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Influence of Arctic sea ice on the North Atlantic Oscillation

James Screen, AGCI, June 2017

Influence of Arctic sea ice on the NAO

- **It's real**
- **It's robust**
- **It's the Barents-Kara Sea**
- **It's predictable**
- **It does not mean colder European winters**

Influence of Arctic sea ice on the NAO

- **It's real**
  Evidence for a physical link between low sea ice and NAO-

- **It's robust**
  Evidence of insensitivity to forcing size and background state

- **It's the Barents-Kara Sea**
  Evidence that only low Barents-Kara sea ice influences NAO

- **It's predictable**
  Evidence that sea ice is a source of skill in seasonal NAO forecasts

- **It does not mean colder European winters**
  Evidence that NAO- events become warmer despite intensification

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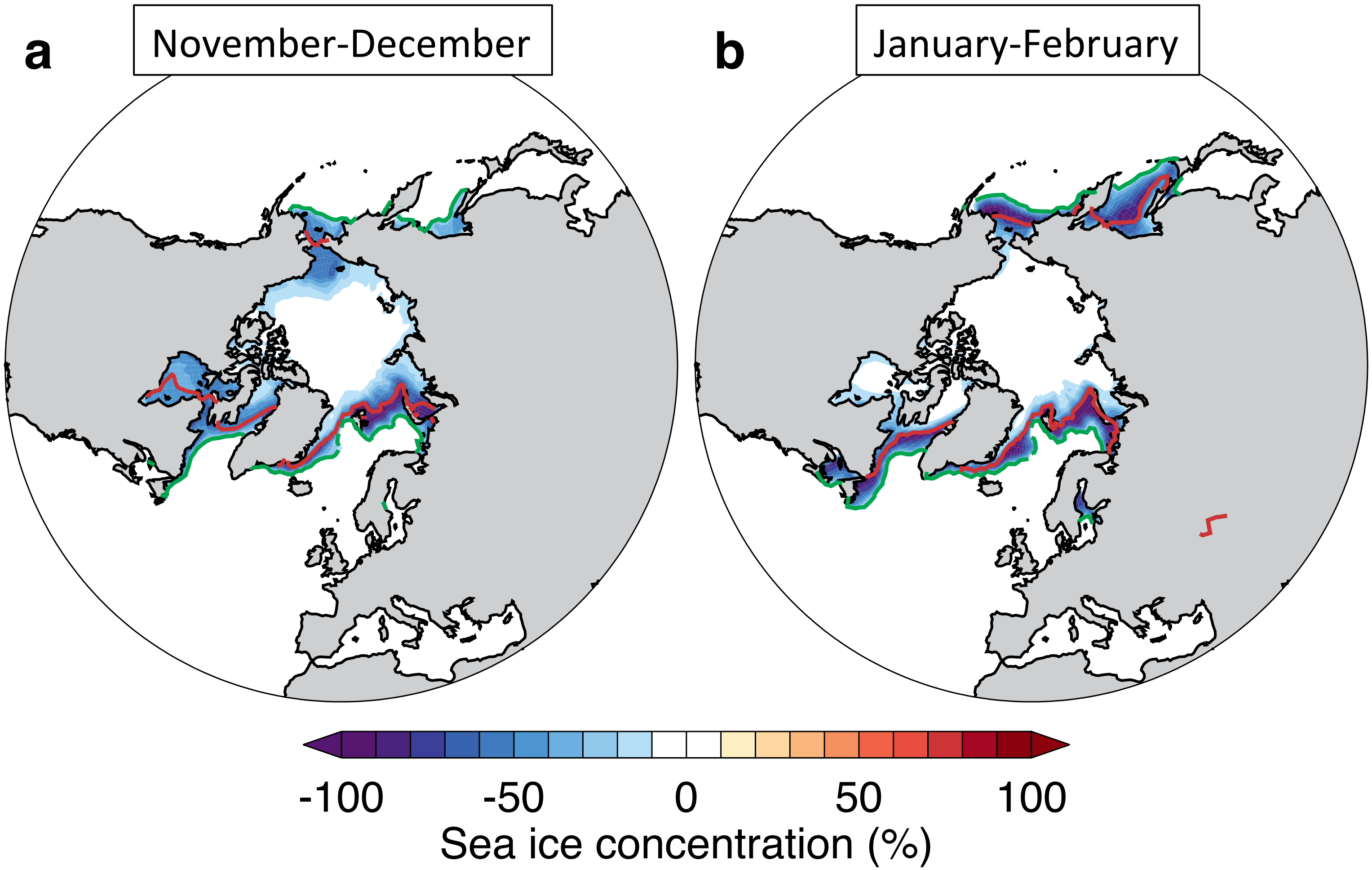
Simulations with pan-Arctic sea ice anomalies



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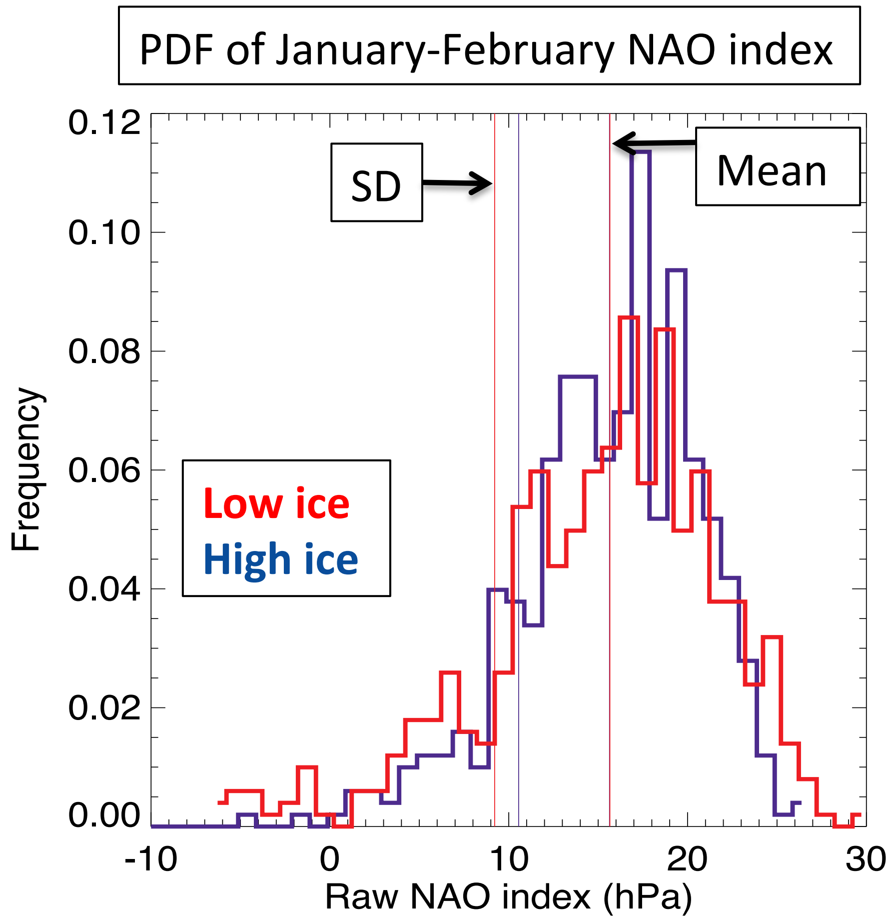
Motivation for focus on NAO- events



2 * 500 year ensemble

4 different background states

Sample winter with NAO <
-1s.d. below mean

Composite differences between NAO- winter in high and low ice simulations

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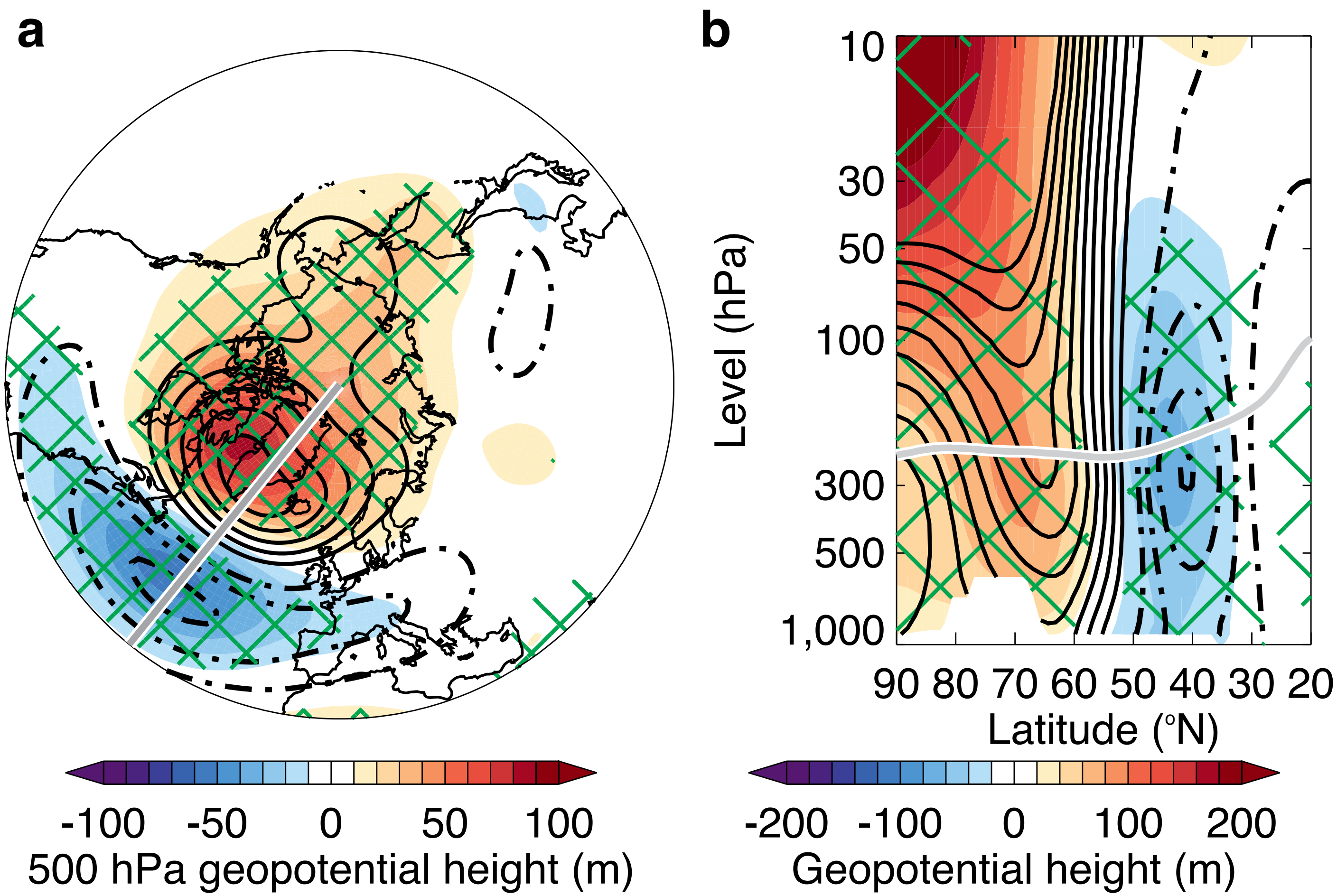
Intensification of NAO- events



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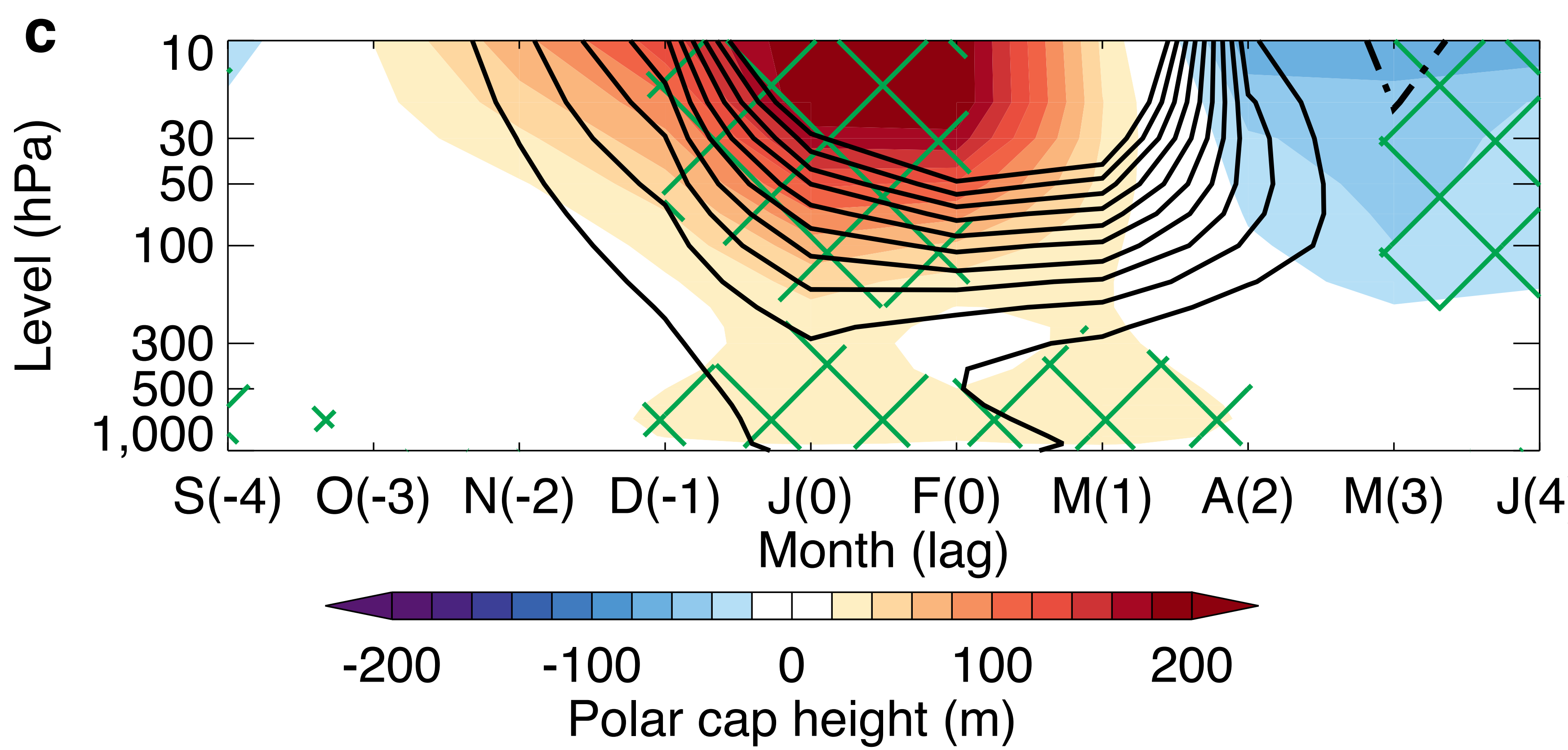
Intensification of NAO- events



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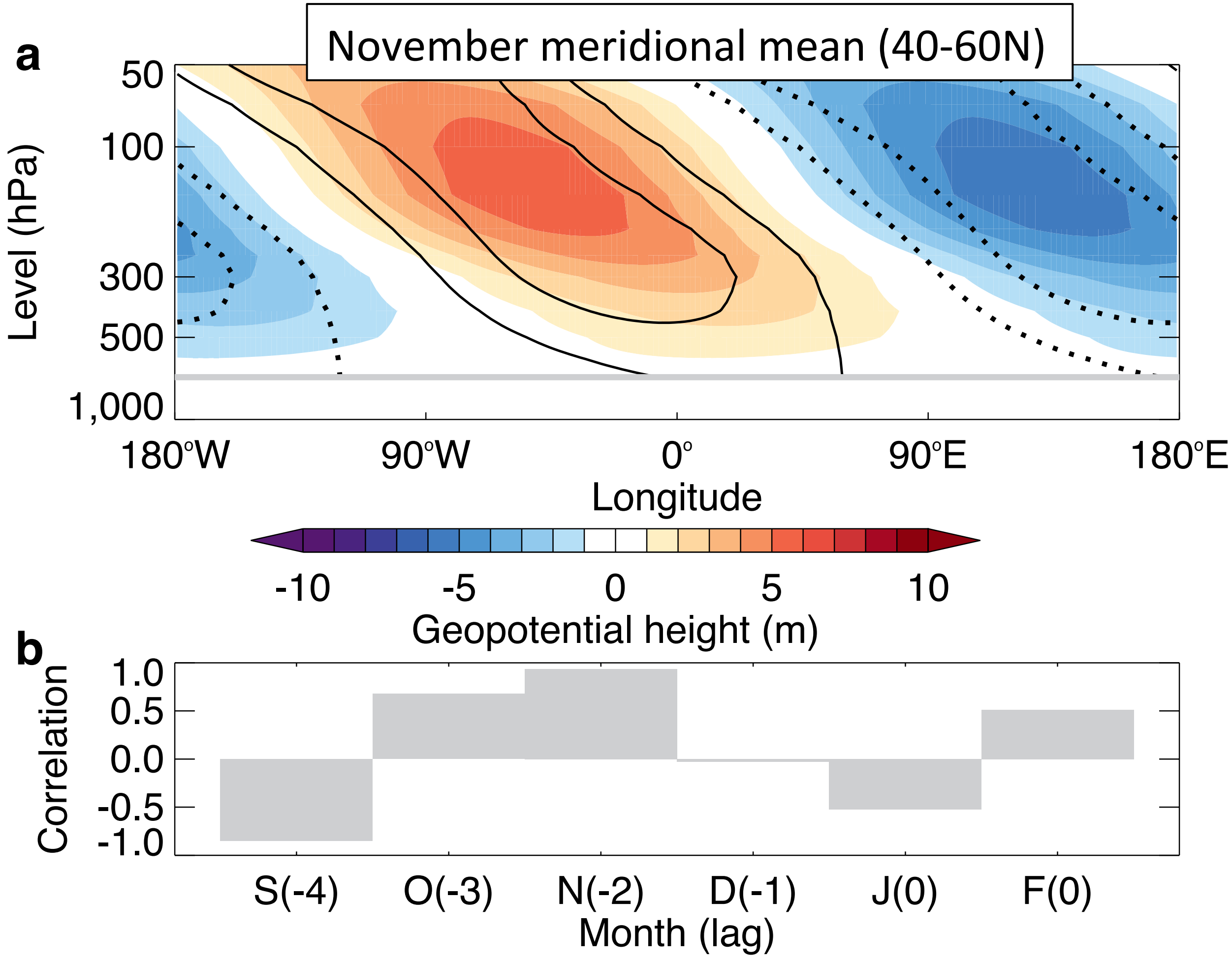
Stationary wave linear interference



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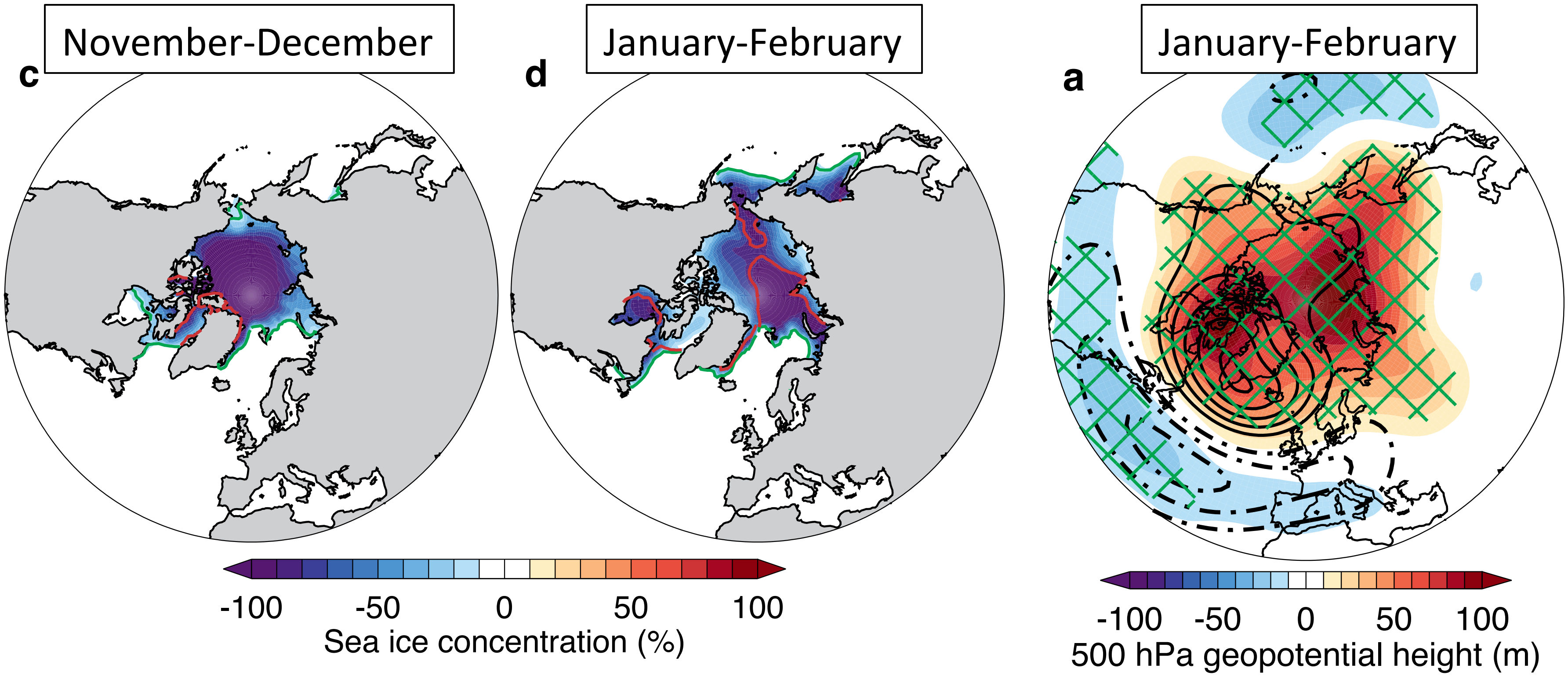
Robustness of response: forcing magnitude



Intensification of NAO- winters found in response to present-day and future sea ice loss

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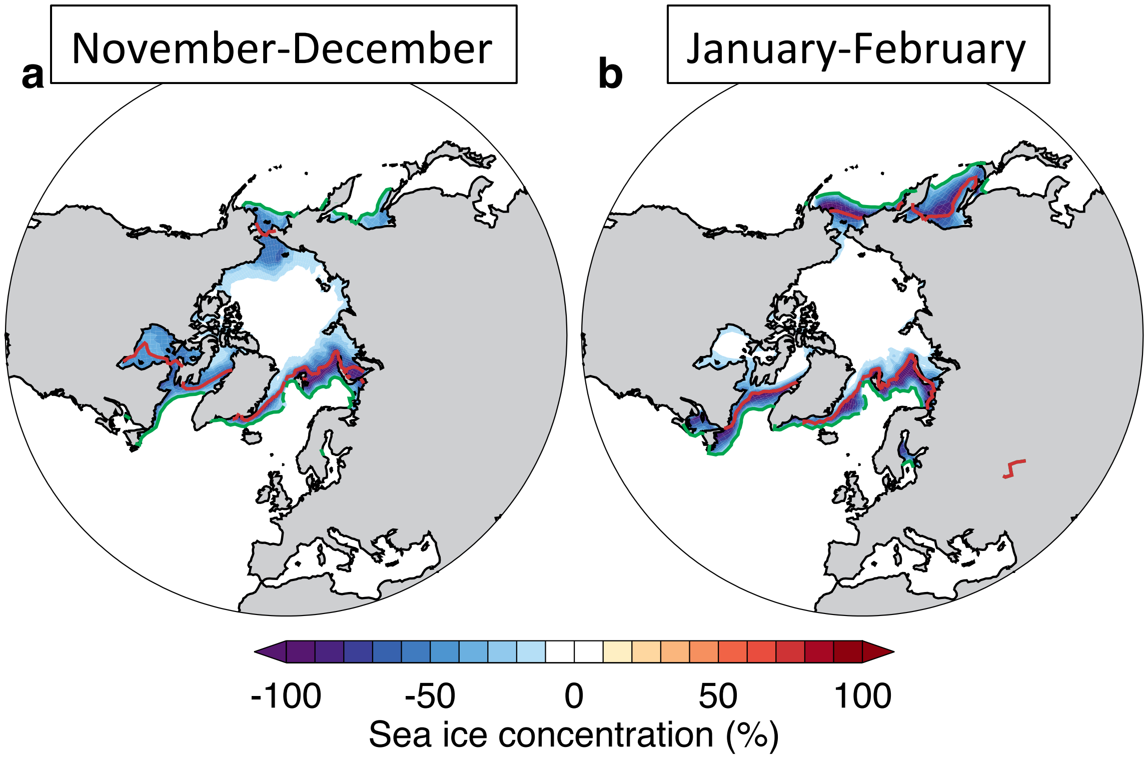
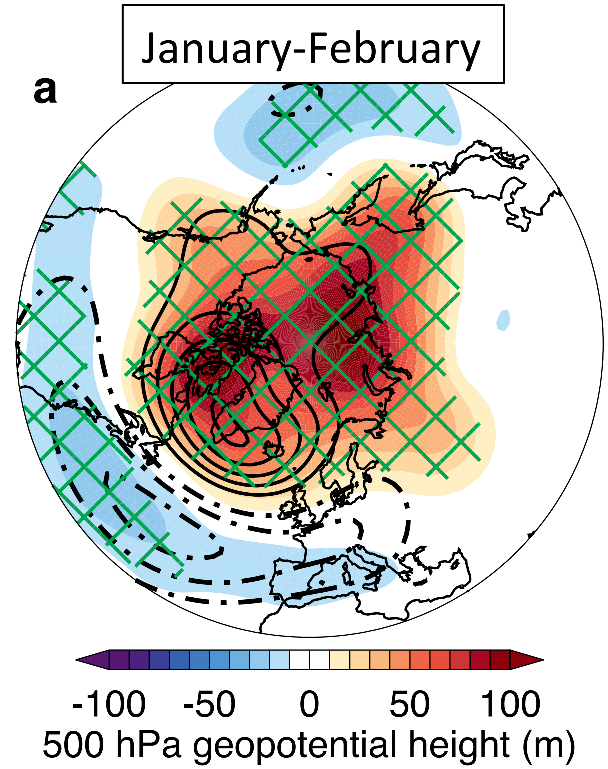
Robustness of response: forcing magnitude





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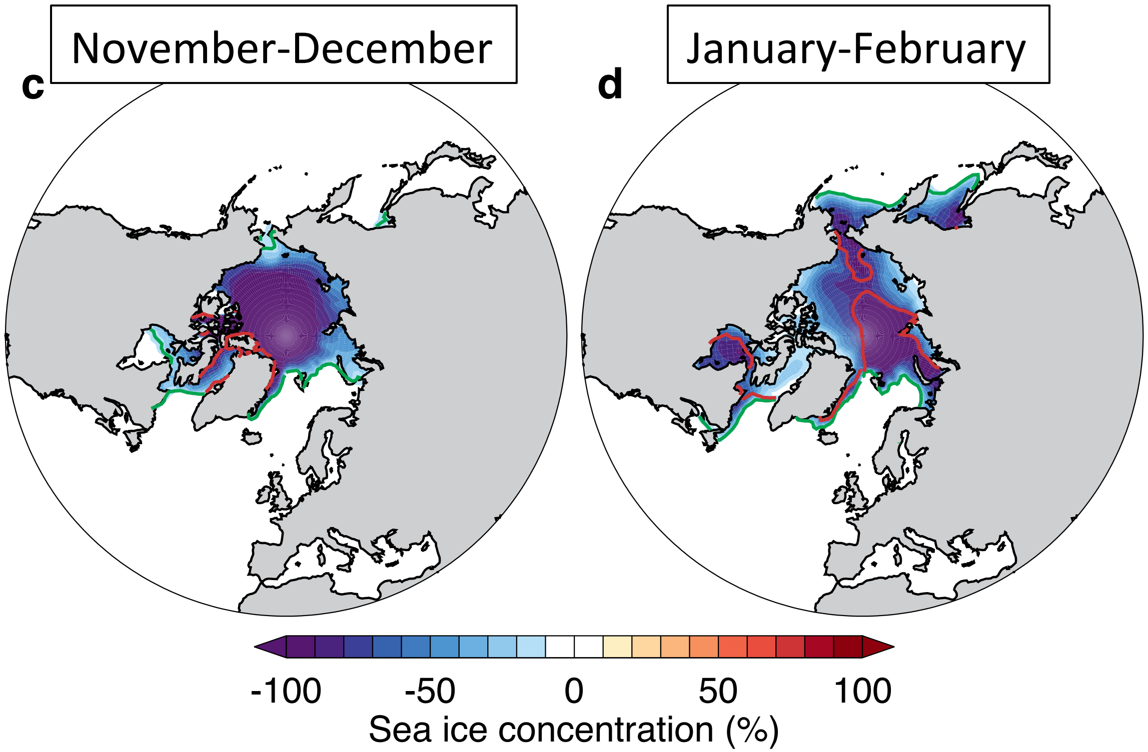
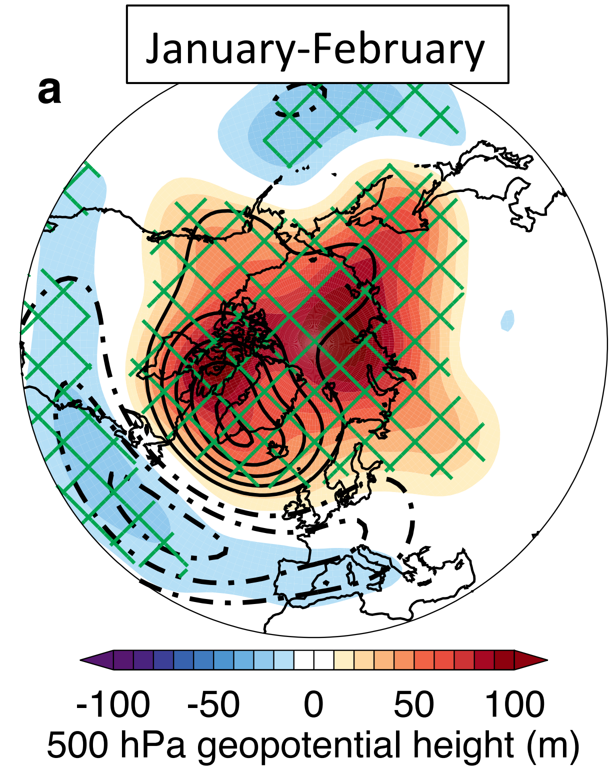
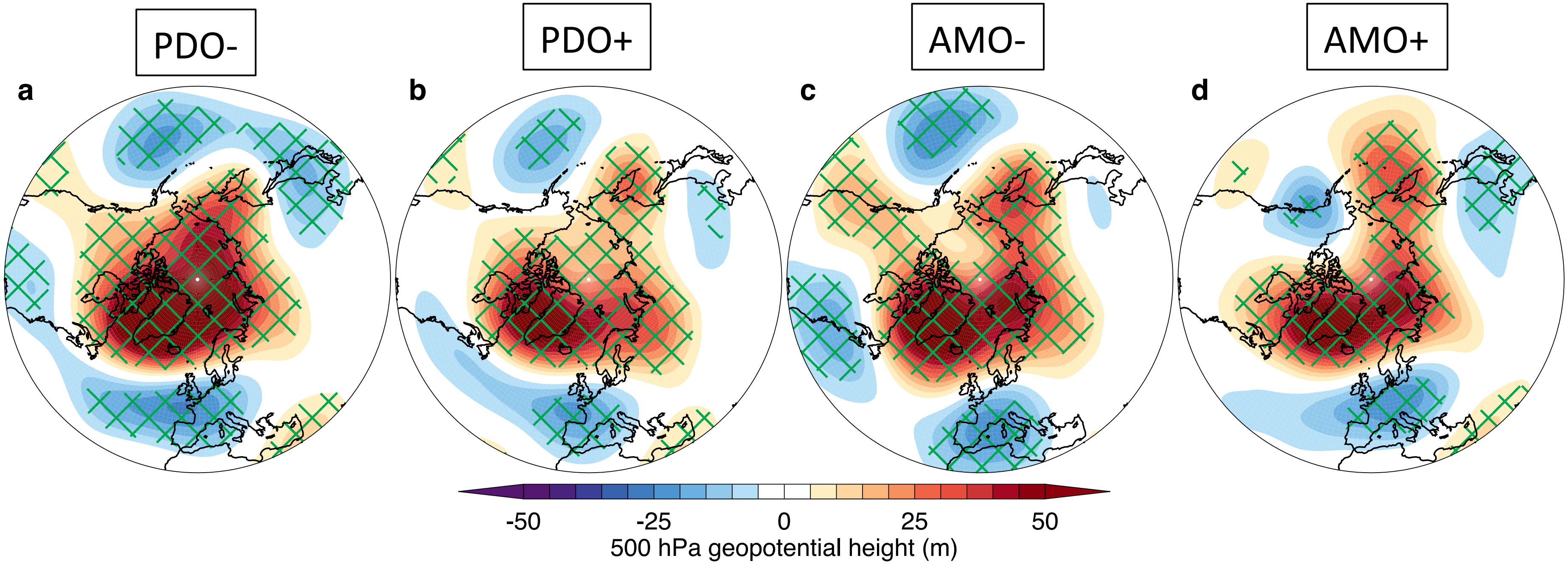




Robustness of response: background state



SST anomalies associated with either phase of AMO and PDO added to climatological SST

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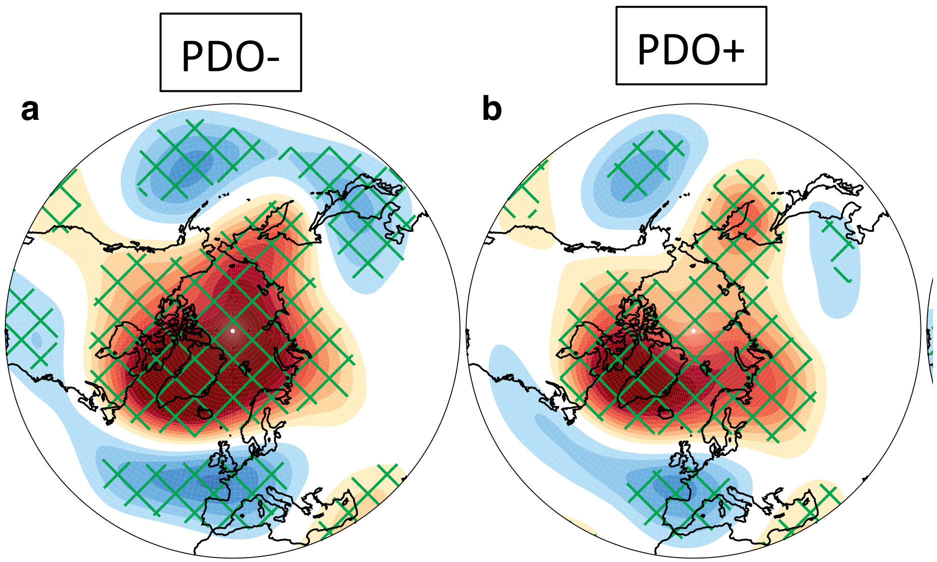
Background state matters for AA



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Contribution of sea-ice loss to Arctic amplification is regulated by Pacific Ocean decadal variability

James A. Screen[1*] and Jennifer A. Francis[2]

The pace of Arctic warming is about double that at lower latitudes—a robust phenomenon known as Arctic amplification[1]. Many diverse climate processes and feedbacks cause Arctic amplification[2-7], including positive feedbacks associated with diminished sea ice[6,7]. However, the precise contribution of sea-ice loss to Arctic amplification remains uncertain[7,8]. Through analyses of both observations and model simulations, we show that the contribution of sea-ice loss to wintertime Arctic amplification seems to be dependent on the phase of the Pacific Decadal Oscillation (PDO). Our results suggest that, for the same pattern and amount of sea-ice loss, consequent Arctic warming is larger during the negative PDO phase relative to the positive phase, leading to larger reductions in the poleward gradient of tropospheric thickness and to more pronounced reductions in the upper-level westerlies. Given the oscillatory nature of the PDO, this relationship has the potential to increase skill in decadal-scale predictability of the Arctic and sub-Arctic climate. Our results indicate that Arctic warming in response to the ongoing long-term sea-ice decline[9,10] is greater (reduced) during periods of the negative (positive) PDO phase. We speculate that the observed recent shift to the positive PDO phase, if maintained and all other factors being equal, could act to temporarily reduce the pace of wintertime Arctic warming in the near future.

Arctic amplification (AA)[1–8] is a robust feature in observations of the recent past[7,8], palaeo-climate reconstructions of the distant past[11], and model projections of the future[12]. The majority of near-surface AA can be explained by feedbacks associated with a diminished sea-ice cover[7,13–15]. Higher in the atmosphere, however, the contribution of sea-ice loss to AA is less well constrained[7,8,13–15], in part because the atmospheric response to sea-ice loss is apparently nonlinear and state-dependent[16–19]. By state-dependent we mean that a similar sea-ice anomaly can lead to a different atmospheric response depending on the background ocean–atmospheric state. So far, such state dependencies have generally been attributed to random internal variability[18]. However, known cycles in the ocean–atmosphere coupled system could have a predictable modulating influence on the atmospheric response to sea-ice loss. Here, for the first time, we present evidence suggesting that the Pacific Decadal Oscillation (PDO) modulates the atmospheric response to sea-ice loss. The PDO is a dominant pattern of sea surface temperature (SST) anomalies that typically persists in predominantly one phase for longer than ten years (sometimes with temporary reversals to the opposite state) and has wide-ranging effects on global weather and the Pacific ecosystem[20]. The PDO is not a single phenomenon, but is instead the result of a combination of different physical processes[21–23], including stochastic variability of the Aleutian Low, remote tropical forcing and local North Pacific air–sea interactions (see Supplementary Discussion), which can operate on different timescales to drive similar PDO-like SST anomaly patterns[21–23] (Supplementary Fig. 1).

The winter PDO index (Fig. 1a) was predominantly negative from winter 1948/49 to 1975/76, mainly positive until winter 2006/07, then negative again in most winters between 2007/08 and 2012/13. In winter 2013/14, the PDO shifted abruptly back to a positive phase and was followed in winter 2014/15 by the most positive PDO value in the 67-year record. Meanwhile, winter Arctic sea-ice area (Fig. 1b) has declined steadily since the late 1970s, one of the most visible indications of human-induced global warming[24–26]. The time series of the PDO and sea-ice area indices are only weakly correlated ($r = -0.25$). Although the PDO does not seem to be a strong driver of winter sea-ice area variability in a pan-Arctic sense, our analysis suggests that the PDO phase affects how the atmosphere responds to sea-ice variability.

Figure 1c,d shows composite-mean differences in air temperature between low ice (LI) and high ice (HI) years during negative PDO (PDO−) and positive PDO (PDO+), respectively. During both PDO phases, negative anomalies in sea-ice area are significantly associated with warmer Arctic air temperatures. The composite anomalies exhibit the classical latitudinal and vertical profile of AA, with greater warming at higher latitudes and at lower altitudes. However, the magnitude of sea-ice-related Arctic warming below 500 hPa is significantly larger during PDO− than during PDO+ (Fig. 1e). At 500 hPa the Arctic-averaged (70–90° N) temperature anomaly is 0.7 °C and 0.3 °C in PDO− and PDO+, respectively. Corresponding values at 700 hPa are 1.0 °C and 0.4 °C, and at 850 hPa are 1.2 °C and 0.5 °C. These results suggest that Arctic warming associated with reduced sea ice is 75–150% greater during PDO− than in PDO+. Larger ice-loss-related Arctic warming is also found during the positive phase of the North Pacific Index (NPI) relative to its negative phase (Supplementary Fig. 2), and also to a lesser extent during the negative phase of the El Niño Southern Oscillation (ENSO) relative to its positive phase (Supplementary Fig. 3). Compared to the PDO, the NPI more directly measures changes in the Aleutian Low, whereas the ENSO index more directly measures changes in tropical Pacific SST[21–23] (see Supplementary Discussion).

Returning to the PDO influence, it is important to emphasize that the composite sea-ice anomalies are non-identical in the two PDO phases: the difference between LI and HI years is larger for PDO− (Fig. 2a,c), largely owing to the fact that the cases are not evenly distributed in time (the mean year for

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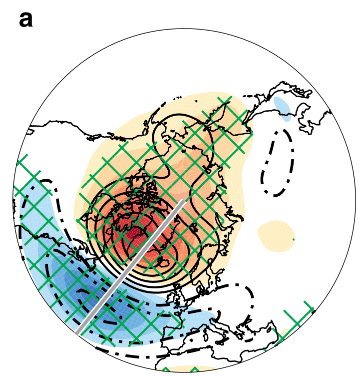
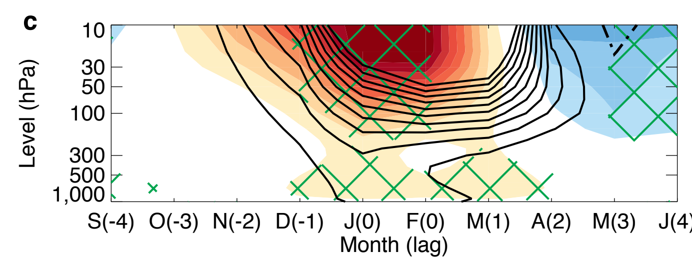
Summary so far

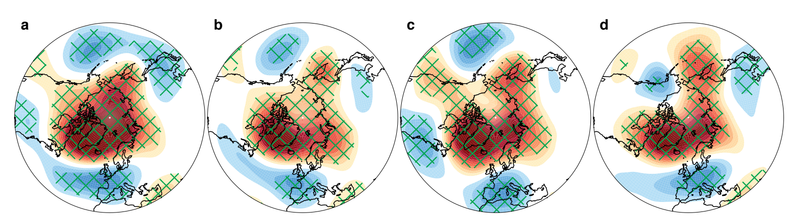
Intensification of NAO- events in response to sea ice loss



Stratospheric pathway consistent with several other studies (e.g., Kim et al., 2014)



Response is **robust**; not strongly dependent on forcing magnitude or background state



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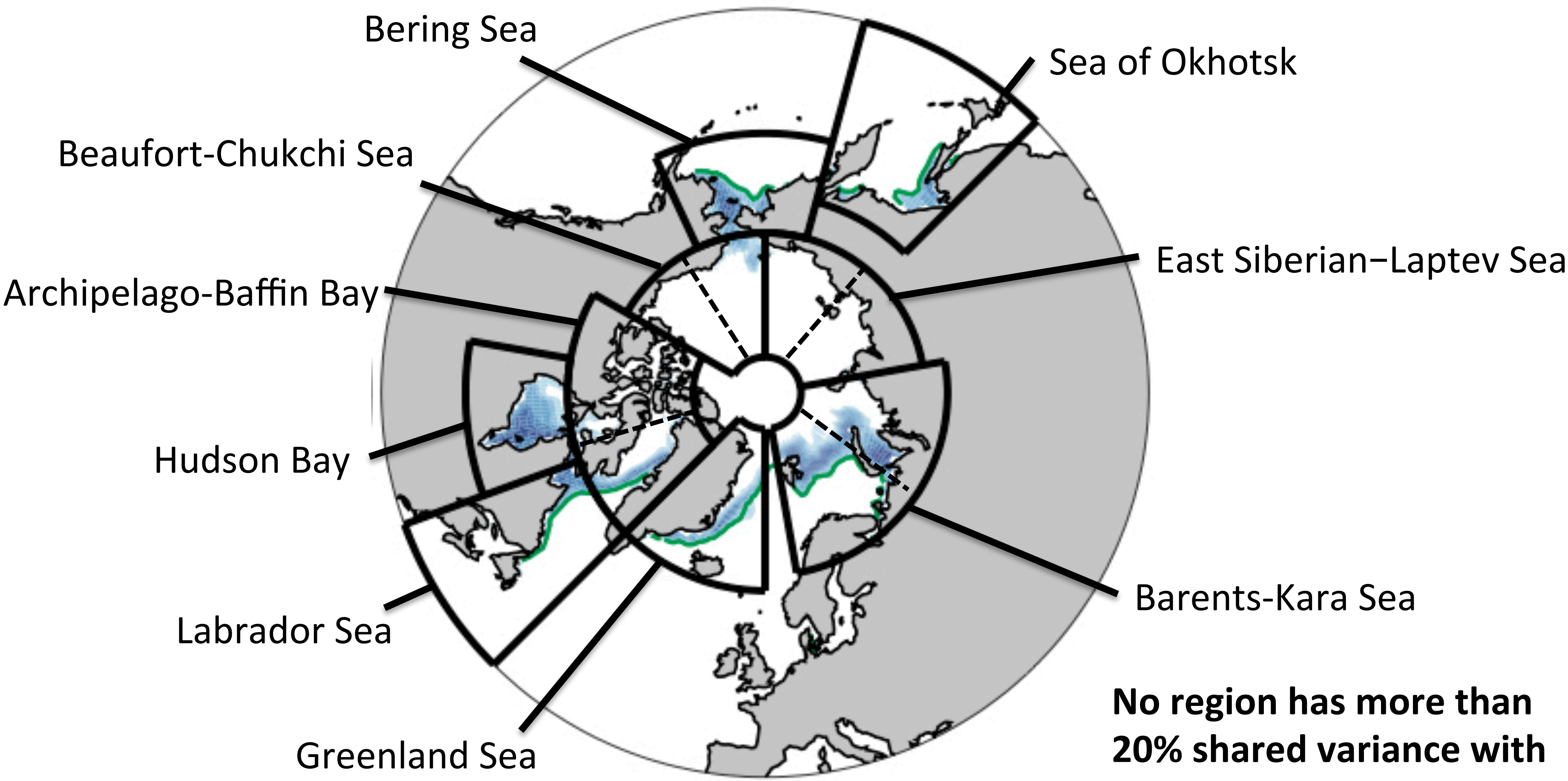
Simulations with regional sea ice loss



No region has more than 20% shared variance with any other region

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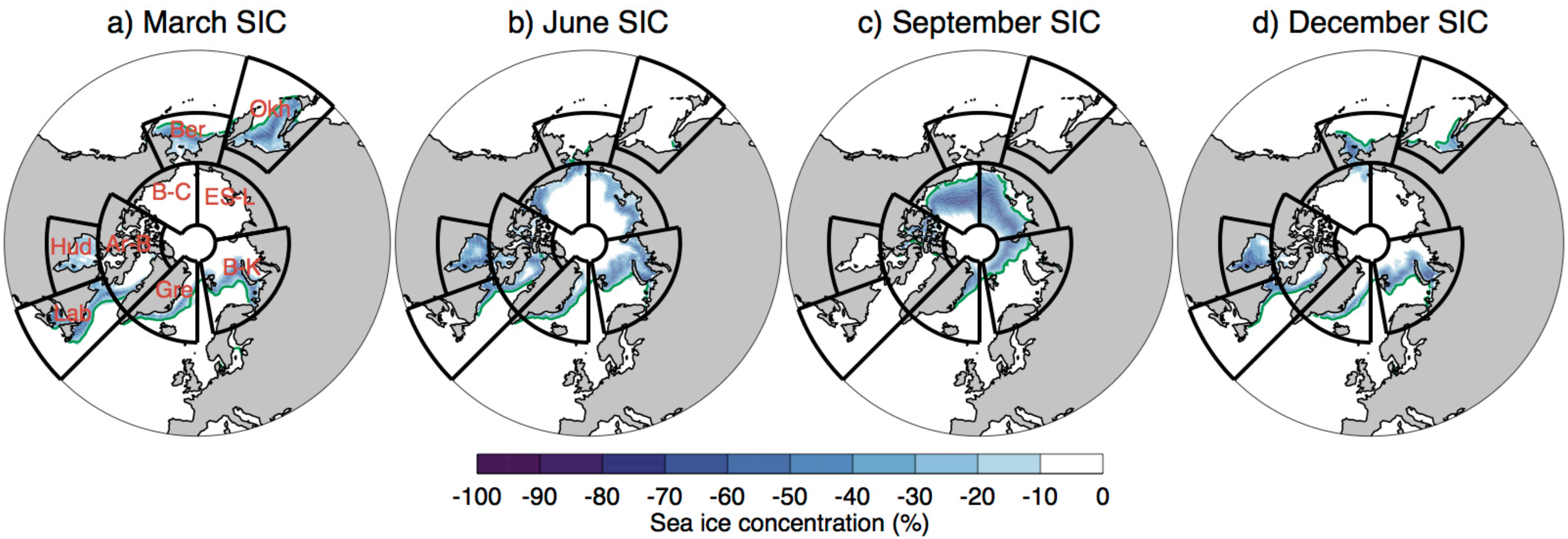
Simulations with regional sea ice loss



HadGEM2; atmosphere-only, with prescribed sea ice and climatological SST

1 x 163-year **control** run with climatological sea ice

9 x 80-year perturbation runs with **reduced sea ice in separate regions**

1 x 80-year perturbation run with **reduced sea ice in all regions**

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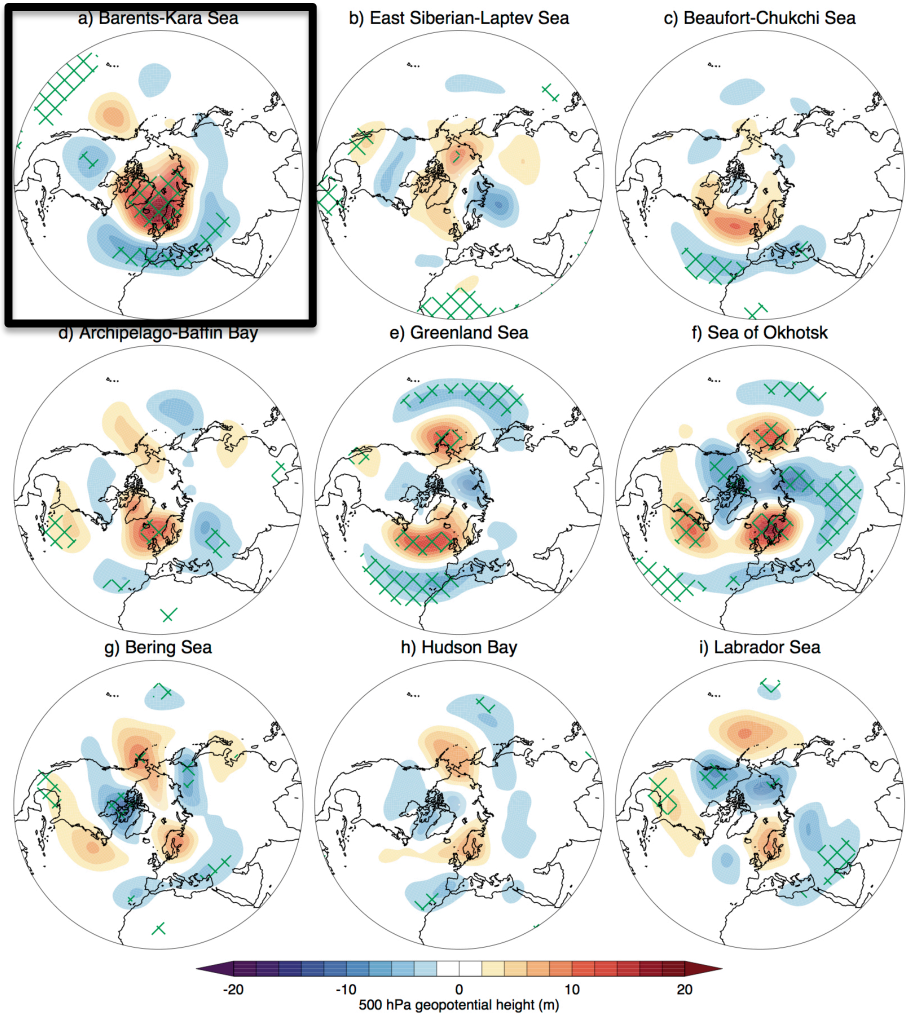
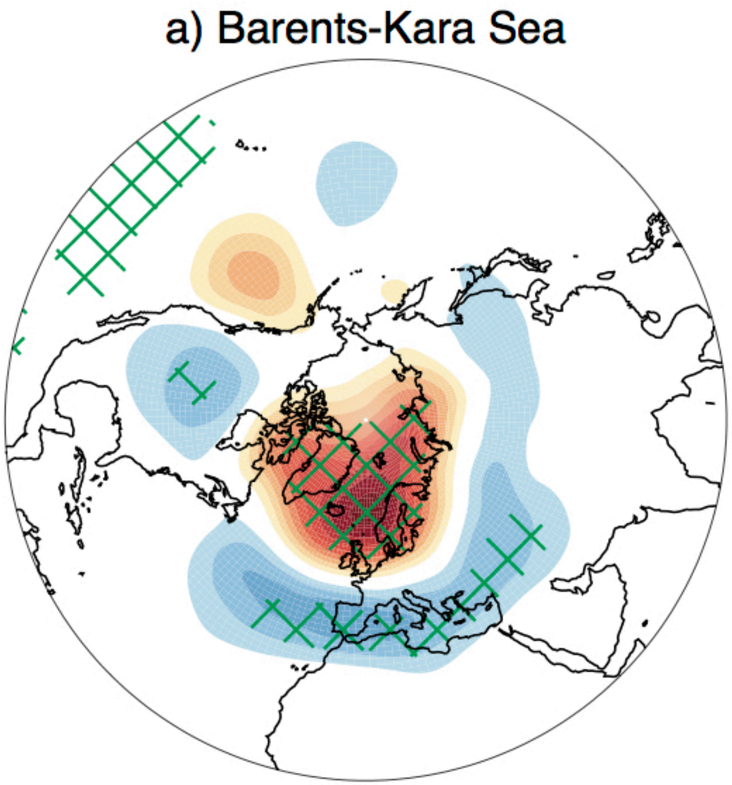
Z500 response to regional sea ice loss





Negative NAO response

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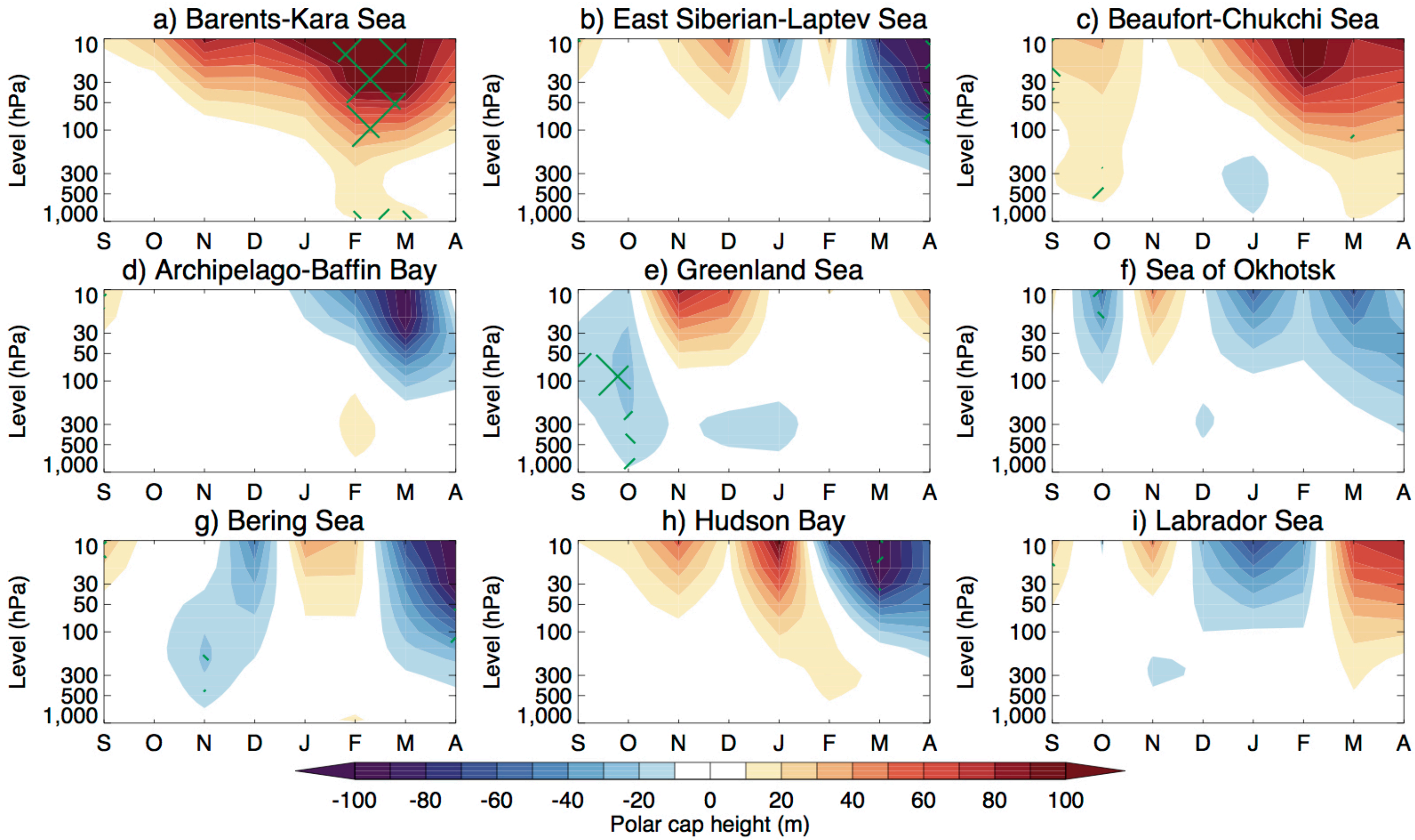
Polar cap height response



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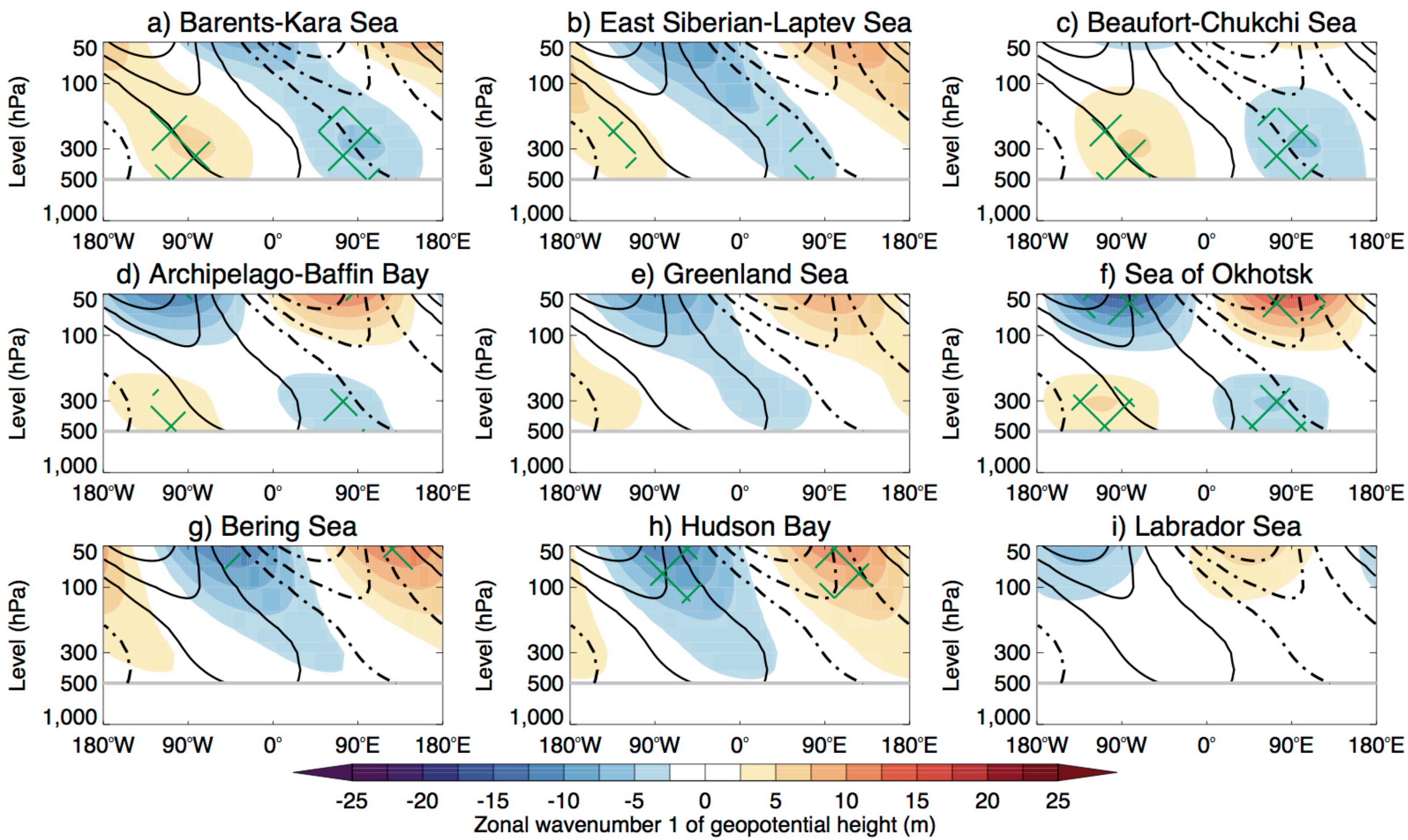
Linear interference



Zonal wavenumber 1 component of the January-February 30-65°N-mean height response

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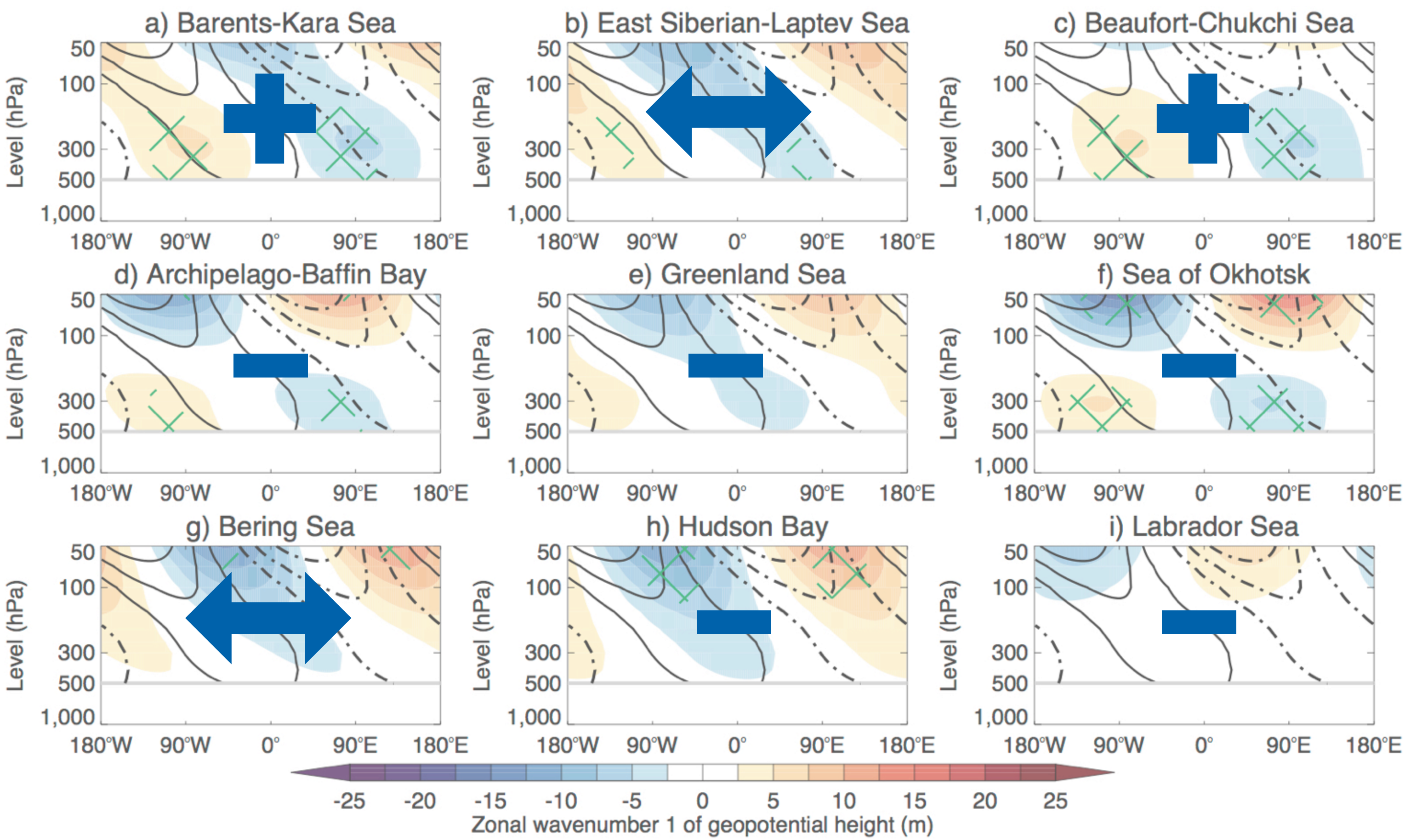
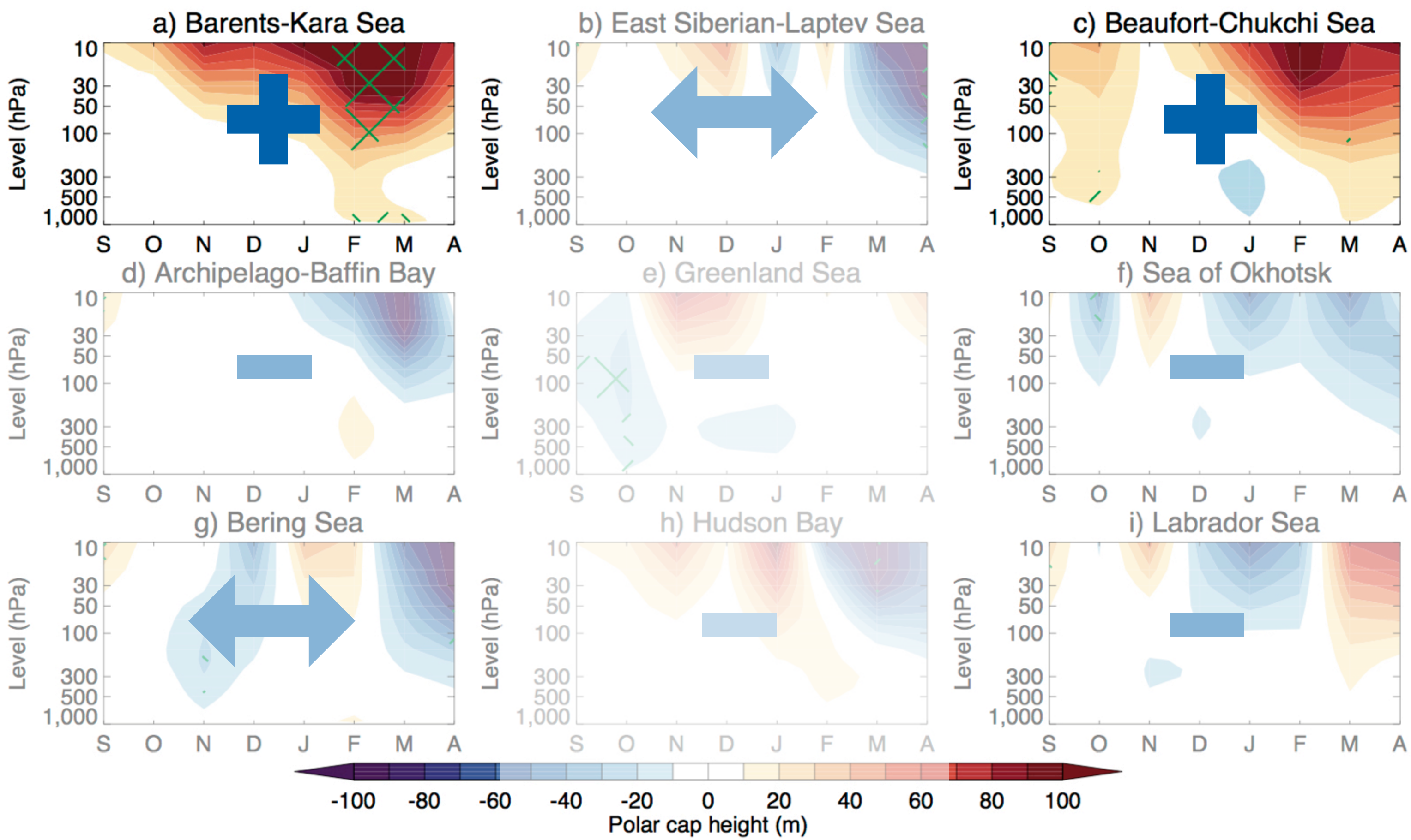
Linear interference



Zonal wavenumber 1 component of the January-February 30-65°N-mean height response

Constructive interference



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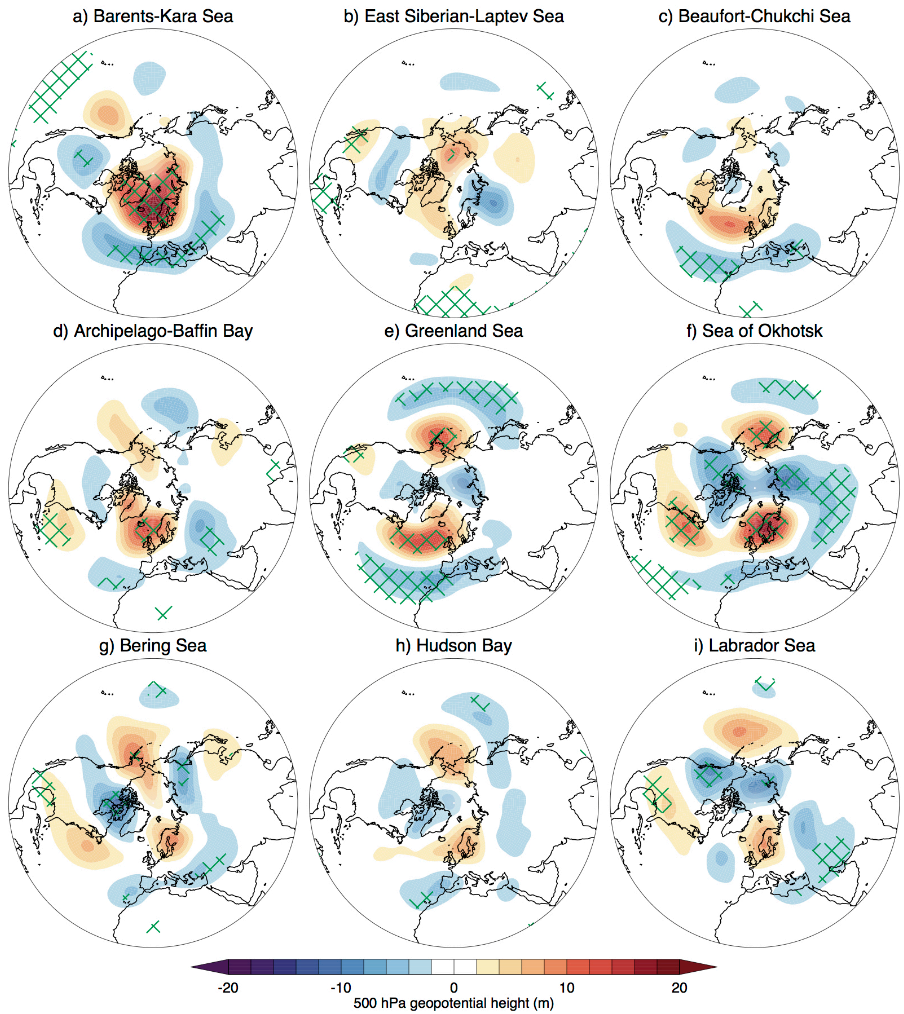
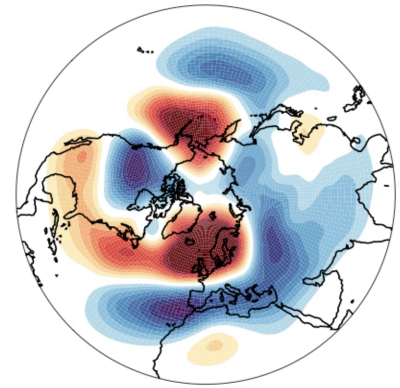
Nonlinearity



Estimated response to pan-Arctic sea ice loss
(sum of responses to regional sea ice loss)



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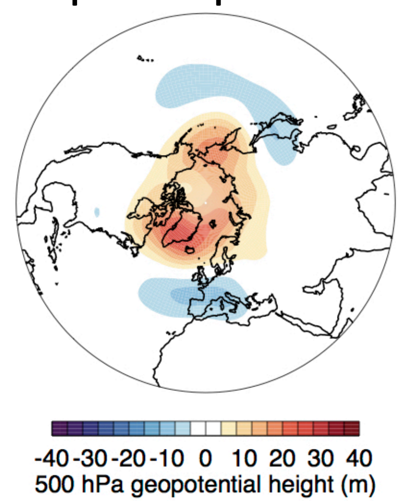

Nonlinearity

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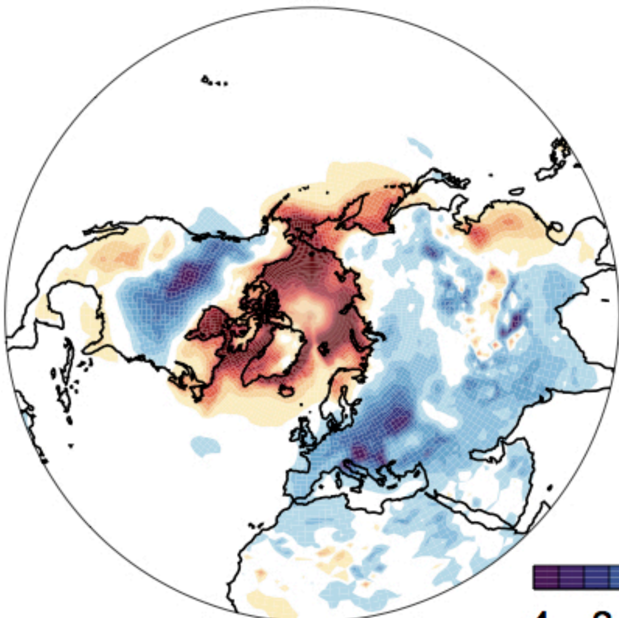
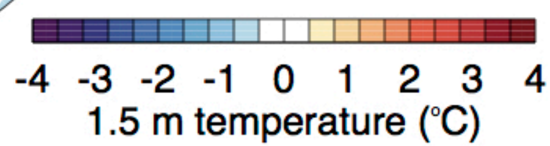
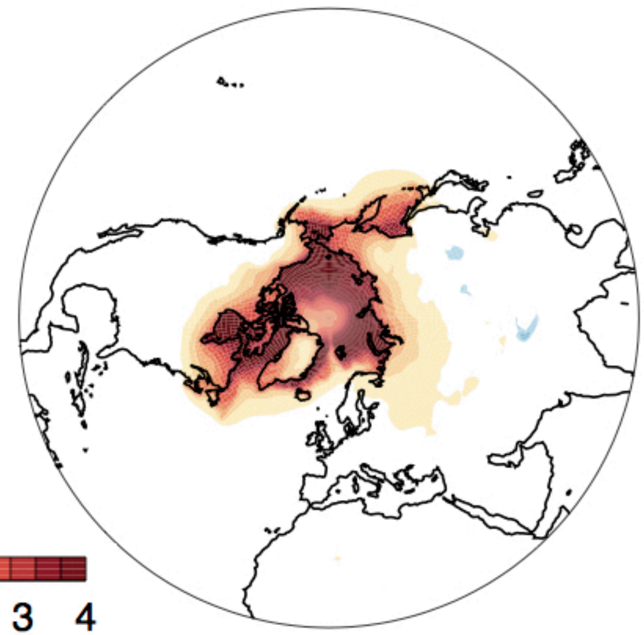




Local warming
Remote dynamically-induced cooling

Simulated response to pan-Arctic sea ice loss



Local warming
No remote cooling

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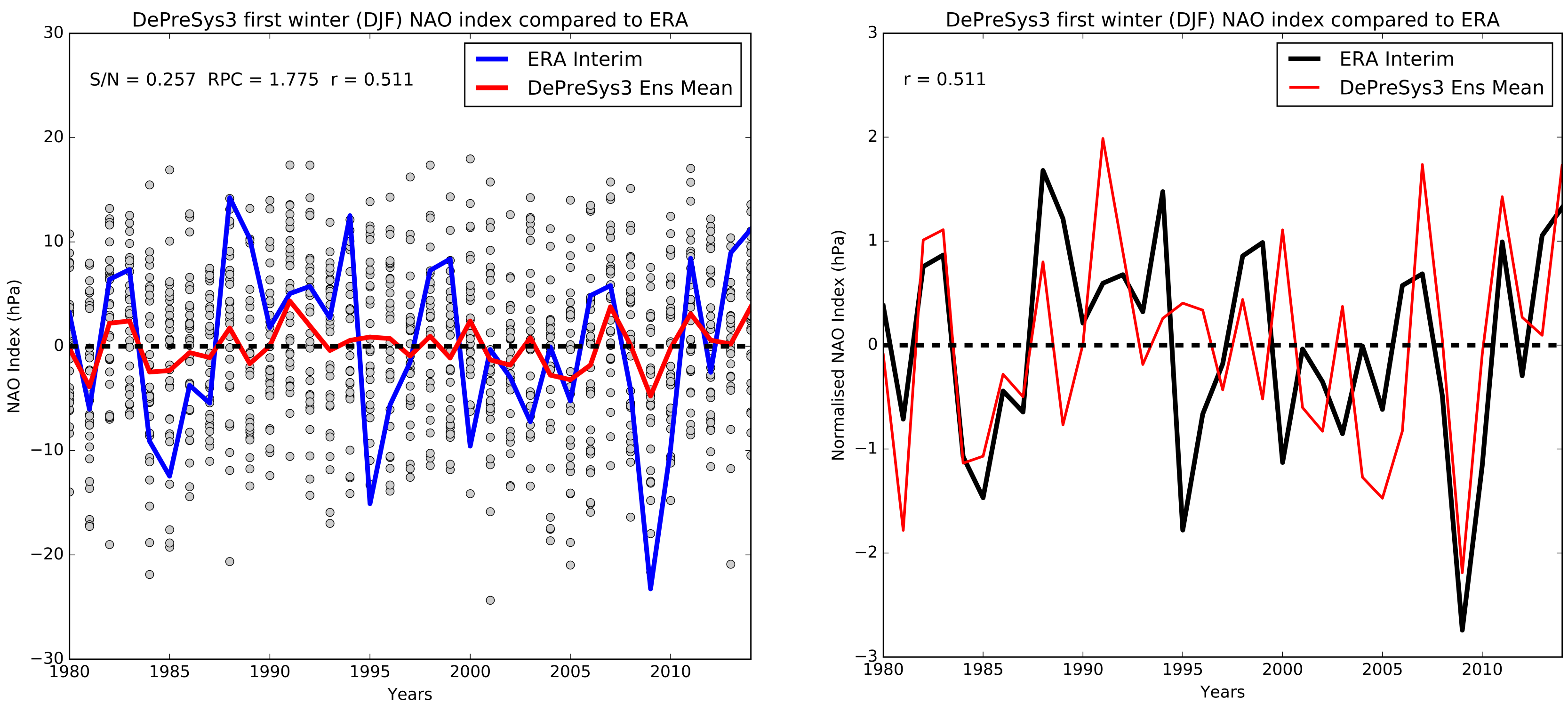
Skillful predictions of the NAO



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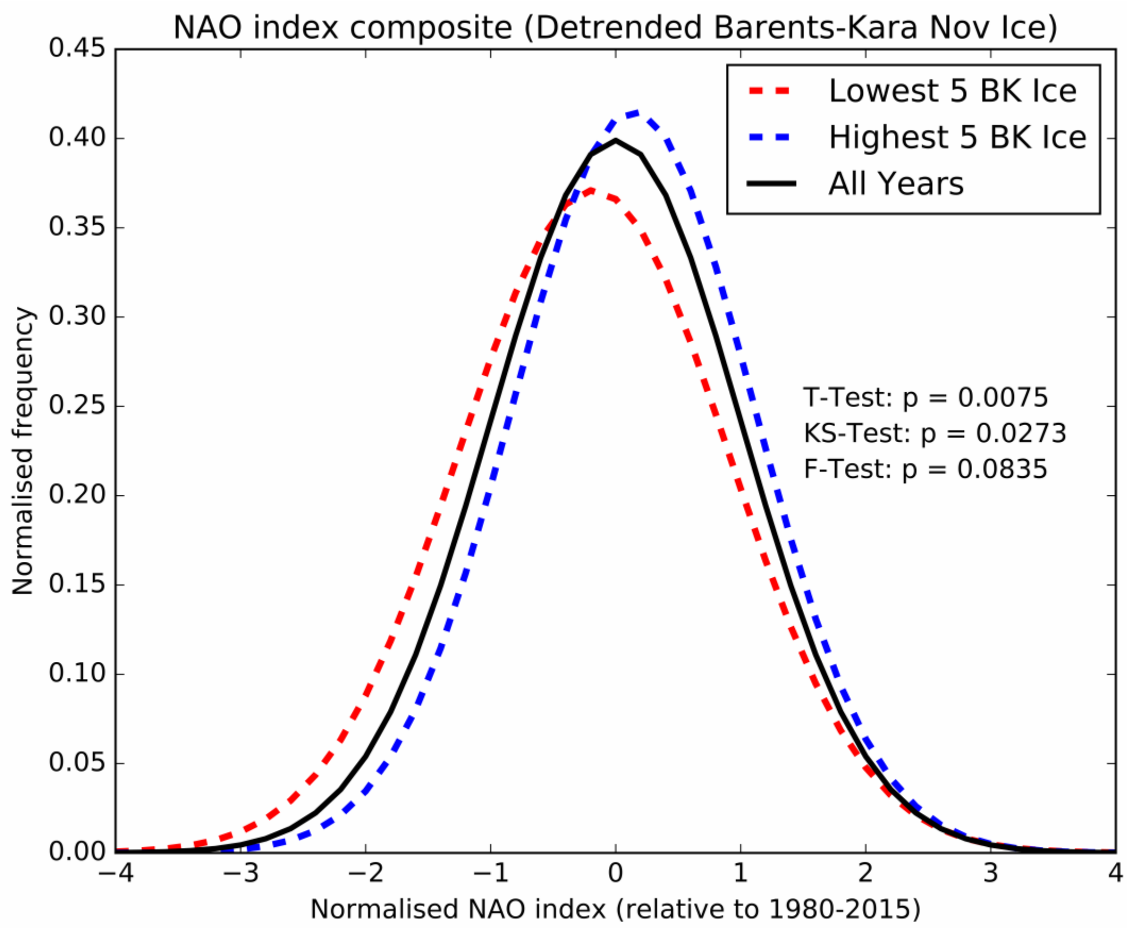
NAO predictability from sea ice?



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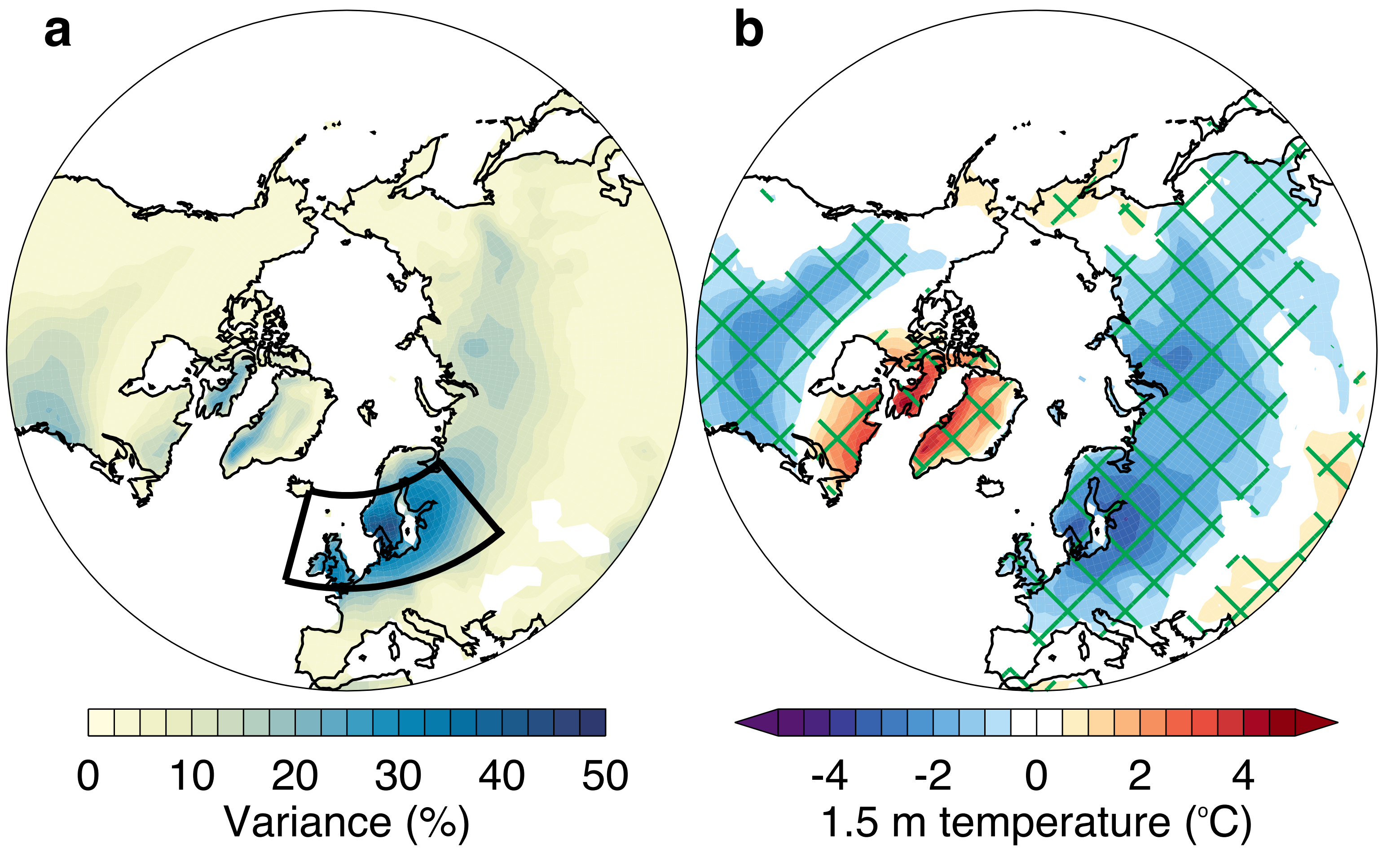
Temperature effects of NAO-



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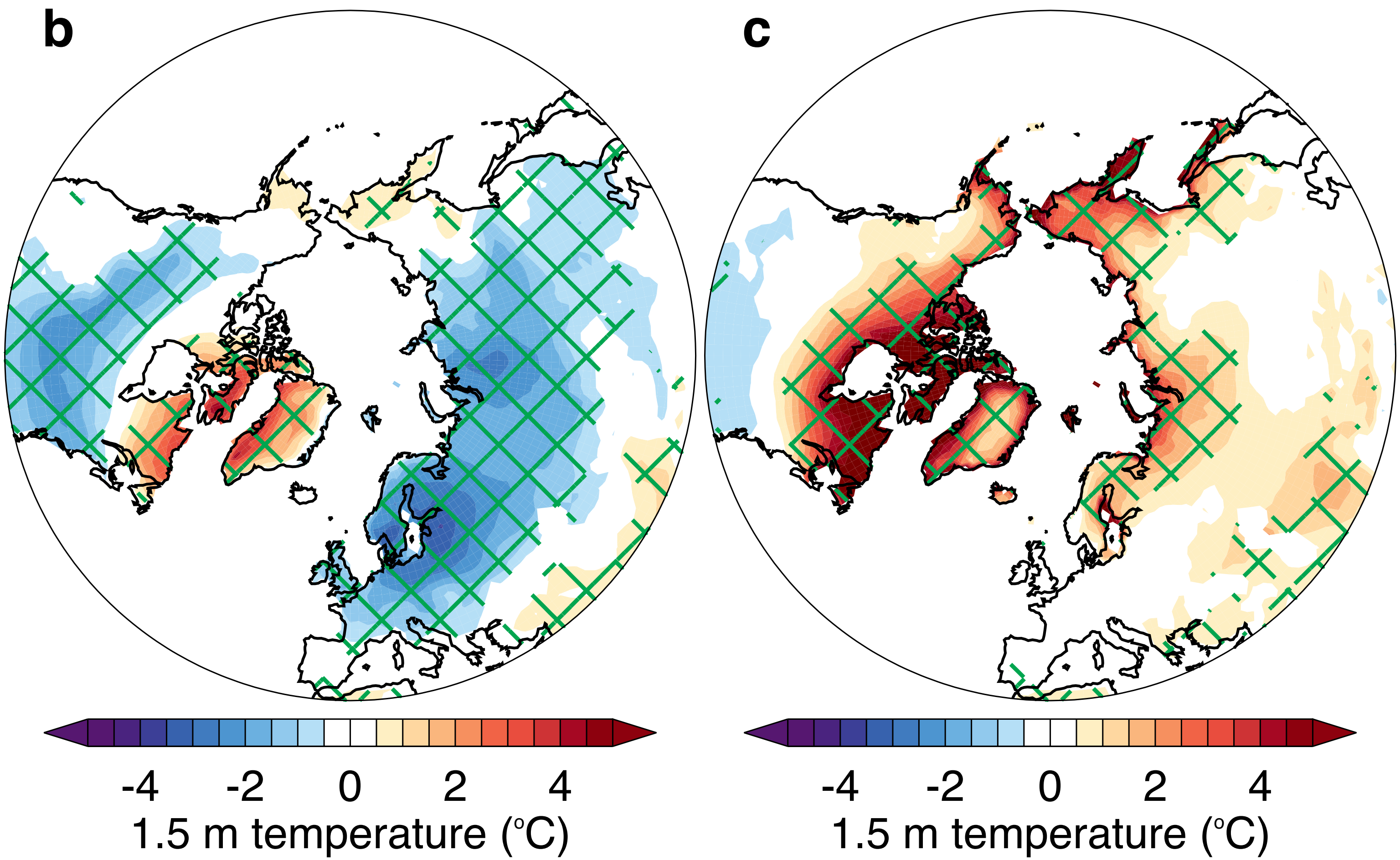
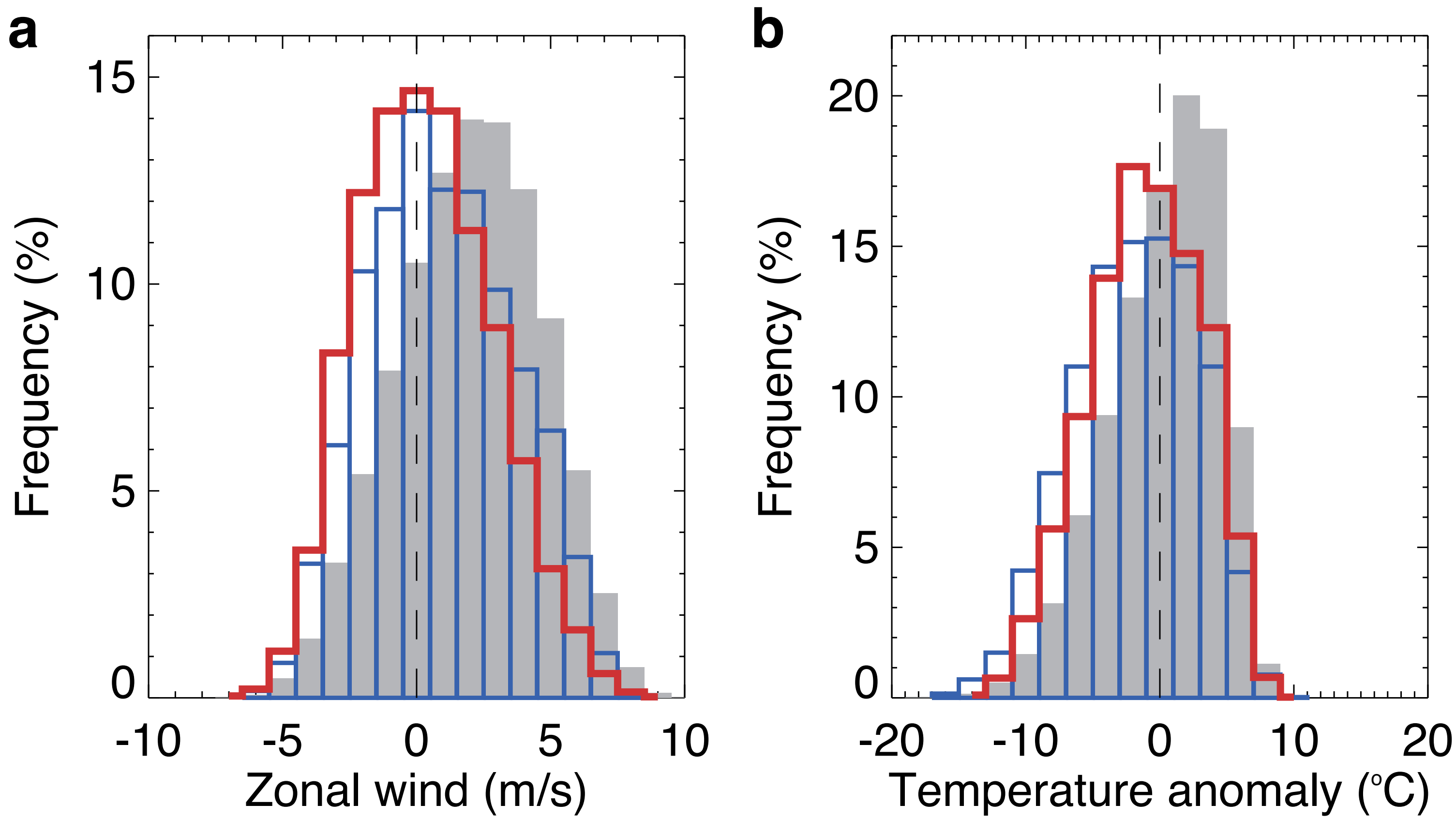
Missing cooling response



Anatomy of NAO- events



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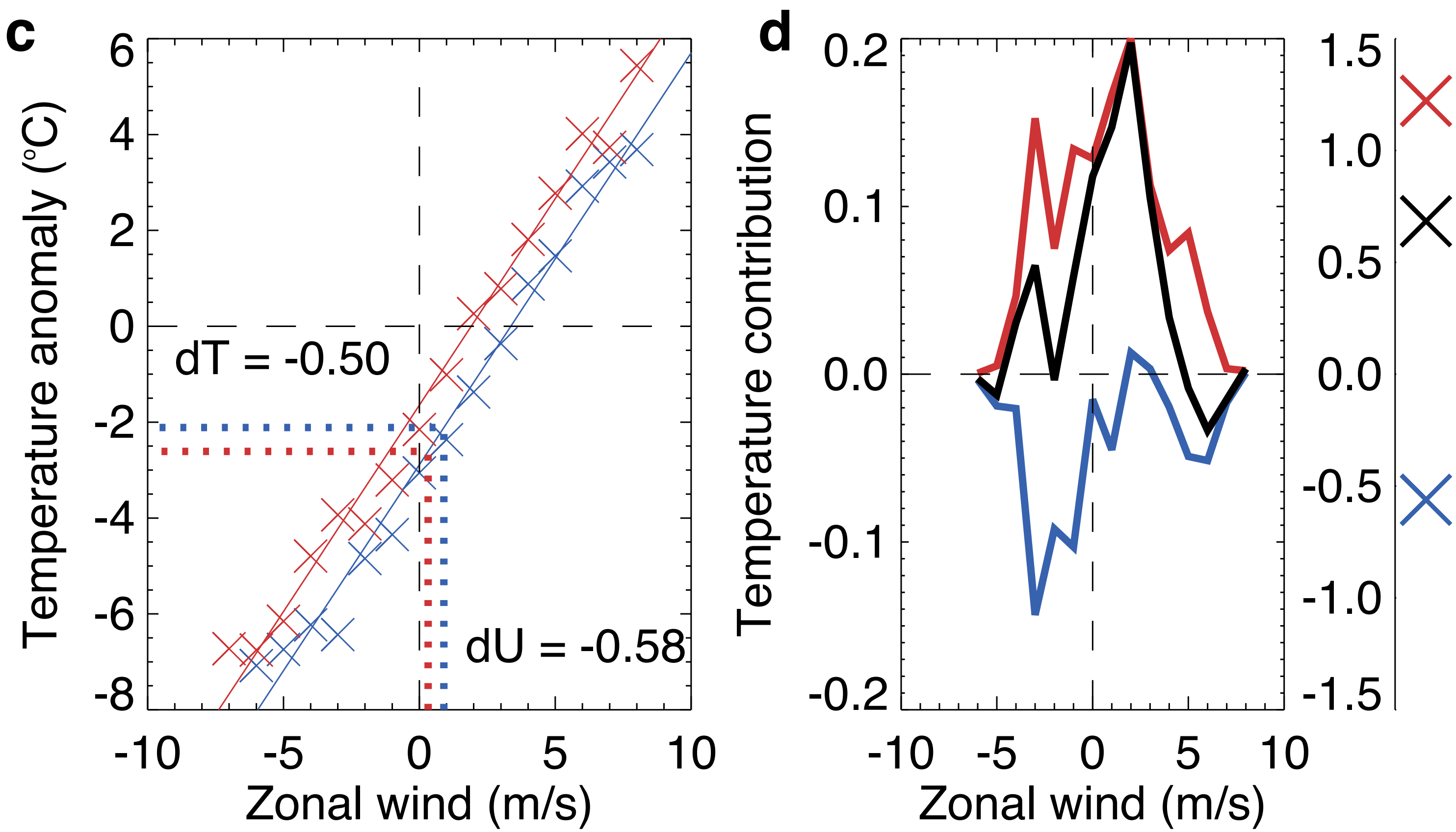
Dynamical and thermodynamical roles



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  Evidence that NAO- events become warmer despite intensification

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Main references

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ARTICLE

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The missing Northern European winter cooling response to Arctic sea ice loss

James A. Screen[1]

Reductions in Arctic sea ice may promote the negative phase of the North Atlantic Oscillation (NAO−). It has been argued that NAO-related variability can be used an as analogue to predict the effects of Arctic sea ice loss on mid-latitude weather. As NAO− events are associated with colder winters over Northern Europe, a negatively shifted NAO has been proposed as a dynamical pathway for Arctic sea ice loss to cause Northern European cooling. This study uses large-ensemble atmospheric simulations with prescribed ocean surface conditions to examine how seasonal-scale NAO− events are affected by Arctic sea ice loss. Despite an intensification of NAO− events, reflected by more prevalent easterly flow, sea ice loss does not lead to Northern European winter cooling and daily cold extremes actually decrease. The dynamical cooling from the changed NAO is 'missing', because it is offset (or exceeded) by a thermodynamical effect owing to advection of warmer air masses.

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Simulated Atmospheric Response to Regional and Pan-Arctic Sea Ice Loss

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(Manuscript received 7 March 2016, in final form 6 January 2017)

ABSTRACT

The loss of Arctic sea ice is already having profound environmental, societal, and ecological impacts locally. A highly uncertain area of scientific research, however, is whether such Arctic change has a tangible effect on weather and climate at lower latitudes. There is emerging evidence that the geographical location of sea ice loss is critically important in determining the large-scale atmospheric circulation response and associated midlatitude impacts. However, such regional dependencies have not been explored in a thorough and systematic manner. To make progress on this issue, this study analyzes ensemble simulations with an atmospheric general circulation model prescribed with sea ice loss separately in nine regions of the Arctic, to elucidate the distinct responses to regional sea ice loss. The results suggest that in some regions, sea ice loss triggers large-scale dynamical responses, whereas in other regions sea ice loss induces only local thermodynamical changes. Sea ice loss in the Barents–Kara Seas is unique in driving a weakening of the stratospheric polar vortex, followed in time by a tropospheric circulation response that resembles the North Atlantic Oscillation. For October–March, the largest spatial-scale responses are driven by sea ice loss in the Barents–Kara Seas and the Sea of Okhotsk; however, different regions assume greater importance in other seasons. The atmosphere responds very differently to regional sea ice losses than to pan-Arctic sea ice loss, and the response to pan-Arctic sea ice loss cannot be obtained by the linear addition of the responses to regional sea ice losses. The results imply that diversity in past studies of the simulated response to Arctic sea ice loss can be partly explained by the different spatial patterns of sea ice loss imposed.

1. Introduction

Satellites have routinely measured Arctic sea ice since the late 1970s. Since then, the sea ice cover has significantly reduced in all calendar months, with the largest trend in September—the month of the annual minimum (Simmonds 2015). The September sea ice extent has declined by 40% and its volume by an estimated 65% (IPCC 2013). Paleoclimate records suggest the sea ice cover is now lower than at any time in the previous 1450 yr (Kinnard et al. 2011). This decline in Arctic sea ice cover is already having profound societal and ecological impacts locally (e.g., Bhatt et al. 2014; Post et al. 2013). An emerging and highly uncertain area of scientific research, however, is whether such Arctic change has a tangible effect on weather and climate at lower latitudes. A recent spate of extreme weather events in the midlatitudes, occurring at a time of record low sea ice, has prompted debate about possible linkages between Arctic sea ice loss and midlatitude weather (e.g., Cohen et al. 2014; Vihma 2014; Walsh 2014; Overland et al. 2015; Barnes and Screen 2015). A number of recent papers have argued for a causal link, based on detailed analyses of atmospheric observations. However, in such a strongly coupled system, diagnosing cause and effect is a nearly intractable problem with observations alone. For this reason, recent work has turned to a ''modeling attribution'' approach and multiple modeling studies have implicated reduced Arctic sea ice cover as an important driver of Arctic and/or lower-latitude climate (Deser et al. 2010, 2015, 2016; Screen et al. 2013, 2014, 2015a,b; Peings and Magnusdottir 2014; Sun et al. 2015; Blackport and Kushner 2016; Cvijanovic and Caldeira 2015; Ayarzagüena and Screen 2016; and many others). While such model experiments have undoubtedly improved our understanding of the atmospheric response to Arctic sea ice loss, existing work has largely focused on the impacts of pan-Arctic sea ice loss (with some exceptions noted later). Yet, the geographical regions of sea ice anomalies vary from year to year, and the spatial pattern of future sea ice loss is highly uncertain. Thus, for both seasonal prediction and climate projections, it is important to better understand the atmospheric response to regional sea ice anomalies. Furthermore, in the literature there exists a wide diversity

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