The Impact of Regional Arctic Sea Ice Loss on Atmospheric Circulation and the NAO

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1 Summary

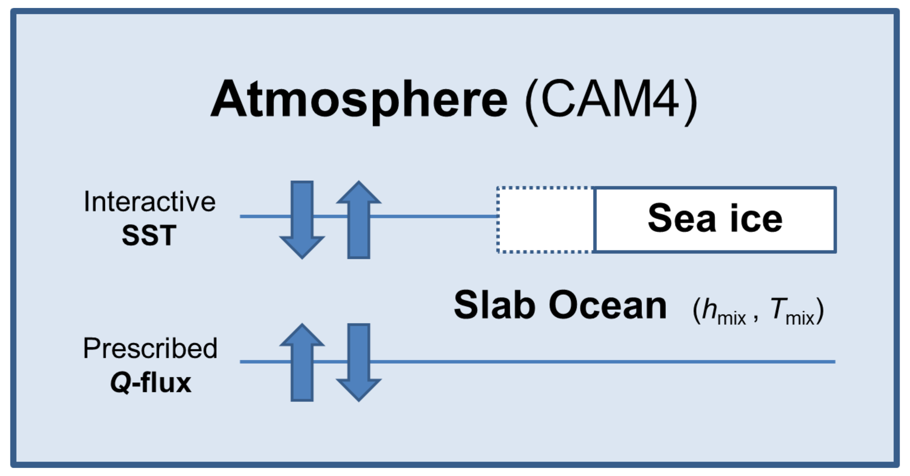
A hybrid slab ocean-specified sea ice setup is used to investigate the impact of sea ice loss in the Atlantic and Pacific sectors of the Arctic.

Despite maximum sea ice loss in September, peak near-surface air warming occurs in winter; with a response resembling the spatial pattern of the sea ice loss.

Geopotential height changes and associated decreases in mid-latitude winds are seen in the Atlantic storm track region. All three scenarios display mainly decreases in the transient eddy kinetic energy field.

Pacific region sea ice loss tends to shift the northern center of action of the NAO eastward, while the sea ice loss in the Atlantic region causes a westward shift.

2 Atmospheric GCM hybrid setup



CESM (NCAR) Hybrid setup:

1. **full atmosphere** (1.9° × 2.5°)
2. **slab ocean** (mixed layer)
3. **prescribed sea ice** (fixed)

→ allow sub-freezing SSTs

A new hybrid setup is used to simulate the isolated impact of sea ice loss. The sea surface temperatures (SST) are not prescribed; the only forcing is a prescribed sea ice loss. The slab ocean setup allows for interaction between the atmosphere and the surface ocean, and can account for the teleconnections dependent on such an exchange (*Chiang and Bitz 2005; Cvijanovic and Chiang 2013*). Ocean temperatures below the freezing point are allowed in order to prevent an unrealistic increase of the heat flux exchange over ice free areas.

3 Sea ice forcing

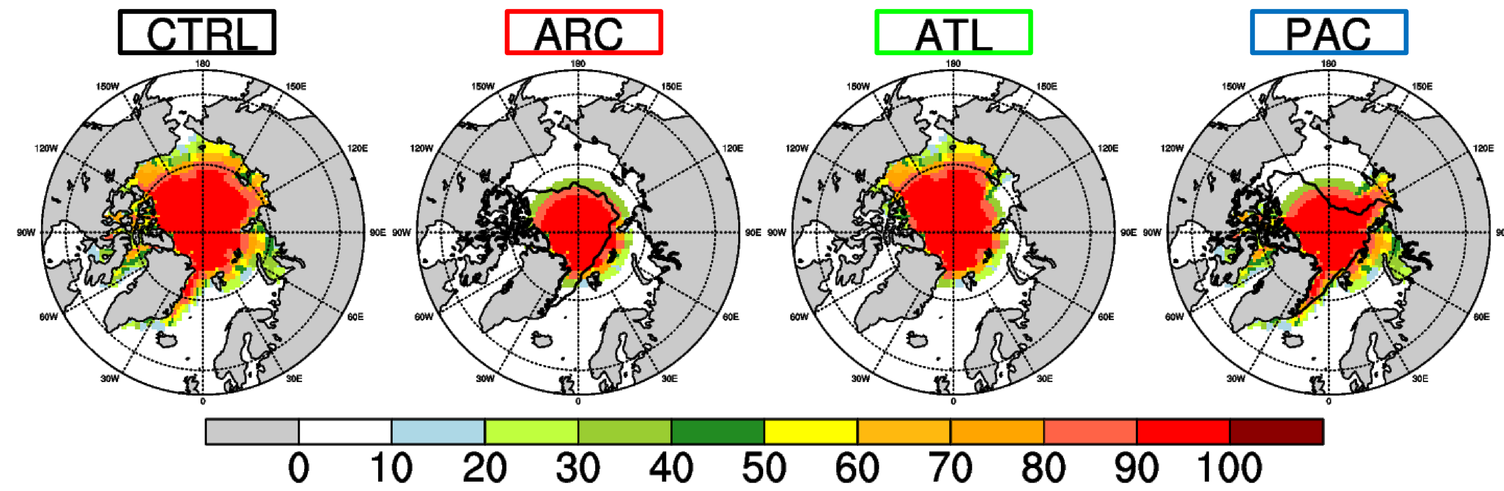
Three sea ice reduction scenarios

- ARC: sea ice loss over the entire Arctic
- ATL: confined to the Atlantic sector
- PAC: confined to the Pacific sector

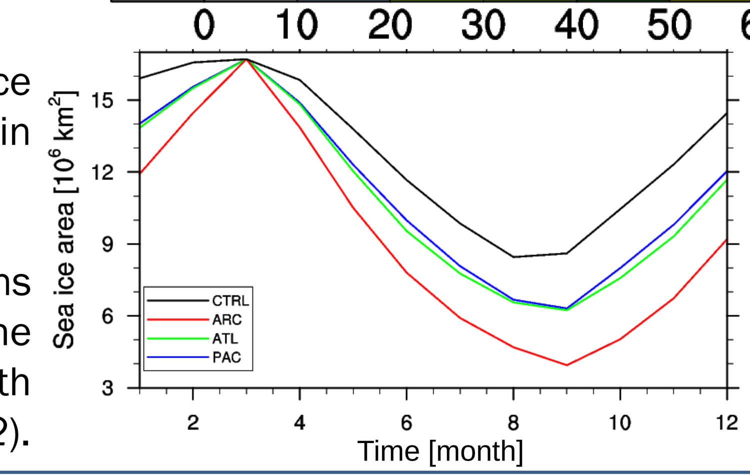
A pre-industrial climate state (CTRL) is used as reference.

ATL and PAC have identical areas of sea ice removed, and their sum equals the reduction in ARC.

Annual cycles are constructed from weighted means between the reduced September conditions and the concentrations from **CTRL** in the given month (assuming no change in March; *Stroeve et al. 2012*).



[↑] September sea ice concentration [%] in the four scenarios. **Black contours** are observed sea ice extent in 2012 (on ARC) and 2007 (on PAC).



[←] Annual cycle of Arctic sea ice area (×10^6 km^2) in the four scenarios.

4 Experiments

Name	CO_2	Sea ice
CTRL	CTRL	CTRL
ARC	CTRL	ARC
ATL	CTRL	ATL
PAC	CTRL	PAC
CO2	2×CTRL	CTRL
ARC+CO2	2×CTRL	ARC

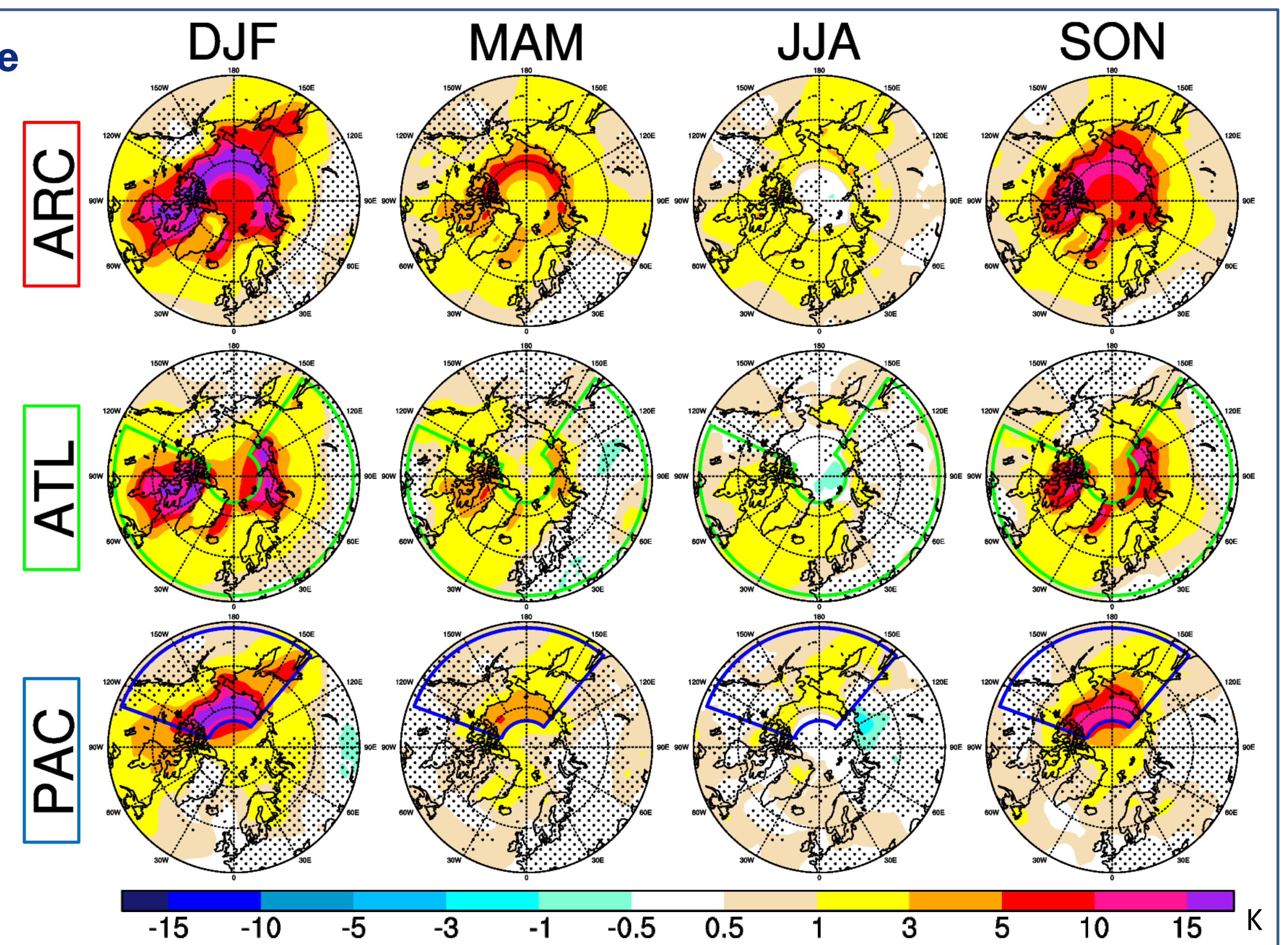
CTRL: Pre-industrial (1850) conditions. Sea ice conditions are obtained from a fully coupled CESM simulation.

5 Surface air temperature

The peak warming is >15K, and is found in winter (DJF) in all three scenarios. DJF warming is mainly driven by turbulent heat flux from the ocean surface due to the loss of the insulating sea ice.

The response resembles the spatial pattern of the sea ice loss; likely related to a limited vertical extent of the warming owing to a very stable structure of the lower atmosphere.

Note that the more remote PAC sea ice loss only seems to cause a limited warming on Greenland.

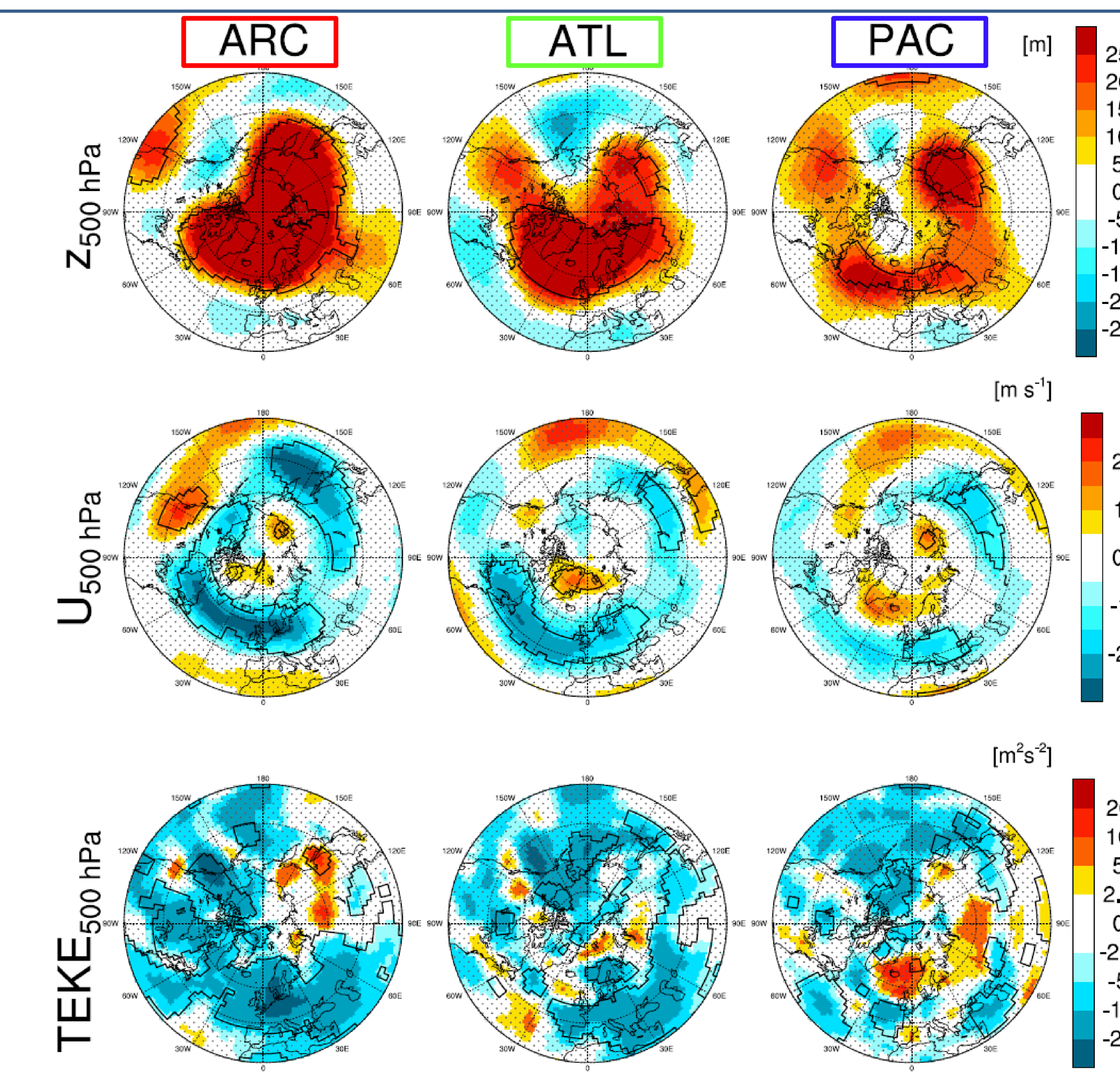


6 Atmospheric circulation [DJF]

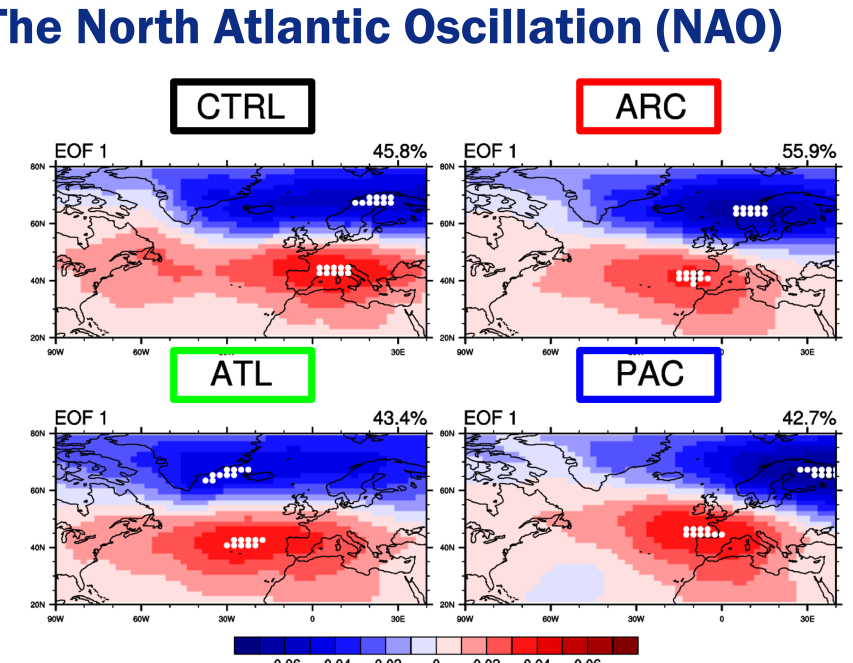
The geopotential height of the 500-hPa pressure surface [*top row*] increases at high latitudes across all three scenarios, as a result of the surface-based warming.

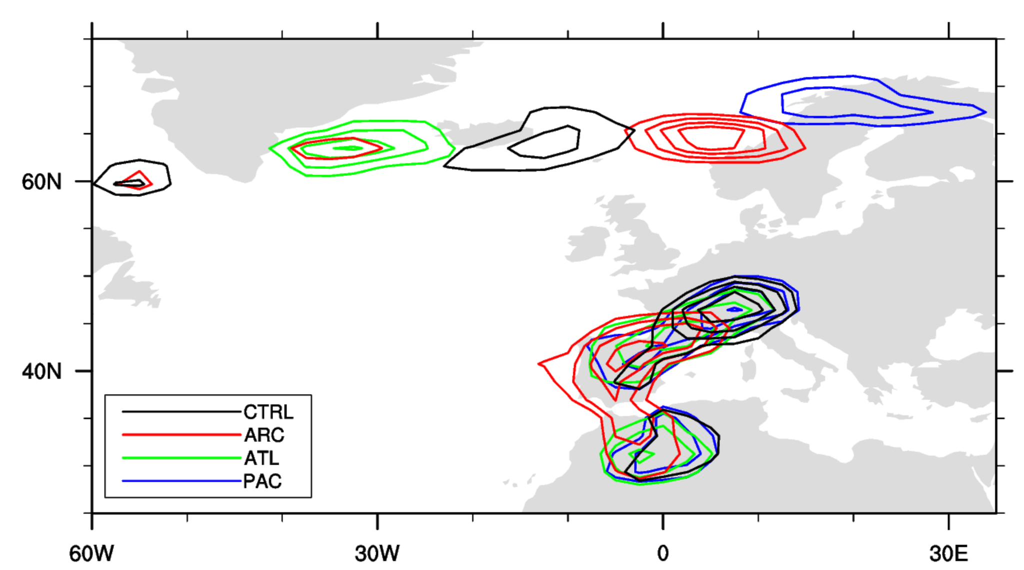
Zonal wind reduction [*middle row*] appears to agree well with the geopotential height changes: Areas of significant zonal wind reduction appear south of regions with geopotential height increases in all three scenarios.

Transient eddy kinetic energy [TEKE, *bottom row*] is generally reduced over the mid-latitudes with ARC showing the strongest trend. The differences between ARC, ATL, and PAC indicate a non-linear response; ARC features regional anomalies which contrast ATL and PAC.



7 The North Atlantic Oscillation (NAO)

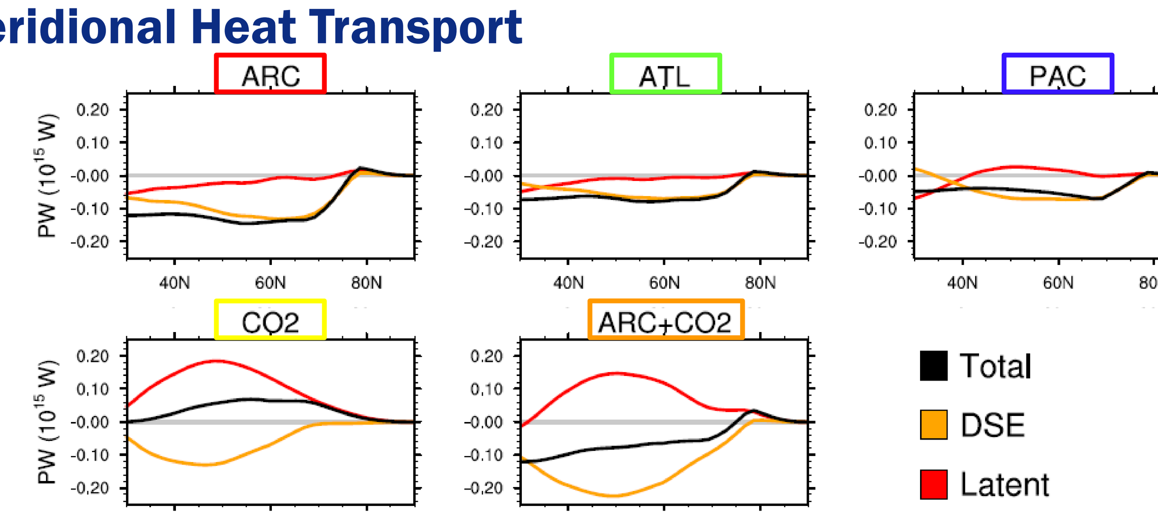




[Left] The leading EOF of the DJF sea level pressure weighted by the square root of cosine of the latitude. White circles mark the ten highest and lowest values, indicating the locations of the NAO centers of action.

[Right] NAO centers of action based on bootstrap sampling. Contours show the total number of occurrences in each grid cell combining all 500 samples: Contour interval is 50 counts, lowest contour at 50.

8 Meridional Heat Transport



Annual mean atmospheric meridional heat transport [MHT] anomalies: **Total**, dry static energy (DSE), and latent heat transport.

ARC, ATL, and PAC all lead to decreased MHT into the Arctic driven by DSE decrease. Compared to the response in ARC, CO_2 doubling (ARC+CO2) further decreases the DSE transport. The total transport is unchanged as the CO_2 driven warming leads to increased latent heat transport. In absence of sea ice changes (CO2), the latent heat increase is large enough to drive a net increased MHT into the Arctic.

9 Conclusions

- Ice loss in the Pacific sector (e.g. the observed extent in 2007) causes only limited warming over the Greenland ice sheet.
- High-latitude geopotential height increases near regions of sea ice loss, albeit with no direct overlap between the spatial patterns of near-surface warming and height of the 500-hPa surface.
- Mid-latitude zonal wind is reduced (cf., thermal wind relation).
- The circulation patterns indicate a non-uniform atmospheric sensitivity to the location of ice loss. While some regions show a similar response (e.g., decreased zonal flow over central Europe and Eastern Asia), other regions are sensitive to the location of the sea ice loss.
- Sea ice loss in the Pacific region of the Arctic tends to shift the northern center of action of the NAO eastward, while sea ice loss in the Atlantic region causes a westward shift.

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References

Pedersen, R. A., Cvijanovic, I., Langen, P. L., & Vinther, B. M. (2016). *The Impact of Regional Arctic Sea Ice Loss on Atmospheric Circulation and the NAO.* Journal of Climate, 29(2), 889–902.

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