Dynamics and predictability of atmospheric response to reduced Arctic sea ice through ensemble sensitivity analysis

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Something is happening in the Arctic

ARCTIC SEA ICE MINIMUM IN 2012

SUMMER ARCTIC SEA ICE BOUNDARY IN 1979
There is emerging evidence that reduced Arctic sea ice can alter the mid-latitude weather patterns.

“. . . research on these linkages is still in its infancy, making it difficult to draw conclusions regarding their existence or their mechanisms.”
Key questions

- What atmospheric responses can be attributed to Arctic sea ice loss, and how sensitive are they to varying amounts of reduced sea ice?
- Is there a consistent change in the large-scale circulation due to reduced Arctic sea ice?
- Does the sea ice loss contribute to extreme cold winters over the Northern Hemisphere continents?
Approach: sensitivity analysis

- NCAR Community Atmosphere Model (CAM 5.3)
  - $1.9^\circ \times 2.5^\circ$ latitude-longitude grid
  - 30 vertical levels up to 3.6 mb
  - Prescribed sea ice and sea surface temperature

- Systematic perturbations of sea ice
  - 7 different sea ice scenarios
  - 55 ensemble members for each ice scenario
  - 385 ensemble members in total
Sea ice scenarios

$\alpha \sim$ September sea ice area anomaly

$\alpha = 3$
$\alpha = 2$
$\alpha = 1$
$\alpha = 0$
$\alpha = -1$
$\alpha = -2$
$\alpha = -3$
Sea ice scenarios

\[ \alpha = 3 \]
\[ \alpha = 2 \]
\[ \alpha = 1 \]
\[ \alpha = 0 \]
\[ \alpha = -1 \]
\[ \alpha = -2 \]
\[ \alpha = -3 \]

\( \alpha \sim \) September sea ice area anomaly

\( \text{composite}_00.00 \) year 00, month 09

\( \text{composite}_{-1.00}_00.00 \) year 00, month 09

\( \text{composite}_{-2.00}_00.00 \) year 00, month 09

\( \text{composite}_{-3.00}_00.00 \) year 00, month 09

\( \text{composite}_{01.00}_00.00 \) year 00, month 09

\( \text{composite}_{02.00}_00.00 \) year 00, month 09

\( \text{composite}_{03.00}_00.00 \) year 00, month 09
Correlation analysis, autumn

2-m temperature

Sea-level pressure

Correlation with \(-\alpha\), autumn

Sep

Oct

Nov
Correlation with $-\alpha$, winter

2-m temperature

Sea-level pressure

Dec

Jan

Feb

Dec

Jan

Feb
Changes in jet stream position

Northern Hemisphere jet stream tracked using vertically integrated mass flux between 400 and 100 hPa.
Self-organizing map classification of wintertime circulation
Self-organizing map classification of wintertime circulation
Self-organizing map
Extreme cold winters

Area averaged wintertime (DJF) 2-m temperature over land in the mid-latitudes.

Smoothed using a moving average over 5 days.

Events definitions

- **extreme** below 2.5th percentile
- **normal** between 48.75th and 51.25th percentile
Extreme cold winters, eastern North America

Close to linear decrease in extreme cold winters with decreasing $\alpha$.

Arctic sea ice loss $\Rightarrow$ less frequent extreme cold winters over eastern North America.
Extreme cold winters, eastern Asia

Significant increase of extreme cold winters for $\alpha = -2$.

Frequency of extreme cold winter days decreases again for $\alpha = -3$. 

2-m temperature (K)  Sea-level pressure (hPa)  500 hPa heights (m)
Conclusions

- Robust and approximately linear atmospheric response over regions of decreased sea ice
- Remote response small compared to the ensemble spread, highly non-linear
- Arctic sea ice loss may favor a negative Arctic Oscillation during winter, but is sensitive to the amount of sea ice loss
- Impact on extreme cold winter days depends on the region; increased frequency over eastern Asia and decreased frequency over eastern North America
Conclusions

- Robust and approximately linear atmospheric response over regions of decreased sea ice
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The remote atmospheric response may be largely non-linear — an event based approach is beneficial
Extra material
Sea ice scenarios

Freezing season

![Graph showing sea ice area over time](image-url)
Sea ice scenarios

Freezing season
Sea ice scenarios

Freezing season

![Graph showing sea ice area over time](image)

Linear interpolation
Sea ice scenarios

Freezing season

![Graph showing the growth of sea ice area over time](image)

Linear interpolation
Sea ice scenarios

Sea ice area (million sq km)

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

α = 3  α = 2  α = 1  α = 0  α = -1  α = -2  α = -3
Sea ice scenarios

- Different scenarios represented with various line colors:
  - \( \alpha = 3 \)
  - \( \alpha = 2 \)
  - \( \alpha = 1 \)
  - \( \alpha = 0 \)
  - \( \alpha = -1 \)
  - \( \alpha = -2 \)
  - \( \alpha = -3 \)

- Sea ice area (million sq km) over months from January to December.
Self-organizing map, 500 hPa geopotential height
Self-organizing map, 500 hPa geopotential height
Self-organizing map, 300 hPa geopotential height
Self-organizing map, 300 hPa geopotential height
Self-organizing map training