Non-local impacts of observed and projected high-latitude climate change

US CLIVAR Polar Amplification Workshop 2024

Xiyue (Sally) Zhang | January 19, 2024
Observed high-latitude climate changes

Hahn et al. (2021); Smith et al. (2019); NSIDC; Rignot et al. (2019)
Observed high-latitude climate changes

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Observed high-latitude climate changes

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Observed high-latitude climate changes

- Southern Ocean cooling
- Minimal Antarctic sea ice trends
- Loss of Antarctica ice mass
- Arctic amplified warming
- Arctic sea ice loss

Hahn et al. (2021); Smith et al. (2019); NSIDC; Rignot et al. (2019)
Projected high-latitude climate changes

Amplified warming at both poles

Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)
Projected high-latitude climate changes

Amplified warming at both poles

Potentially ice-free Arctic

Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)
Projected high-latitude climate changes

Amplified warming at both poles

Increased ice melting from Antarctica

Potentially ice-free Arctic

Hahn et al. (2021); IPCC AR6 WG1 Ch4; Noël et al. (2023)
Teleconnection pathways

**Atmosphere**
- Circulation changes due to changes in meridional temperature gradient
- Troposphere-stratosphere interaction

**Air-sea interaction**
- Wind-evaporation-SST feedback
- Seasonal footprinting mechanism

**Ocean**
- Deep (overtturning) and shallow (gyre, subtropical cell) circulation
- Equatorward ventilation
- Ocean waves

Liu and Alexander (2007)
Observed warming and sea ice loss in the Arctic

Rantanen et al. (2022)
Arctic/midlatitude weather linkages
Observational studies support winter linkage

• Inferring causality from observations (or reanalyses) is challenging
• Decoupling from internal atmospheric variability is difficult
Arctic/midlatitude weather linkages

Modeling studies are inconclusive

- Modeling studies suggest many mechanisms and plausible pathways
- Models have biases (e.g., underestimate the observed eddy feedback strength)
- Different modeling protocols and setup can lead to different conclusions
Non-local impacts of projected sea ice loss
Polar Amplification Multi-model Intercomparison (PAMIP)

• Coordinated modeling effort from 16 models
• Each model has 98–300 ensemble members

Smith et al. (2022)
Non-local impacts of projected sea ice loss

Polar Amplification Multi-model Intercomparison (PAMIP)

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Disagreement between individual models on the sign of the response over Eurasia
Summary: Non-local impacts of Arctic amplification

Barnes & Screen (2015)

Do rapid Arctic warming and sea ice loss have a tangible impact on midlatitude weather?

• **Can it?** Modeling studies suggest so, yet disagreement on the response remains.

• **Has it?** Perhaps, but small compared to internal atmospheric variability.

• **Will it?** Arctic amplification is one of many factors that will influence midlatitude weather.

“…there is *low confidence* in the relative contribution of Arctic warming to mid-latitude atmospheric changes compared to other drivers.”

– IPCC AR6 WG1 Ch10
Diverging trends in observed surface temperature

- SO surface temperatures have cooled, as opposed to the Arctic
- Modeled SO surface temperatures warmed, as opposed to observed

Smith et al. (2019)
Observed changes in the Southern Ocean (SO)

SST (colors) and sea ice (contour) trends

Zhang et al. (2021); Zhang et al. (in review)
Impacts of observed SO surface cooling

SO pacemaker experiment

Historical simulation with observed SO cooling - Radiatively-forced response = SO-driven response

Fig. 1. Box- and-whisker plot of pattern correlations of SST trends in each ensemble member with those in the ensemble-mean. Significant at 95% confidence level. (A) ERSSTv5. The trapezoidal region in (B) [HIST1], (C) SO-driven1. Triangles show the ensemble-mean values and black horizonal line shows the observed value.

Annual-mean SST trends between 1979 and 2013 in (A) [SOPACE1], (B) HIST2, (C) SO-driven2. However, the contributions from the shortwave radiative feedback and the WES feedback are the dominant effect and the WES feedback is is sufficiently strong in CESM1. However, it is important to note that the simulated cooling as large as with observations, whereas the bottom 25% of

For the ensemble member of SOPACE2 that simulates the most significant at 95% confidence level. In response to observed Southern Ocean cooling, the southeast-Pacific region is likely to trigger cooling in the Southeast Pacific, which then stabilizes the resultant increase in high-latitudes, enhancing the evaporative cooling, thereby promoting equatorward propagation of a surface cooling response. What are the processes that contribute to the intermodel differences: the shortwave radiative feedback and the WES feedback are the dominant effect and the WES feedback is sufficiently strong in CESM1. However, it is important to note that the simulated cooling as large as with observations, whereas the bottom 25% of

The trapezoidal region in (B) [HIST2], (C) SO-driven1, (D) [SOPACE1], (E) SO-driven2. However, the contributions from the shortwave radiative feedback and the WES feedback are the dominant effect and the WES feedback is sufficiently strong in CESM1. However, it is important to note that the simulated cooling as large as with observations, whereas the bottom 25% of

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CESM1

[B] [SOPACE1] [A] [HIST1] [C] [SO-driven1]

CESM2

[E] [SOPACE2] [D] [HIST2] [F] [SO-driven2]

Zhang et al. (2021); Kang et al. (2023)
Stronger subtropical low-cloud feedback leads to stronger SO-driven tropical response

**CESM1**
- SO-driven1 SUM
- SO-driven1 SW

**CESM2**
- SO-driven2 SUM
- SO-driven2 SW

Kang et al. (2023); Kim et al. (2022)
Impacts of observed SO warming

SO cooling-driven response

Zhang et al. (in review)
Impacts of observed SO warming

Figure 1. Observed and simulated SST for the SO cooling period (1979–2013) and SO warming period (1949–1978).

Time series of observed (a) global mean (black) and SO (blue), and (b) southeast tropical Pacific (green, region highlighted in Figure 3c-e) SST anomalies from ERSSTv3b. Thin lines show the annual-mean anomalies, while the thick lines show smoothed time series with 10-year running mean. Red shading indicates the SO warming period and blue shading indicates the SO cooling period. SST trend maps from ERSSTv3b (c-e), SOPACE.

SO warming-driven response

SO cooling-driven response

Zhang et al. (in review)
Recent changes in Antarctic sea ice and SO temperatures

There have been 3 record-breaking low sea ice summers in the past 7 years, accompanied by ocean warming

Purich et al. (2023)
Impacts of projected Antarctic sea ice loss

Atmosphere-only

With coupled ocean dynamics

England et al. (2018); England et al. (2021)
Impacts of projected Antarctic sea ice loss
A coupled model study

\[ a) \Delta \text{sic} \]

\[ b) \Delta \text{TS} \]

Arctic sea ice loss
Warming mediated by tropical warming

England et al. (2020)
Comparing the impact of projected Arctic and Antarctic sea ice loss

Response to Arctic sea ice loss

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England et al. (2021)
Comparing the impact of projected Arctic and Antarctic sea ice loss

**Response to Arctic sea ice loss**

**Response to Antarctic sea ice loss**

Stronger tropical warming in response to Antarctic sea ice loss

England et al. (2021)
Impacts of projected Antarctic meltwater input
Southern Ocean Freshwater Input from Antarctica (SOFIA)

Meltwater-induced surface temperature anomaly

SOFIA forcing scenarios
Summary: non-local impacts of SO and Antarctic changes

Observed and projected changes in the SO and Antarctica are weaker than (and sometimes opposite to) Arctic changes

- Southern Ocean surface cooling in recent decades can partially contribute to the observed tropical Pacific cooling
- Antarctic sea ice loss can lead to warming that reaches the Arctic
- Antarctic meltwater can induce extensive cooling and northward circulation shift

Exciting opportunities ahead to quantify the remote impact of Antarctic climate change
Additional slides
Arctic/midlatitude weather linkages

Number of studies on the link between Arctic amplification and increased severe winter weather as of 2020...

Cohen et al. (2020)

“…there is low to medium confidence in the exact role and quantitative effect of historical Arctic warming and sea ice loss on mid-latitude atmospheric variability.”

– IPCC AR6 WG1 Ch10
Asymmetric response to extratropical forcing

ETIN-MIP idealized experiment

Southern extratropical forcing induces cooling that reaches the Arctic, while the impact of northern extratropical forcing only reaches SH subtropics.

Kang et al. (2019)
Antarctic meltwater leads to cooling in a coupled model

CESM1 shows meltwater-induced cooling trend (2006–2100) throughout SH and slight warming trend in NH midlatitude ocean.

Dong et al. (2022);
see also Bronselaer et al. (2018); Golledge et al. (2019); Sadai et al. (2020);