Parker Walsh

Hilary Palevsky

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Effect of Arctic Oscillation phase on Arctic sea ice extent during boreal winter

Introduction

The Arctic Oscillation (AO) is an index designed to measure the strength of the Arctic polar vortex. It is calculated using the leading function of the empirical orthogonal function of the AO loading pattern, which is the geopotential height anomalies at 1000 hPa in the Northern Hemisphere. It has a distinct negative and positive phase. In the negative phase, the sub-tropical jet is weak and has a significant meridional component. This allows colder air to penetrate further into the midlatitudes, since the polar vortex cannot contain it as tightly. But it also cannot block warm air from flowing north as effectively. In the positive phase, the subtropical jet is strong and significantly zonal, isolating the high latitudes from warmer air to the south. The signal is strongest during boreal winter. It is a primary driver of winter weather in the boreal midlatitudes.

The sea ice index is a composition of ice extent and concentration. Sea ice has an important function in modulating climate due to its high albedo. The sun’s energy is reflected into space as opposed to being absorbed by the planet and put into the climate system. Arctic sea ice has been declining in age and extent since modern records began because of anthropogenic warming. Understanding if and how sea ice affects a primary driver of boreal winter would advance predictive knowledge.

Thus, the topic of focus is the effect of AO phase on the sea ice extent during boreal winter in the Northern Hemisphere. The specific question entails looking at time series of AO index values and Arctic sea ice extent and determining whether specific phases are reflected in changes in ice extent. My hypothesis is that positive AO phase is correlated with higher sea ice extent during winter. This would be because warmer, moister air from the subtropics cannot penetrate the poles well and impede sea ice formation. The reverse is hypothesized for the converse case.

Methods

NOAA Climate Prediction Center maintains daily and monthly AO value records beginning on 1 January 1950. The monthly values through March 2020 were obtained. Figure 1 displays the distribution of AO index values for each month. In this analysis, since the AO signal is strongest in winter, annual January–March means were used. The decision had to be made which months to use, particularly as whether December or March would be used in the three-month seasonal mean. December has a minimum/maximum of -3.4/2.3 and a standard deviation of 1.3. March has a minimum/maximum of -3.2/3.0 and a standard deviation of 1.4. Keeping in mind the principles of lag time in the climate systems and that March has a larger range of values, I chose to include March and exclude December.

National Ice and Snow Data Center maintains various datasets related to ice and snow. For this project I used the Arctic sea ice extent, which begins January 1979 when reliable satellite measurements of sea ice extent began. I calculated the January–March seasonal mean for each year since 1979. I used basic statistical functions through MATLAB in my calculations. To remove the anthropogenic warming signal, a linear detrending was performed by performing a linear best fit and subtracting the regressed values from the JFM mean values.

A correlation analysis was performed to determine if a relationship was present between the AO index and the detrended sea ice extent.

Results

Figure 2 is a graph of the AO index seasonal mean (January–March) since 1950. The five-year moving average is helpful in looking past the year-to-year variability. Except for a period 1973–1975, the 5-year AO seasonal mean was negative 1950–1988 until it turned positive in 1989. After 1989 there has been 16 additional years where the 5-year AO seasonal mean is positive. There are two noticeable long duration positive spells: 1989–1995 and 2015–2020. A trend line has been fitted over the whole period; it has a slope of +0.0186 yr^{-1}.

Figure 3 is a plot of the Arctic sea ice extent seasonal mean (January–March) since 1979. The anthropogenic warming signal is present in the form of a long-term decline in areal extent and volume. A linear regression yields a slope of -0.0441 M km yr^{-1}.

Figure 4 is a plot of the detrended sea ice extent. The regressed values previously mentioned were subtracted from the extent values. The new dependent variable is now the difference of the sea ice extent from the expected trend value for each year. The AO index for 1979–2020 is superimposed on the plot. No apparent similarities are noted.

Figure 5 is a correlation plot of the AO JFM seasonal mean and the detrended sea ice anomaly. A weak r^2 value was returned: 0.19. An even weaker correlation was found using the AO 5-year moving mean: 0.12.

Discussion

Looking at the AO index plot, the positive trend is notable. It would suggest a long-term strengthening of the polar vortex. 1989 appears to be when the AO hit a tipping point. The 1950-1988 mean is -0.66. The 1989–2020 mean is 0.28. Natural variability continues, but it seems the index wintertime baseline from which it fluctuates jumped upward considerably. I can only speculate as to a cause. It could be due to anthropogenic forcing or be part of a low-frequency natural oscillation of which 70 years is too short a record to capture fully.

A positive but weak correlation exists between the AO index and Arctic sea ice extent. The null hypothesis cannot be rejected at this time. There are several factors one can think of to explain why. A significant factor is that the length of the sea ice record (1979–2020) is sixty percent of the length of the AO record (42 years). Consequently, the first 29 years of the AO record must be discarded. Additionally, those years are also the most negative AO values of the whole record. So, the AO data loses a significant amount of variance that may have otherwise helped form a correlation.

Another possibility may be that the linear detrending of sea ice is insufficient to effectively remove the anthropogenic signal. Relatedly, even if the detrending is sufficient, other confounding variables like ENSO may have stronger first-order effects on sea ice that impair retrieval of the correlation. Or it may genuinely be the case that the strength of the Arctic polar vortex does not influence the extent of sea ice. Finally, human error is always a possibility.

Conclusion

In sum, I fail to reject the null hypothesis. My method does not support a correlation between Arctic sea ice extent and the AO. There are a few avenues to pursue for future work. One would be to find reconstructed figures for sea ice extent and AO index values to extend the record and improve the robustness of the analysis. Another would be to take the finding of a strengthening polar vortex and research the potential climate implications for boreal winter precipitation and temperature in the subtropics and poles. Relatedly, investigating the mechanism that caused the AO base state to jump higher could prove useful in identifying other tipping points in atmospheric teleconnections as the anthropogenic forcing continues.

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Statement of Code

Code and data needed to reproduce this work can be found at: https://tinyurl.com/yrwbpkuj

Appendix of Figures

Figure 1.

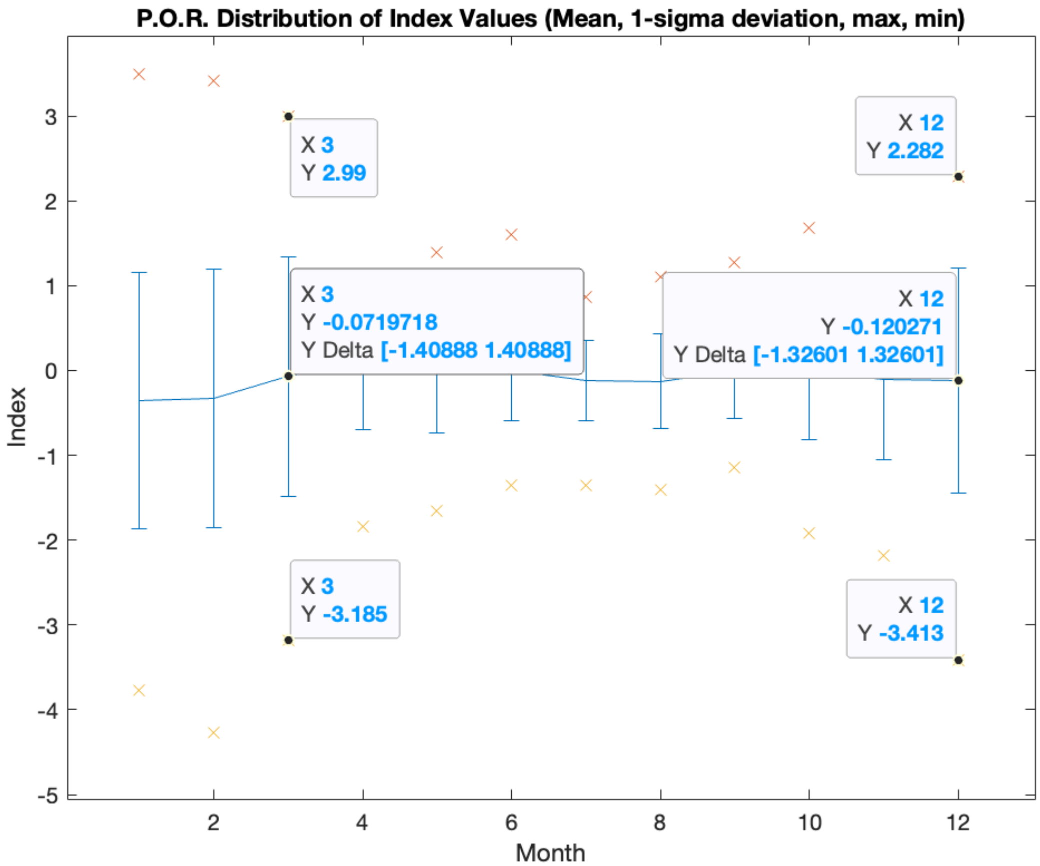


Figure 2.

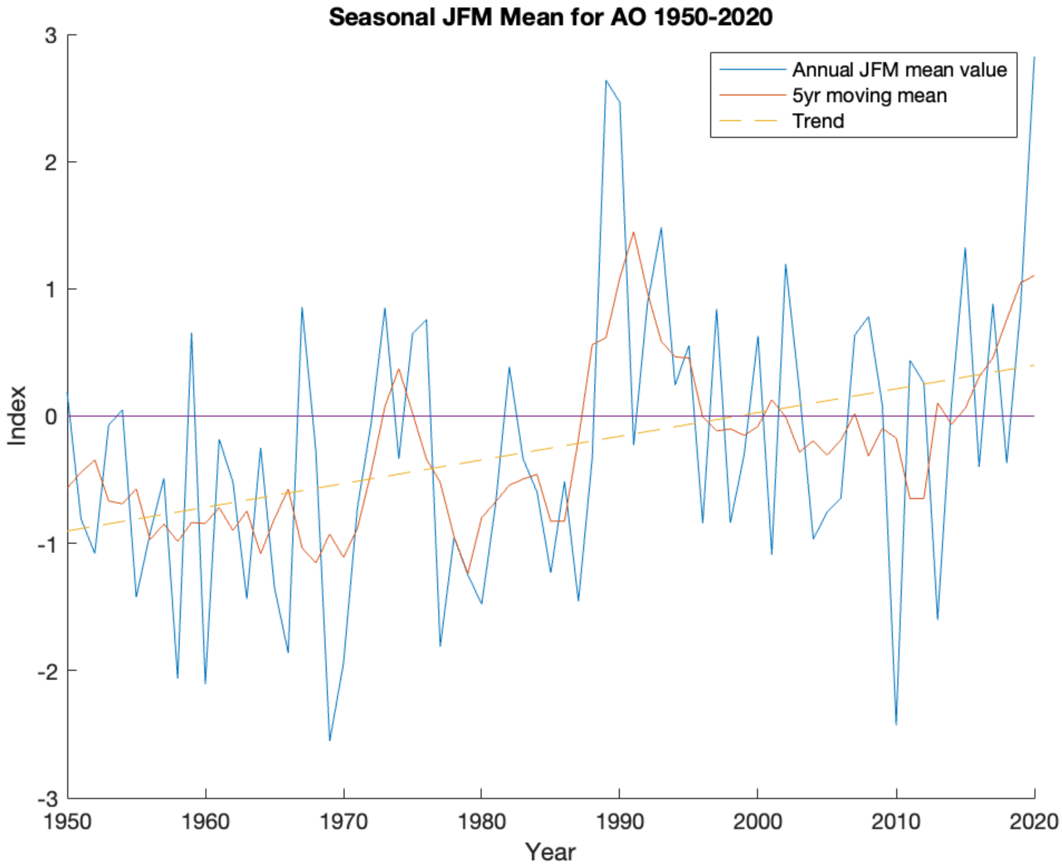

Seasonal JFM Mean for AO 1950-2020
Annual JFM mean value
5yr moving mean
Trend
Index
Year
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
2010
2020

Figure 3.

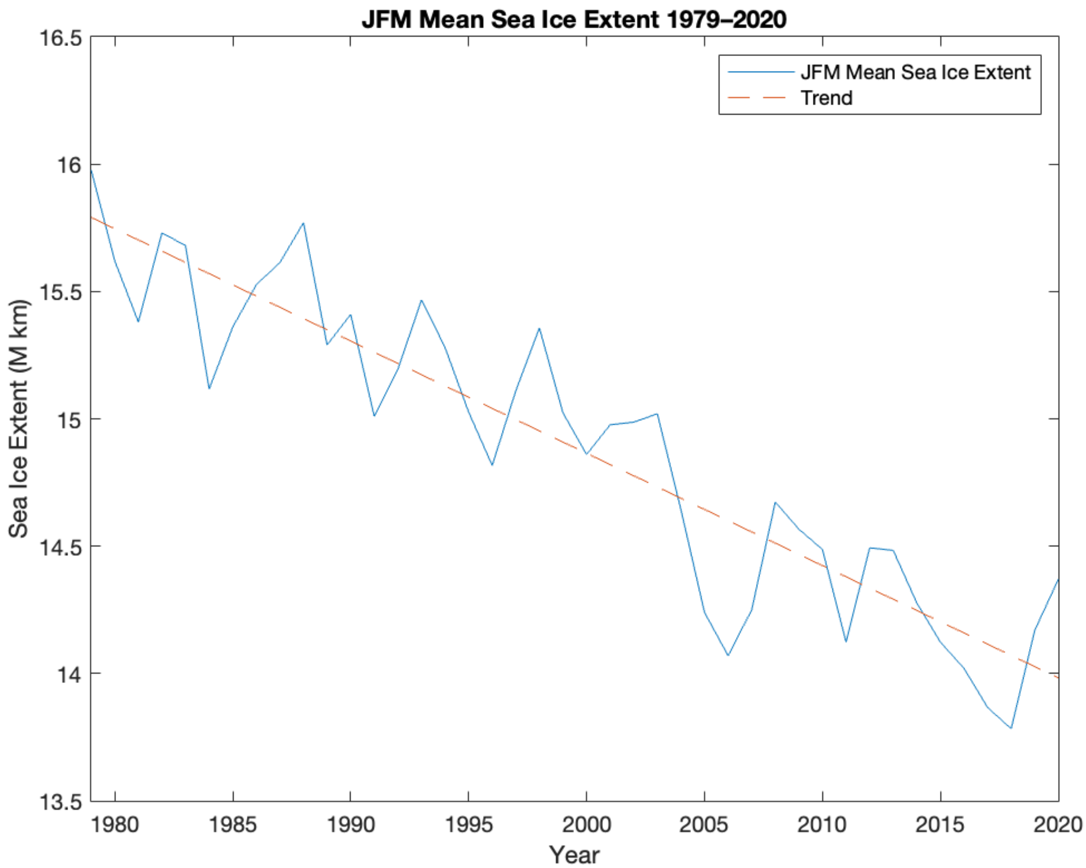

JFM Mean Sea Ice Extent 1979–2020
JFM Mean Sea Ice Extent
Trend
16.5
16
15.5
15
14.5
14
13.5
Sea Ice Extent (M km)
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

Figure 4.

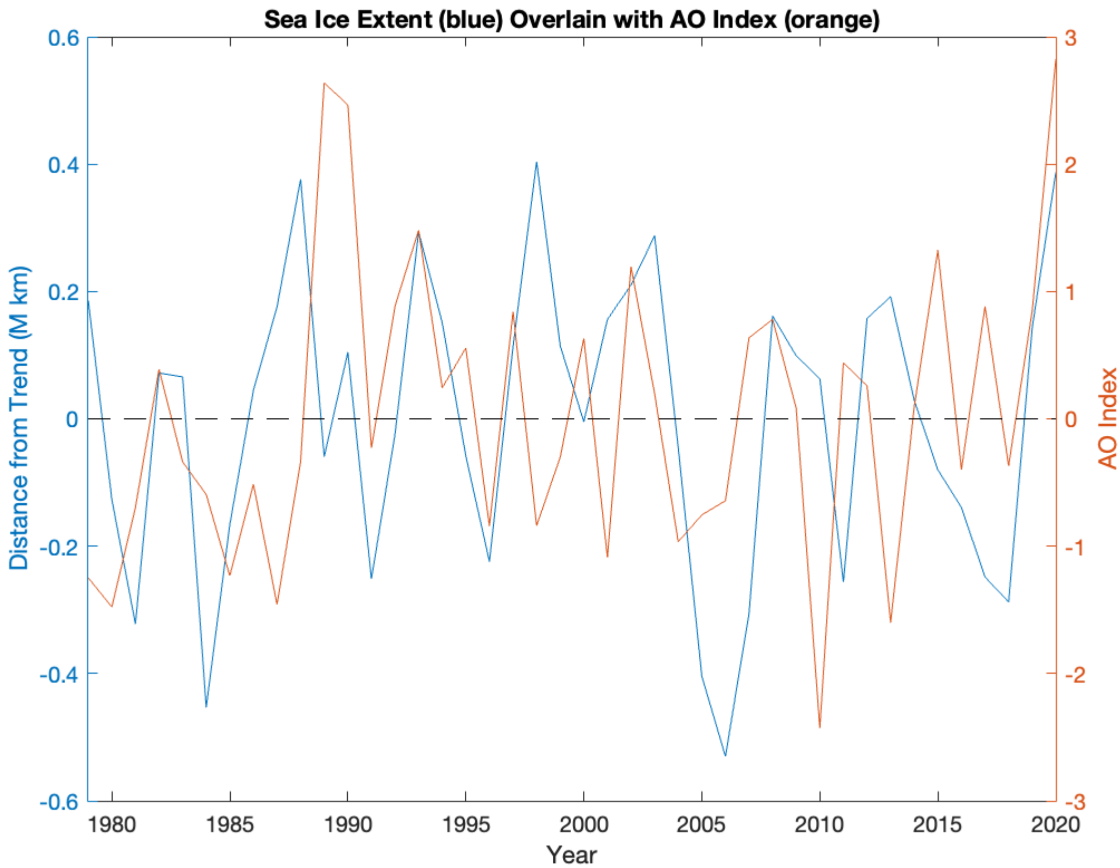
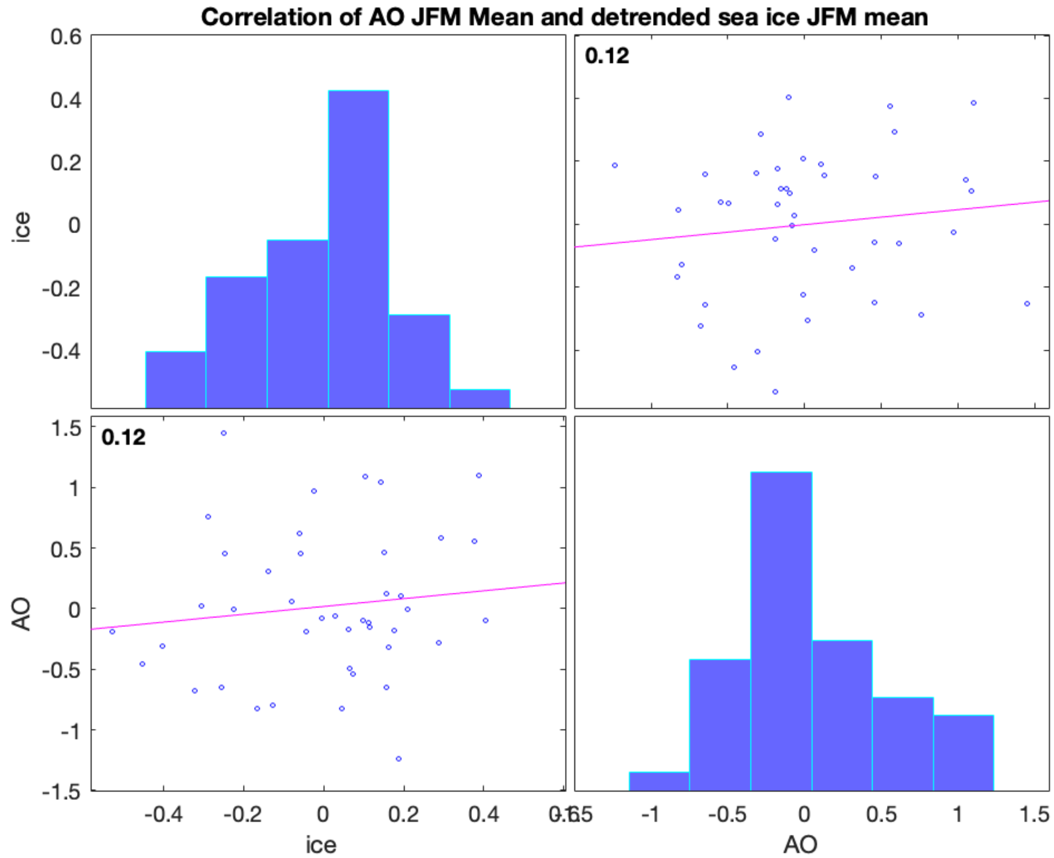

Sea Ice Extent (blue) Overlain with AO Index (orange)
Distance from Trend (M km)
AO Index
Year
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
3
2
1
0
-1
-2
-3
1980
1985
1990
1995
2000
2005
2010
2015
2020

Figure 5.



Correlation of AO JFM Mean and detrended sea ice JFM mean
0.12
0.12
ice
AO
ice
AO