The robustness of mid-latitude weather pattern changes due to Arctic sea ice loss

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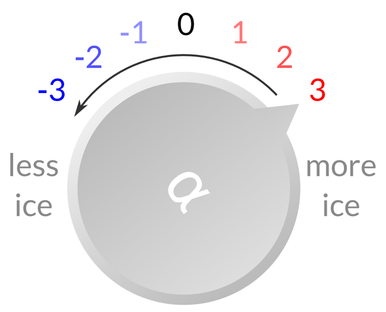
Question



What happens to the atmospheric response to Arctic sea ice loss when we gradually decrease the Arctic sea ice cover in a GCM?

Experimental setup

- NCAR Community Atmosphere Model 5.3.
- 10 sea ice scenarios, each starting from 55 initial conditions, yielding a total of 550 ensemble members.
- Horizontal resolution of 1.9° latitude $\times$ 2.5° longitude.
- Prescribed sea ice concentration and sea surface temperature fields derived from the HadISST dataset over the 1979–2013 period.

How were the sea ice scenarios created?

- **Step 1:** Perturb climatological mean seasonal cycle of Arctic sea ice area.

First perturb September sea ice area by a number of climatological standard deviations, denoted by α. Then perturb sea ice areas in other months based on observed persistence of sea ice area anomalies.

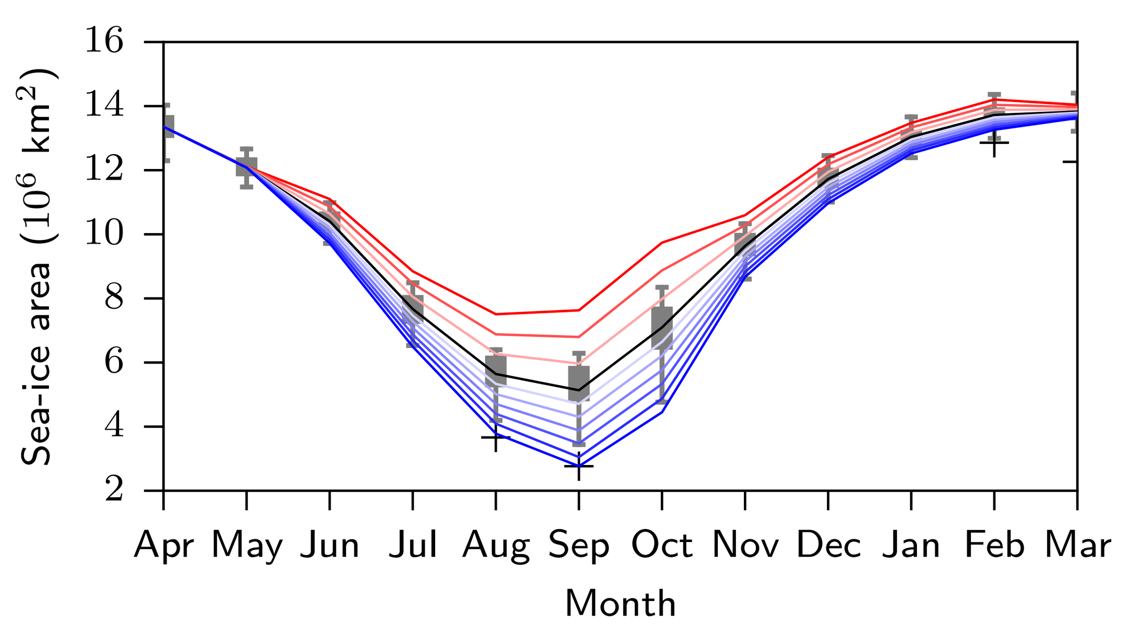


Fig. 1. Seasonal cycle of sea ice area for α ranging from 3 (red) to -3 (blue). The climatological mean seasonal cycle is shown in black.

- **Step 2:** Find sea ice concentration fields in the climatological mean seasonal cycle that correspond to the desired sea ice areas.

Sea ice concentration fields with smaller sea ice areas approach the September 2012 sea ice conditions.

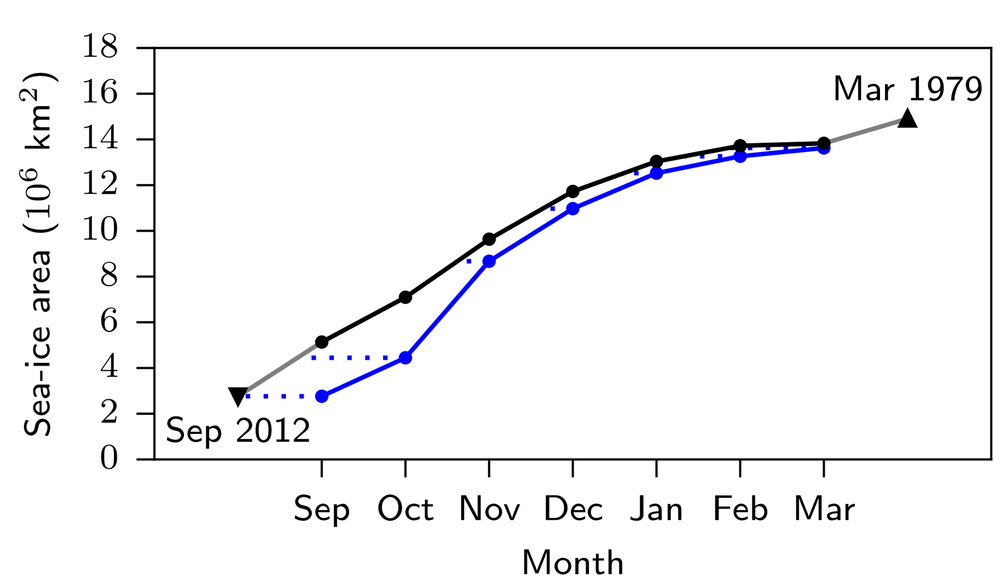


Fig. 2. Sea ice areas for the climatological mean seasonal cycle (black) and the α = -3 scenario (blue) during the freezing season, and their correspondence.

Sea ice concentration perturbations

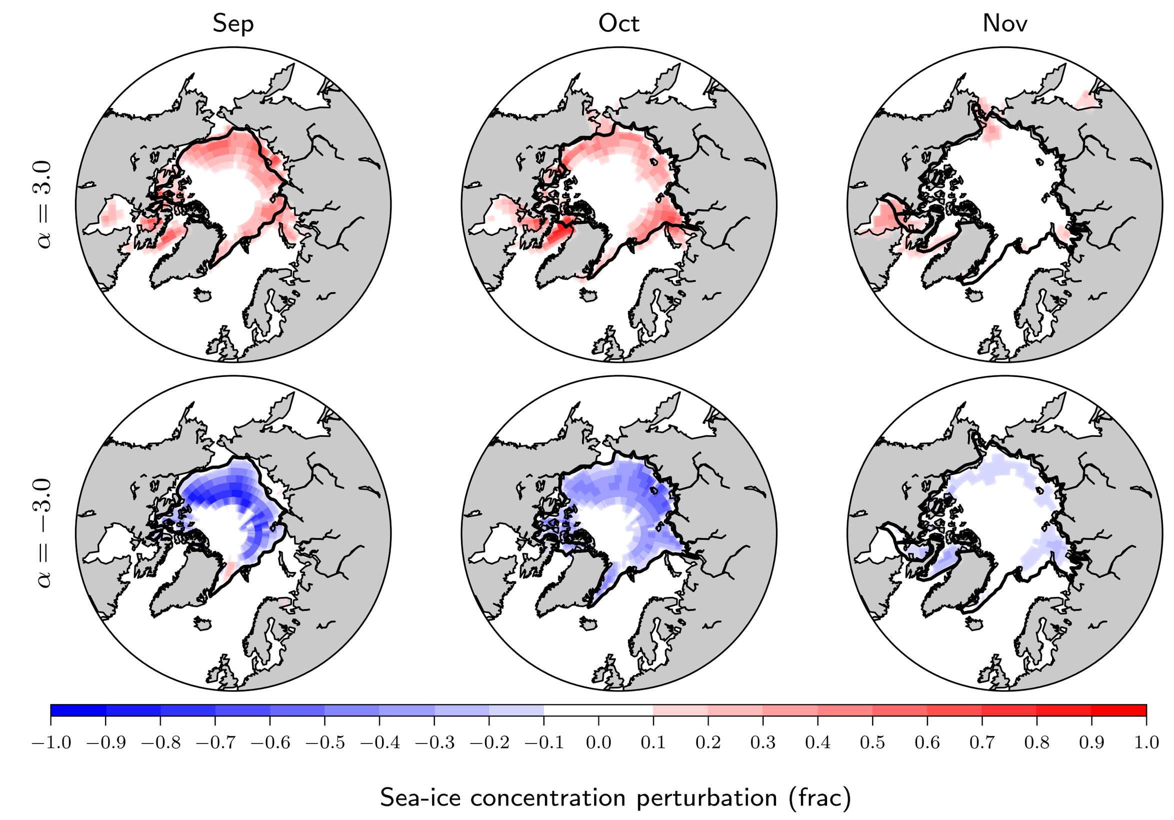


Fig. 3. Monthly mean sea ice concentration for the 3 and -3 scenarios.

Sea surface temperatures were perturbed in grid points with changed sea ice concentration to correspond to the new sea ice conditions.

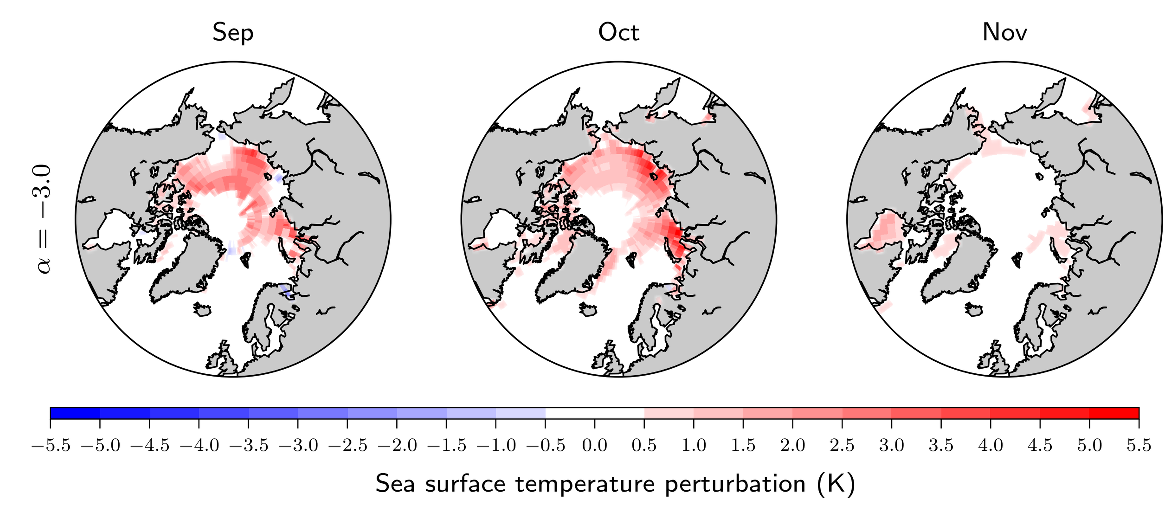


Fig. 4. Monthly mean sea surface temperature for the -3 scenario.

Ensemble correlations

Correlate atmospheric variables with $-\alpha$, similar to regressing variables onto the sign-reversed sea ice area.

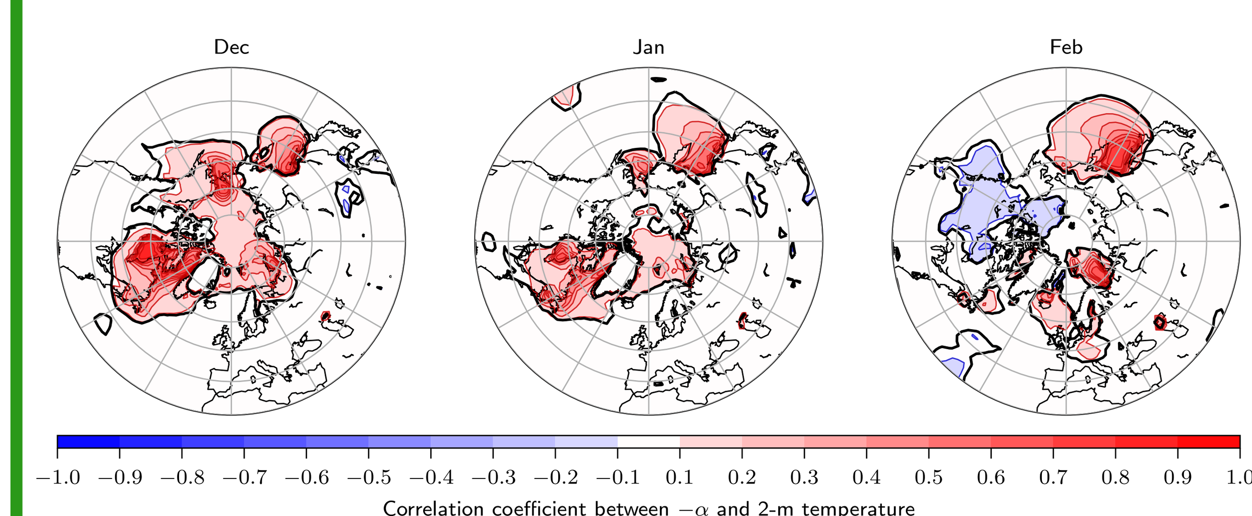


Fig. 5. Linear relation between 2-m temperature and sea ice forcing.

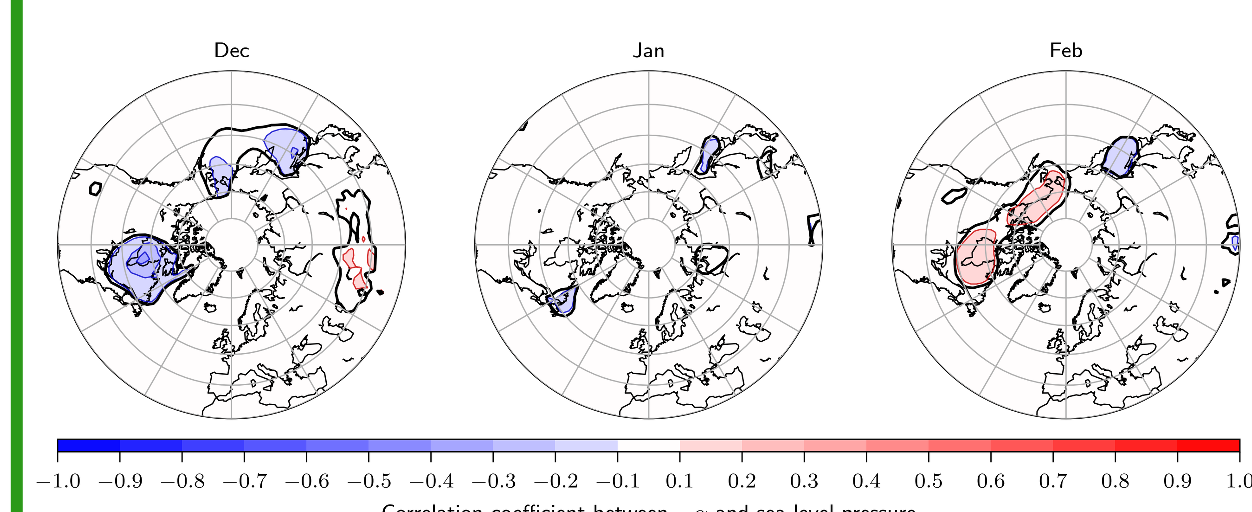


Fig. 6. Linear relation between sea-level pressure and sea ice forcing.

Planetary wave amplitude

Calculate the meridional extent of large-scale planetary waves as the difference between the maximum and minimum latitude of a specific 500-hPa isohypse for a range of isohypses. Average maximum daily wave extends over each month to obtain monthly averages.

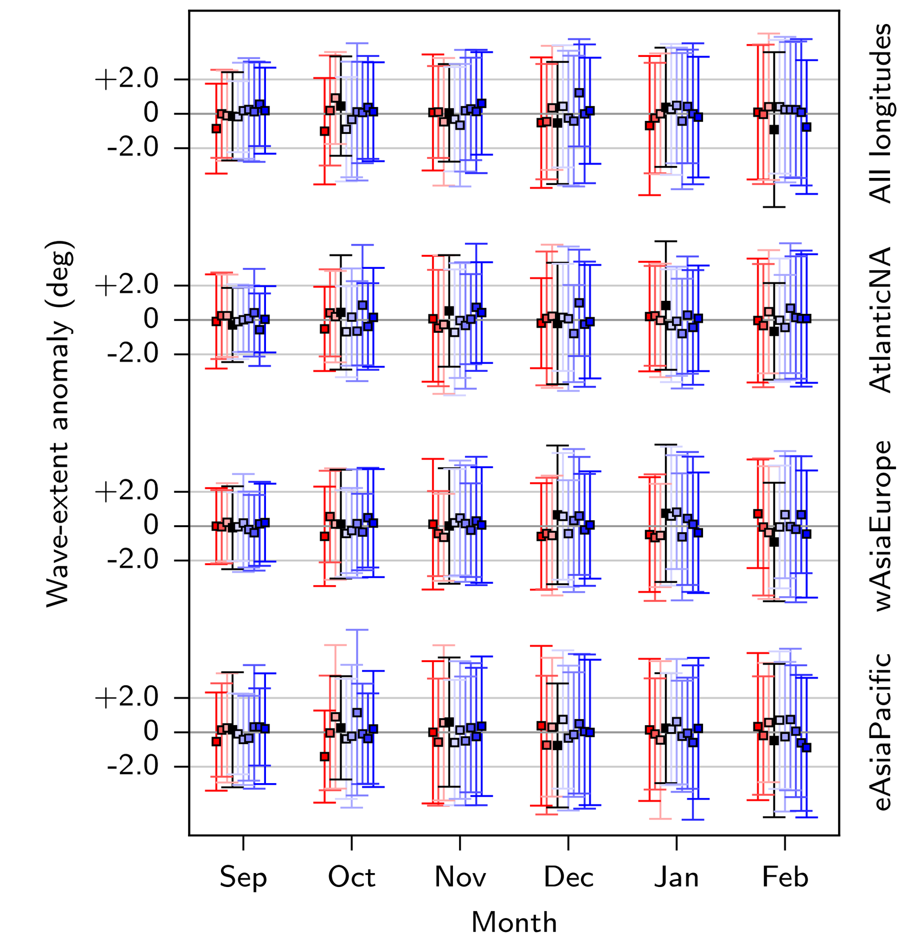


Fig. 7. Changes in meridional extent of 500-hPa isohypses.

Large-scale circulation patterns

Cluster daily wintertime sea-level pressure anomaly patterns northward of 30°N using a self-organizing map.

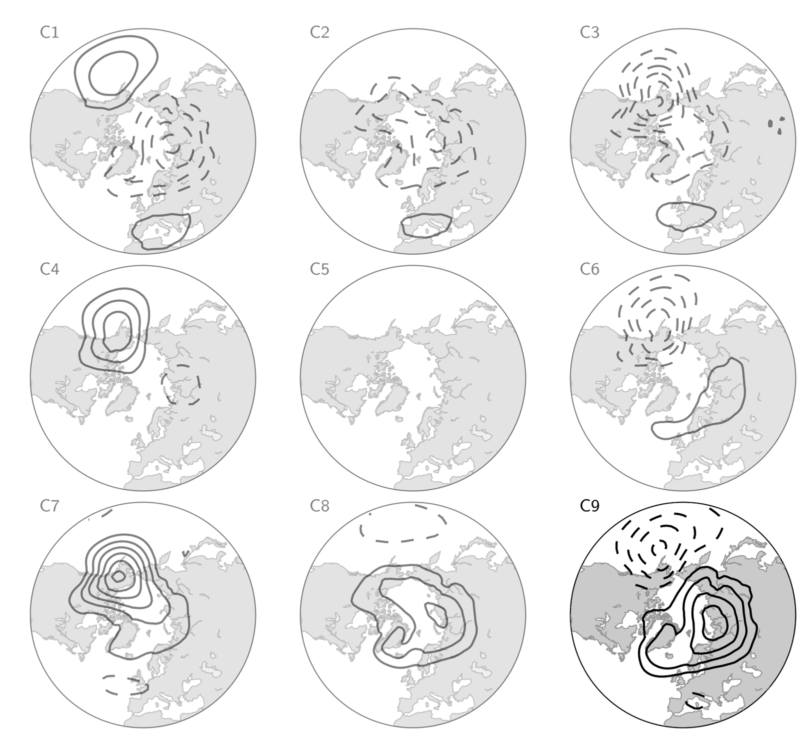


Fig. 8. Clusters of daily sea-level pressure anomaly patterns in winter.

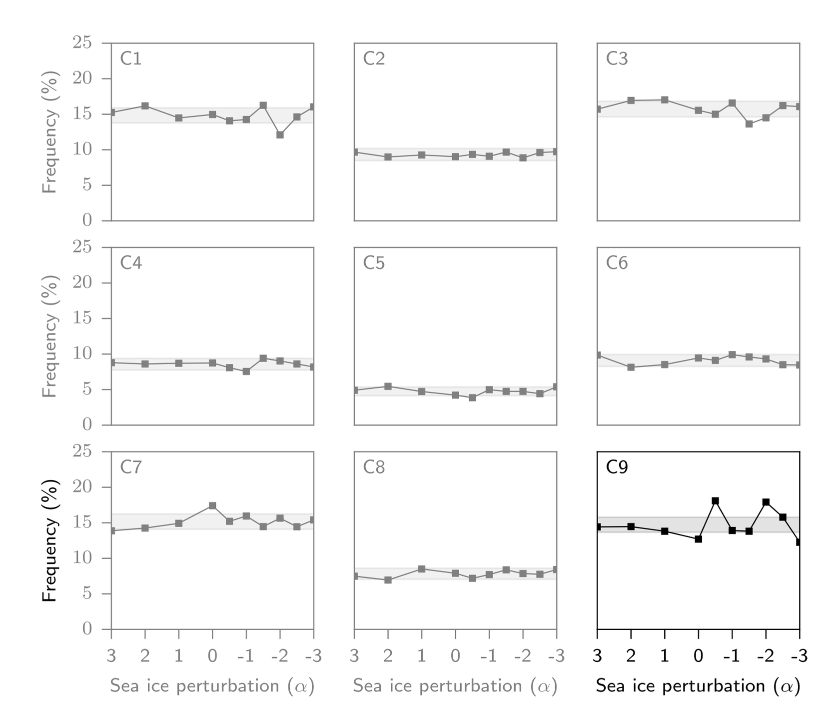


Fig. 9. Frequency of occurrence of each sea-level pressure anomaly cluster.

Extreme cold winter events

For each mid-latitude region, define an extreme cold event as a winter day when the area-averaged 2-m temperature over land falls below the 2.5th percentile of all ensemble members.

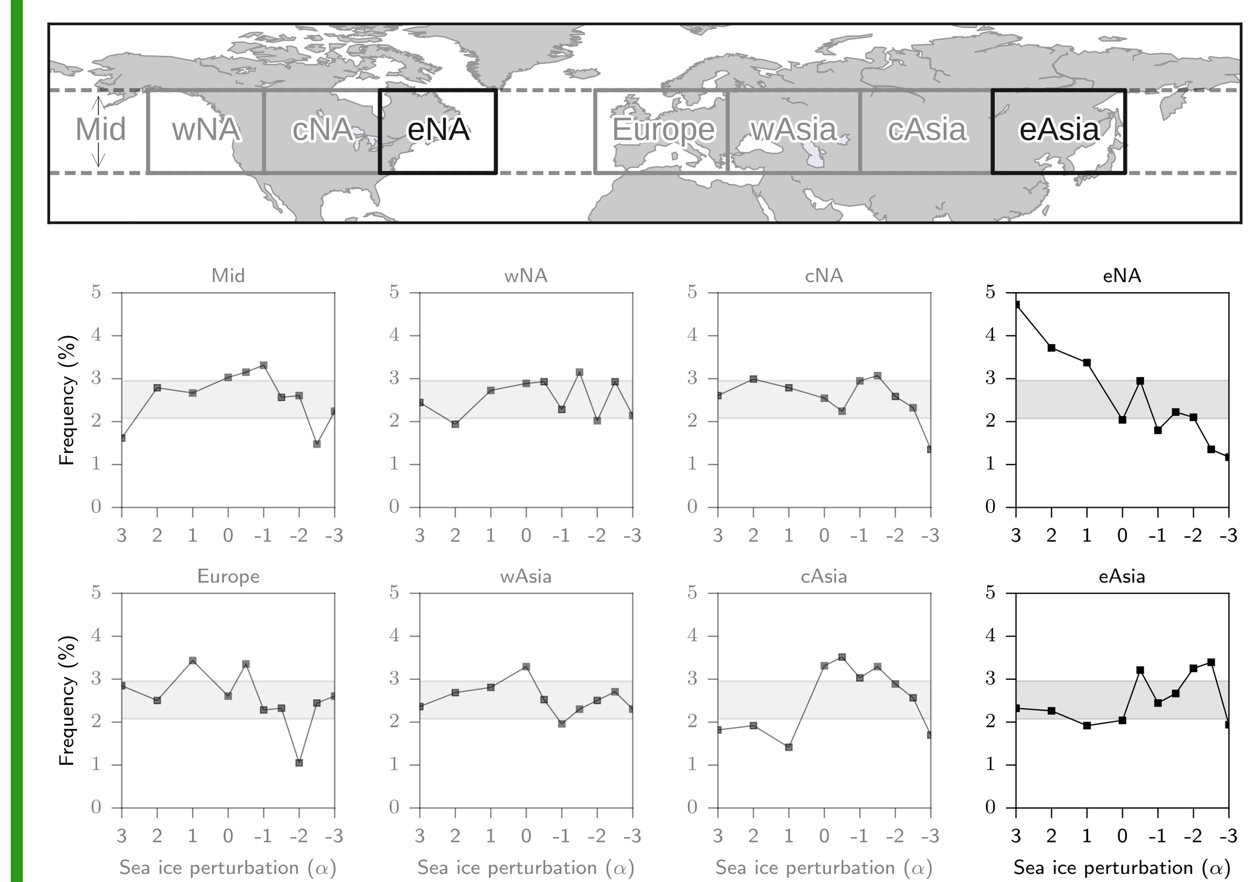


Fig. 10. Frequency of occurrence of extreme cold winter days in mid-latitude regions.

Conclusions

- Arctic sea ice loss results in a local warming that scales linearly with the sea ice forcing, but the remote signals are weak or nonlinear (Fig. 5).
- Changes in the meridional extent of upper-level planetary waves due to Arctic sea ice loss are much smaller than the intrinsic variability (Fig. 7).
- As the Arctic sea ice cover decreases, there is sometimes a significant increase in the occurrence of a large-scale circulation pattern that is reminiscent of the negative phase of the Arctic Oscillation. However, the changes do not scale linearly with the sea ice forcing (Fig. 9).
- The scenario with most severe Arctic sea ice loss shows a significant decrease of occurrence of the negative Arctic Oscillation.
- Related to the circulation changes, Arctic sea ice loss may lead to an increased frequency of occurrence of extreme cold winter days in east Asia by almost 50 %, but the changes are again highly nonlinear (Fig. 10).
- The frequency of occurrence of extreme cold winter days in eastern North America decreases linearly, to a good approximation, with decreasing Arctic sea ice area (Fig. 10).

Take-home message: Different modeling studies may find different atmospheric responses to Arctic sea ice loss simply due to the nonlinearity of the climate system.

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