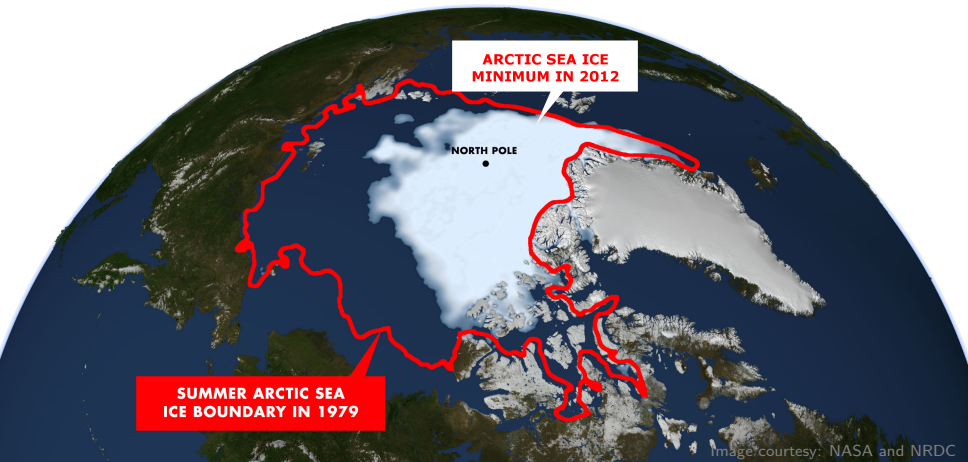


# Dynamics and predictability of atmospheric response to reduced Arctic sea ice through ensemble sensitivity analysis

Hans Chen and Fuqing Zhang

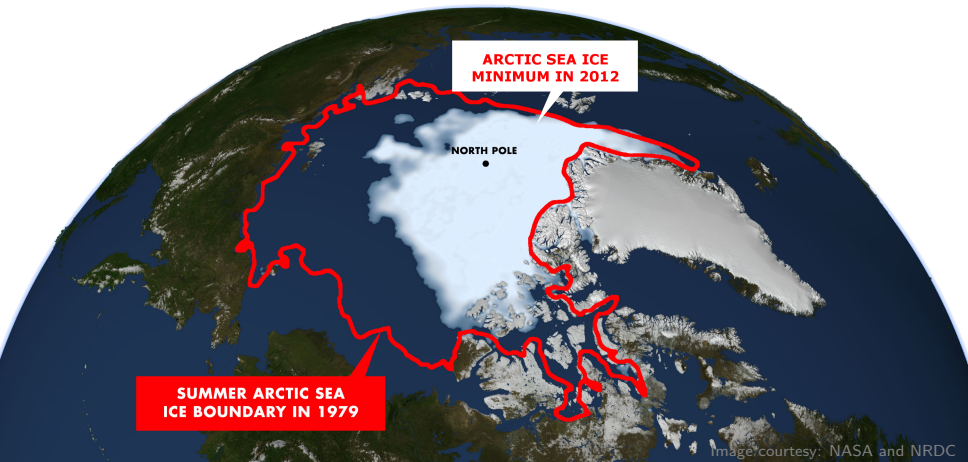
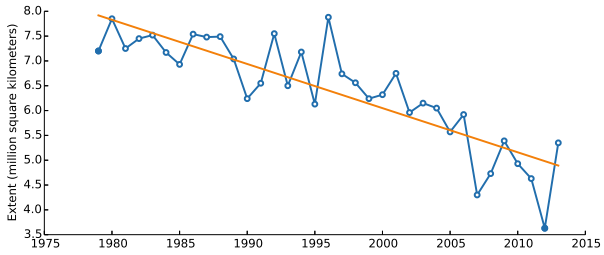
Department of Meteorology  
The Pennsylvania State University

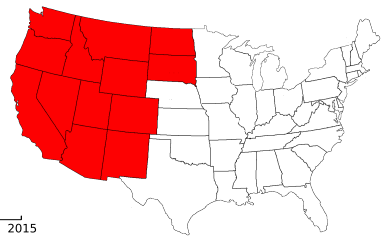
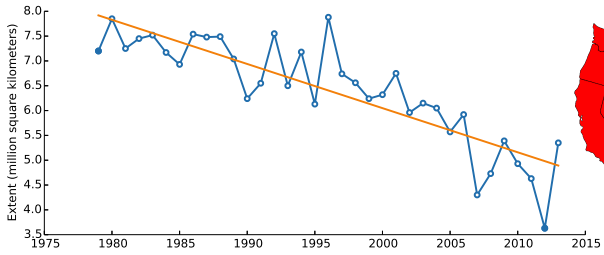


**ARCTIC SEA ICE  
MINIMUM IN 2012**

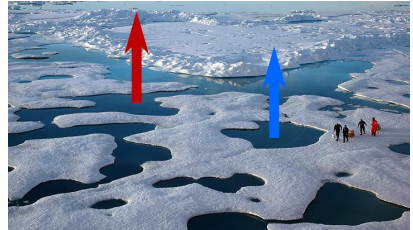
**NORTH POLE**

**SUMMER ARCTIC SEA  
ICE BOUNDARY IN 1979**





# Why should you care?



## Melting Arctic sea ice could be altering jet stream

More studies look at links to extreme weather.

by Scott K. Johnson - Dec 11 2013, 1:30pm EST

EARTH SCIENCE 78

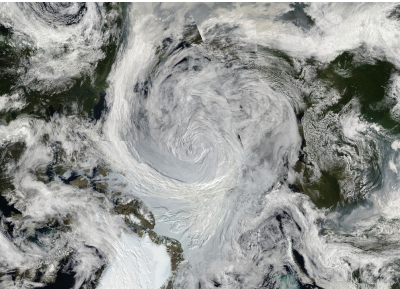
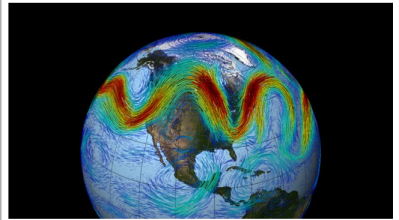
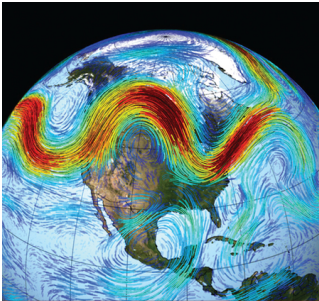


Image courtesy: NASA and NOAA

Article from: Ars Technica

# What do we know?



## Linkages Between Arctic Warming and Mid-Latitude Weather Patterns

Summary of a Workshop

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES

“... research on these linkages is still in its infancy, making it difficult to draw conclusions regarding their existence or their mechanisms.”

“... the large natural variability of the atmosphere and Arctic sea ice makes attribution difficult.”

# Key questions

- What local and remote atmospheric responses in autumn and winter can be attributed to Arctic sea ice loss?
- How sensitive is the atmospheric response to varying amounts of reduced sea ice?
- Does Arctic sea ice loss have a consistent impact on the large-scale circulation?

One-sentence summary:

The atmospheric response in the region of sea ice loss is robust and approximately linear; however, the remote response is highly non-linear and sensitive to the sea ice perturbation.



# Key questions

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One-sentence summary:

The atmospheric response in the region of sea ice loss is robust and approximately linear; however, the remote response is highly non-linear and sensitive to the sea ice perturbation.



# Approach

- NCAR Community Atmosphere Model (CAM 5.3)
  - $1.9^\circ \times 2.5^\circ$  latitude-longitude grid
  - 30 vertical levels up to 3.6 mb
  - Prescribed sea ice and sea surface temperature
- Main contribution: ensemble of seven sea ice scenarios
  - 55 members for each ice scenario with different initial conditions
  - In total 385 ensemble members

NCAR | CESM  
UCAR | COMMUNITY EARTH SYSTEM MODEL

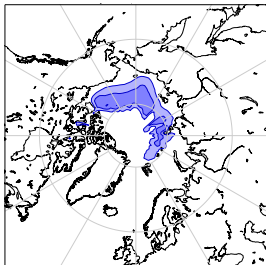


# Sea ice scenarios



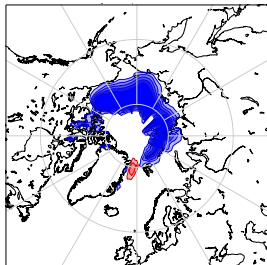
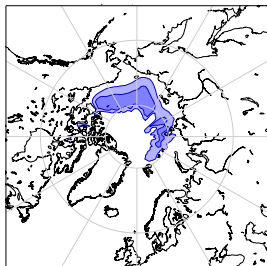


# Sea ice scenarios

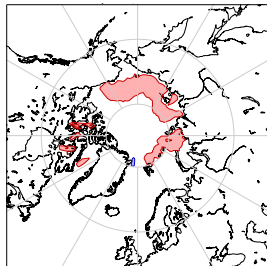
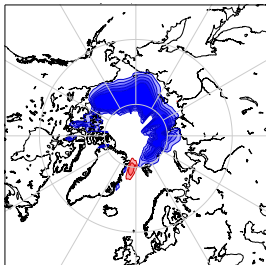
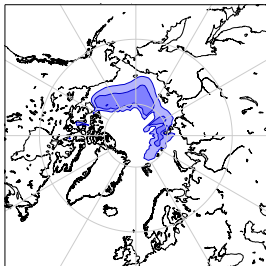




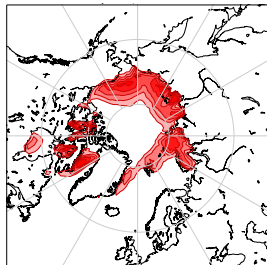
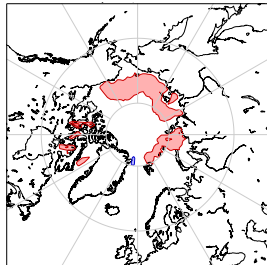
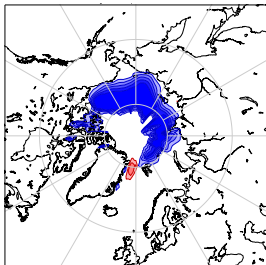
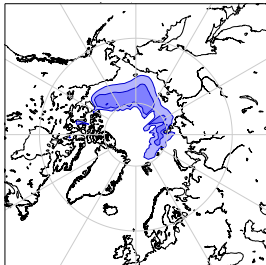
# Sea ice scenarios



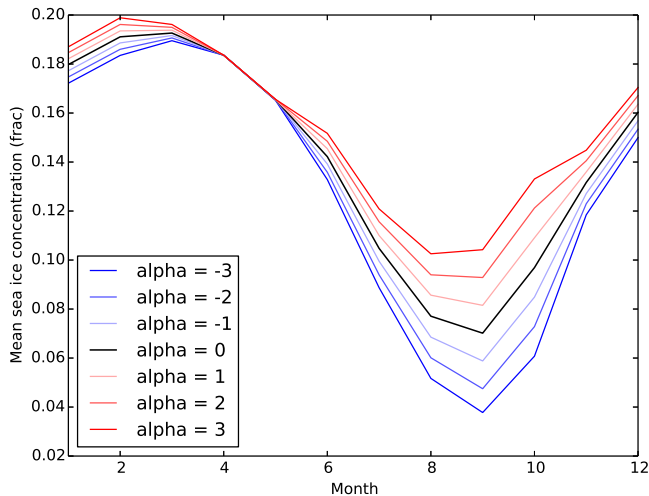
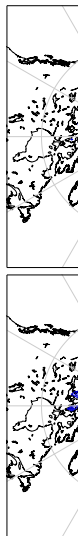
# Sea ice scenarios



# Sea ice scenarios



# Sea ice scenarios



Smaller  $\alpha$  = more and faster ice melt

# Atmospheric response

Previous questions:

- What local and remote atmospheric responses in autumn and winter can be attributed to Arctic sea ice loss?
- How sensitive is the atmospheric response to varying amounts of reduced sea ice?

## Method

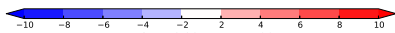
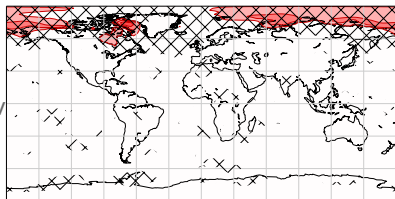
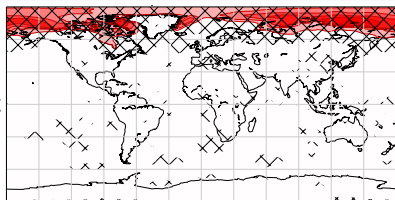
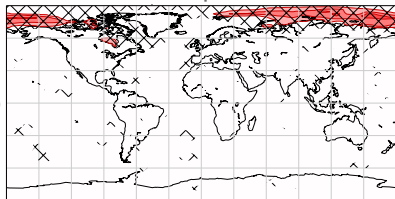
Ensemble mean difference, significance from a two-sided Student's t-test.

Correlation between atmospheric response and the sea ice perturbation  $\alpha$ .

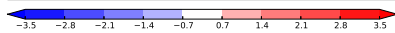
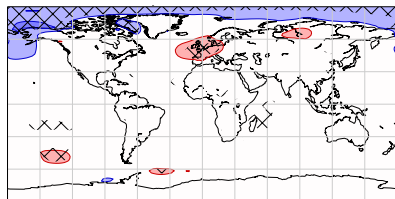
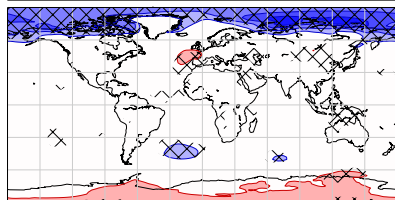
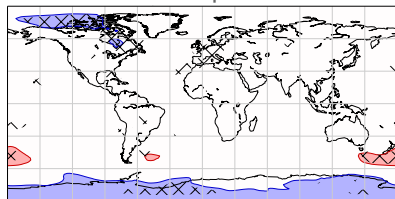


# Ensemble mean difference, autumn

## 2-m temperature

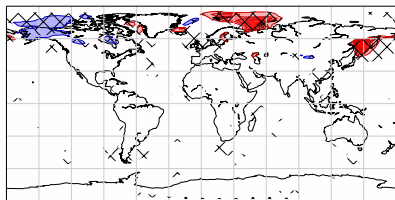
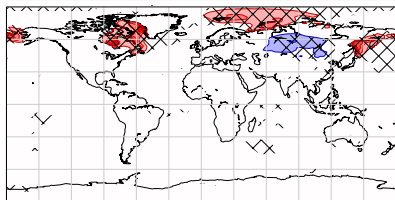
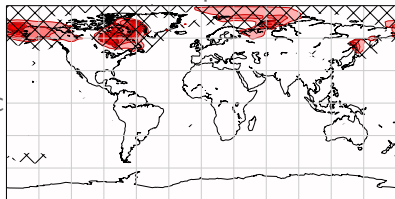


## Sea-level pressure

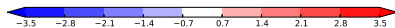
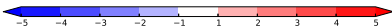
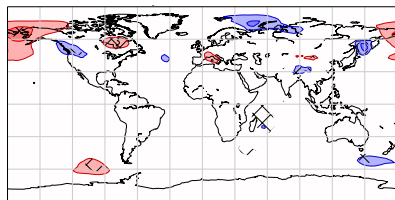
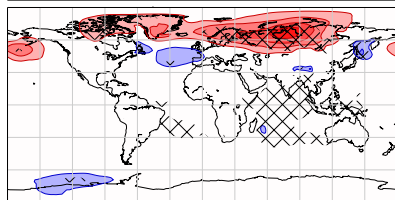
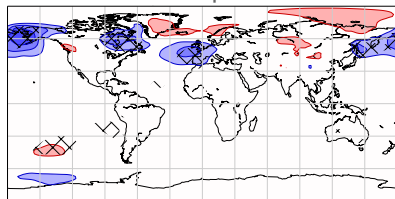


# Ensemble mean difference, winter

## 2-m temperature



## Sea-level pressure

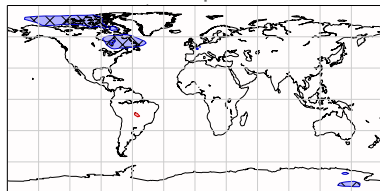
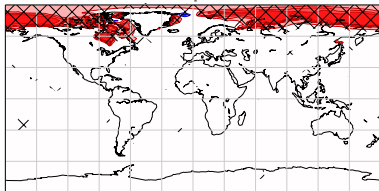


# Correlation with $\alpha$ , autumn

## 2-m temperature

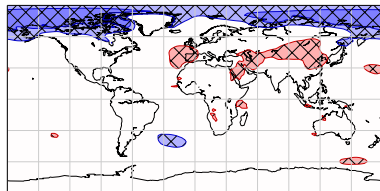
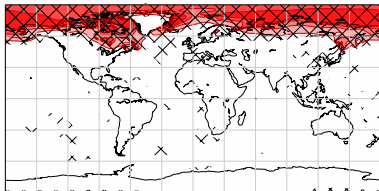
## Sea-level pressure

Sep



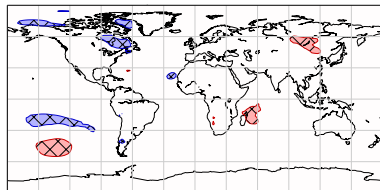
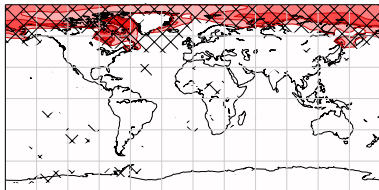
Sep

Oct

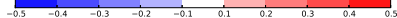
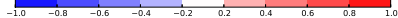


Oct

Nov



Nov

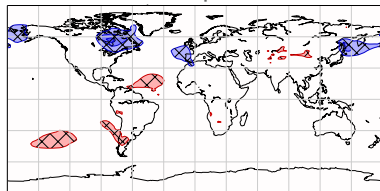
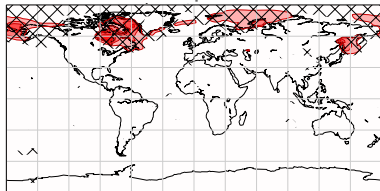


# Correlation with $\alpha$ , winter

## 2-m temperature

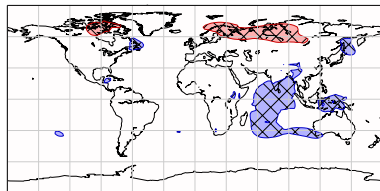
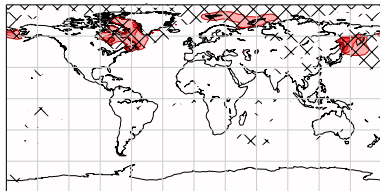
## Sea-level pressure

Dec



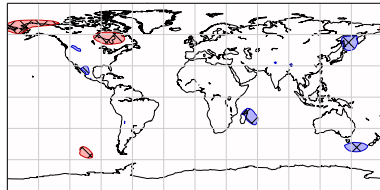
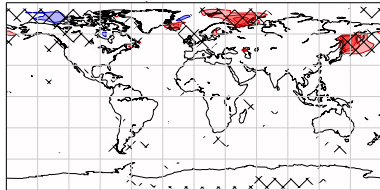
Dec

Jan

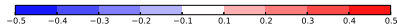
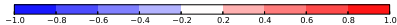


Jan

Feb



Feb



# Large-scale circulation

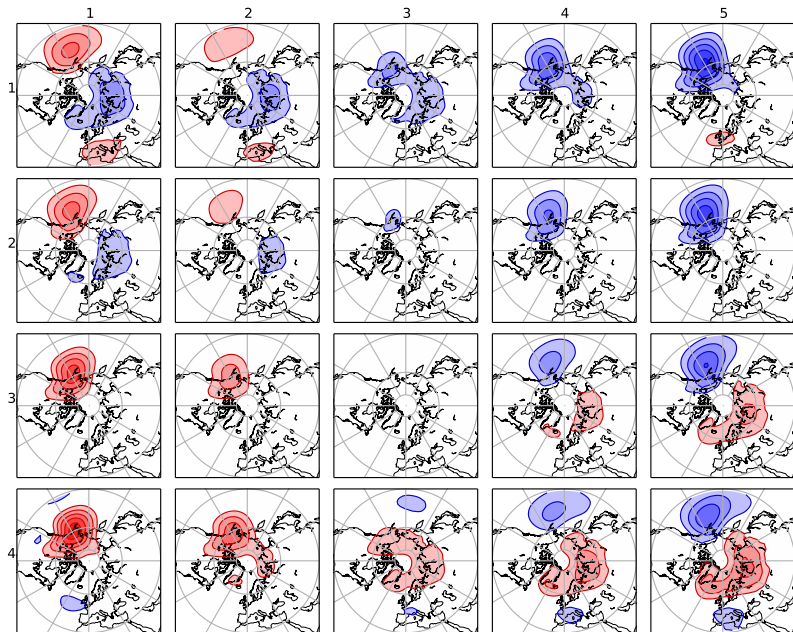
Previous question:

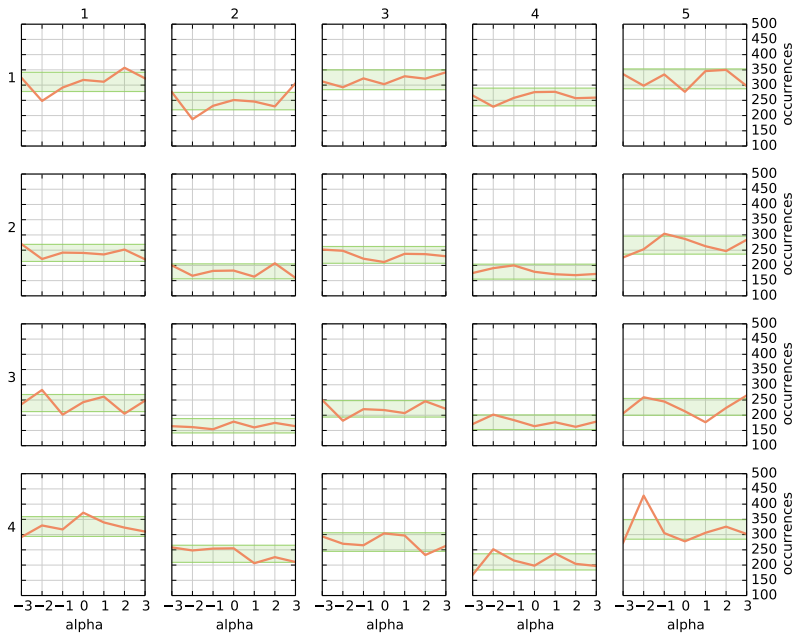
- Does Arctic sea ice loss have a consistent impact on the large-scale circulation?

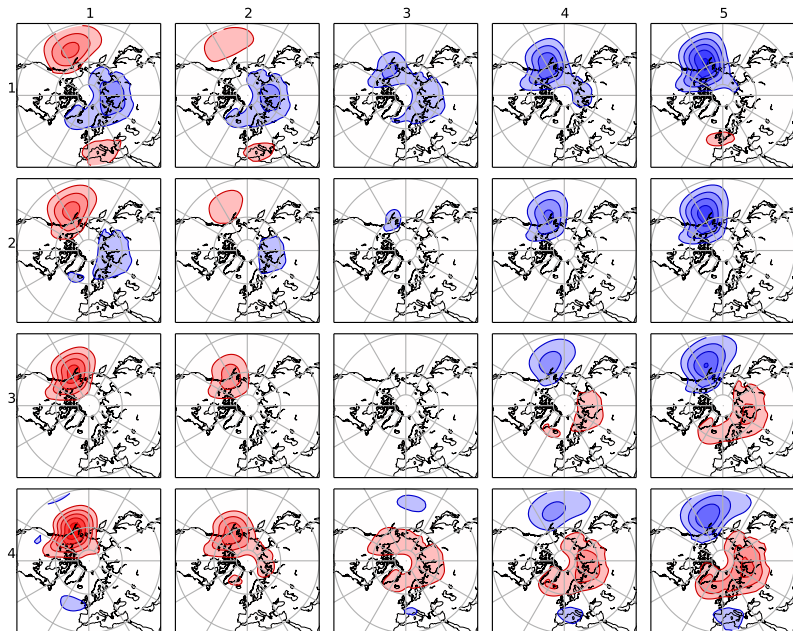
## Method

Categorize wintertime large-scale circulation from all ensemble members using self-organizing maps.

Count the occurrence of each pattern for the different sea ice scenarios.









# Conclusions

- The local atmospheric response to Arctic sea ice loss is robust, with a nearly linear increase in 2-m temperature and below normal sea-level pressure.
- There is an indication of cooler temperatures over Russia in January, associated with a high pressure system over northern Russia.
- The remote atmospheric response is generally small and not directly linearly related to the Arctic sea ice loss.
- Reduced Arctic sea ice may favor a negative Arctic Oscillation during winter, but it is highly dependent on the amount of sea ice loss.