Impact of Extreme Arctic Oscillation on the Northern Atlantic Ocean

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Abstract

This study investigates the long-term impacts of extreme high and low-pressure patterns of the Arctic Oscillation (AO) on ocean dynamics, sea ice, and weather patterns in the Northern Hemisphere. Using the Community Earth System Model, we recreate three historical winter scenarios: an extreme negative phase (1976-77), an extreme positive phase (1988-89), and a neutral period (1953-54). We examine our key variables by comparing model outputs for 4 years of the extremes. We aim to gain insight into the lasting effects of prolonged negative and positive AO phases on regional climate systems. We noticed that particularly along many of the air and ocean currents near the bottom of Greenland, the North coast of Alaska, and the Arctic Ocean above the Labrador Sea and Europe, the positive phases of the AO had higher surface heat flux, sea surface temperatures, and more sea ice and snow.

Plain Language Summary

The Arctic Oscillation (AO) is a large-scale climate system that affects weather in the Northern Hemisphere. It describes how air pressure is distributed between the Arctic and mid-latitudes, which can influence various aspects of weather phenomena. Understanding how extreme AO events impact climate over time is crucial for predicting long-term weather patterns and environmental changes in northern regions. This study used advanced computer modeling to recreate three historical winter scenarios with different AO conditions: extreme negative, positive, and neutral. We examined how 4 straight years these different patterns affect ocean currents, sea ice, and weather over a four-year period following each case. We noticed within our areas of study that the positive phases of the AO had warmer temperatures but also more sea ice and snow.

1 Introduction

The Arctic Oscillation (AO) is a powerful climate pattern that influences weather and environmental conditions across the Northern Hemisphere. During the extreme winter AO event of 2019/20, the AO was responsible for a staggering 75% of temperature spikes in northern regions (Kim et al., 2022). This showcases the AO's crucial role in shaping regional climate patterns.

The AO's impact reaches far beyond temperature alone. Scientists have found the ability to forecast or predict future mid-to-high latitude weather patterns is actually higher during negative AO phases, especially when combined with anomalies in Arctic sea ice and sudden stratospheric warming (Zheng et al., 2021). This suggests the AO interacts with other complex atmospheric phenomena in intricate ways. Its influence even extends to East Asia, where positive AO phases can weaken the winter monsoon, leading to milder winters with fewer cold snaps (He et al., 2017).

Recent studies have revealed the complex nature of the AO. researchers have identified at least five distinct AO-like patterns, influenced by both high-frequency weather systems and larger-scale wave patterns. Interestingly, the El Niño-Southern Oscillation seems to modulate when these AO patterns emerge (Dai & Tan, 2017). The AO's impact is not limited to temperature and precipitation; the AO, along with the Pacific-North American pattern, significantly influences fire danger across different regions, with up to 70% of fires north of 50°N occurring during positive AO phases (Justino et al., 2022). Additionally, Wettstein and Mearns (2002) observed that increased NAO-AO phases correlate with more extreme temperature events in the northeastern U.S. and Canada1. Building upon this collective understanding, our study aims to investigate the long-term effects of extreme high and low-pressure patterns of the Arctic Oscillation on ocean dynamics, sea ice, and weather patterns in the Northern Hemisphere.

2 Methods

Input Data:

1. Negative AO Extremes Values: (1976 - 1977)
    1. Dec 1985: -2.074
    2. Jan 1986: -3.767
    3. Feb 1986: -2.010
2. Positive AO Extremes Values: (1988 - 1989)
    1. Dec 1988: 1.679
    2. Jan 1989: 3.106
    3. Feb 1989: 3.279
3. AO near 0 Values: (1953 - 1954)

1. Dec 1953: 0.575
2. Jan 1954: -0.148
3. Feb 1954: -0.181

Using the Community Earth System Model (CESM) version 2.2.2, we used component set GIAF with a resolution of f19_g17. We used the data atmosphere, POP 2 Ocean and CICE 5 simulations of the GIAD compset. The resolution of f19 for the atmosphere and land has a 1.9° latitude resolution and 2.5° longitude resolution. The resolution of g17 is for the ocean and sea ice with a latitude and longitude resolution of 1/7° (NCAR, 2022). To edit the name lists user_nl_data and user_nl_drof. We used the data set CORE2 to input our data, which ranged from Jan 1953 to Jan 1959, Jan 1976 to Jan 1982, and Jan 1988 to 1994 (NCAR, 2022).

We used a control case where the AO index is near 0. The AO index is near 0 when the atmosphere pressure is at average levels and neither strongly negative nor positive. We selected the winter of Dec 1953 to Feb 1954 for this case. Our two test cases are extreme negative AO and extreme positive AO. Our first test case was extreme negative AO during the winter of Dec 1976 to Feb 1977. In extreme negative AO, pressure is high in the Arctic causing cold air to move south. Our second test case was extreme positive AO during the winter of Dec 1988 to Feb 1989. In extreme positive AO, pressure is low in the Arctic and high pressure is experienced at mid-latitude levels. We selected our test cases using the AO index from 1950 to the present day. We focused on the winter months of December, January, and February and selected different winters that had the most negative AO index, the most positive AO index, and an AO index near 0.

We tested what effects the ocean and sea ice would experience if we were to have the conditions of an extreme negative AO and extreme positive AO for 4 consecutive years. We will determine results by running the months with the most negative AO for 4 years and the most positive AO for 4 years and creating difference plots between the negative test case and control and the positive test case and control. Using the difference plots, we can see the impact of the extreme negative AO and extreme positive AO on the Northern Hemisphere's oceans and sea ice.

3 Results

1. **Surface Heat Flux (W/m^2)**

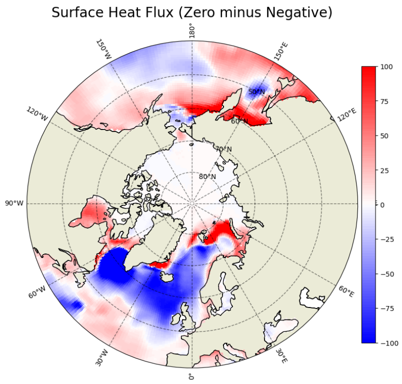

Figure 1. The figure depicts the difference in surface heat flux in watts per meter squared between the zero and negative test cases.

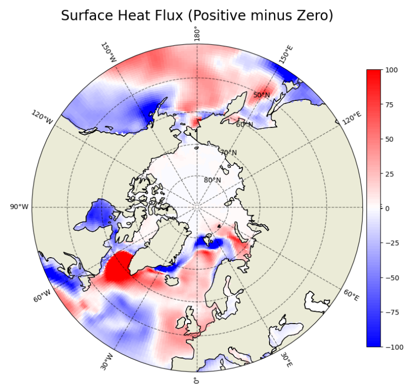

Figure 2. The figure depicts the difference in surface heat flux in watts per meter squared between the positive test case and control.

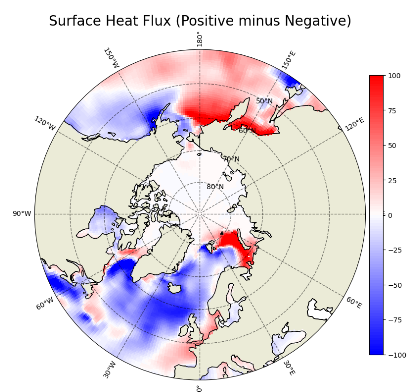

Figure 3. The figure depicts the difference in surface heat flux in watts per meter squared between the positive and negative test cases.

2. Sea Surface Height (m)

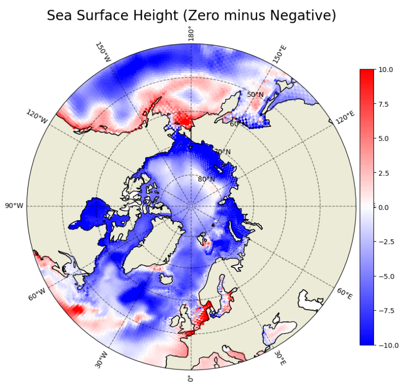

Figure 1. The figure depicts the difference in sea surface height in meters between the control and negative test cases.

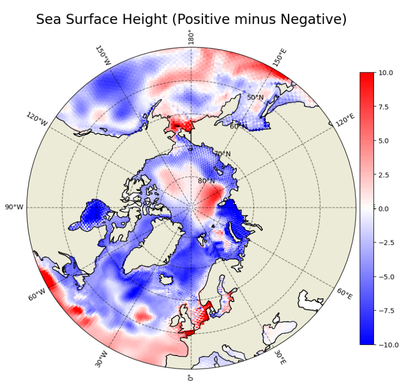

Figure 2. The figure depicts the difference in sea surface height in centimeters between the positive and control test cases.

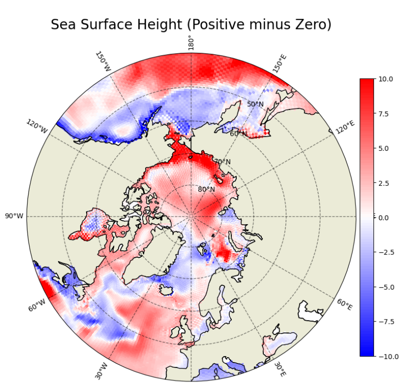

Figure 3. The figure depicts the difference in sea surface height in meters between the positive and negative test cases.

3. Sea Surface Salinity (g/km)

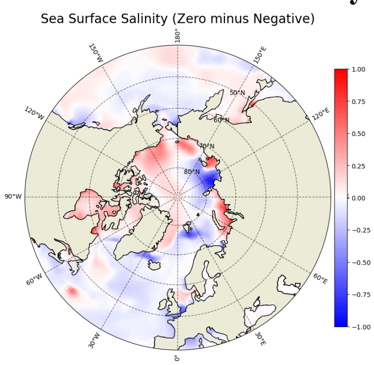

Figure 1. The figure depicts the difference in sea surface salinity in grams of salts per kilogram between the neutral and negative test cases.

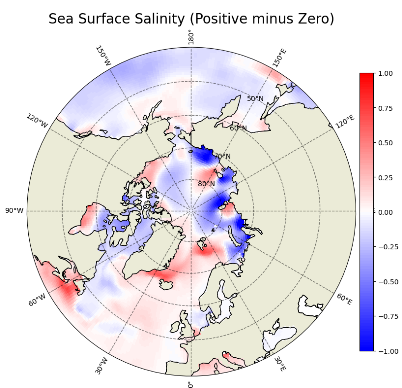

Figure 2. The figure depicts the difference in sea surface salinity in grams of salts per kilogram between the positive and neutral test cases.

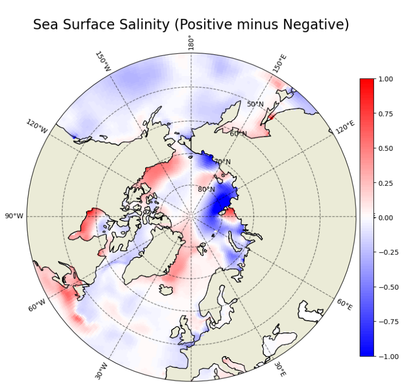

Figure 3. The figure depicts the difference in sea surface salinity in grams of salts per kilogram between the positive and negative test cases.

4. Snowfall Rate (day)

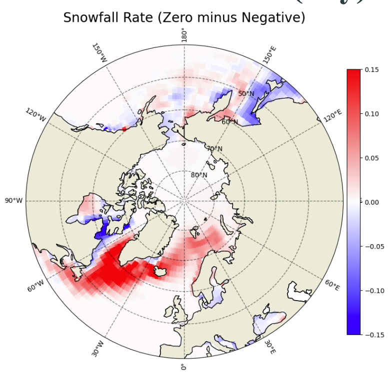

Figure 10. The figure depicts the difference in sea surface height in meters between the control and negative test cases.

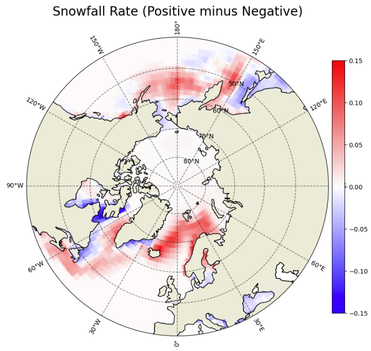

Figure 11. Difference in average snowfall rate per day between positive and neutral AO extremes.

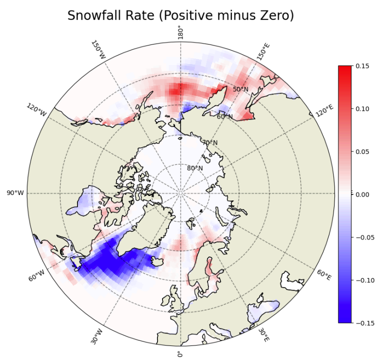

Figure 12. Difference in average snowfall rate per day between positive and negative AO extremes.

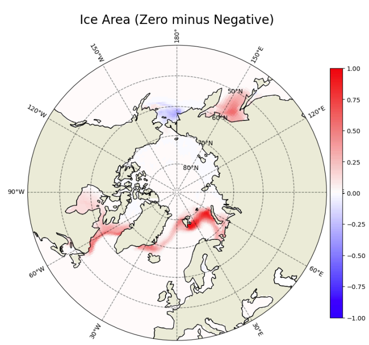

Figure 13: Displays the difference between the percentage of ice covered with snow between the median and the negative cases.

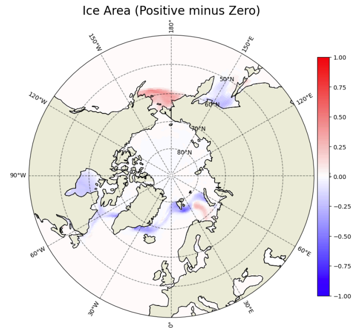

Figure 14: Displays the difference between the percentage of ice covered with snow between the positive and median cases.

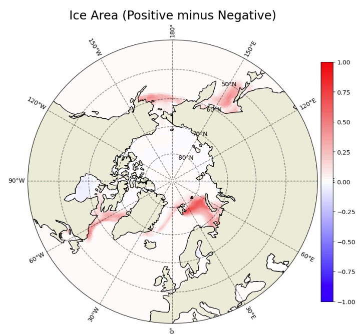

Figure 15: Displays the difference between the percentage of ice covered with snow between the positive and negative cases.

5 Conclusions

Acknowledgments

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References

Chang, P., Zhang, S., & Danabasoglu, G. (2020). An unprecedented set of high-resolution Earth system simulations for understanding multiscale interactions in climate variability and change. *Journal of Advances in Modeling Earth Systems*, *12*(11). https://doi.org/10.1029/2020MS002298

Dai, P., & Tan, B. (2017). The nature of the Arctic Oscillation and diversity of the extreme surface weather anomalies it generates. *Journal of Climate, 30(*14*),* 5563-5584. *https://doi.org/10.1175/JCLI-D-16-0467.1*

He, S., Gao, Y., Li, F., Wang, H., & He, Y. (2017). Impact of Arctic Oscillation on the East Asian climate: a review. *Earth-Science Reviews, 164,* 48-62. https://doi.org/10.1016/j.earscirev.2016.10.014

Justino, F., Bromwich, D. H., Schumacher, V., DaSilva, A., & Wang, S. H. (2022). Arctic Oscillation and Pacific-North American pattern dominated-modulation of fire danger and wildfire occurrence. *npj Climate and Atmospheric Science*, *5*(1), 52. https://doi.org/10.1038/s41612-022-00274-2

Kim, S. H., Kryjov, V. N., & Ahn, J. B. (2022). The roles of global warming and Arctic Oscillation in the winter 2020 extremes in East Asia. *Environmental Research Letters*, *17*(6), 065010. https://doi.org/10.1088/1748-9326/ac7061

National Weather Service Climate Prediction Center. (n.d.). Teleconnections: Arctic Oscillation. Retrieved from October 4, 2024, from https://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml

NCAR (2022), COREv2 air-sea surface fluxes, *COREv2 Air-Sea Surface Fluxes | Climate Data Guide*. https://climatedataguide.ucar.edu/climate-data/corev2-air-sea-surface-fluxes

Wettstein, J. J., & Mearns, L. O. (2002). The influence of the North Atlantic–Arctic Oscillation on mean, variance, and extremes of temperature in the northeastern United States and Canada.

Journal of Climate, *15*(24), 3586-3600. https://doi.org/10.1175/1520-0442(2002)015%3C3586:TIOTNA%3E2.0.CO;2

Zheng, Z., Ban, J., & Li, Y. (2021). The effect of the Arctic Oscillation on the predictability of mid-high latitude circulation in December. *Frontiers in Physics*, *9*, 736085. https://doi.org/10.3389/fphy.2021.736085