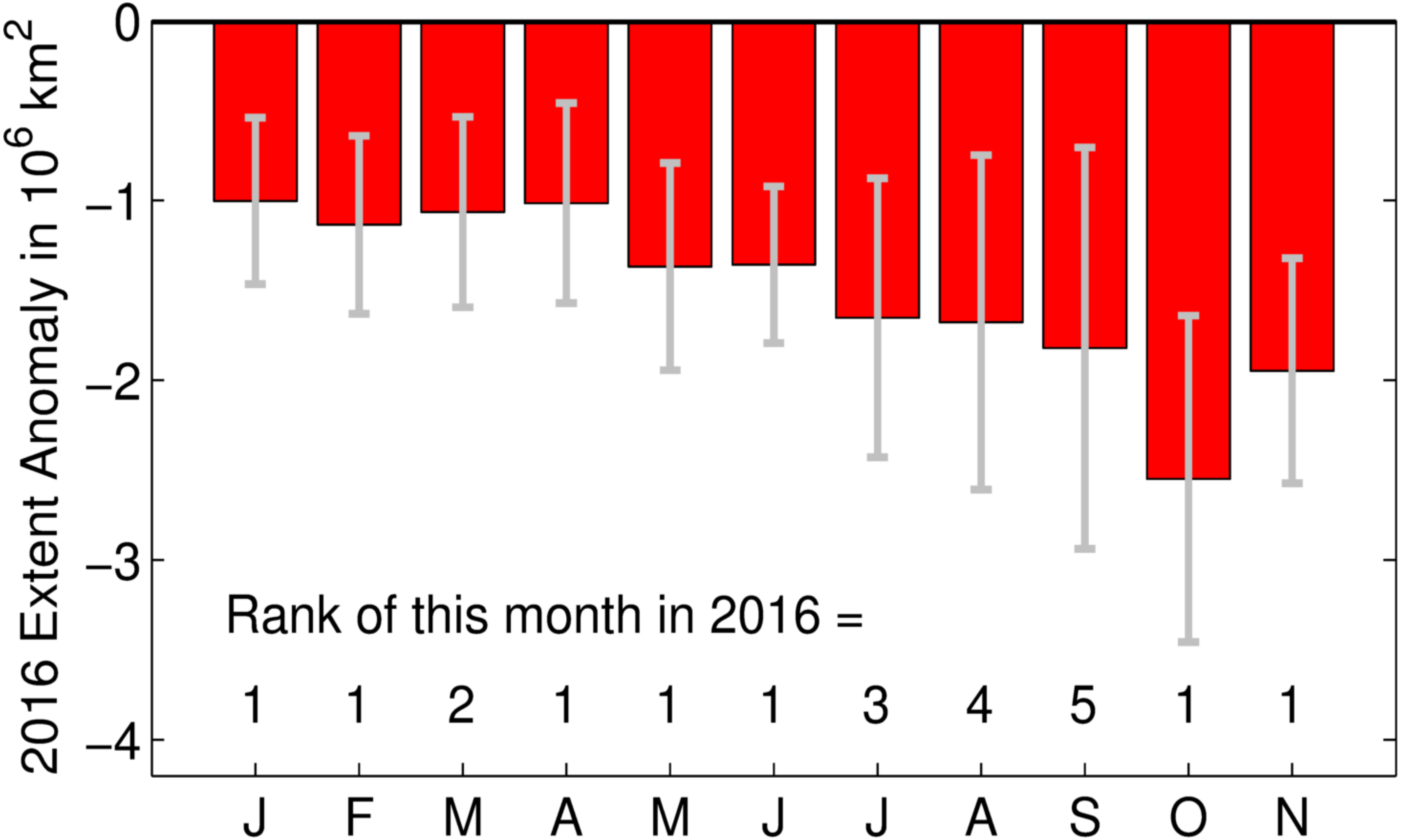
Sea Ice and Snow Cover Decline



Annual Cycle of Arctic Temperatures



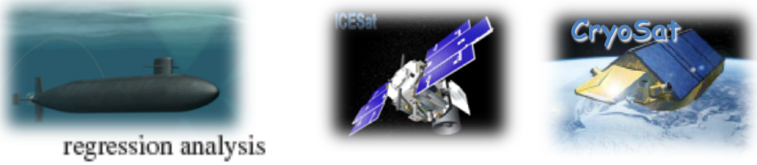
Sea Ice Extent

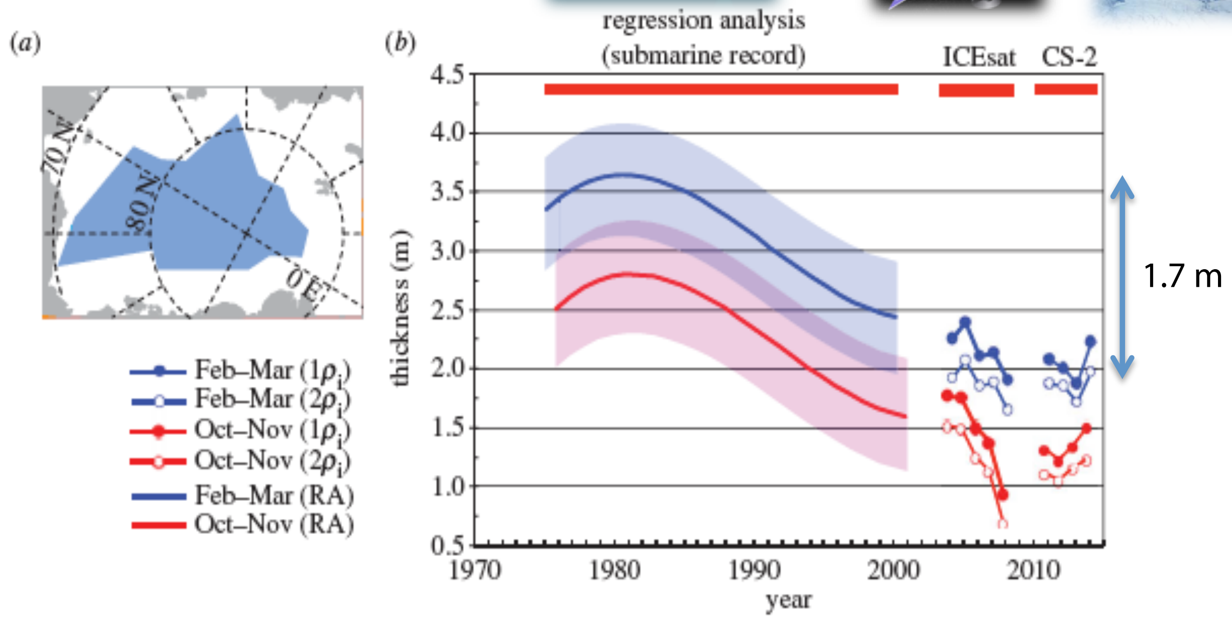


SIPN Final Report 2016

Weather/ Sea ice loss Feedbacks

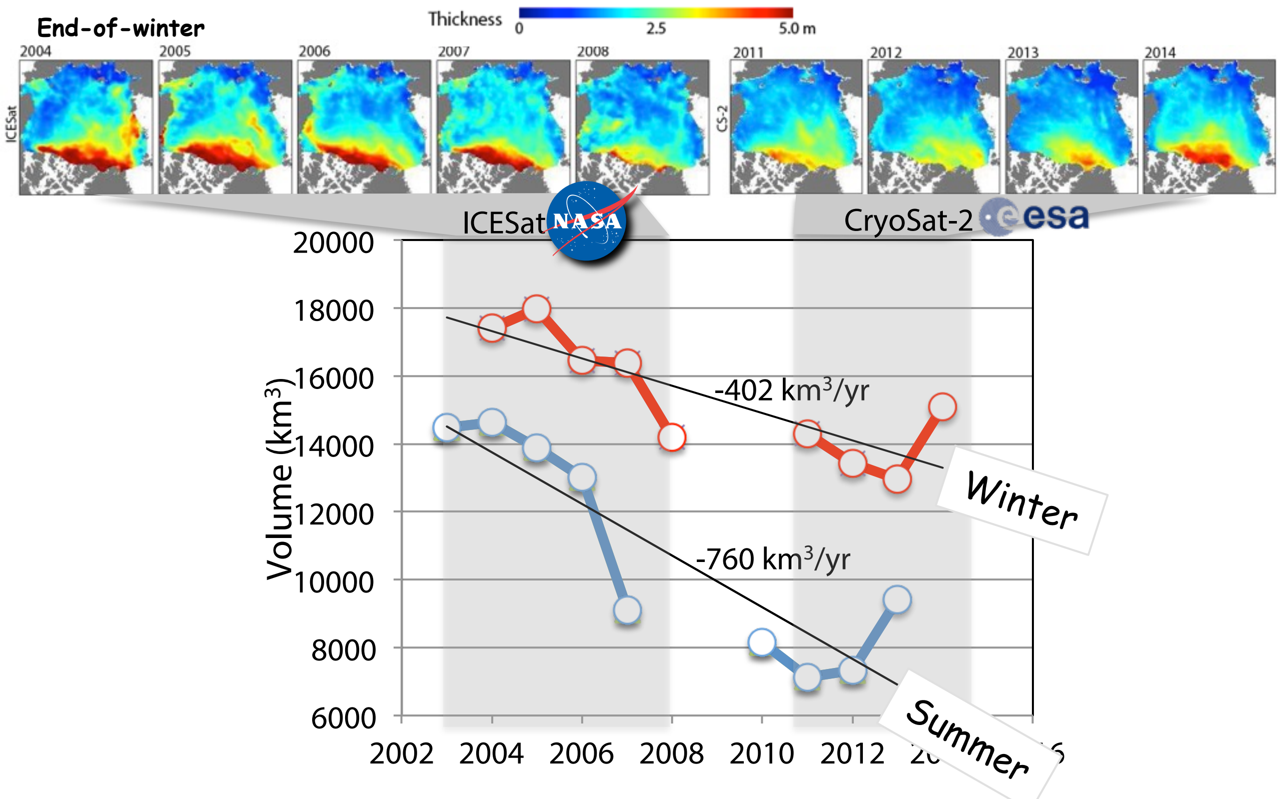
Thinning of central Arctic from combined Submarine, ICESat, and CryoSat-2 records





Kwok and Cunningham (2015)

Trends in Arctic Sea Ice Volume Since 2003

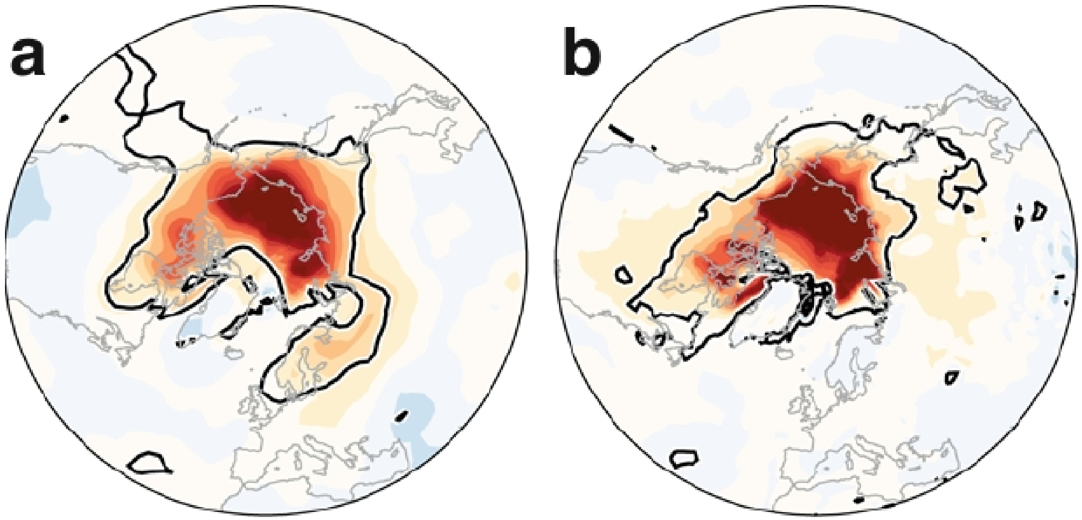


Kwok and Cunningham (2015)

Sea Ice Loss and Arctic Temperatures

1) Local response to sea ice loss and causes for Arctic Amplification

Response of autumn (SON) surface temperature to observed sea ice loss



CAM3

UM7.3

Screen et al. (2014)

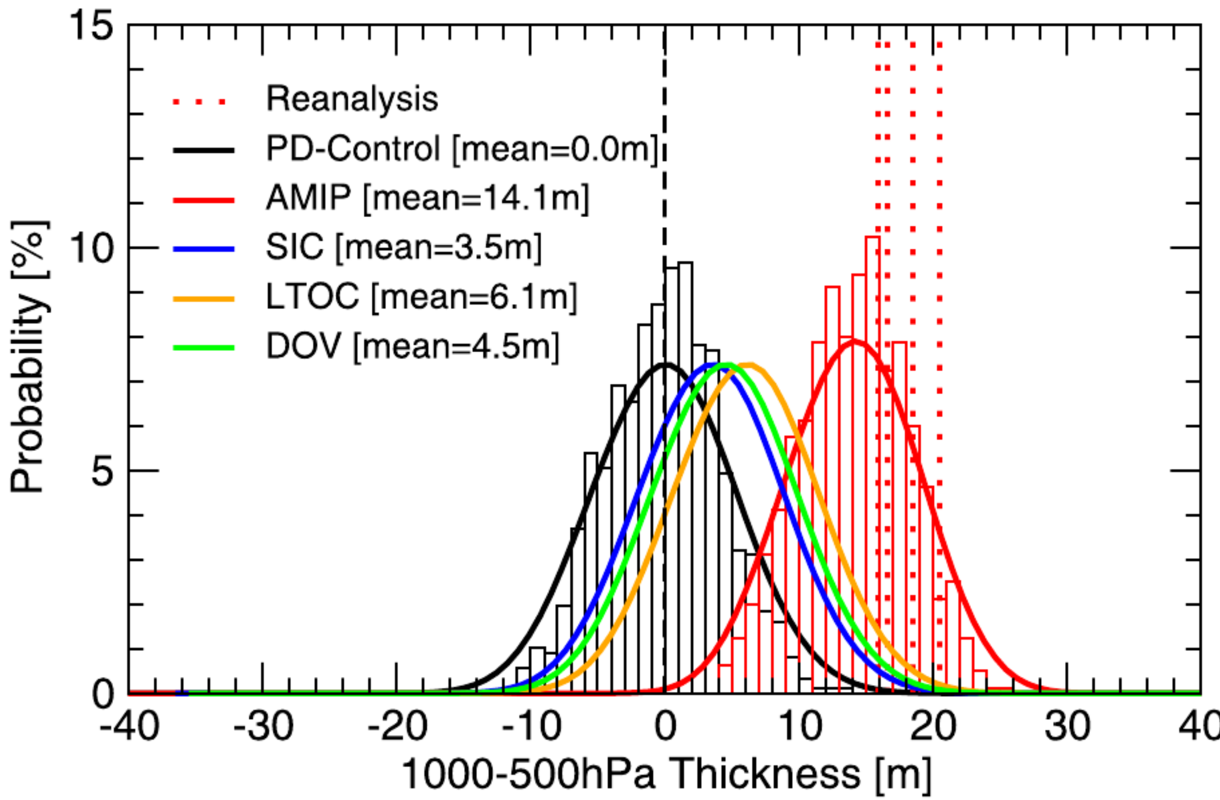
Increase in surface temperature (decrease of the surface temperature inversion)

Increase in cloud cover, moisture, precipitation

Warming and increase in thickness of the lower troposphere

Sea Ice loss and full AA

Role of SIC vs decadal ocean variability and internal variability



AMIP : SST + sea ice

SIC : sea ice only

LTOC : long-term oceanic trend

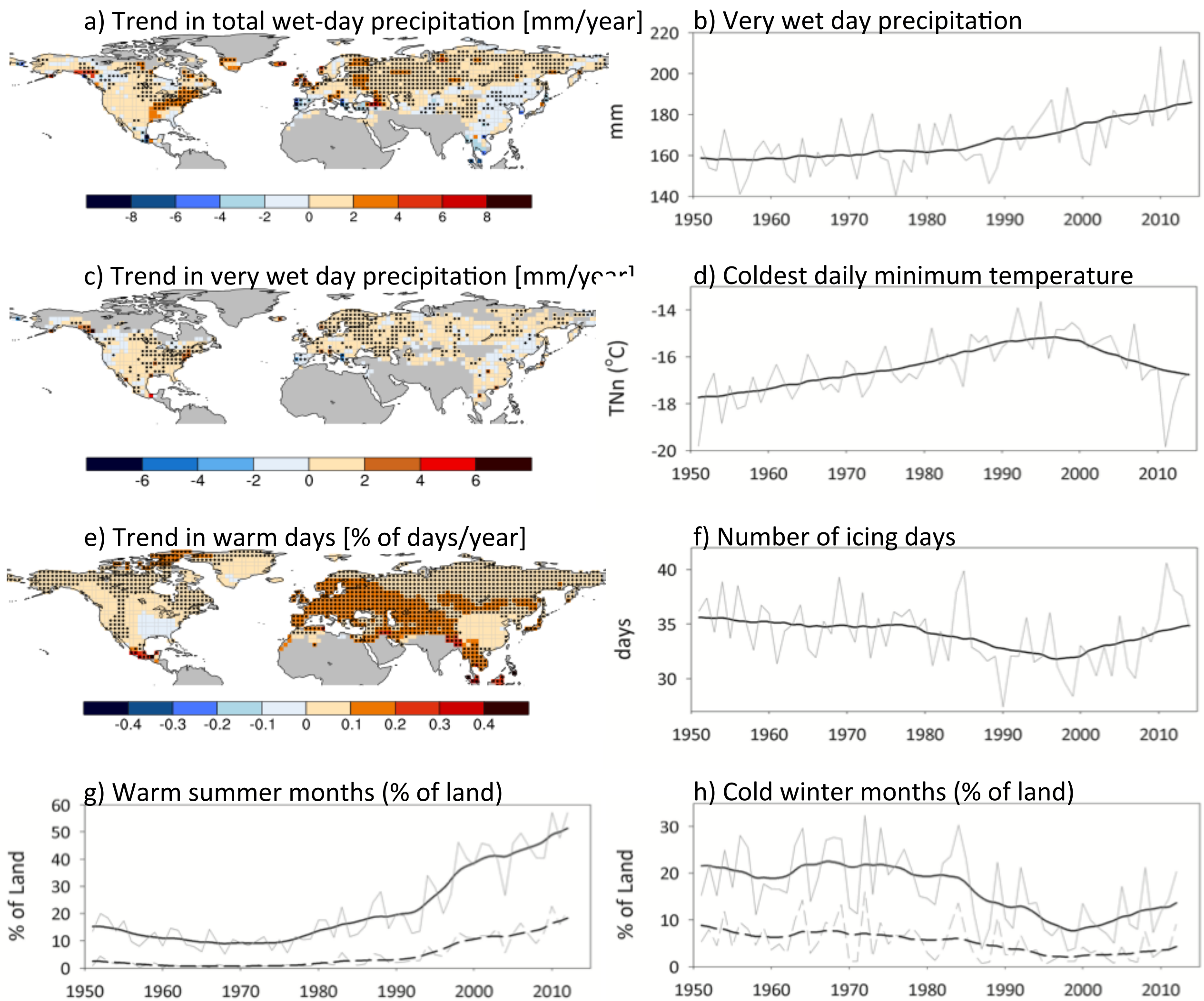
DOV : decadal oceanic variability

Perlwitz et al. (2015)

Sea ice loss is not the only contributor to AA

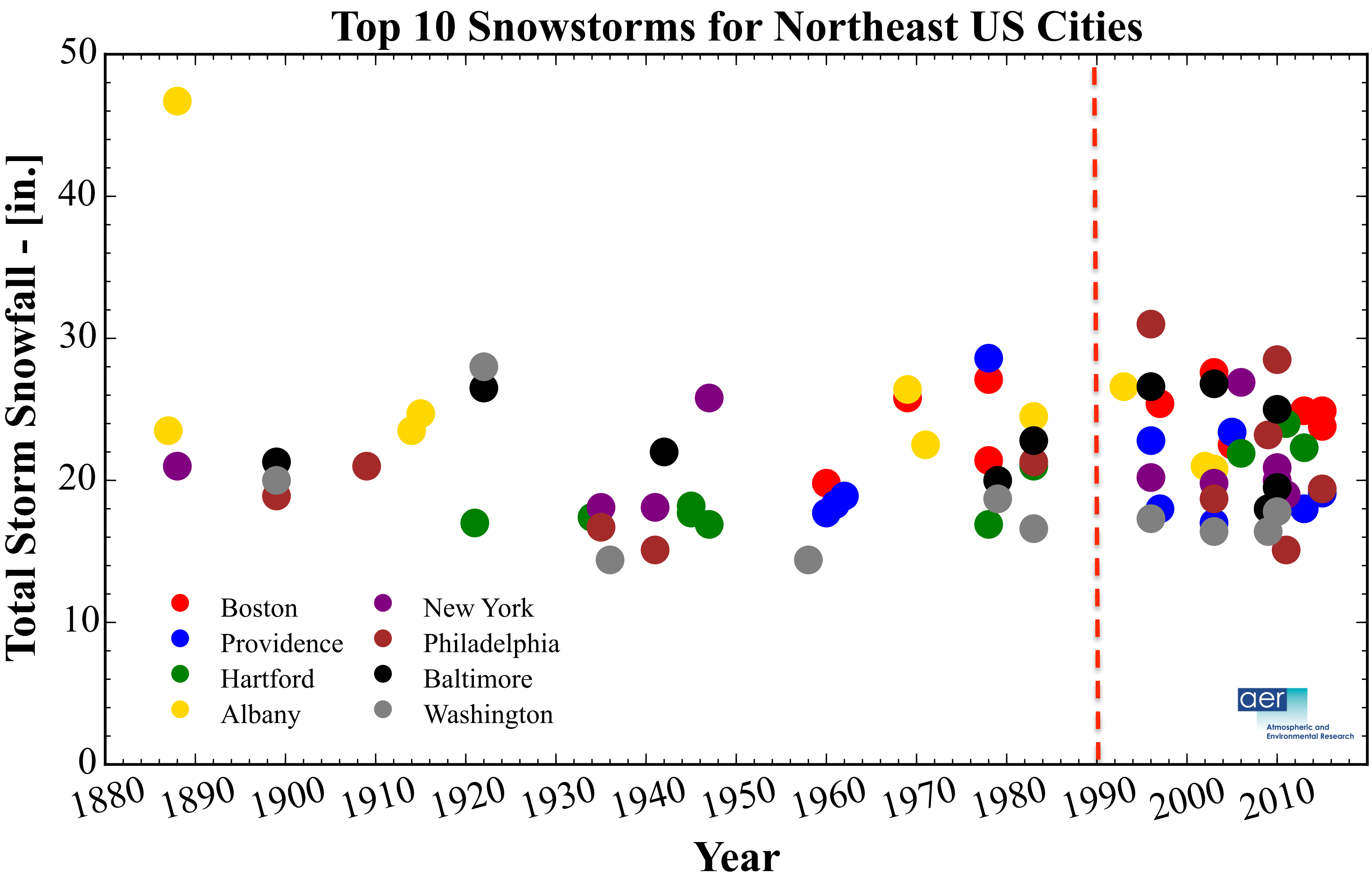
EXTREMES

Extreme Weather

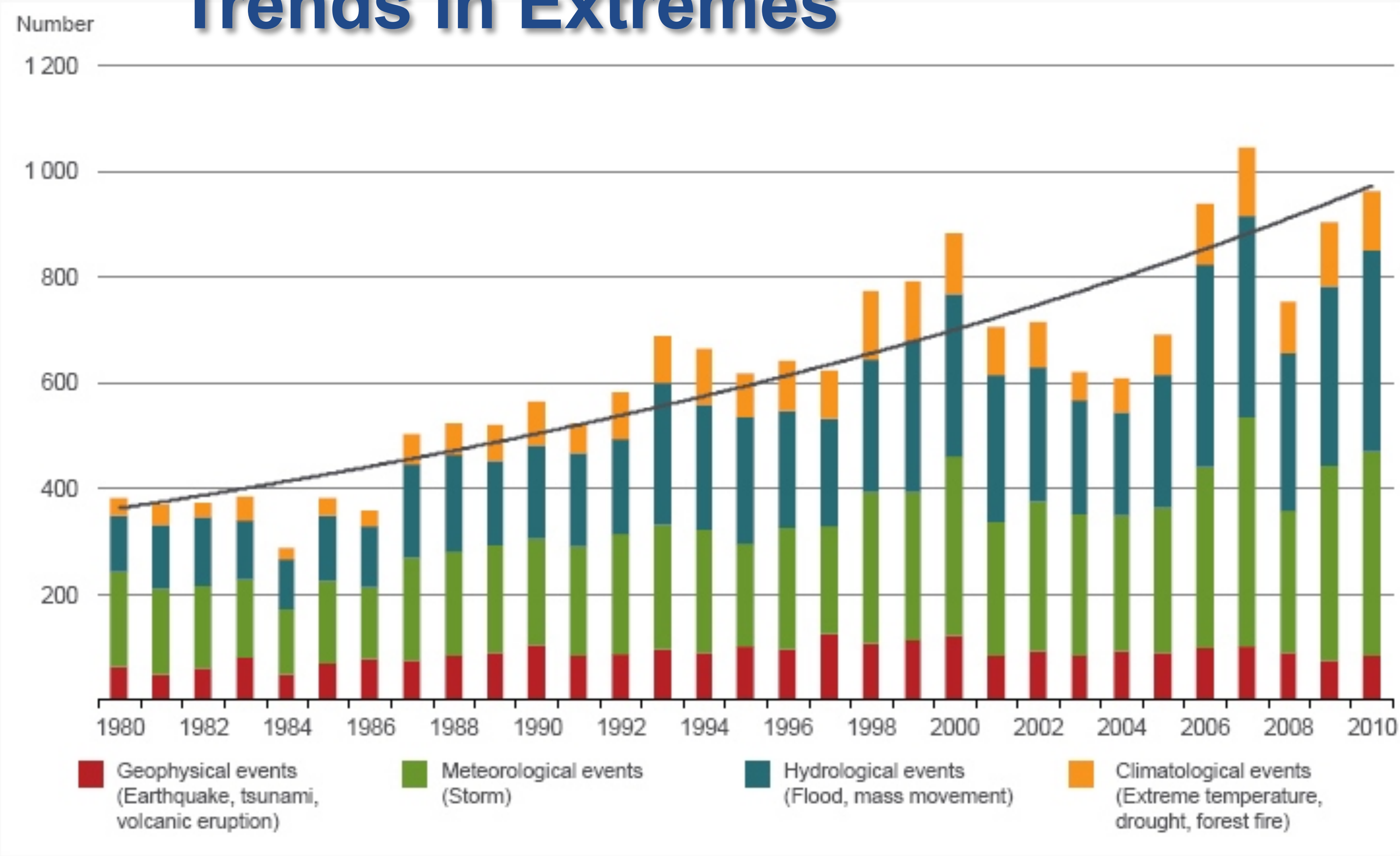


Cohen et al. 2014

Extreme Snowfall



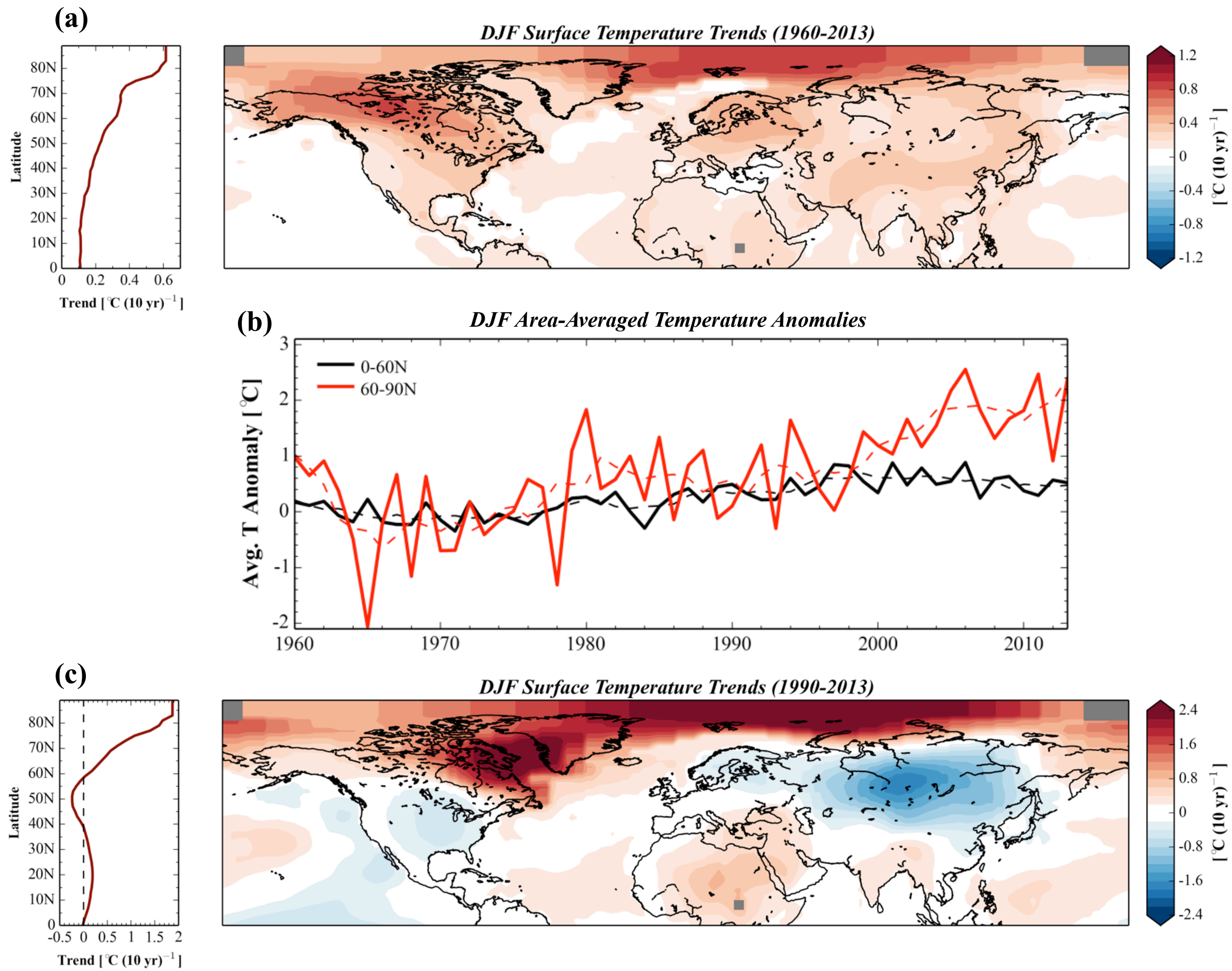
Trends in Extremes



Source: MunichRe

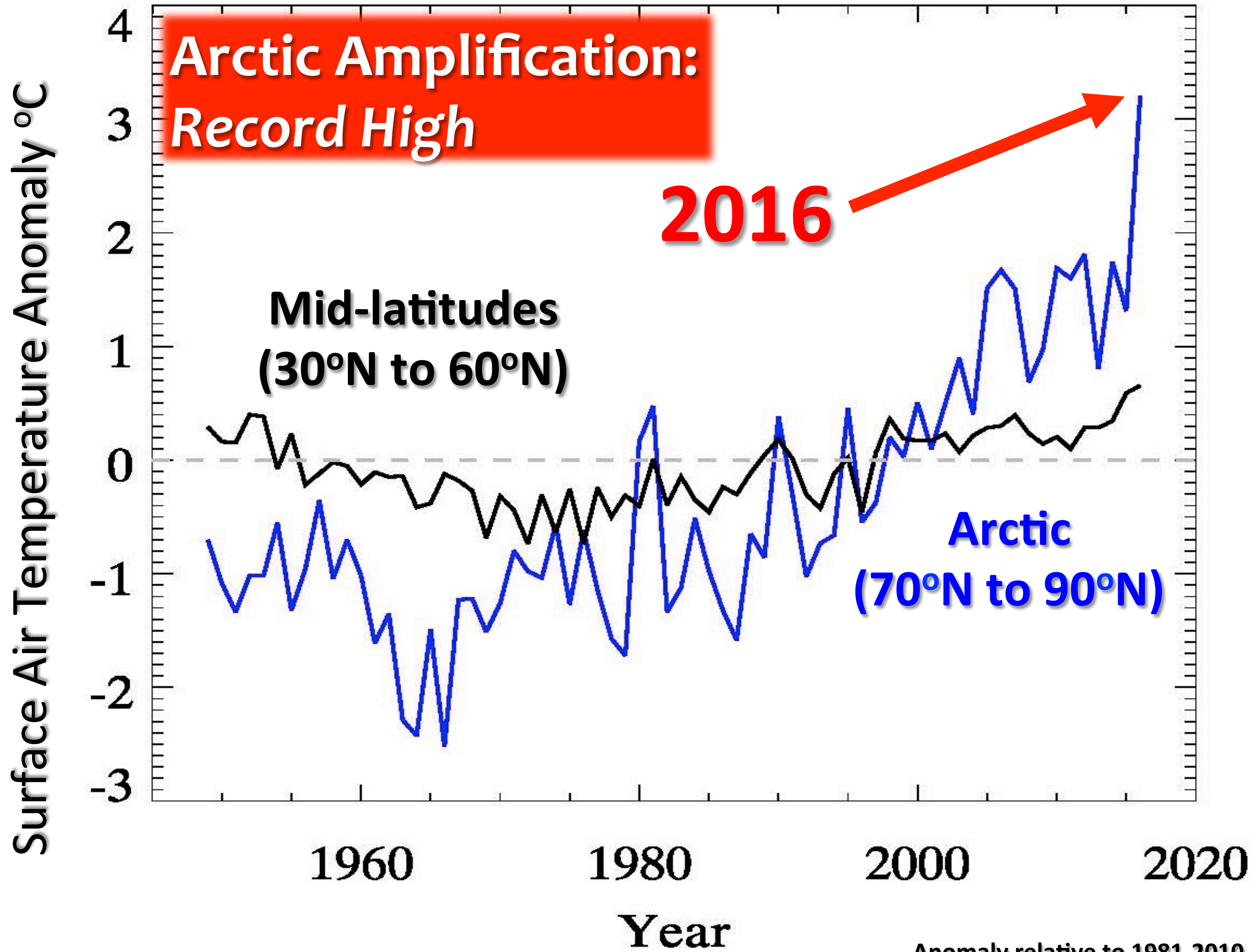
WARM ARCTIC/COLD CONTINENTS

Arctic Amplification



Cohen et al. 2014 Review paper

January-October Air Temperature Anomalies



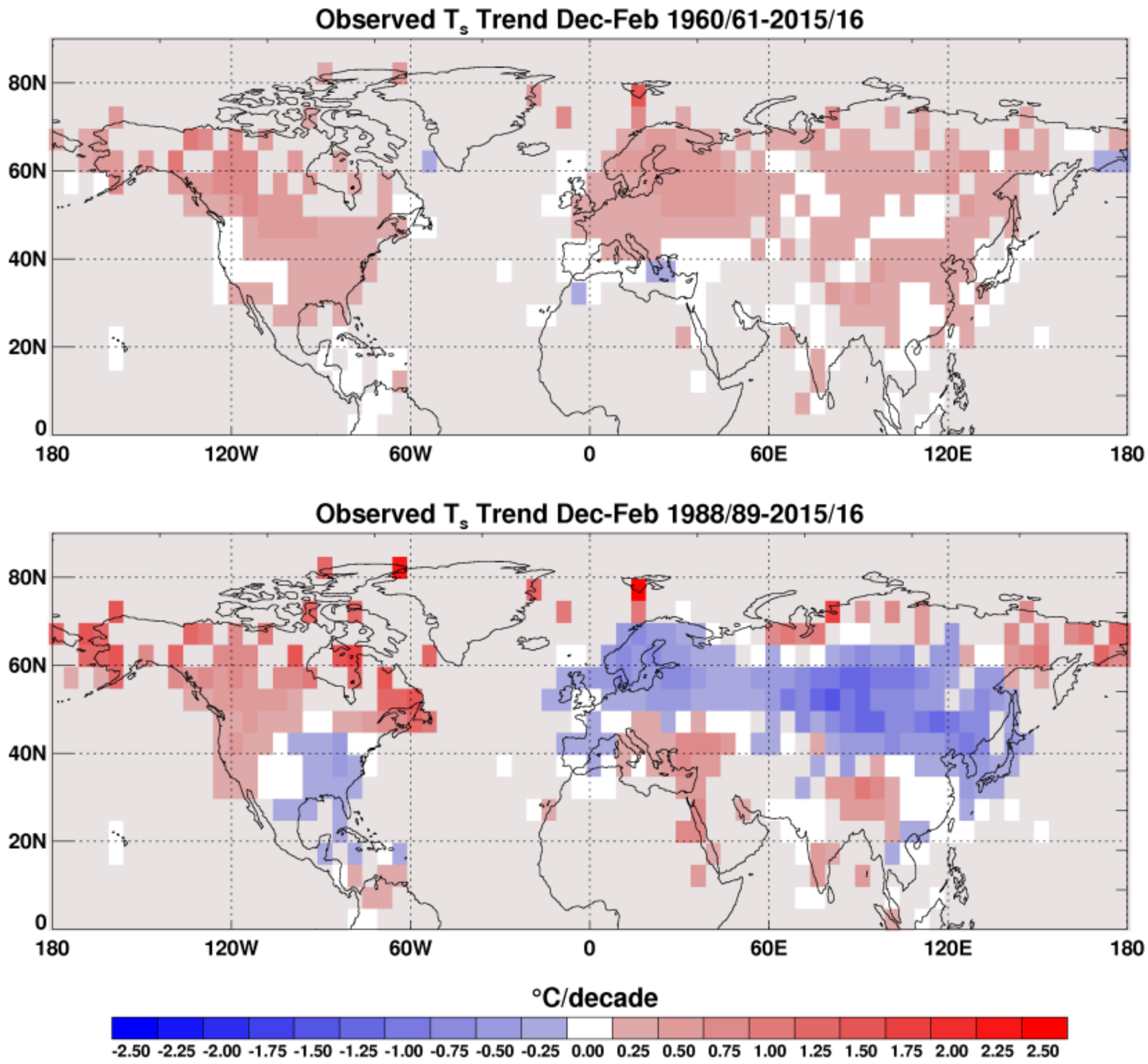
Anomaly relative to 1981-2010

J. Francis: *francis@imcs.Rutgers.edu*

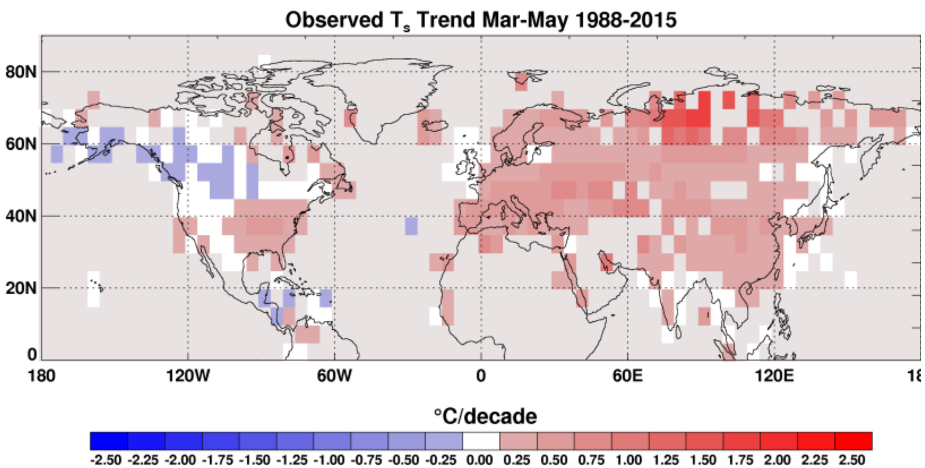
Data from NOAA/NCEP/ESRL

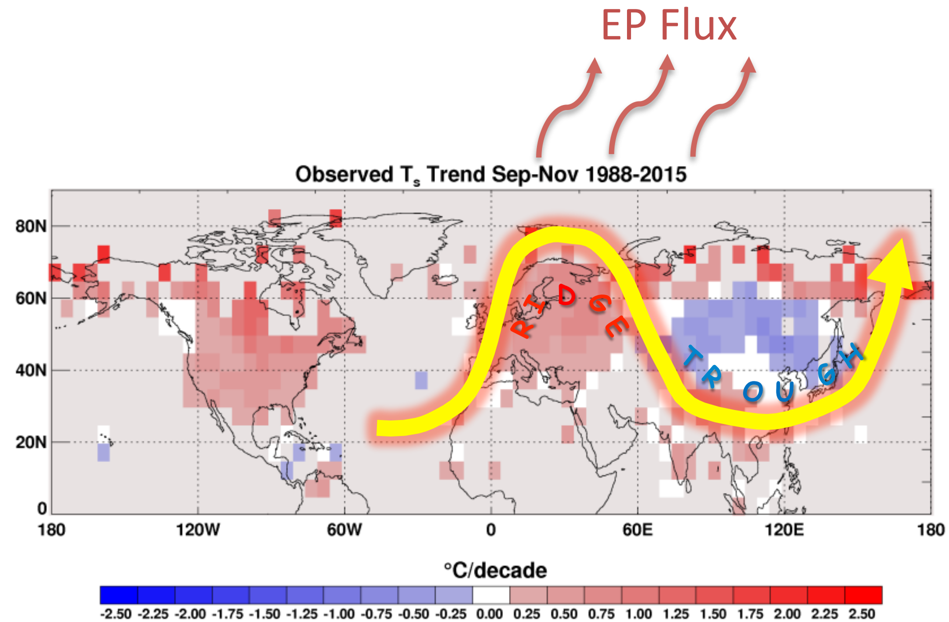
Warm Arctic Cold Continents

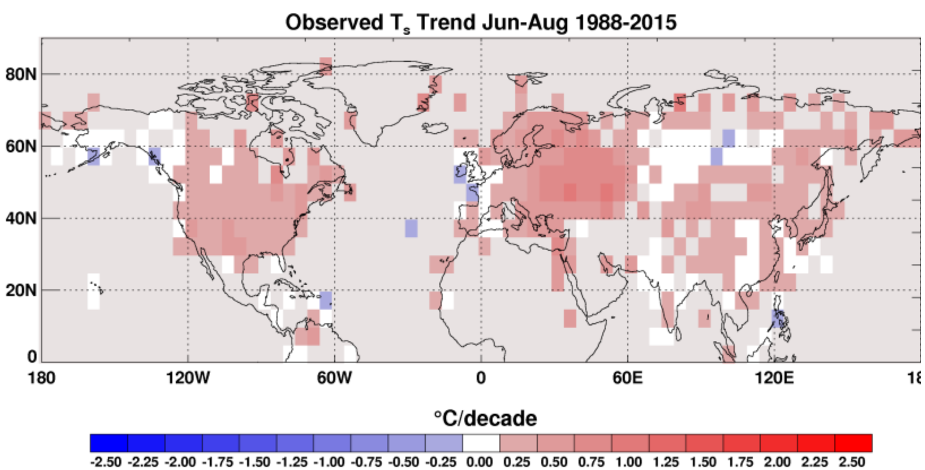
CRU
land data
only

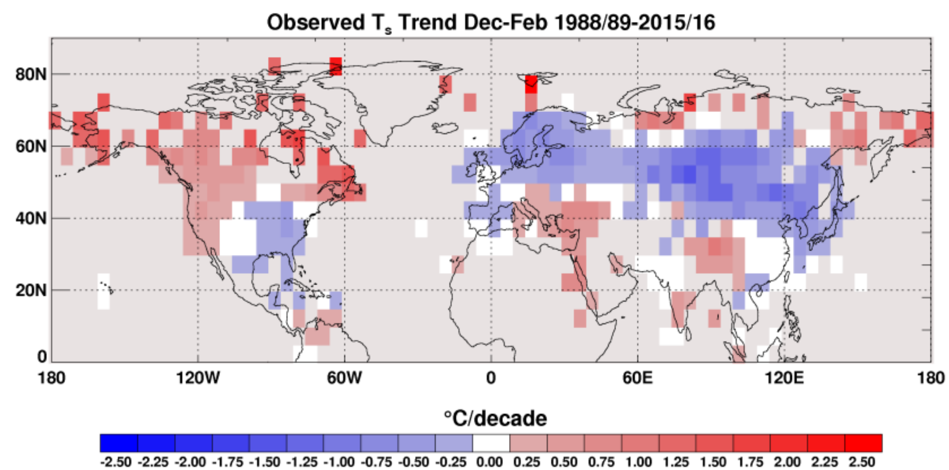


Seasonal Trends





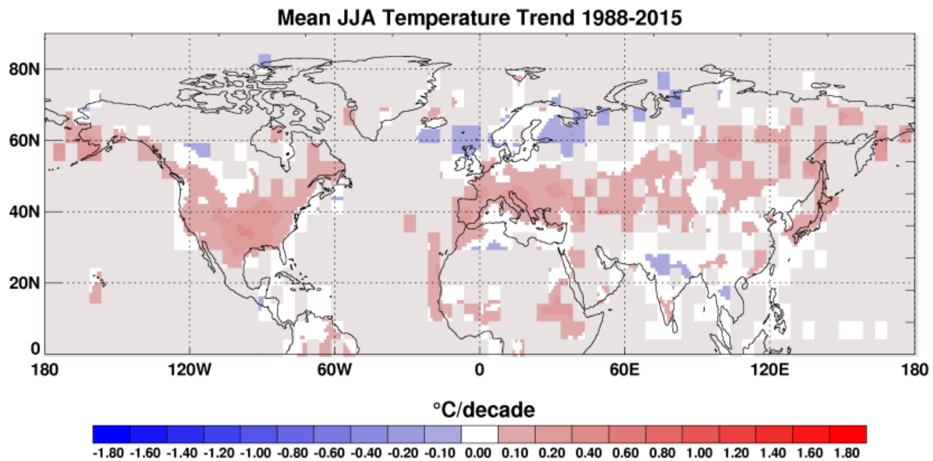


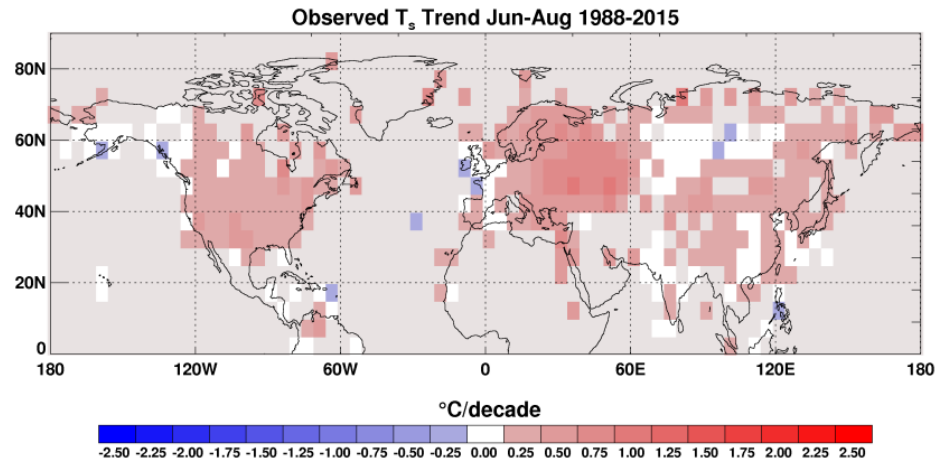


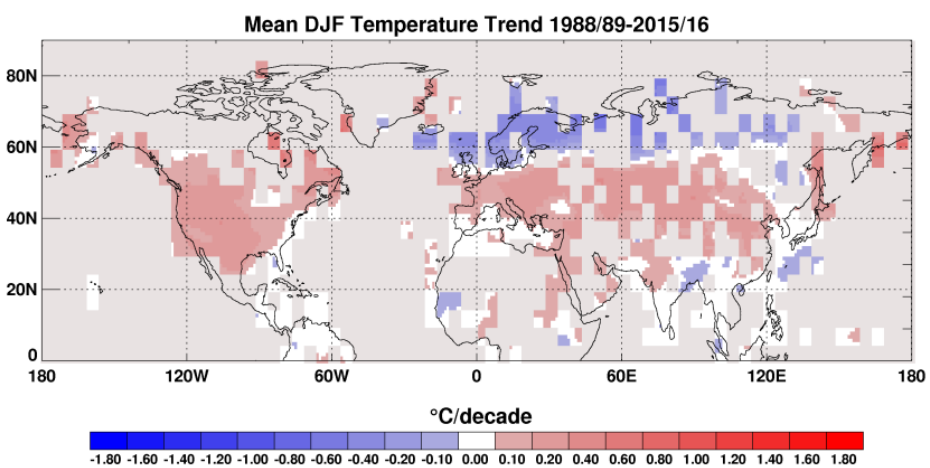
Seasonal Forecast Trends

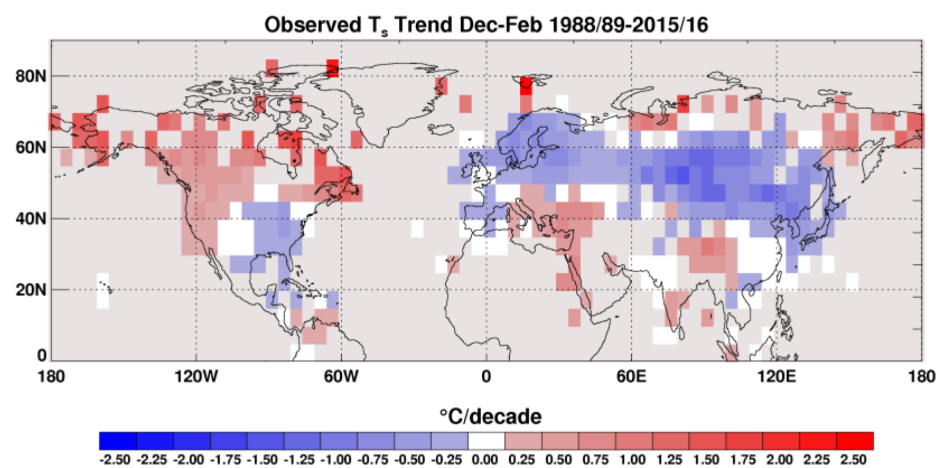
CMIP3

Observations







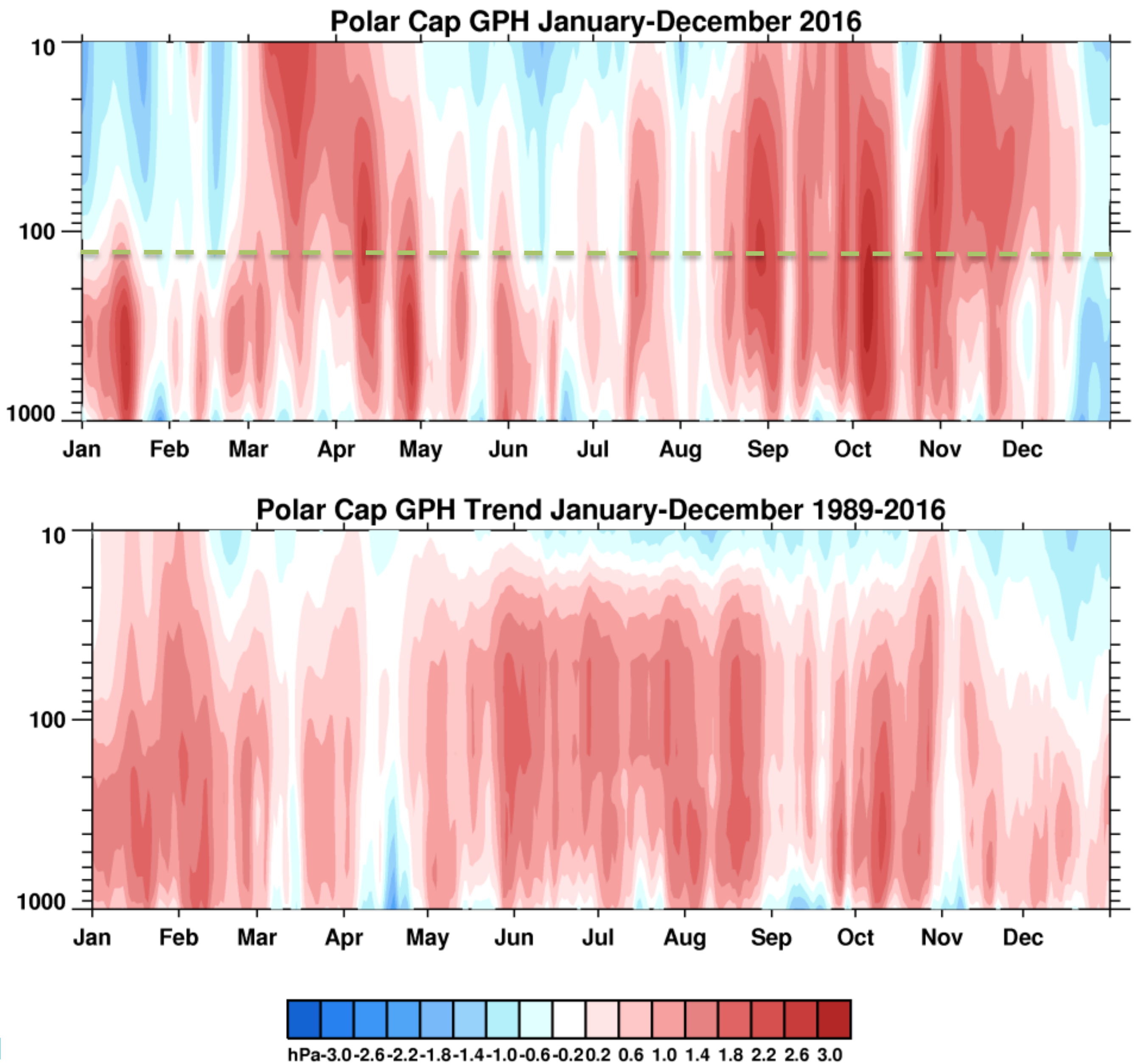


ARCTIC AMPLIFICATION AND MID-LATITUDE WEATHER

Theories linking AA to Mid-latitude Weather

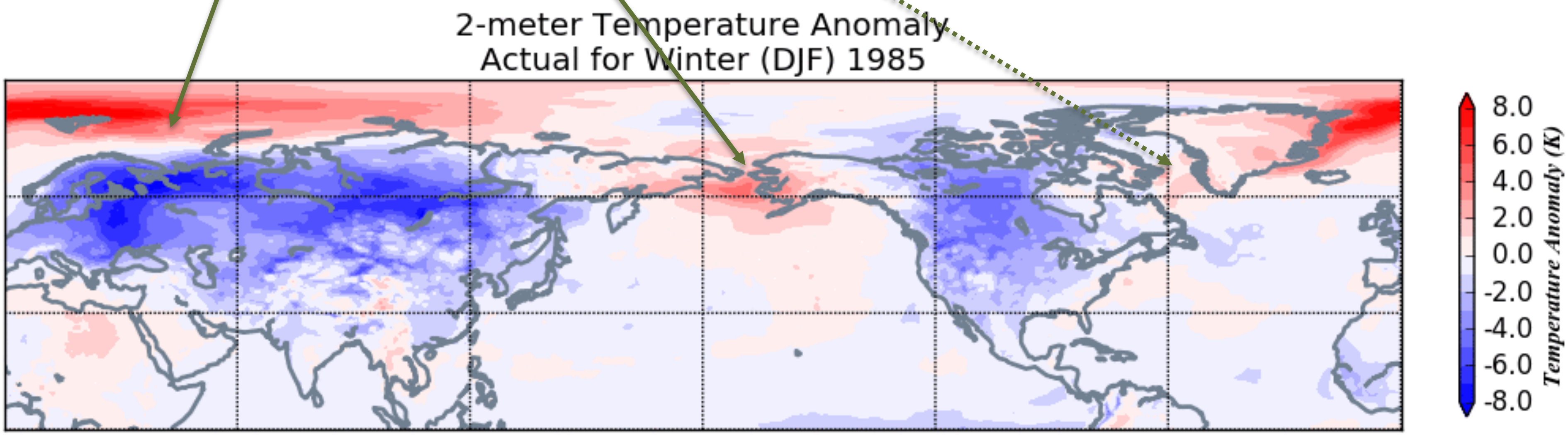
- Changes to latitudinal temperature gradient
- Changes to the Jet Stream/blocking/wave speed
- Changes to atmospheric waves:
  - Planetary waves (winter)
  - Synoptic scale waves (summer)
- Changes to troposphere-stratosphere coupling
- Support of these theories are conditional and challenged by imperfect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

Arctic Warmth reaches to the Stratosphere



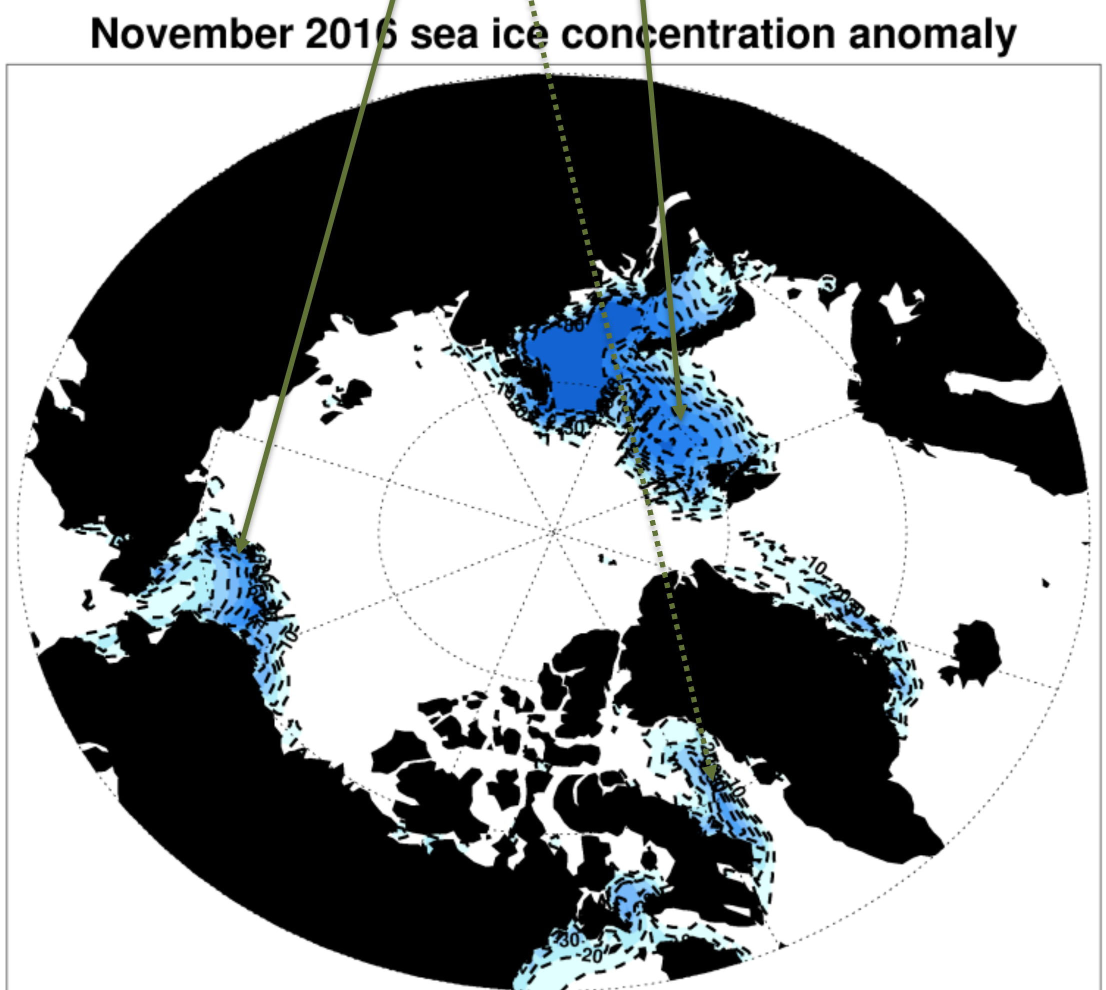
Warm Arctic Cold Continents

Triggers for/out of phase with continental temperature anomalies



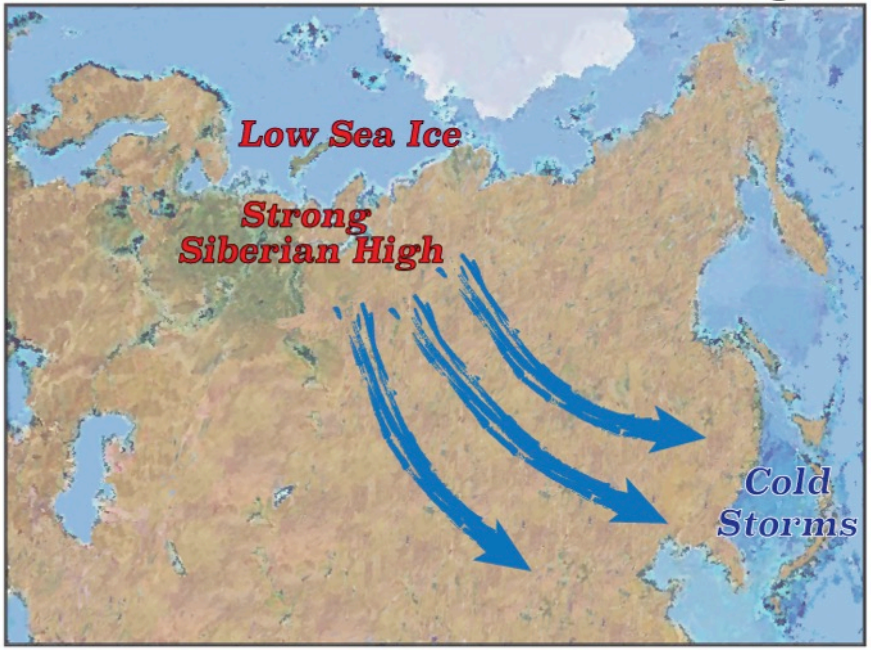
November 2016 Sea Ice Anomalies

Triggers for/out of
phase with continental
temperature anomalies



Biggest sea ice extent anomalies are in the Beaufort Sea and especially in the Barents-Kara seas - favorable for a cold Eurasia.

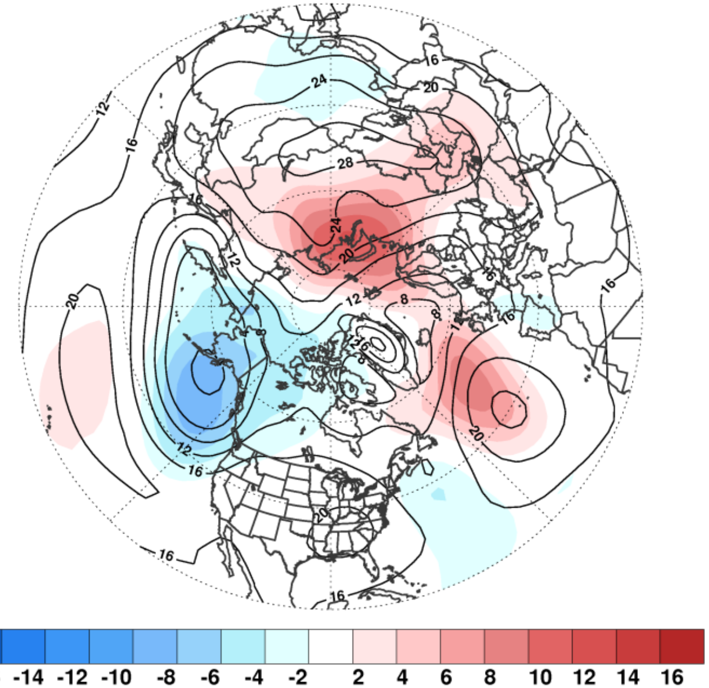
Asia: Arctic-Midlatitude Weather Linkages

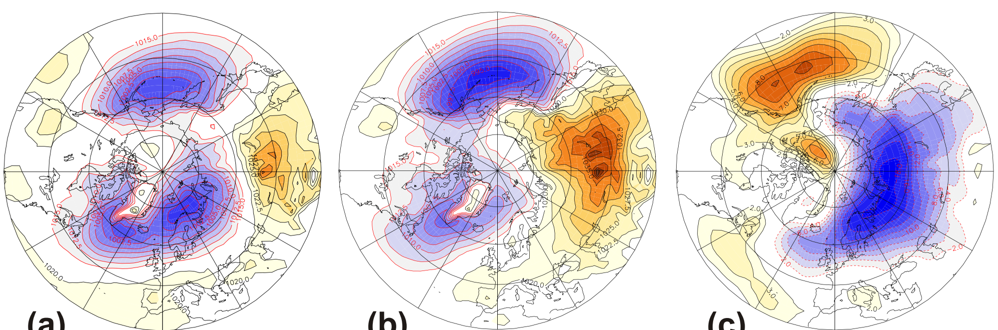


Outten and Esau 2012
Kim et al. 2014

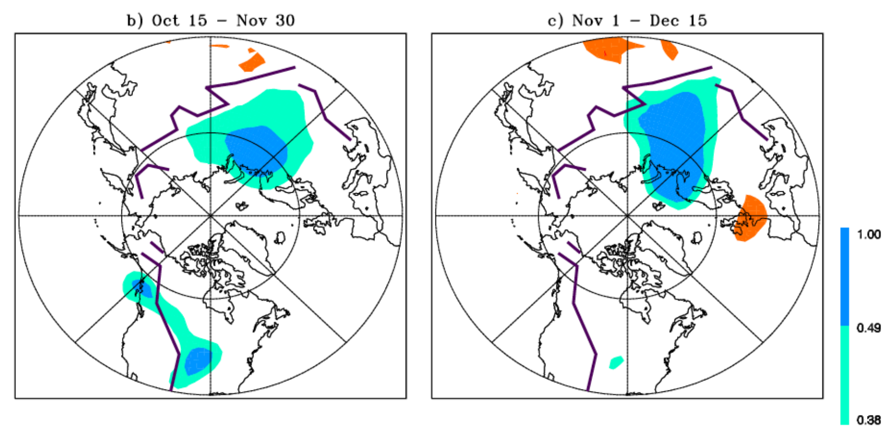
James Overland

Observed Sea Level Pressure Anomaly: Nov 1 - Nov 30 2016

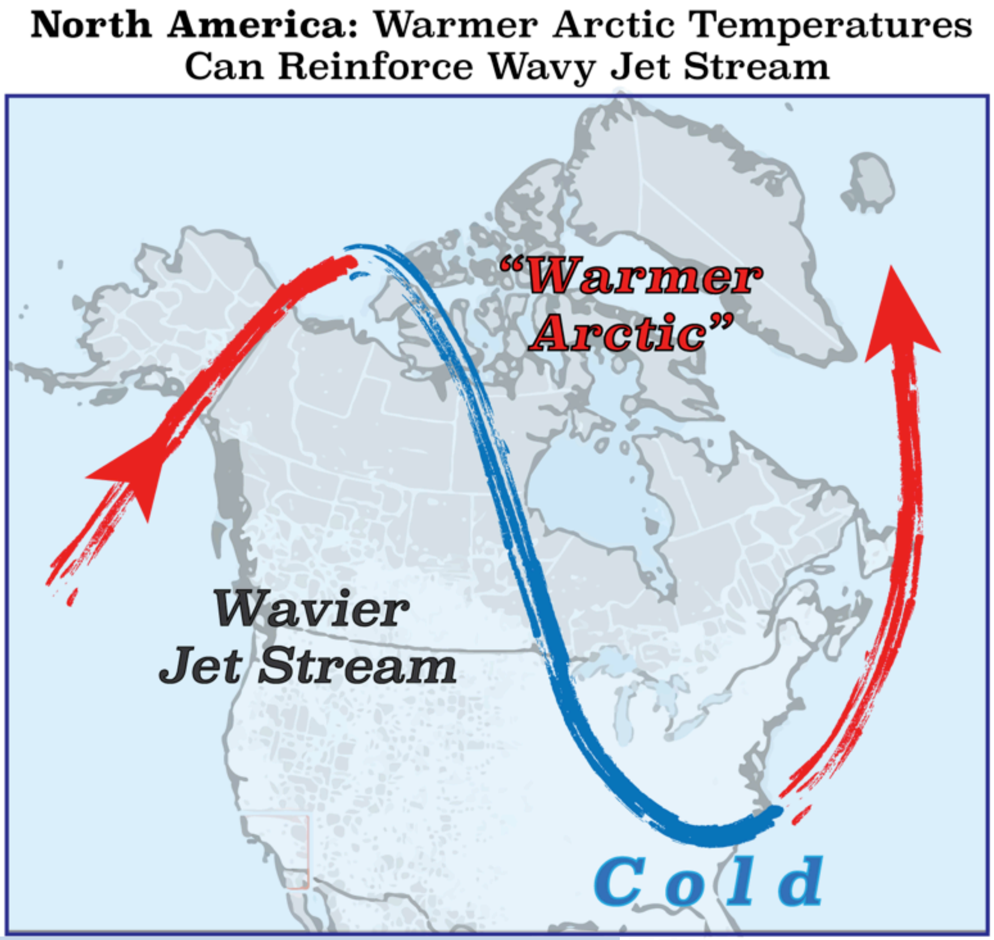


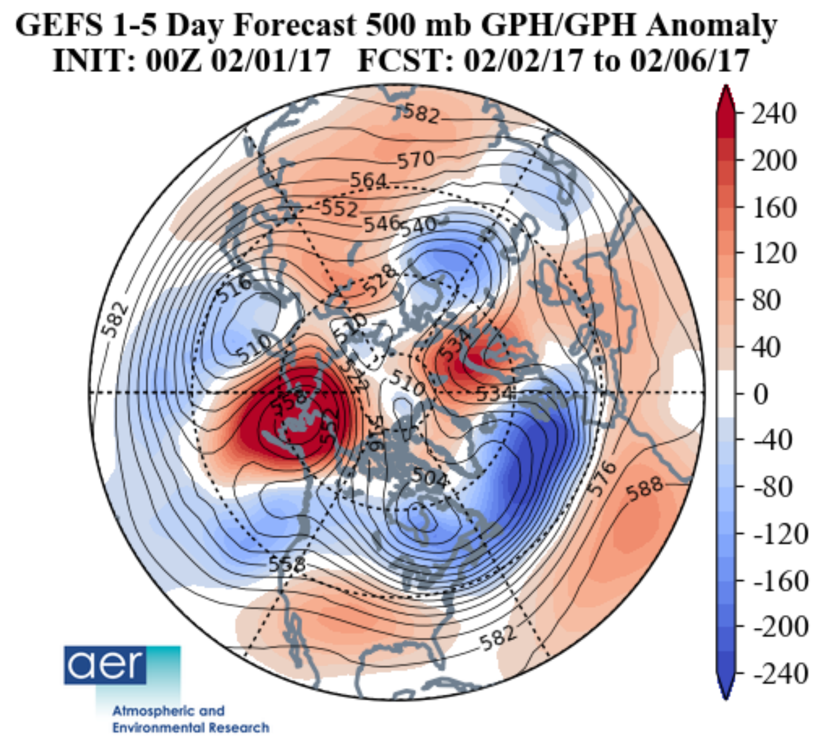


sea ice - Zhang et al. 2008



snow cover - Cohen et al. 2000



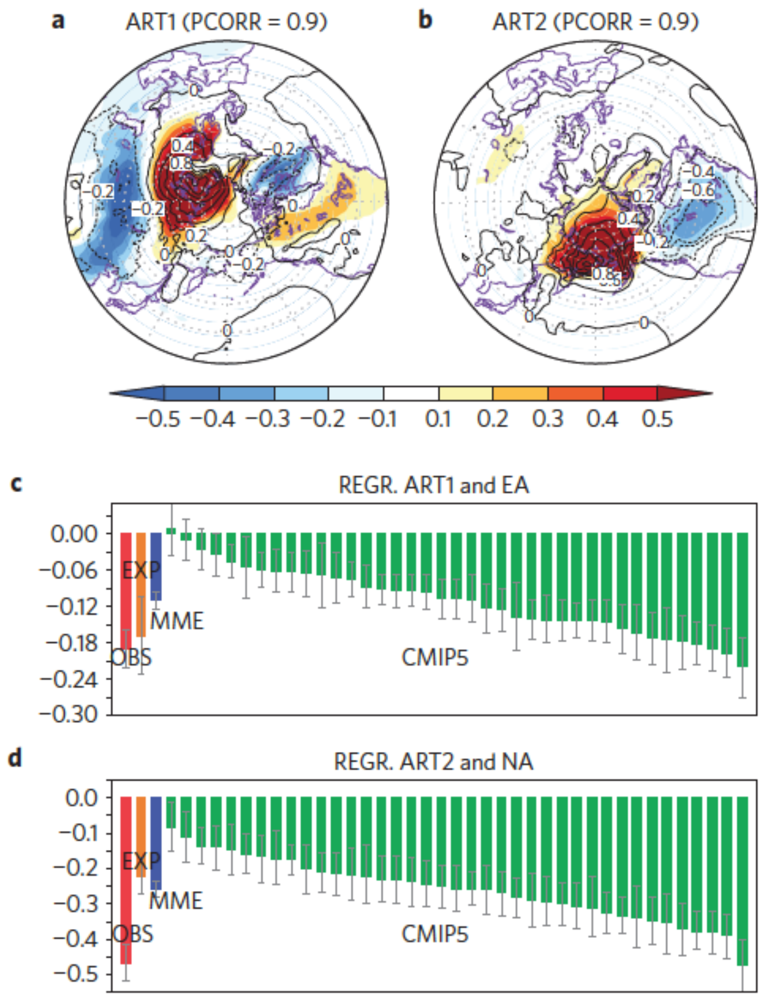


Francis and Vavrus 2015
Hartmann 2015

James Overland

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

Warm Arctic Forced Cold Signal



Shown are both observations and models

Kug et al. 2015

TROPOSPHERE VS. STRATOSPHERE PATHWAY

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 and Vavrus 2012

Arctic Amplification – Mid-latitude Weather

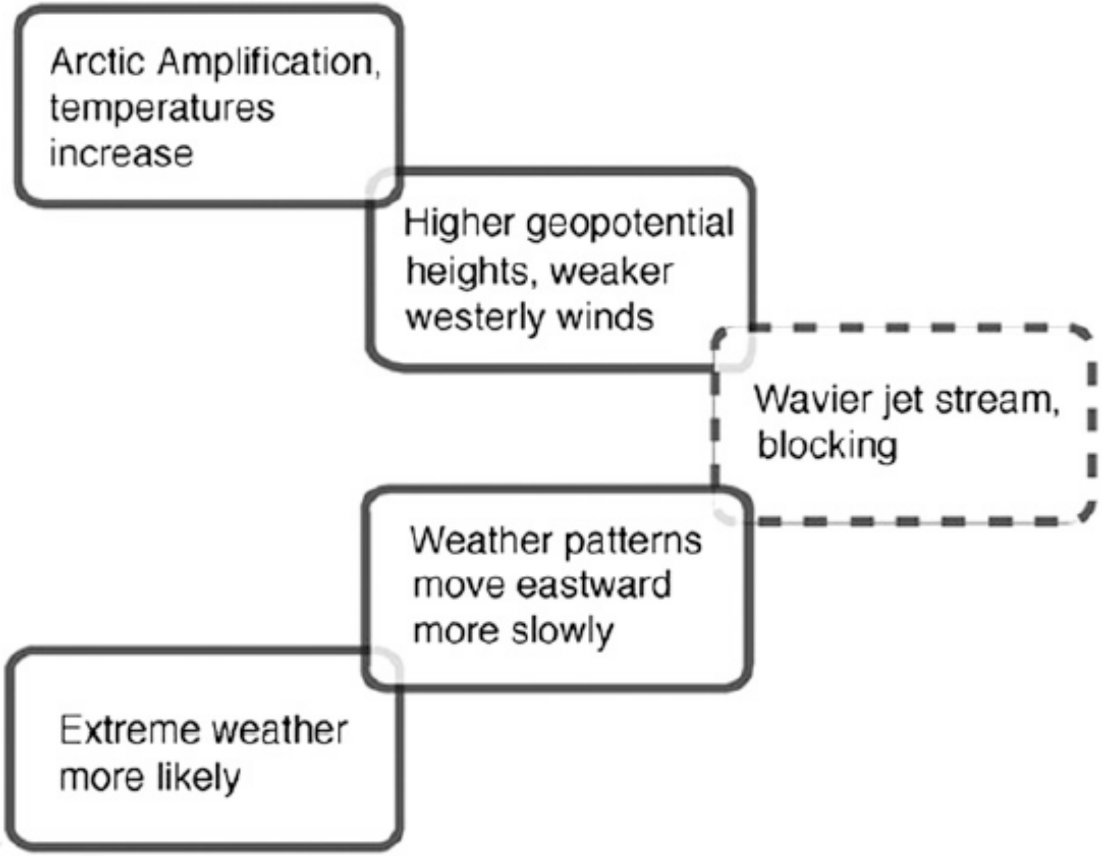
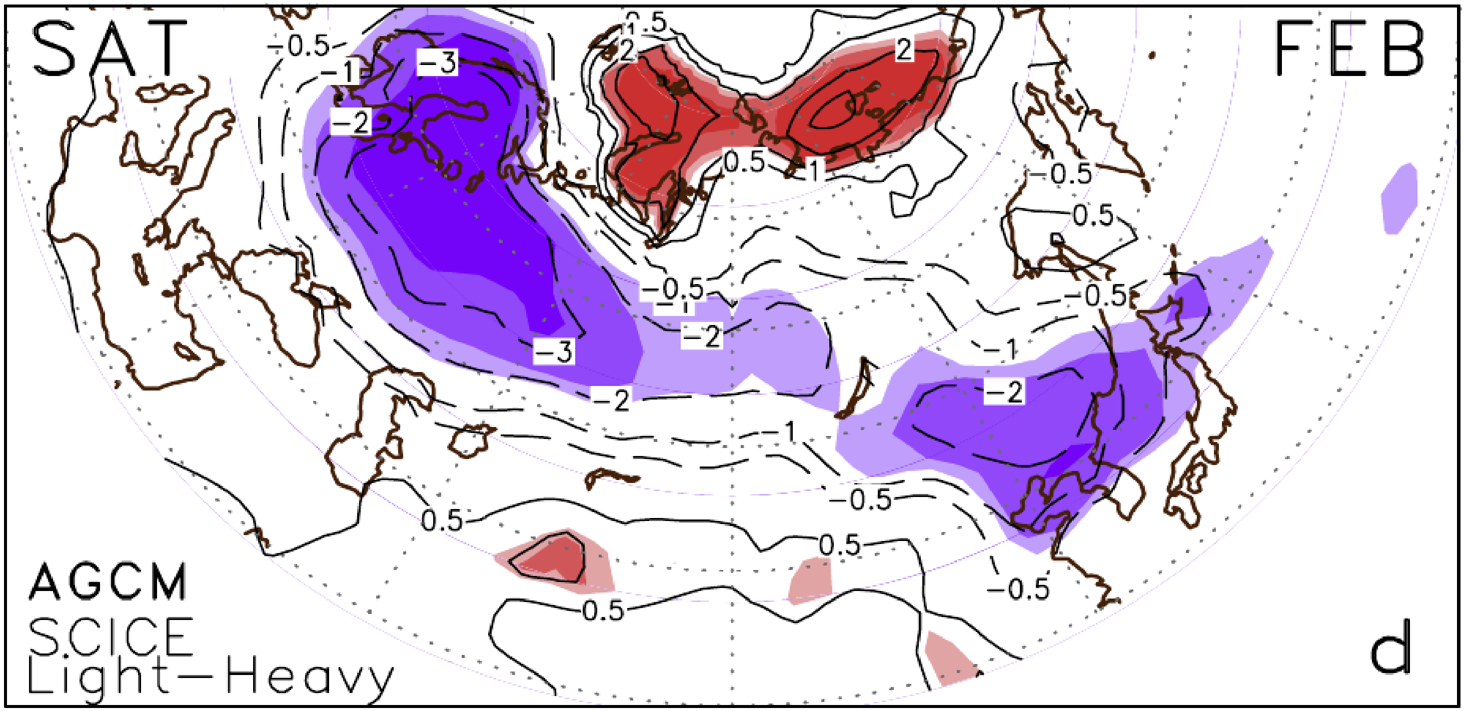


FIG. 2. Hypothesized steps linking Arctic amplification with extreme weather events in Northern Hemisphere midlatitudes.

Overland et al. 2015

Reduced Sea Ice Forced Cold Signal

Response of February air surface temperature to Barents-Kara sea ice anomalies

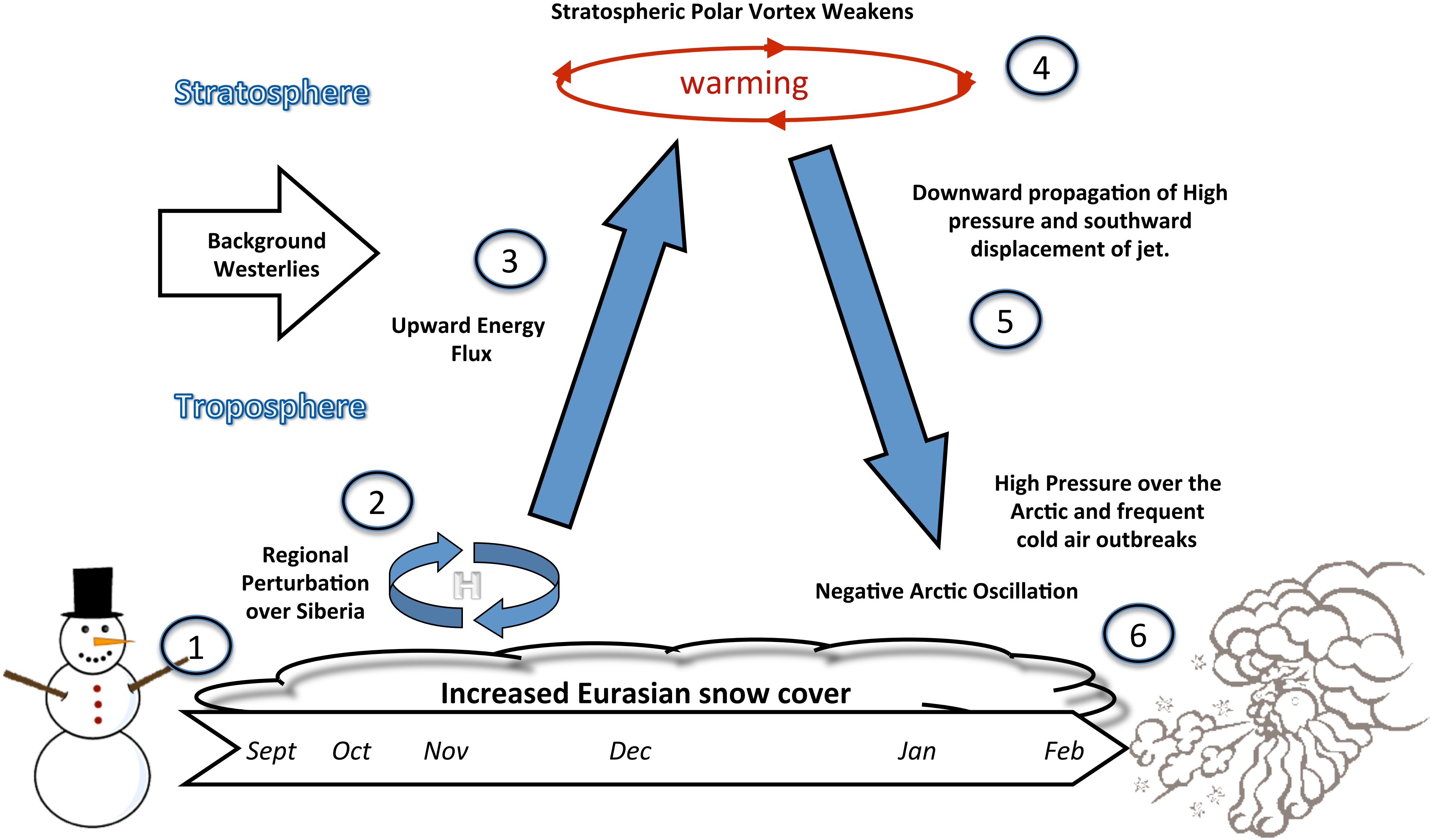


Honda et al. 2009

Less sea ice, warming in the Barents-Kara Seas induce a cooling over Siberia/central Asia

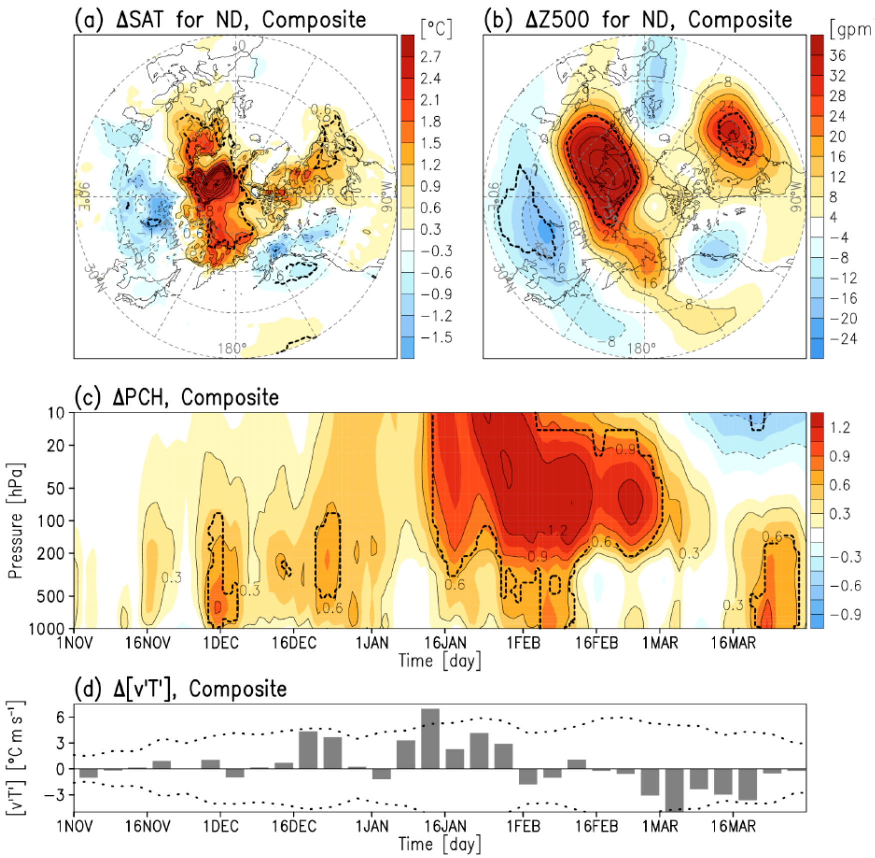
Supported by, e.g., Kim et al. 2014, Kug et al. 2015, Liu et al. 2012, Mori et al. 2014, Pethoukov and Semenov 2010

Extensive Snow Forced Cold Signal

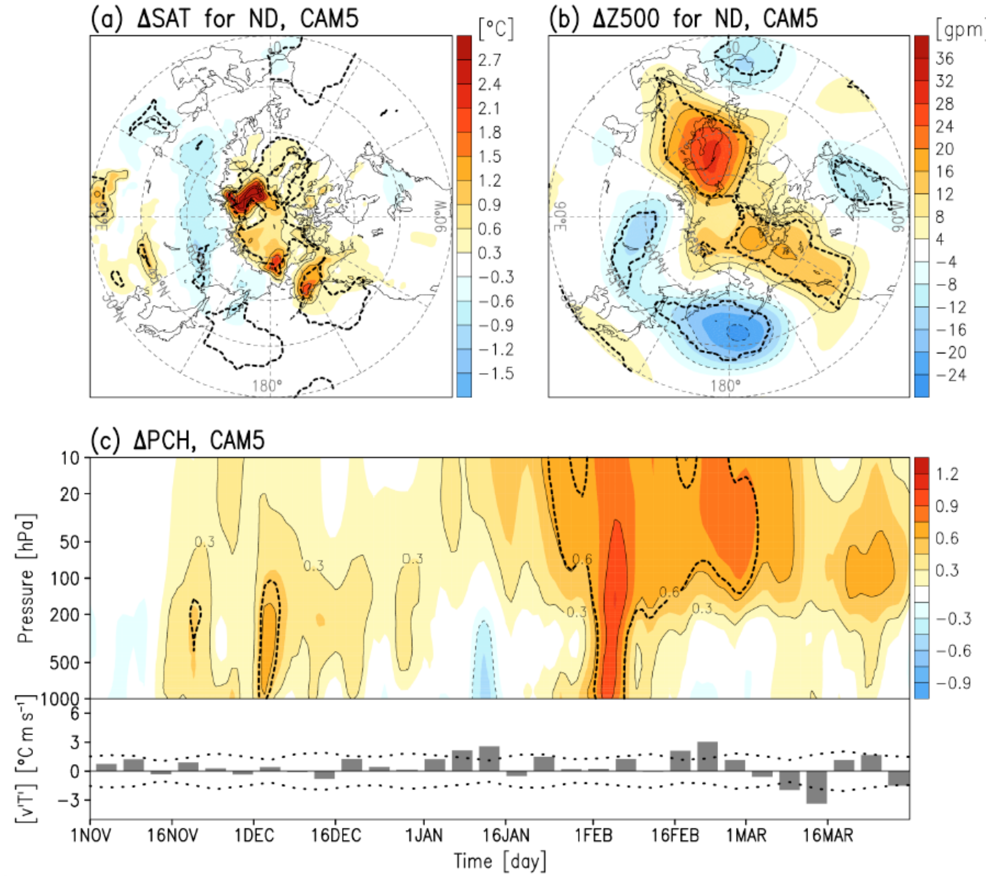


Reduced Sea Ice Forced Cold Signal

observations



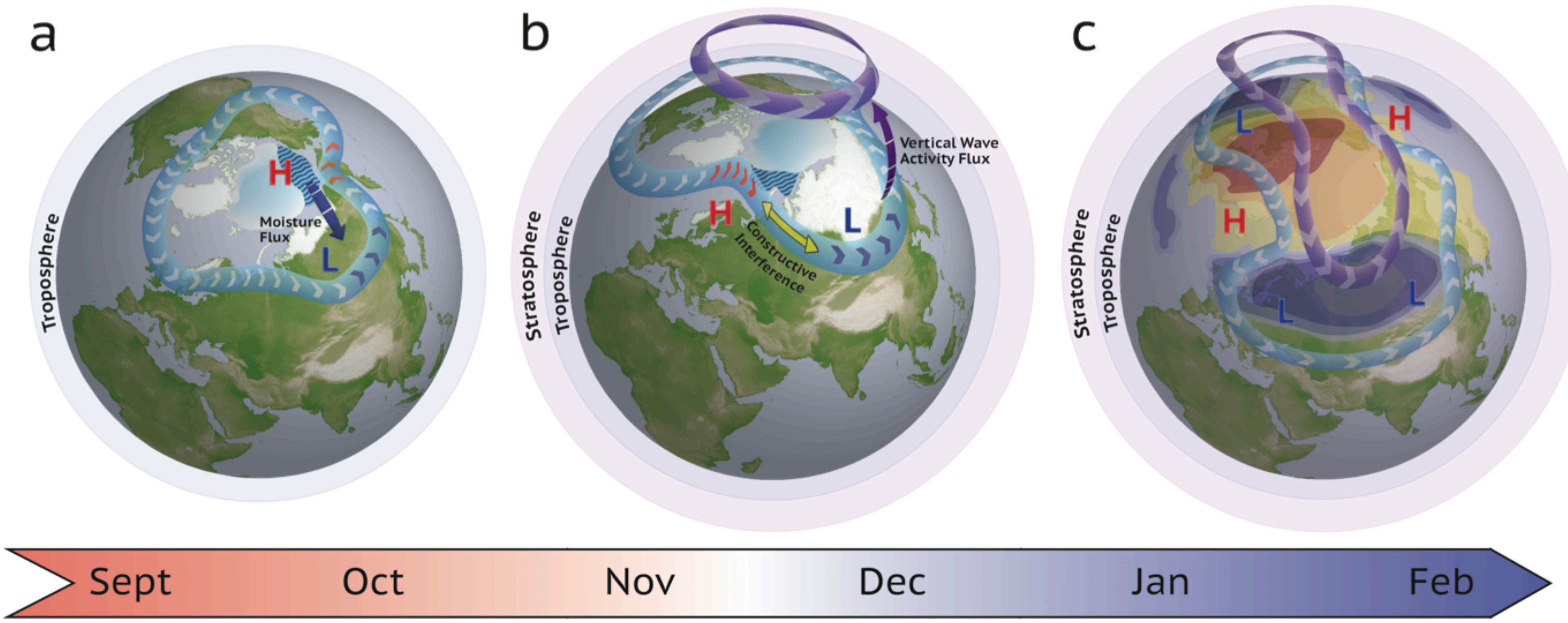
model



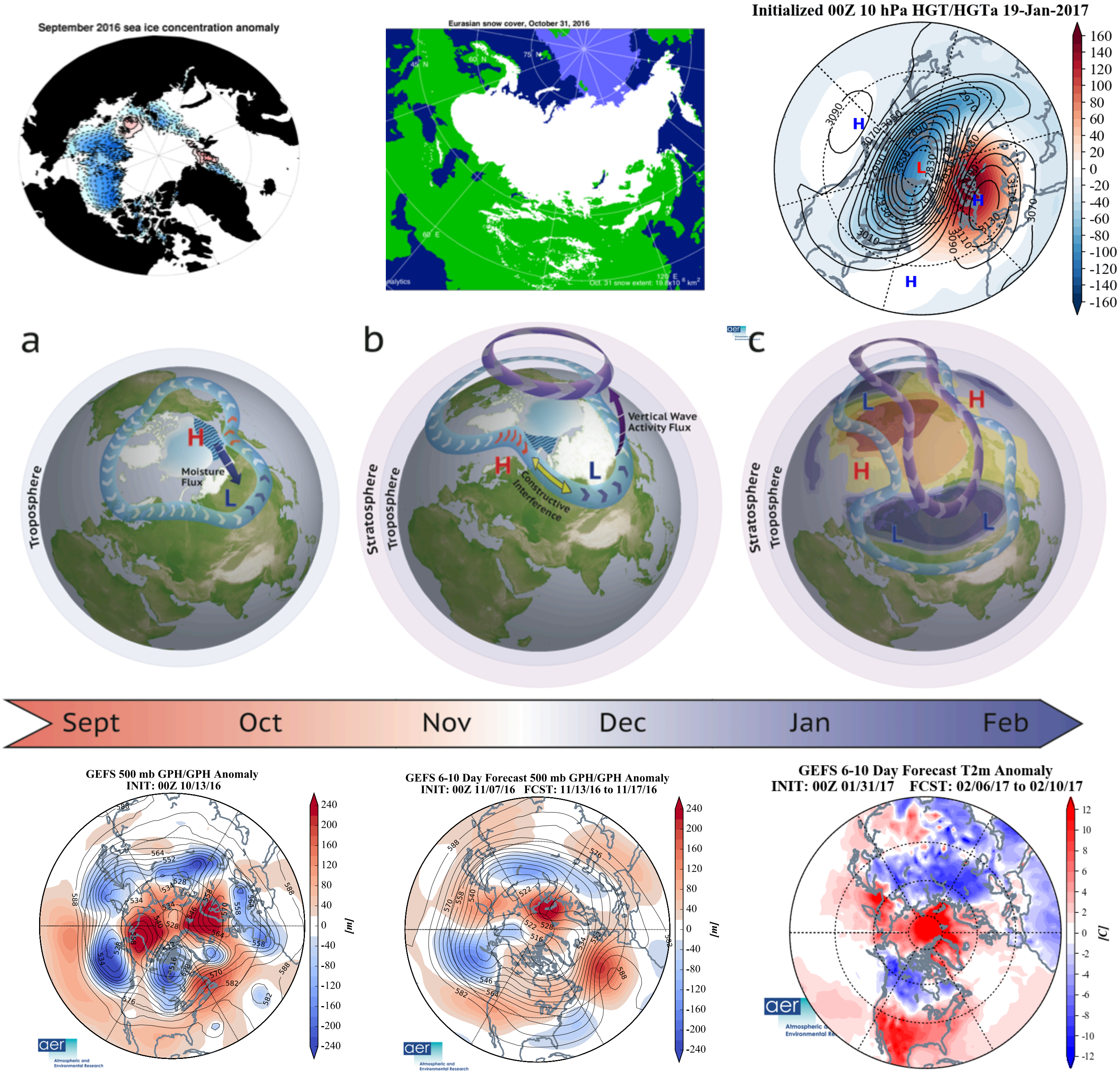
Some model runs forced with low sea ice have been able to simulate atmospheric response as observed.

Kim et al. 2014

Synthesis of Sea Ice and Snow Cover



Cohen et al. 2014 Review paper



September 2016 sea ice concentration anomaly
Eurasian snow cover, October 31, 2016
Oct. 31 snow extent: 19.8x10⁶ km²
Initialized 00Z 10 hPa HGT/HGTa 19-Jan-2017
[dam]
a
b
c
Troposphere
Stratosphere
Moisture Flux
Vertical Wave Activity Flux
Constructive Interference
H
L
Sept
Oct
Nov
Dec
Jan
Feb
GEFS 500 mb GPH/GPH Anomaly
INIT: 00Z 10/13/16
GEFS 6-10 Day Forecast 500 mb GPH/GPH Anomaly
INIT: 00Z 11/07/16 FCST: 11/13/16 to 11/17/16
GEFS 6-10 Day Forecast T2m Anomaly
INIT: 00Z 01/31/17 FCST: 02/06/17 to 02/10/17
[m]
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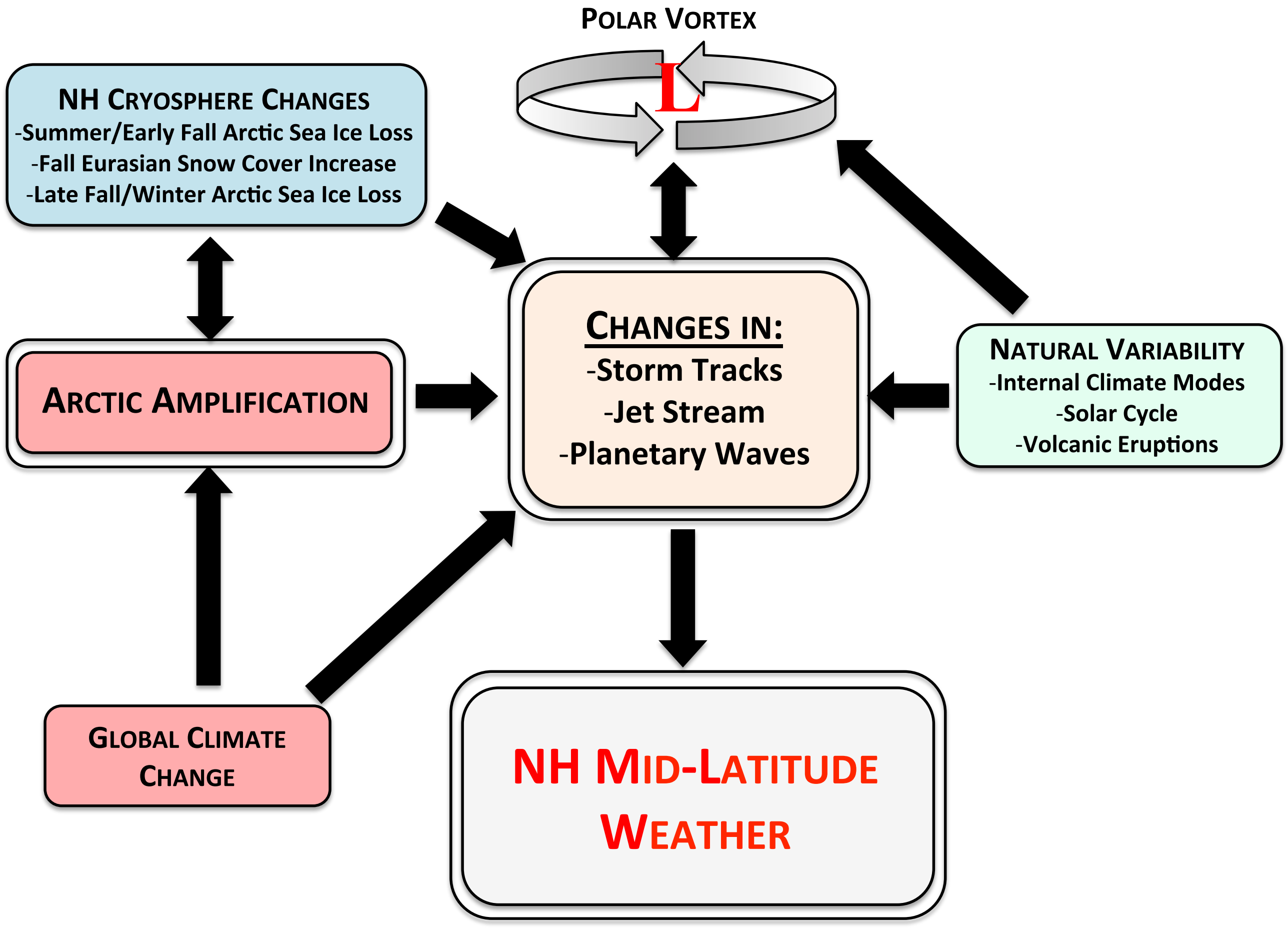
Atmospheric and Environmental Research

CHALLENGES- THEORY, OBSERVATIONS AND MODELS

Challenges with Data and Models

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

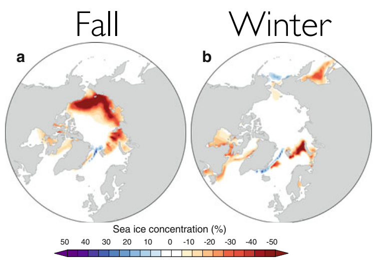
Mid-latitude Weather is Complicated



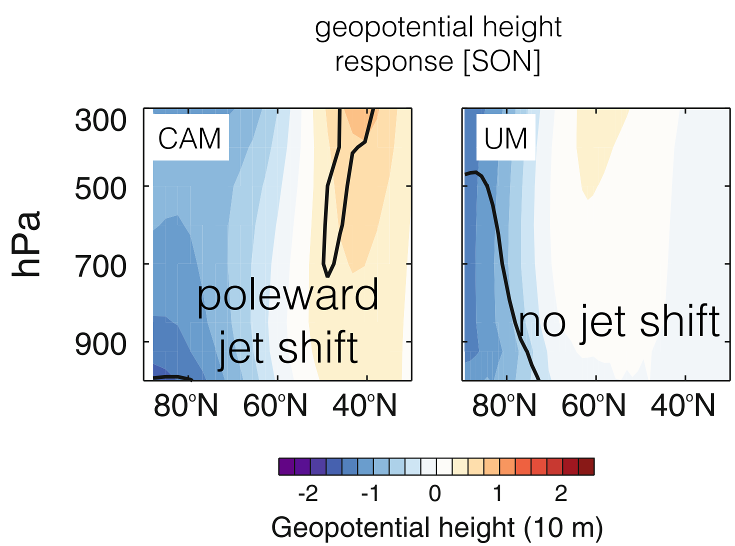
Cohen et al. 2014

Same sea ice forcing – different model response

Internal atmospheric variability is large

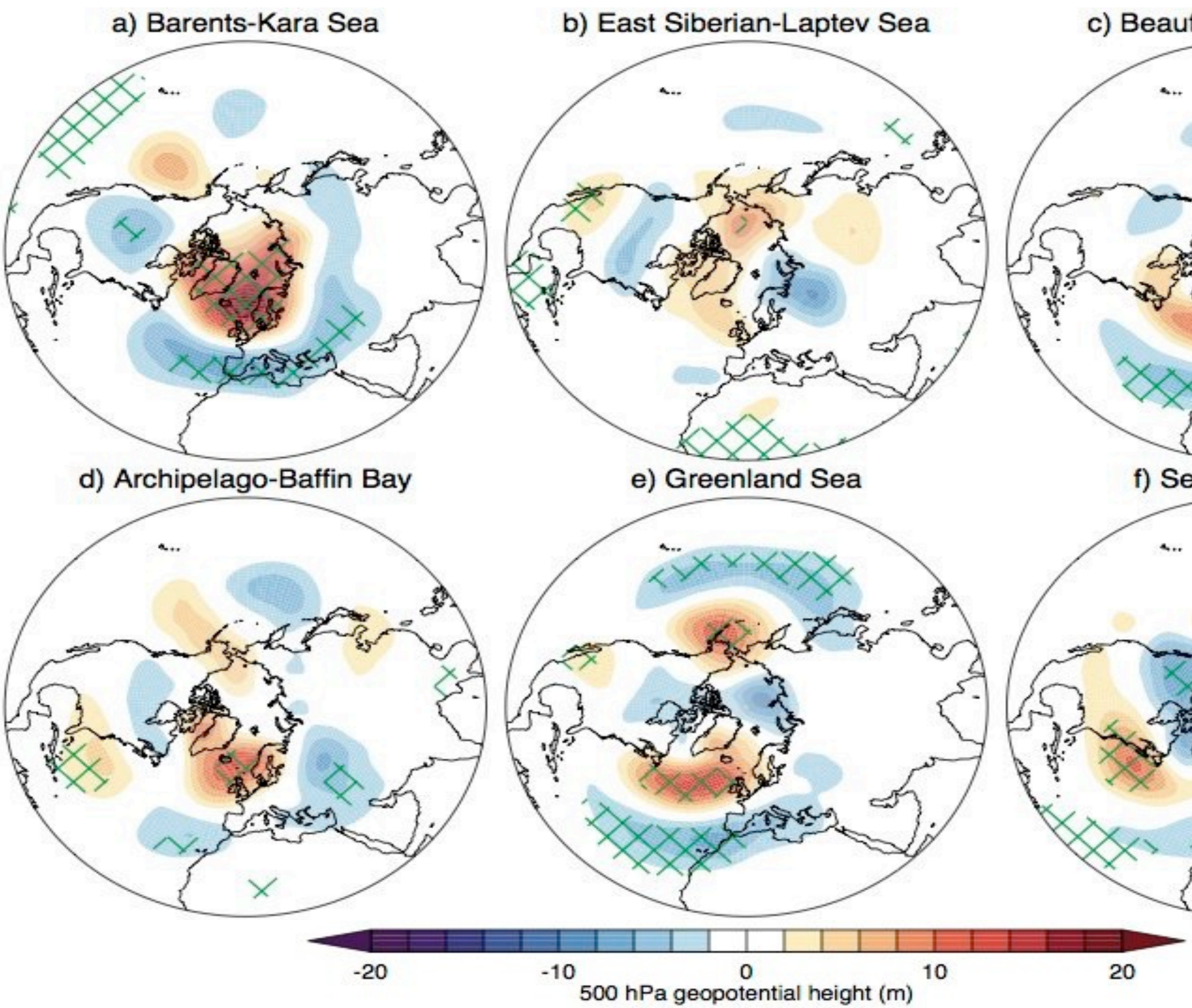


perturbed sea ice minus control (similar to 2009-1979)



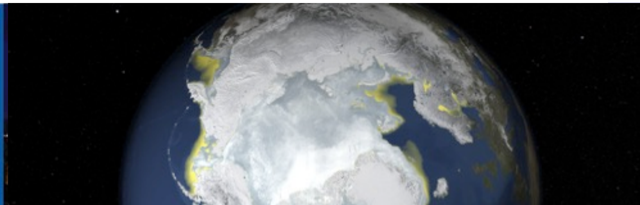
- AMIP experiments with high and low sea-ice concentrations based on observed trends (1979-2009)
- same forcing…different response!

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



UNIVERSITY OF EXETER

j.screen@exeter.ac.uk



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.
- It is a challenge to identify which extremes may or may not be influenced by AA.
- Still extreme weather is what the public is most concerned about.

NATURAL VARIABILITY

Recent Cold Winters not Well Simulated

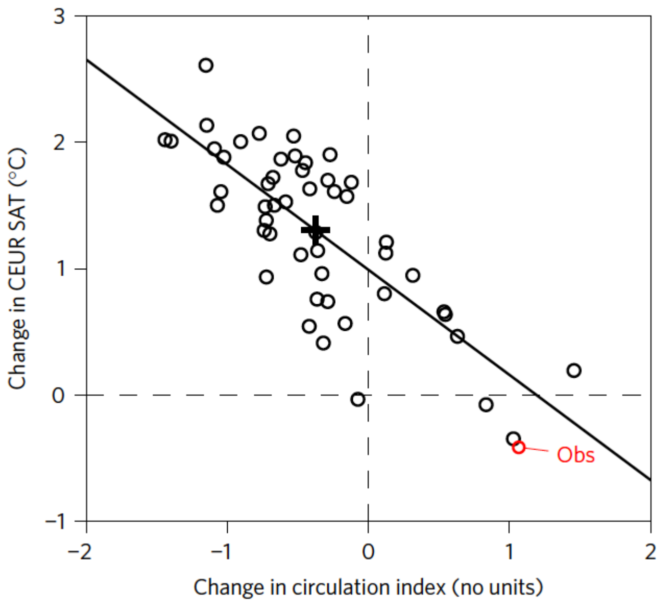


Figure 3 | Relationship of changes in observed and simulated circulation index to CEUR SAT changes. Changes from 1979–1989 to 2002–2012 for each AOGCM simulation (black) and for observed changes (red) in circulation index, ΔZ (ref. 25), and SAT[1]. The cross indicates the forced response (AOGCM mean), and the line indicates the AOGCM linear regression ($r = -0.77$ and $p < 0.0001$).

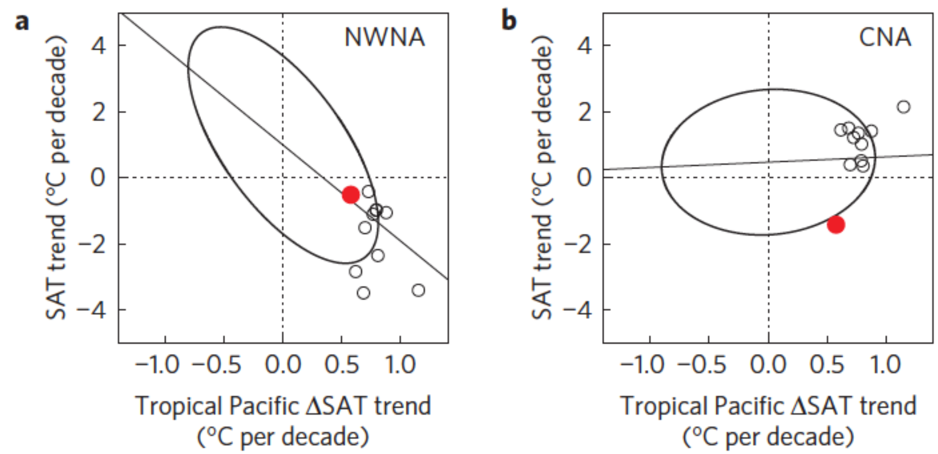
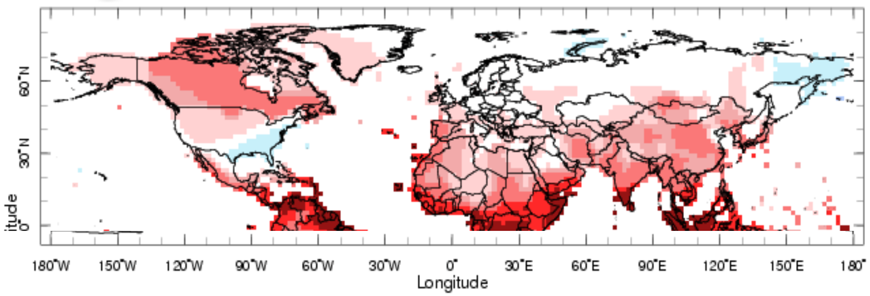


Figure 3 | Simulated and observed winter trends from 2001–2002 to 2013–2014 in North American SAT and the tropical Pacific SAT gradient. **a**,**b**, SAT trends averaged over northwest North America (**a**) and central North America (**b**) versus trends in the tropical Pacific ΔSAT. The red dot represents the observations. The trends in the ensemble of fully coupled model simulations are depicted by the ellipses (encompassing 95% of the ensemble members) and the straight line (representing the best linear fit). The open circles denote the trends in the pacemaker simulations.

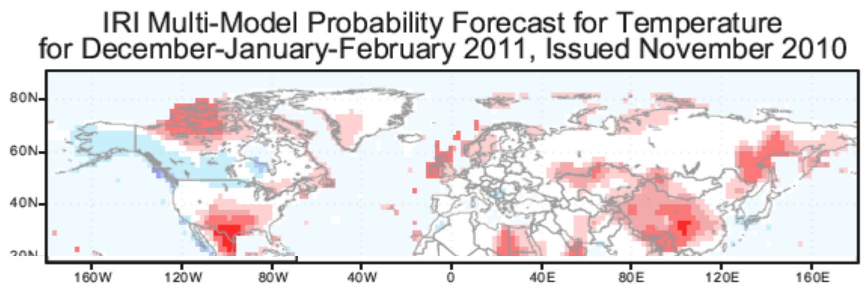
Central Asia (McCusker et al 2016)

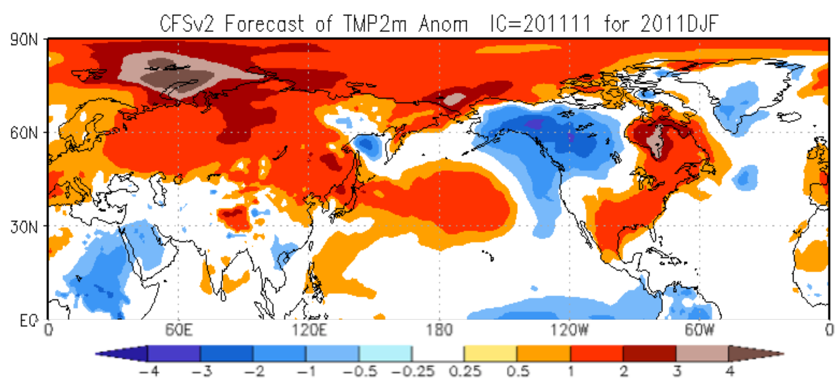
Central N America (Sigmond et al 2016)

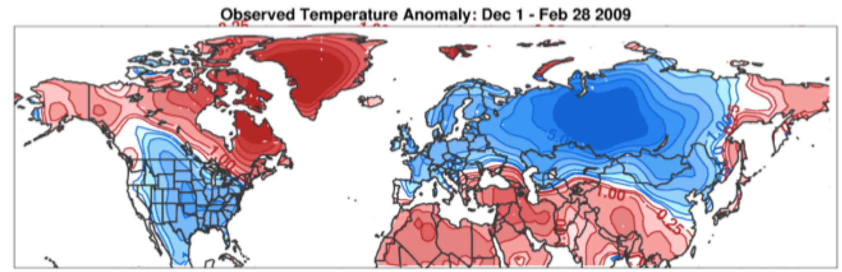
Dynamical Winter Forecasts 2009/10-15/16

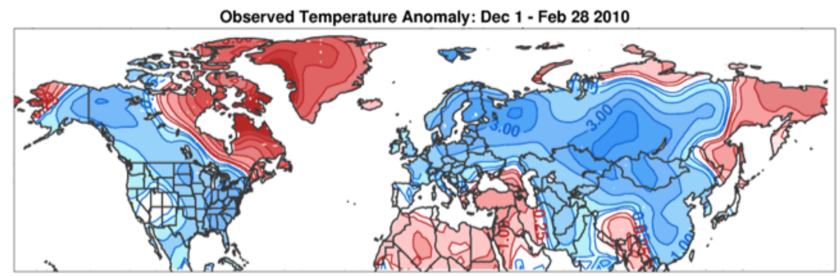


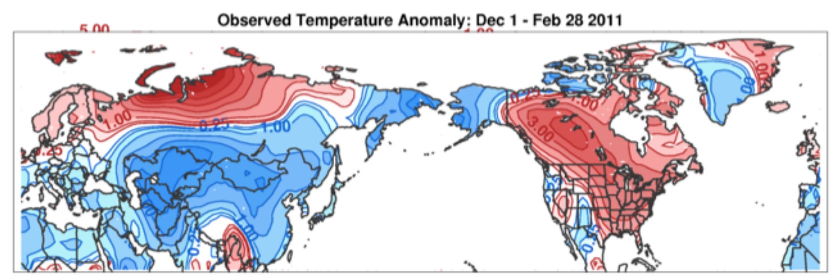
Dec 2009 - Feb 2010 IRI Seasonal Temperature Forecast issued Nov 2009

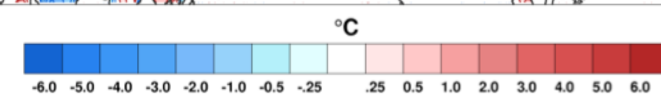




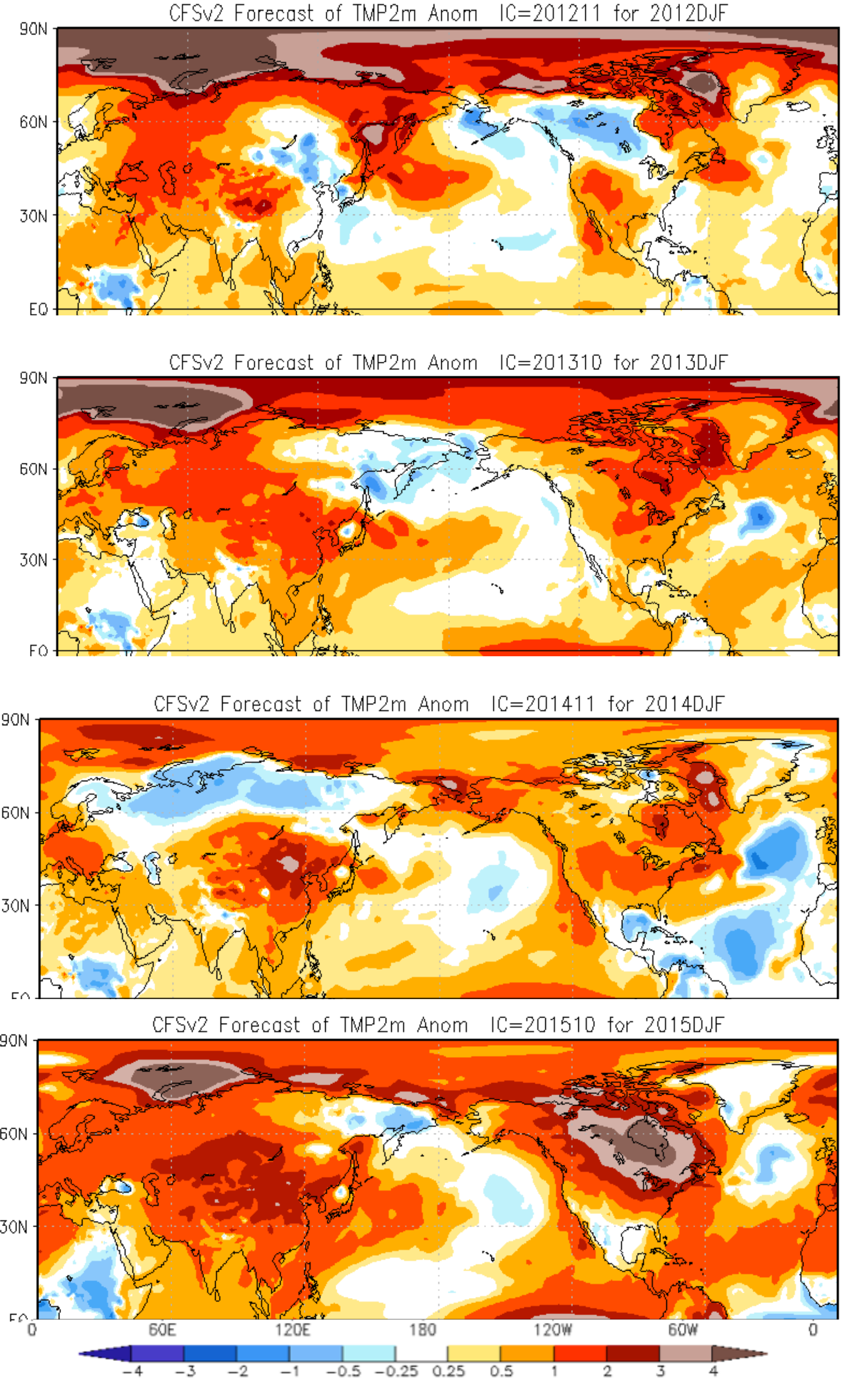


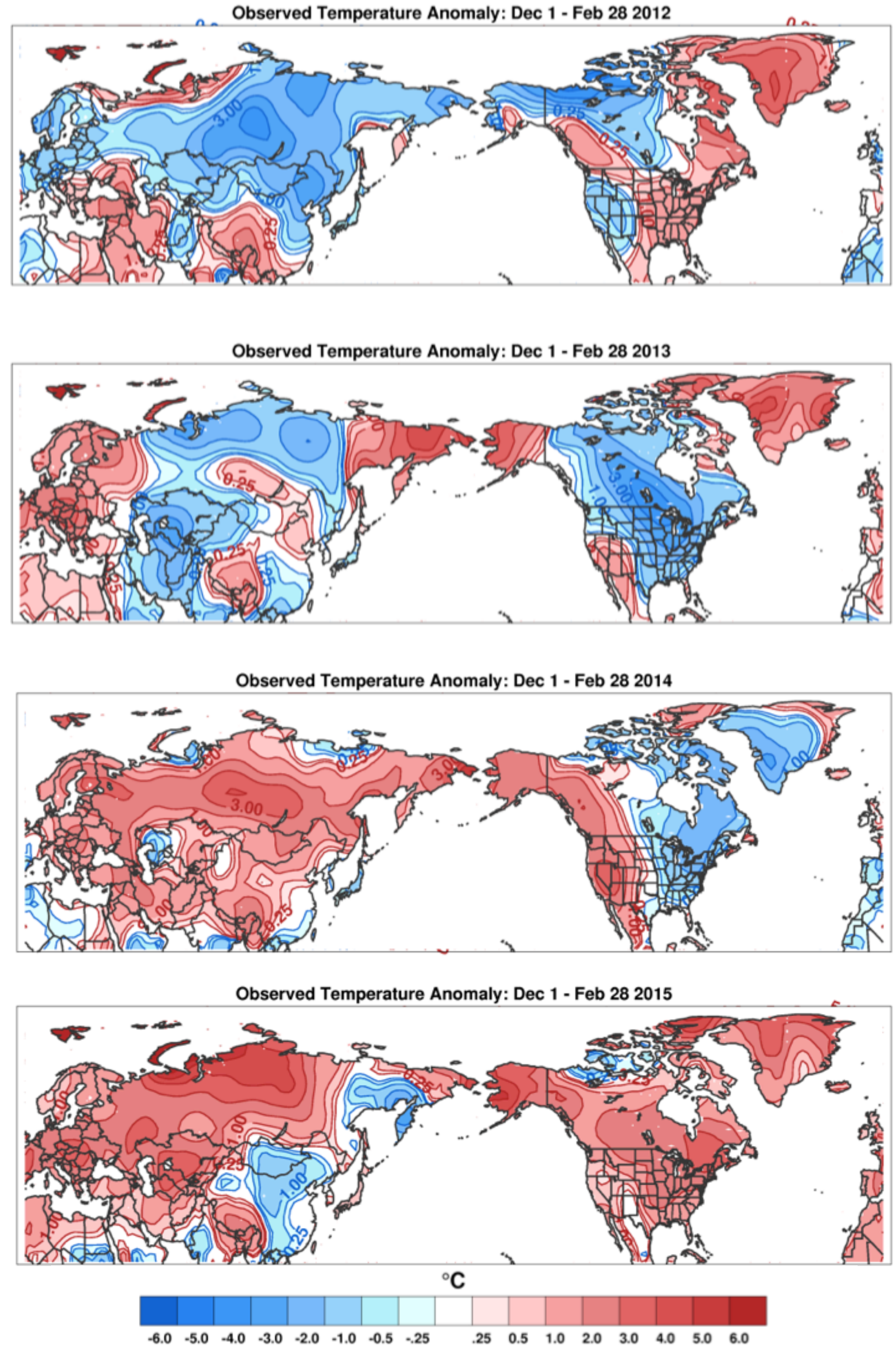






Models exhibit warm bias relative to observed winter temperatures.

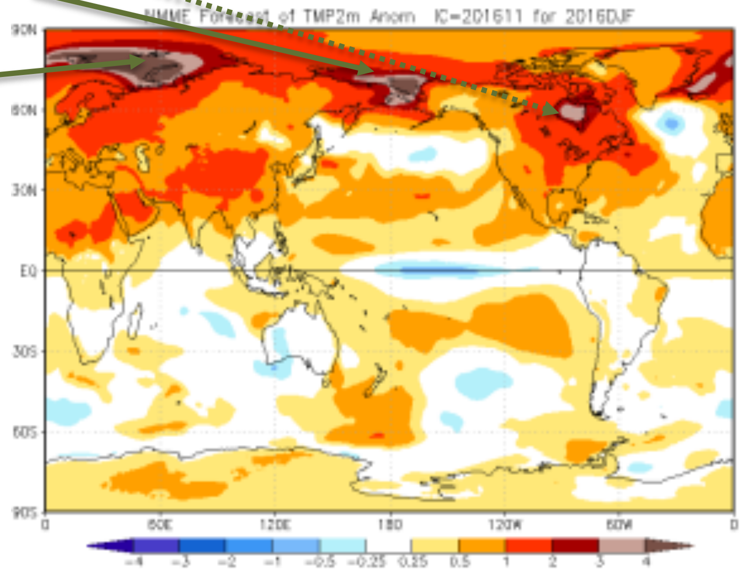

CFSv2 Forecast of TMP2m Anom IC=201211 for 2012DJF
CFSv2 Forecast of TMP2m Anom IC=201310 for 2013DJF
CFSv2 Forecast of TMP2m Anom IC=201411 for 2014DJF
CFSv2 Forecast of TMP2m Anom IC=201510 for 2015DJF
90N
60N
30N
EQ
0
60E
120E
180
120W
60W
0
−4 −3 −2 −1 −0.5 −0.25 0.25 0.5 1 2 3 4

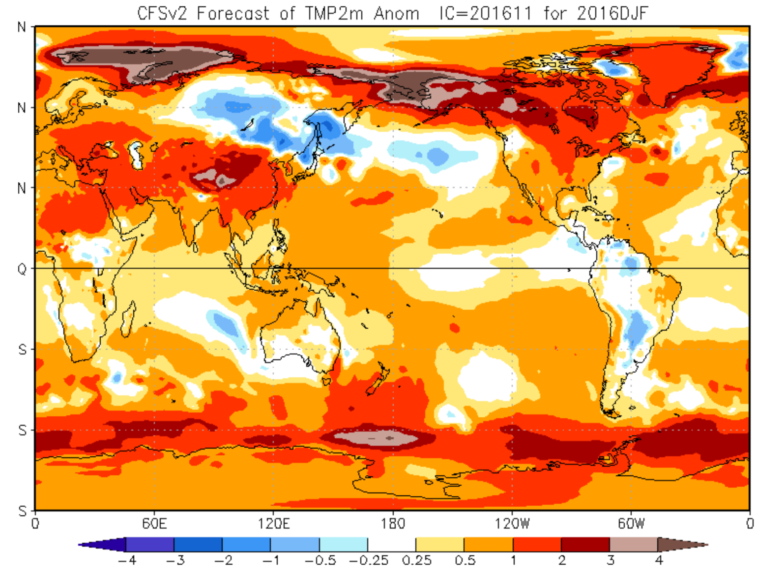

Observed Temperature Anomaly: Dec 1 - Feb 28 2012
Observed Temperature Anomaly: Dec 1 - Feb 28 2013
Observed Temperature Anomaly: Dec 1 - Feb 28 2014
Observed Temperature Anomaly: Dec 1 - Feb 28 2015
°C
-6.0 -5.0 -4.0 -3.0 -2.0 -1.0 -0.5 -.25 .25 0.5 1.0 2.0 3.0 4.0 5.0 6.0

Dynamical Winter Forecasts 2016/17

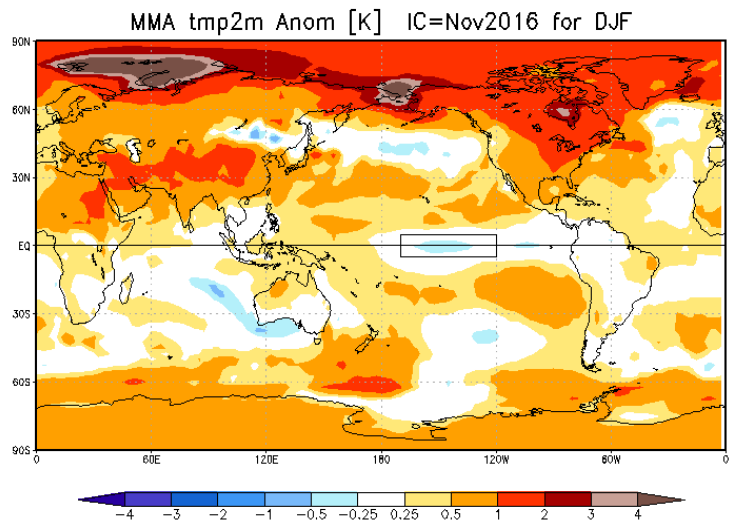
Triggers for/out of phase with continental temperature anomalies

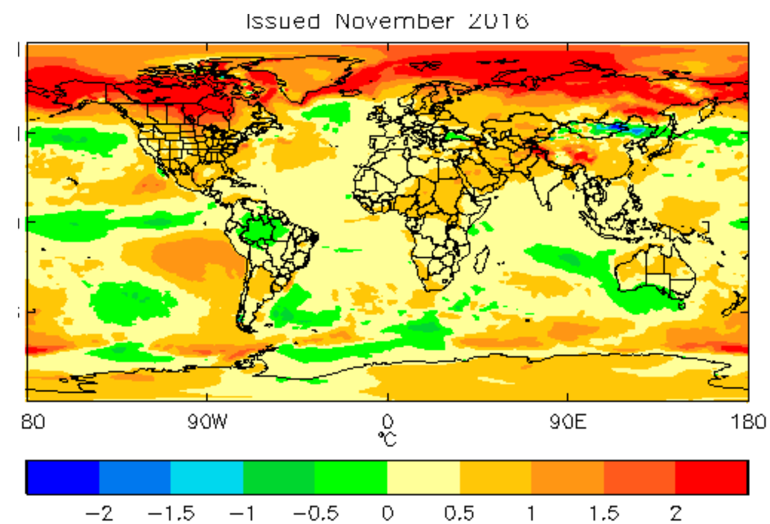
US Models



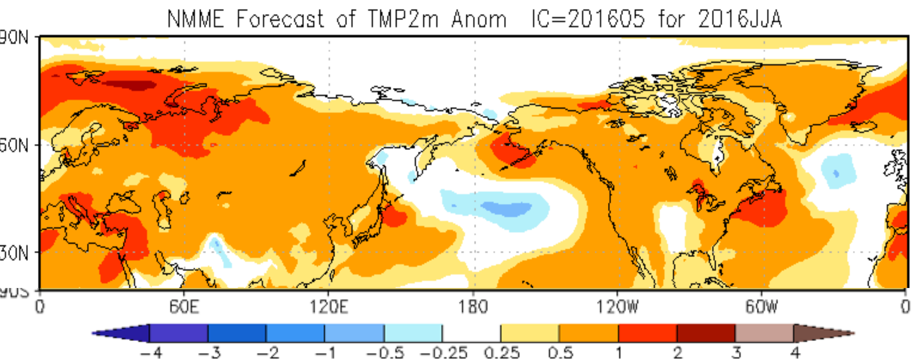


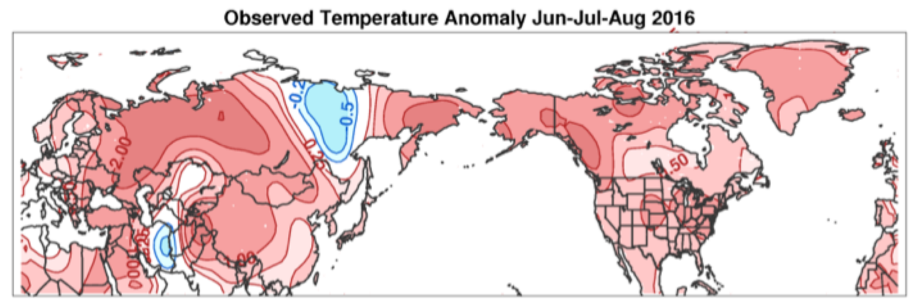
International/
European Models

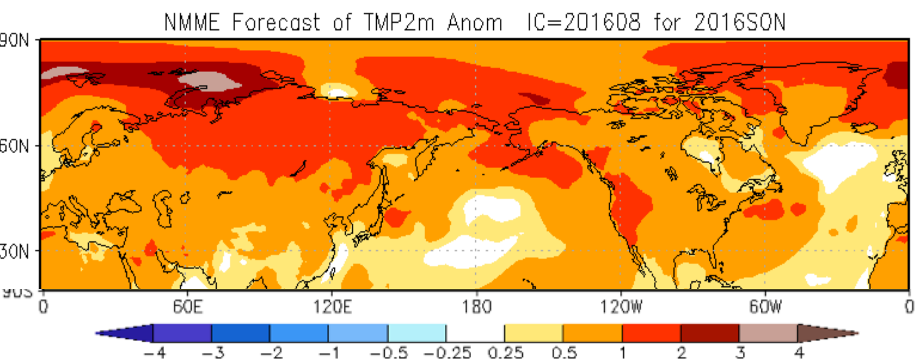


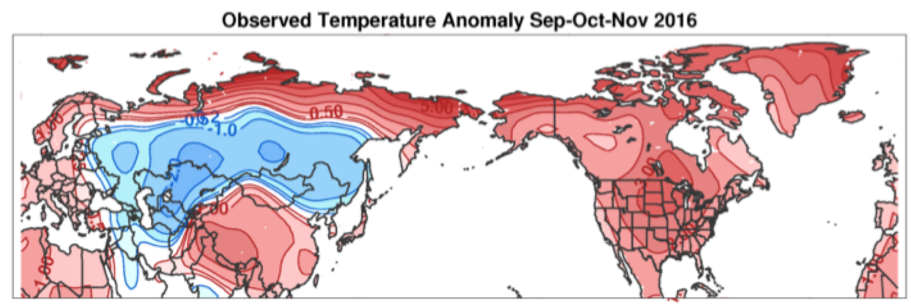


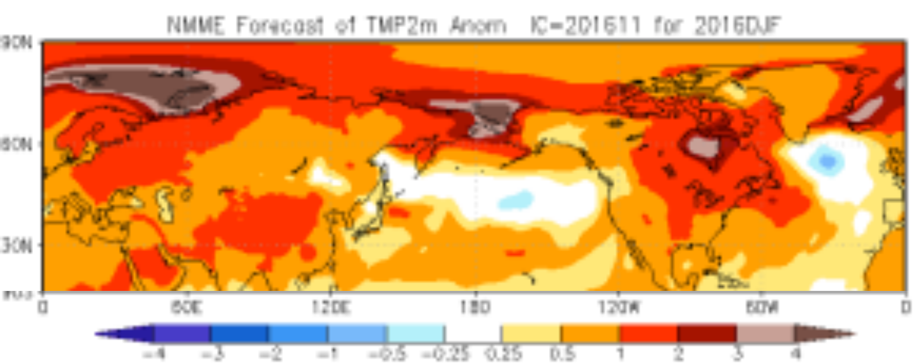
Dynamical Winter Forecasts 2016

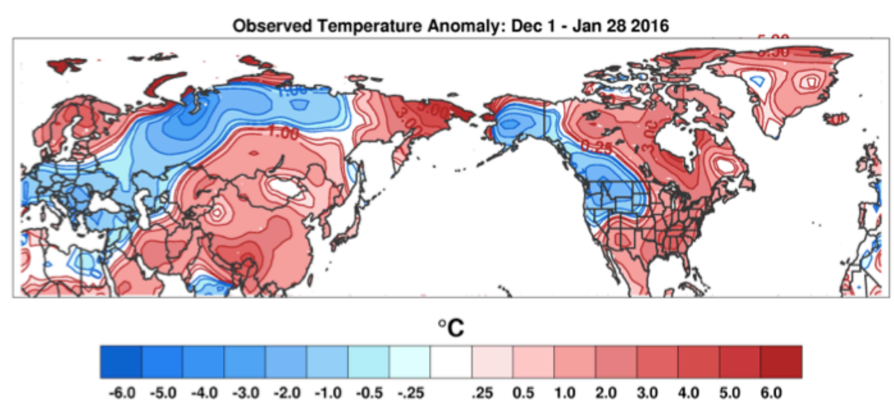




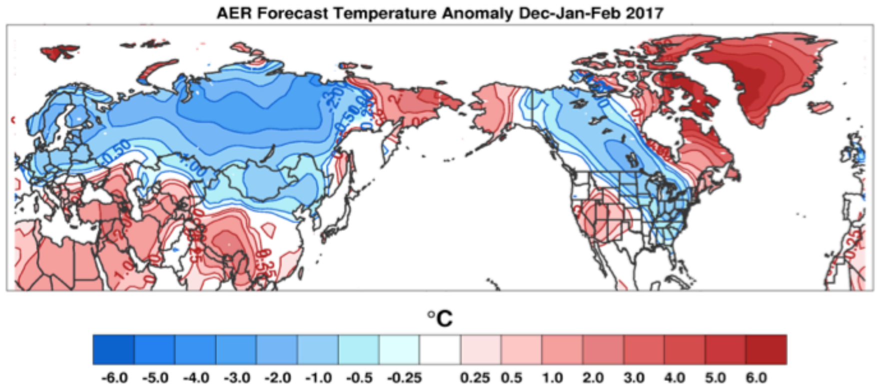


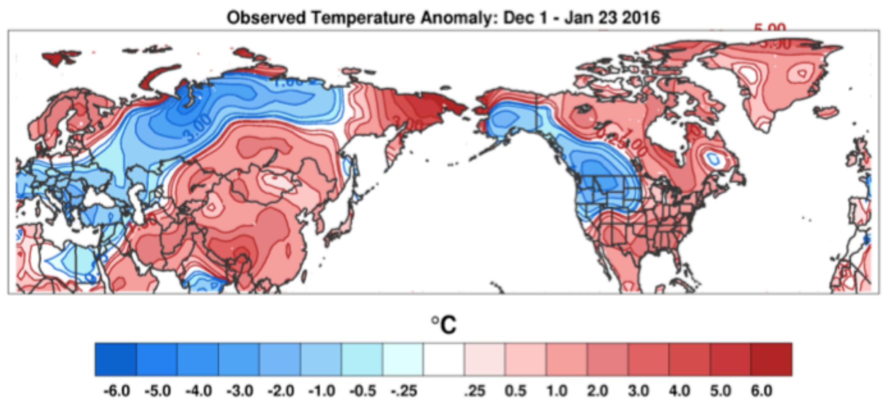


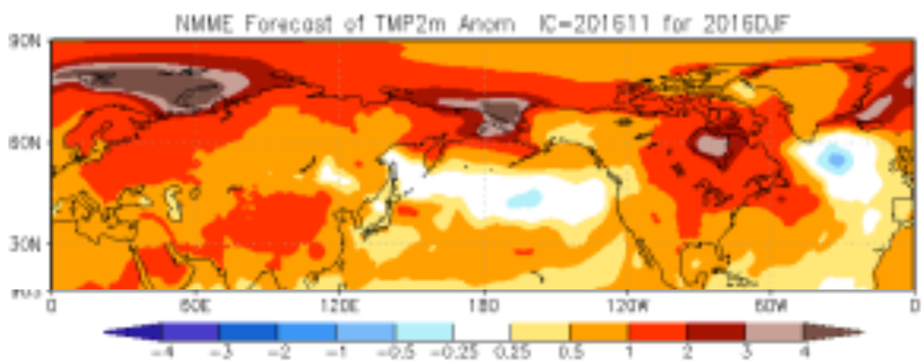




Winter Forecasts 2016







Is it Natural Variability?

- How to explain the dramatic temperature change from warm to cold from fall to winter, like an on/off switch?
- There is strong radiative forcing to warm the climate and the predictions were for winter amplification.
- The dynamical models have incorrectly predicted all as warm winters over continents.
- It is seven/eight years running of cold winters (obs vs. forecast), which less than 1% probability due to chance.
- Forecasts that are based on boundary forcings have performed better.
- The temperature anomalies for this fall/winter match long term trends and those theorized based on AA.

GOALS/REVIEW PAPER

Previous Workshops

- 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

Goals

- White Paper
- Review Paper
- Special Issue

- Put forth five ideas where we have made advances
  - Arctic hot spots/mid-latitude response

Review Paper

- Arctic rapid change
  - Thermodynamic forcing
  - Dynamic forcing
  - Teleconnection, i.e., Tropical forcing
- Arctic mid-latitude linkages – Focus on seasonal and regional linkages, sources of inconsistence, controversy, and uncertainties
  - Warm Barents-Kara Seas - Cold Eurasia
  - Warm Beaufort Sea – Cold North America
  - Slower Jet Stream
  - Greenland Blocking/ice sheet melt
  - More amplified waves/persistent weather
  - Summer extremes
- Next steps
  - Observations
  - Modeling

Arctic Mid-latitude Linkages

White paper outline --- To be refined/improved during the workshop

US CLIVAR Arctic-ML Linkage Workshop OC – Jennifer Francis, Thomas Jung, Ronald Kwok, James Overland, Xiangdong Zhang, Judah Cohen

Arctic rapid change – Emergence of new forcing (external and internal) for atmosphere circulation

1. Prominent Evidence: (1) amplification of warming - temperature trend divergence between high- and mid- latitudes; (2) acceleration of sea ice and snow decline (regionally and seasonally varying).
2. Thermodynamic forcing: (1) anthropogenic forcing – downwelling longwave radiation; (2) albedo feedback - induced by sea ice and snow retreat; (3) greater water vapor including local and remote sources; (4) increasing ocean heat content.
3. Dynamic forcing: (1) atmospheric circulation change – local and hemispheric; (2) poleward heat transport in atmosphere and ocean; (3) poleward moisture transport and cloud radiative forcing.
4. Teleconnection: Tropical forcing – convection induced changed in atmospheric circulation.
5. Consequence: Changes in SLP, geopotential height, polar vortex.

Arctic mid-latitude linkages – Focusing on seasonal and regional linkages and emphasizing on sources of inconsistence, controversy, and uncertainties of existing studies

1. Observations: (1) seasonal climate - anomalously cold winter and hot summer; (2) extreme events – statistics of cold spells, heat waves, floods, and droughts.
2. Most studied/proposed mechanisms – (1) in depth review of mechanisms ranked by consensus; (2) uncertainties due to metrics and analysis approaches employed.
3. Warm Barents Kara Seas – cold Eurasia
   a) Northwestward expansion and strengthened Siberian high
   - Due to low sea ice
   - Due to high Eurasian snow cover
   - Rossby wave train
   - Enhanced poleward heat flux

   b) Weakened polar vortex
   c) Spatial shift of hemispheric atmospheric circulation
   d) Changes in storm track dynamics
4. Warm Beaufort Sea/Bering Strait – cold North America
   a) Rossby wave train
   b) Slower zonal Jet Stream and amplified waves – persistent circulation pattern
   c) Greenland Blocking - Greenland Ice sheet melt
5. Alteration or modulation by tropical and extratropical forcing – e.g., ENSO, AMOC, PDO

Next steps – recommendations

1. Observations
   a) Forcing data sets available to investigate Arctic-midlatitude linkage
   b) Arctic air-ice-sea interaction – pathways of Arctic forcing signals into hemispheric atmospheric circulation
   c) Metrics to identify forced signals of atmospheric circulation from natural variability

2. Modeling
   a) Uncertainties caused by Experiment design and forcing prescription
   b) Uncertainties caused by model systematic errors
   c) Coordinated experiments

Summary

- The globe is warming with the past three years the warmest in the observational record.
- The Arctic is warming two to three times as fast as the rest of the globe (AA) in part due to melting sea ice and snow cover and heat/moisture transport.
- Concurrently it appears that extreme weather has been increasing.
- Theories exist linking AA to mid-latitude weather including extreme weather.
- Natural variability, observational limitations and model shortcomings make this a difficult problem.
- Correct understanding/simulation of cryosphere coupling remains a challenge but presents great opportunities and our hope that this workshop will make a significant contribution to future progress.