Influence of Arctic sea ice on the North Atlantic Oscillation

James Screen, AGCI, June 2017
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- It’s robust

- It’s the Barents-Kara Sea

- It’s predictable

- It does not mean colder European winters
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  Evidence for a physical link between low sea ice and NAO-

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  Evidence of insensitivity to forcing size and background state

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  Evidence that sea ice is a source of skill in seasonal NAO forecasts

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  Evidence that NAO- events become warmer despite intensification
Simulations with pan-Arctic sea ice anomalies

November-December

January-February

Sea ice concentration (%)
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
Intensification of NAO- events

a

b

-100  
-50 
0 
50 
100

500 hPa geopotential height (m)

90 80 70 60 50 40 30 20

Latitude (°N)

Level (hPa)

-200  
-100  
0  
100  
200

Geopotential height (m)

-100  
-50  
0  
50  
100

500 hPa geopotential height (m)
Intensification of NAO- events

The image shows a contour plot with axes labeled as follows:

- **Level (hPa)**: Y-axis ranging from 1,000 to 10 hPa
- **Polar cap height (m)**: X-axis ranging from -200 to 200 m
- **Month (lag)**: X-axis with months labeled from S(-4) to J(4)

The colorscale ranges from purple to red, indicating varying intensities of the NAO events.
Stationary wave linear interference

November meridional mean (40-60N)

Correlation

S(-4) O(-3) N(-2) D(-1) J(0) F(0)

Month (lag)

Geopotential height (m)

Level (hPa)

Longitude
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

a) November-December

b) January-February

-100 -50 0 50 100
Sea ice concentration (%)

-100 -50 0 50 100
500 hPa geopotential height (m)

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Robustness of response: forcing magnitude

- November-December
- January-February

Sea ice concentration (%)

-100 -50 0 50 100

500 hPa geopotential height (m)

-100 -50 0 50 100

Temperature anomaly (°C)

dT = -0.63
dU = -0.60

Zonal wind (m/s)

-10 -5 0 5 10

Temperature contribution

-1.0 -0.5 0.0 0.5 1.0

Zonal wind (m/s)

-20 -10 0 10 20

Sea ice concentration (%)

-100 -50 0 50 100

November-December

January-February

January-February

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Robustness of response: background state

SST anomalies associated with either phase of AMO and PDO added to climatological SST
Background state matters for AA

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

James A. Screen* and Jennifer A. Francis

The pace of Arctic warming is about double that at lower latitudes—a robust phenomenon known as Arctic amplification. Many diverse climate processes and feedbacks cause Arctic amplification, including positive feedbacks associated with diminished sea ice [1]. However, the precise contributions from different factors is still being debated [2]. Through analyses of both observations and model simulations, we show that the contribution of sea-ice loss to the recent observed Arctic warming 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 polar gradient of geospheric thickness and to more pronounced reductions in the upper-level westerlies. Given the cyclical 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 large-scale sea-ice decline is greater (weaker) during periods of the negative (positive) PDO phase, with a diminished sea-ice cover of near-surface AA can be explained by feedbacks associated with diminished sea ice [1].

We speculate that the observed recent shift to the positive PDO (reduced) during periods of the negative PDO phase can be explained by feedbacks associated with diminished sea ice [1].

We conclude with the need to state that the PDO phases, if maintained and all other factors being equal, could act to temporarily reduce the pace of Arctic warming in the near future.

Arctic amplification (AA) is a robust feature in observations of recent past 7, paleo-climate reconstructions of the distant past [1] and model predictions of the future [8]. The majority of near-surface AA can be explained by feedbacks associated with a diminished sea-ice cover [1,9]. Higher in the atmosphere, however, the contribution of sea-ice loss to AA is less well constrained [10-13], in part because the atmospheric response to sea-ice loss is apparently nonlinear and context-dependent. By state-dependant we mean that a similar sea-ice anomaly can lead to different atmospheric responses depending on the background ocean-atmospheric state. So far, such state-dependant responses have generally been attributed to random internal variability [10,14]. 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 predominately 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 [15]. The PDO is not a simple phenomenon, but is instead the result of a combination of different physical processes, including stochastic variability of the Aleutian Low, remote tropical forcing and local North Pacific air-sea interactions (see Supplementary Discussion).

In Fig. 1, the composite time series of the PDO index more directly measures changes in the Aleutian Low, whereas the ENSO 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 index more directly measures changes in the Aleutian Low, whereas the ENOS index more directly measures changes in tropical Pacific SST (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. 1a,c), largely owing to the fact that the cases are not exactly distributed in time (the mean year for...
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
Simulations with regional sea ice loss

No region has more than 20% shared variance with any other region
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
Z500 response to regional sea ice loss

Negative NAO response
Polar cap height response

a) Barents-Kara Sea

b) East Siberian-Laptev Sea

c) Beaufort-Chukchi Sea

d) Archipelago-Baffin Bay

e) Greenland Sea

f) Sea of Okhotsk

g) Bering Sea

h) Hudson Bay

i) Labrador Sea

Level (hPa)

Polar cap height (m)
Linear interference

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

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

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

Simulated response to pan-Arctic sea ice loss
Nonlinearity

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

Simulated response to pan-Arctic sea ice loss

Local warming
Remote dynamically-induced cooling

Local warming
No remote cooling

1.5 m temperature (°C)

-4 -3 -2 -1 0 1 2 3 4
Skillful predictions of the NAO

DePreSys3 first winter (DJF) NAO index compared to ERA

- S/N = 0.257
- RPC = 1.775
- $r = 0.511$

- ERA Interim
- DePreSys3 Ens Mean

DePreSys3 first winter (DJF) NAO index compared to ERA

- $r = 0.511$

- ERA Interim
- DePreSys3 Ens Mean
NAO predictability from sea ice?

NAO index composite (Detrended Barents-Kara Nov Ice)

- Lowest 5 BK Ice
- Highest 5 BK Ice
- All Years

T-Test: $p = 0.0075$
KS-Test: $p = 0.0273$
F-Test: $p = 0.0835$
Temperature effects of NAO-

a

Variance (%) 0 10 20 30 40 50

b

1.5 m temperature (°C) -4 -2 0 2 4

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Missing cooling response

b

1.5 m temperature (°C)

-4 -2 0 2 4

c

1.5 m temperature (°C)

-4 -2 0 2 4

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Anatomy of NAO- events

(a) Frequency distribution of zonal wind (m/s) for NAO- events.

(b) Frequency distribution of temperature anomaly (°C) for NAO- events.

- $dT = -0.50$
- $dU = -0.58$

Temperature contribution
Dynamical and thermodynamical roles

\[ dT = -0.50 \]
\[ dU = -0.58 \]
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The missing Northern European winter cooling response to Arctic sea ice loss

James A. Screen

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 as an 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 a 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.

Main references

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 45% 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 (Kimnard et al. 2013). This decline in Arctic sea ice cover is already having profound societal and ecological impacts locally (e.g., Bhart 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. 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 examines ensemble simulations with an atmosphere-ocean 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 Sea 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 region and the Sea of Okhotsk, however, different regions assume greater importance in other seasons. The atmospheric response varies differently to regional sea ice losses than to pan-Arctic sea ice loss, and the responses to pan-Arctic sea ice loss cannot be obtained by the linear addition of the responses to regional sea ice losses. These results imply that diversity in past studies of the simulated responses to Arctic sea ice loss can be partly explained by the different spatial patterns of sea ice loss imposed.

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