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Nonlinear atmospheric response to Arctic sea-ice loss under different sea ice scenarios

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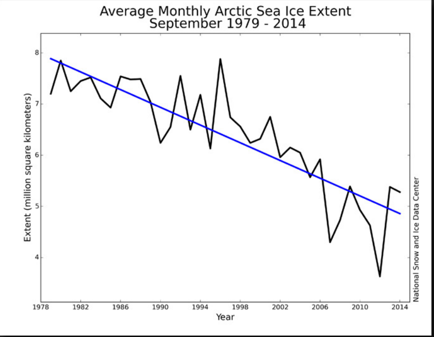
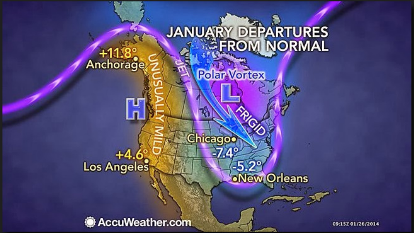
Will we get an unusually cold winter?

Melting Arctic ice may be driving this winter's chill

Cold winters tied to drop in Arctic sea ice

Wobbly polar vortex triggers extreme cold air outbreak





Reduced Arctic sea ice $\longrightarrow$ more cold extremes?

What is the nature of the link between Arctic sea-ice loss and

- the jet stream?
- mid-latitude atmospheric circulations?
- extreme cold events over the mid-latitude continents?

Approach – systematically decrease sea ice

10 different sea ice scenarios with systematically decreasing Arctic sea-ice coverage.

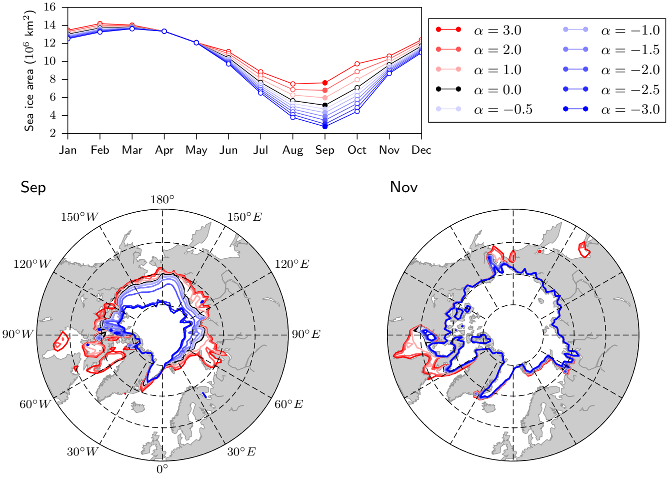
55 ensemble for each scenario, in total 550 simulations.

NCAR Community Atmosphere Model (CAM 5.3) with prescribed sea ice and sea surface temperature.

Horizontal resolution of $1.9^\circ \times 2.5^\circ$ and 30 vertical levels up to 3.6 hPa.

NCAR UCAR CESM COMMUNITY EARTH SYSTEM MODEL

Sea ice scenarios



1 climatological scenario

Climatological seasonal cycle was perturbed to obtain:

3 scenarios with above-average Arctic sea ice

6 scenarios with reduced sea ice

The thing to remember

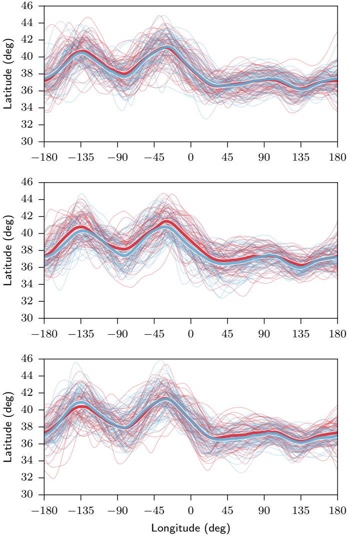
Smaller $\alpha \rightarrow$ smaller Arctic sea-ice coverage

Jet stream changes are small

1 and -1

2 and -2

3 and -3



Northern Hemisphere jet stream track in December.

Thin lines show the track of ensemble members and thick lines are the ensemble mean tracks.

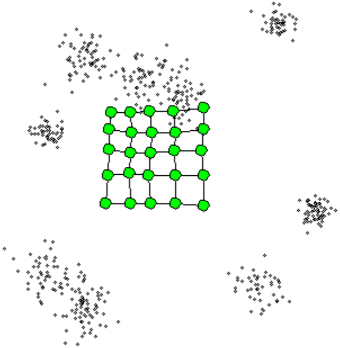
- Changes in mean jet stream position are small compared to ensemble spread
- No evidence of increased wave amplitude due to Arctic sea-ice loss
- Location of jet stream shifts are generally different between scenarios

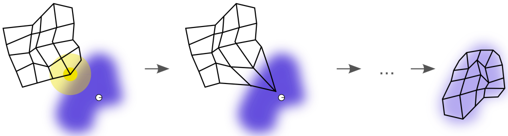
Atmospheric circulation clustered into 12 patterns

We clustered wintertime (DJF) sea-level pressure anomalies northward of 30°N into 12 patterns using a self-organizing map.

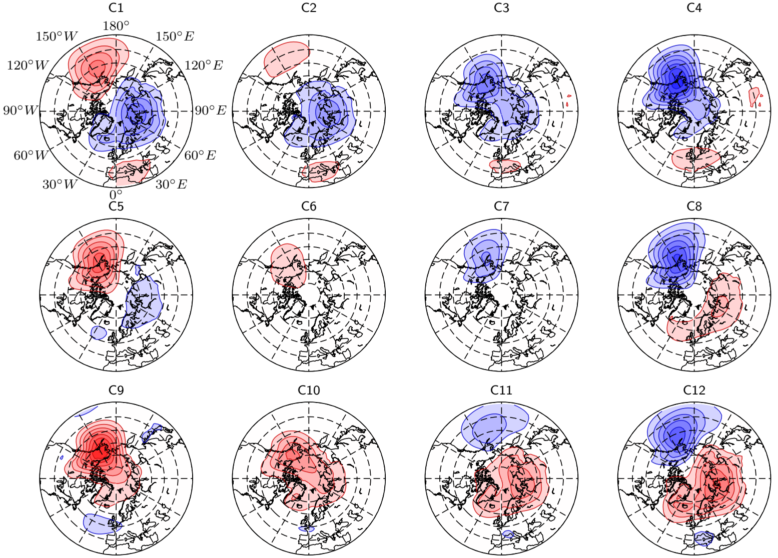
All sea ice scenarios were used in the training of the map.

We then counted the number of occurrences of each circulation pattern for each sea ice scenario.





Self-organizing map of wintertime circulation



Circulation patterns of sea-level pressure anomalies contoured every 2 hPa.

- C1 and C12 resemble the Arctic Oscillation
- C4 and C9 are related to the Pacific-North American pattern

Frequency of circulation patterns

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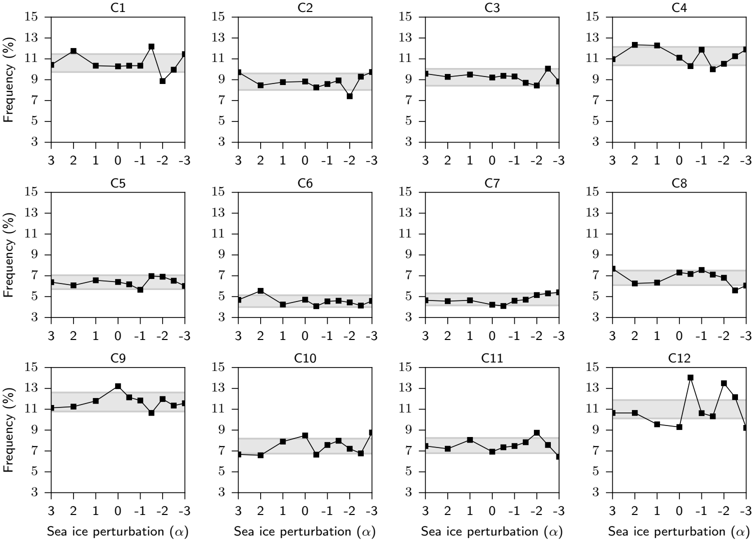
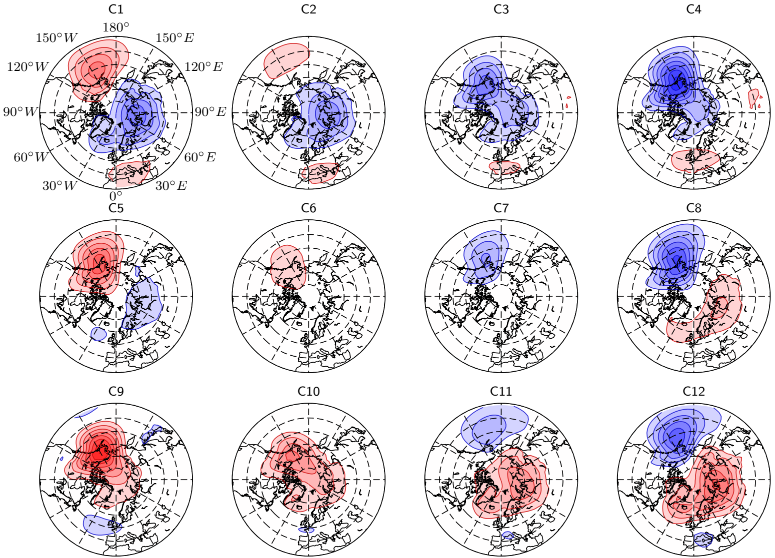


Frequency of circulation patterns as a function of Arctic sea-ice coverage.

Gray shading indicates insignificant changes.

- Significant increased frequency of C12 circulation pattern
- Decrease of C1 and C2 in the -2 scenario

Frequency of circulation patterns



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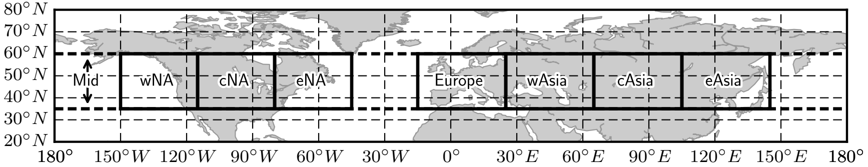
Extreme cold winters

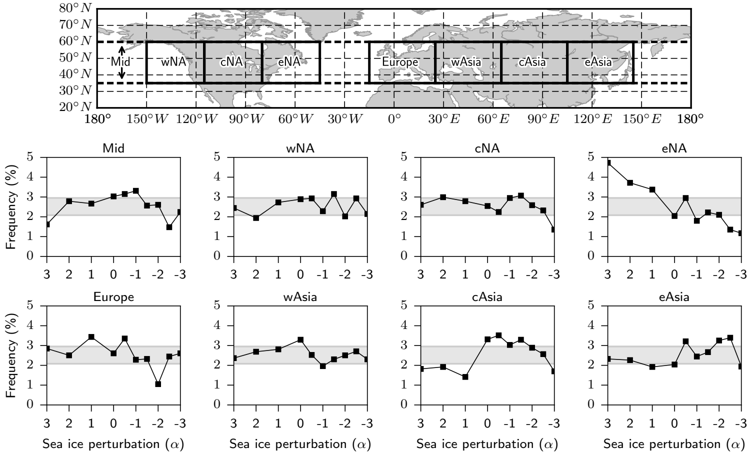


Mid-latitude continents divided into 8 regions.

Temperature index:
2-m temperature over land, area averaged over a region and smoothed using a moving average over 5 days.

Extreme cold event:
Winter days (DJF) when the temperature index falls below the 2.5th percentile from all scenarios for that day.

Frequency of extreme cold winter events



- Increased frequency of extreme cold events over central and eastern Asia
- Approximately linearly decreasing frequency in eastern North America
- Unchanged or decreased frequency of extreme cold events in all regions for the −3 scenario

Conclusions

- Atmospheric response in the mid-latitudes is strongly nonlinear with respect to Arctic sea-ice loss
- Reduced sea ice may favor a negative Arctic Oscillation during winter, but this response is sensitive to the amount of sea-ice loss
- The negative Arctic Oscillation-like circulation may lead to an increased frequency of extreme cold winter events over central and eastern Asia
- There is a general decrease of extreme cold events associated with severe sea-ice loss, most notably over eastern North America

Take-home message

Arctic sea-ice loss may lead to an increased frequency of cold winters in some regions; however, this link is strongly nonlinear and may change in the future.