Analysis of Extreme Negative Arctic Oscillation (AO) Values and the Relationship to Southeast U.S. Cold Air Outbreaks

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Introduction

The purpose of this study is to investigate the connection between extremely negative Arctic Oscillation (AO) values and significant cold air outbreaks in the southeastern United States. Daily AO index values have been recorded since 1950. For this analysis, all 23,100 values were sorted from negative to positive. Within the lowest 100 values (0.43%) there are eleven distinct periods of four or more consecutive days that were classified as events. Minimum temperatures and departures from normal for three stations (Columbia, SC; Raleigh, NC and Atlanta, GA) were examined and compared to the AO behavior before, during and after each event. Studying the spatiotemporal progression of circulation features during these episodes helped determine the onset and extent of each cold air outbreak. Eight out of the eleven events occurred during meteorological winter (DJF) and those events, along with their descriptions, are plotted to the right. The results of all eleven events are included in the table below.

Background

The Arctic Oscillation (AO) is an influential climate pattern characterized by sea level pressure variability in the polar region that affects U.S. weather, particularly in the winter. The AO is represented by an index which reflects the state of the atmospheric circulation over the Arctic and consists of a positive and negative phase. The index is computed by taking the geopotential height difference poleward of 20°N. The positive phase exhibits negative geopotential height anomalies and a strong polar low, resulting in stronger Westerlies and a stronger mid-latitude jet stream, forcing cold air to stay further north. The negative phase is associated with positive geopotential height anomalies, a weaker polar vortex and higher pressure in the polar region, resulting in weaker Westerlies and a more southerly jet stream track. This allows Arctic air to penetrate further south into the mid-latitudes. In the southeastern U.S., the AO has a strong winter temperature signal predominantly yielding colder (warmer) temperatures in the negative (positive) phase. Unlike ENSO, that can affect both temperature and precipitation, the AO precipitation signal is not significant.

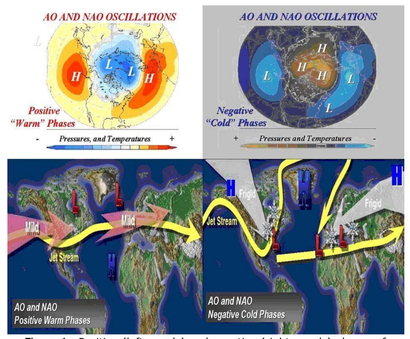


Figure 1. Positive (left panels) and negative (right panels) phases of Arctic and North Atlantic Oscillations. Image Source: NOAA/CPC


The Miami Herald
Thursday, January 20, 1977
Severe Cold Again Today and Tonight
THE DAY IT SNOWED IN MIAMI
The Day It Snowed in Miami
Bitter Cold, High Wind Turn Killers

Figure 2. *The Miami Herald*, January 20, 1977


The Columbia Record
Below-zero temperature numbs Columbia residents

Figure 3. *The Columbia Record*, January 21, 1985

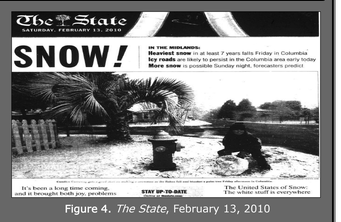

The State
SNOW!
STAY UP-TO-DATE

Figure 4. *The State*, February 13, 2010

Conclusion

Results suggest that after a period of highly negative AO values, there is a temperature response on the east coast that lags the negative AO episode by a few days. Each of the eleven events analyzed for the southeast was either a record temperature event, a prolonged significant cold air outbreak, or both. Winter precipitation was reported in at least one of the three locations during or after each event.

Geopotential height anomaly composite maps show strong positive height anomalies poleward of about 55°N, indicating the weaker polar vortex (Fig 5). The associated AO index values fluctuated, but most ranged from -4.6 to -7.4. The lowest recorded value, -7.433 (January 15, 1977), coincided with record low minimum temperatures at multiple locations.

Greatest minimum temperature departures during the events ranged from -11° to -40°, with the average being -20°F. Greatest minimum temperature departures after the events (when the AO had slightly rebounded) ranged from -17° to -42° with the average being -26.6°F and occurring on average about 9 days after the events. This signifies that the coldest air usually arrived after the AO event had concluded.

Out of the eleven events, only one occurred during a La Nina (1985). This is potentially due to the fact that circulation patterns associated with a Neutral or El Nino phase are more likely influenced by resultant jet modification from a negative AO, but further research is necessary to confirm this. Typically, a La Nina is associated with a weaker and more northerly jet stream, which prevents cold air intrusions into the Southeast. However, the 1985 event was not only climatologically atypical, but also record-breaking. During this event, the polar vortex dipped southward into the U.S. breaking numerous temperature records.

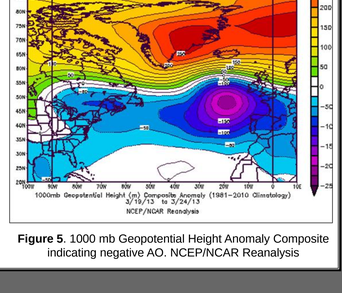


Figure 5. 1000 mb Geopotential Height Anomaly Composite indicating negative AO. NCEP/NCAR Reanalysis

Event Analysis

Event Descriptions

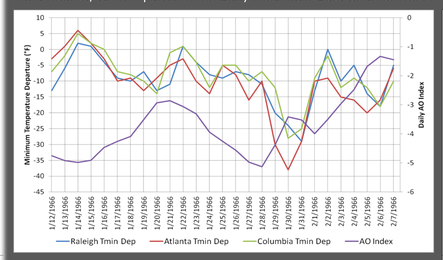
Mid-January through early February of 1966 was unseasonably cold. A persistent trough across the eastern half of the country and a periodical ridge across the Western U.S. & Canada allowed a series of continental arctic air masses to penetrate into the Southeast. Record lows occurred on the mornings of January 29 – 31, the coldest being -3°F in Atlanta on the 30th. A snowstorm produced 9.7" of snow in Raleigh January 25 -27.

During mid-February of 1969, a prolonged period of negative AO values coincided with a persistent trough along the east coast of the U.S. Although there were no records set during this period, minimum temperatures averaged 5 to 10 degrees below normal. A strong low developed off the Southeast coast and produced up to 17 inches of snow across the mountains of North Carolina and South Carolina.

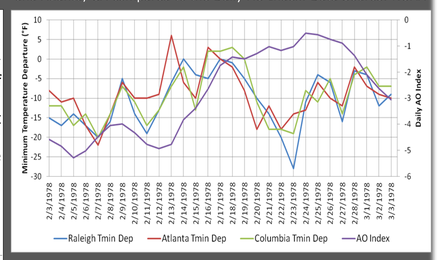
From late December 1976 through much of January 1977, the AO remained very negative. A pronounced ridge took hold across Western North America, and periodically, parts of the polar vortex dropped southward into Eastern Canada. A persistent trough across the eastern U.S. kept temperatures below normal and several records were broken from Atlanta to Raleigh. On January 17th, the low in Raleigh was -1°F and the city broke 4 record lows during this period.

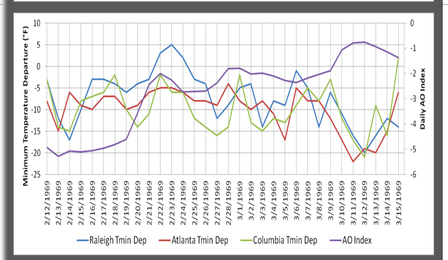
A very pronounced trough pushed as far south as Cuba with 500 mb level heights at 5580 m and 500 mb temperatures at -15° over Miami, FL. Minimum surface temperatures remained ≤ 20°F in Columbia, Raleigh, and Atlanta for four consecutive days. January 19, 1977 brought snow to Miami, the only time it snowed in South Florida in the 20th century. The lowest AO value on record (-7.433) occurred a few days prior, on January 15. (Fig 2). January 1977 was also the coldest January on record.

Minimum Temperature Departures (°F) at Raleigh, NC; Columbia, SC and Atlanta, GA compared to the Daily AO Index. Data Source: NOAA

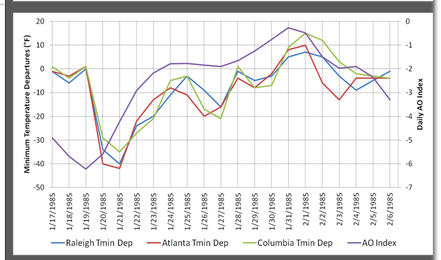


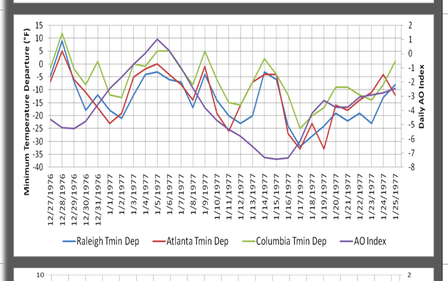
In February 1978, minimum temperatures averaged 10 to 15 degrees below normal for a majority of the month. A prolonged period of negative AO values resulted in a persistent trough across the East Coast and ridge across Western North America. Although there was only one record low during the period, temperatures remained quite cold. On the morning of January 23rd Raleigh set a record low of 7°F.



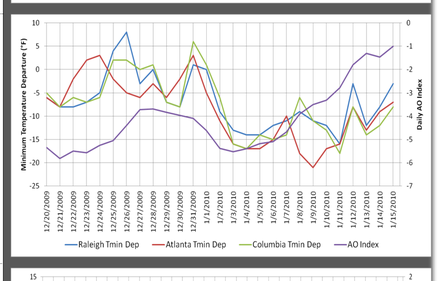


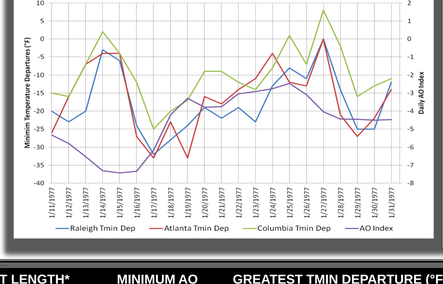
In January 1985, a deep mid-latitude closed low over the Great Lakes associated with an extensive broad trough allowed arctic air to penetrate into the Southeast setting multiple all-time record minimum temperatures. The arctic outbreak peaked 2 days after the AO reached its lowest point. On January 21, Raleigh, NC (-9°F), Columbia, SC (-1°F) and Atlanta, GA (-8°F) set all-time minimum temperature records. (Fig 3)



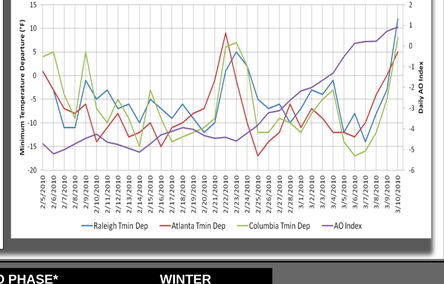


In the period of December 2009 through January 2010 a persistent and deep trough developed across the eastern half of the U.S. A large (1050 mb) area of high pressure developed over North/Central Canada and build southward into the Southeast. Although no records were set during this period, temperatures averaged around 15 degrees below normal.





A persistent pattern consisting of a ridge across the western U.S. and Canada and a trough over the eastern U.S. occurred during much of February 2010, resulting in an average minimum temperature departure at all three sites of -7°F. On February 12 and 13, low pressure moved into the Carolina coast from the Gulf of Mexico producing widespread snowfall. Columbia, SC received 8.6", the highest snowfall totals in 37 years (Fig 4).



EVENT DATES	EVENT LENGTH* (DAYS)	MINIMUM AO (DURING EVENT)*	GREATEST TMIN DEPARTURE (°F) (DURING EVENT)*	GREATEST TMIN DEPARTURE (°F) (AFTER EVENT)*	ENSO PHASE*	WINTER PRECIPITATION
11/13/59 - 11/19/59	7	-5.896	-21	-19 (11 days after)	Neutral	YES
1/12/66 - 1/15/66	4	-4.985	-13	-38 (15 days after)	El Nino	YES
2/12/69 - 2/19/69	8	-5.282	-17	-22 (20 days after)	El Nino	YES
3/3/70 - 3/11/70	9	-6.365	-11	-23 (5 days after)	Neutral	YES
12/27/76 - 12/30/76	4	-5.287	-18	-33 (18 days after)	El Nino	YES
1/10/77 - 1/17/77	8	-7.433	-33	-33 (2 days after)	Neutral	YES
2/3/78 - 2/6/78	4	-5.291	-17	-28 (17 days after)	El Nino	YES
1/17/85 - 1/20/85	4	-6.226	-40	-42 (1 day after)	La Nina	YES
12/19/09 - 1/7/10*	20	-5.821	-17	-21 (2 days after)	El Nino	YES
2/5/10 - 2/15/10*	11	-5.205	-15	-17 (10 days after)	El Nino	YES
3/19/13 - 3/24/13	6	-5.688	-18	-17 (3 days after)	Neutral	YES
*two separate periods close enough to be combined into one	*number of consecutive days AO was below -4.564 (100th lowest AO index value)	*for all locations	*out of all three locations	*out of all three locations	*Based on MEI Index. -0.5 to 0.5 = Neutral >0.5 = El Nino <0.5 = La Nina	*during or after event at either location – sleet, ice, snow or freezing rain

*Blue snowflakes indicate events analyzed in this study

Daily Arctic Oscillation Index (AO) Values from 1950 to 2013