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Chadrick D. Skyberg
Iowa State University

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Attribution of Lake Okoboji Variability to Atmospheric Oscillations

Chadrick D. Skyberg

Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa

Dr. Kristie J. Franz

Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa

ABSTRACT

A certain degree of variability in atmospheric and hydrological elements can be attributed to atmospheric oscillations. This study aimed to uncover how much variance could be explained by atmospheric oscillations at a Midwest freshwater lake, Lake Okoboji, IA. The following variables were used to detect variability: Temperature, Precipitation, number of snowy days, number of ice-residence days, and lake gauge height (lake level). Atmospheric Oscillations used were the: Southern Oscillation (SOI), Artic Oscillation (AO), North Atlantic Oscillation (NAO), Pacific North-American Pattern (PNA), and the Pacific Decadal Oscillation (PDO). A 30-year climate period from 1981 to 2010 defined the period of analysis. The study utilized 210 Spearman correlations, whereby each oscillation was subdivided into a positive, neutral, and negative part. Likewise, variables were split into four seasons. Thirteen correlations returned strong to very strong measures of either direct or inverse relationships amid variables and oscillations. Seven of the thirteen occurred over the December, January, February mean, possibly suggesting more oscillatory influence in the winter months. Five of thirteen correlations included the positive phase of the PNA, suggesting the PNA may be the most indicative of the five indices analyzed. Five multiple linear regressions proposed a percentile of variance that oscillations could explain in a given variable. Three of five regressions returned an explained variance of ≥ 10%. Beta coefficients further broke down the explained variance contributed by each oscillation. A maximum variation of about 3˚F, four snowy days, and seven days of ice on the lake can be attributed to the five oscillations analyzed in this study.

1. Introduction

The driving mechanism of climate variability remains one of the largest unknown aspects of climate science. The majority of research in this domain aims to provide an explanation of the possible impacts, positive or negative, of natural oscillations on climatic variables. Such variables include temperature, precipitation, snowy day count and a wide array of other atmospheric conditions. Given the connection between climatic conditions and the surface hydrologic cycle, hydrological elements, such as ice residence time, lake levels, and various other factors have all been shown to fluctuate with natural oscillations (Ghanbari and Bravo, 2009; Bai et al., 2012; Changnon, 2004). Understanding local conditions under different oscillation regimes can help predict what near-term climate may be like while in those phases.

Xing and Stefan (1998) predicted that the effects of climate change - specifically, rising CO_2 levels - impacts small lake's ice-duration; in that, our changing climate lessens the number of days where ice resides on a small lake. Since ice-duration is evidently controlled by temperature of the surroundings, an inference supports that small lakes will warm in the coming decades. The study over the small lakes suggests variances in climate provide windows of procession and recession of the climate signal (Bai et al., 2015). This is just one example of a recommendation to research variance analysis. Whereby, the research enables local policy makers, industries, and citizens to utilize climate variances as a decision-making tool to better the outcome of a given variability scenario. In turn, this boosts economic returns, lowers expenditures, and lessens risk of personal injury (Xing and Stefan, 1998).

This study aims to determine the relationship between various climate oscillations on changing conditions of a Midwest United States lake system. Midwest lake systems are vulnerable to algae blooms, winter fish kill, and toxic sedimentation from agriculture pesticides. Lake Okoboji – a common reference to the compilation of three lakes: Spirit Lake, West Okoboji, and East Okoboji – in Northwest Iowa serves as the focus for this research. This study aims to [1] correlate Lake Okoboji variables, both hydrologic and atmospheric, to natural oscillations in the climate system and [2] determine the amount of climate variability that can be explained by natural oscillations at Lake Okoboji. Due to tangentially related results (Ghanbari and Bravo, 2009; Bai et al., 2012; Changnon, 2004), we hypothesize that variability at Lake Okoboji correlates with numerous natural oscillations and a discernable amount of variance can be explained by oscillations.

2. Background

a.) Scale of Analysis

Modern research in climate variability focuses greatly on regional analysis, for example Bai et al. (2012) studied variability within the Great Lakes region. For definitive purposes, regional analysis references an area of approximately $1 \times 10^6 km^2$. Contrary to a smaller scale, regional scale analysis natively smooths mesoscale-induced weather fluctuations over the climate record, such as increases or decreases derived from thunderstorms, squall lines, and land-sea breezes (Bai et al., 2012). In turn, smaller, local scales intrinsically exhibit larger, more sporadic fluctuations in climate records. The Lake Okoboji area spans roughly $220 km^2$, including intermediate land mass. Observation sites logging data across this area span $517 km^2$. Both areas fall within small scale analysis. By averaging four separate weather observation stations, small scale fluctuations in mesoscale phenomenon are in part accounted for, but should be realized when interpreting the results.

b.) Natural Oscillations

Natural oscillations are expressed using standardized, unitless indices, allowing for comparison to any number of other variables. Most often this index is calculated based on a difference in pressure between two specific locations. For example, the Southern Oscillation Index represents the El Niño Southern Oscillation (ENSO). A standardized difference in mean sea level pressure (MSLP) from Tahiti, French Polynesia to Darwin, Australia (NOAA, 2017) quantifies this condition. Though these oscillations may not be direct contributors, teleconnection studies find they correlate with many aspects of the climate system, making them useful for climate variance analysis (NOAA, 2017). This study will use five oscillation indices to correlate variance in the climate system to Lake Okoboji. These indices are derived from the: ENSO, Arctic Oscillation (AO), Pacific/North American Pattern (PNA), North Atlantic Oscillation (NAO), and Pacific-decadal Oscillation (PDO). The wavelength, frequency, and amplitude varies from one oscillation to the next, sometimes with seemingly random properties. In most cases, this leads studies to evaluate time-series data by defining a positive (+), neutral (=), and negative (-) phase for each oscillation. The methodology section of this study further breaks down these components.

c.) Related Research

Kellner and Niyogi (2015) analyzed the impact of climate variance on United States "corn belt" states. Both ENSO and AO returned statistically significant correlations with Iowa's temperature and precipitation. Correlation between ENSO phase and temperature in Iowa was strongest in August and December. Greatest AO temperature impact on Iowa was observed in April, with moderate impact over the summer months. A Neutral AO correlated with greater precipitation than average.

Lake Mendota, WI lies $450km$ to the East of Lake Okoboji at near the same latitude and experiences a similar climate to that of Lake Okoboji. A study conducted by Ghanbari and Bravo (2009) found Lake Mendota correlates with the PDO and ENSO on interdecadal and interannual timeframes, respectively. Therefore, a clear teleconnection to the hydrosphere has been found in the small lake study. The study, however, did not return correlations of both hydrosphere and atmosphere. A second study (Bai et al., 2012) also found correlation between ice-cover variance and oscillations. Unlike the previous study, this research focused on the Great lakes, a much larger hydrosphere component, to find correlation between the NAO / ENSO and the Great Lakes. A positive correlation could be observed between the NAO / ENSO and ice-cover days.

Rogers and Coleman (2004) found that the PNA and the North-Pacific Index (NPI) correlate to winter streamflow and precipitation in Ohio, with an r value as high as r = 0.7. Furthermore, several other negative correlations within this study indicate a lag in the hydrosphere responding to the climate system. Lake Okoboji has both inflow and outflow from Loon Creek and Milford Creek, respectively. Because our study uses additional oscillation indices, the likelihood of finding other correlations to precipitation increases in the area.

Research from the various sources above utilized specific indices to understand the effects of just one or two variables. This research seeks to include five oscillations known to be linked to climate variance over five dependent variables. An atmospheric and hydrologic variance study at Lake Okoboji, to our knowledge, has not yet been performed. Our research furthers the understanding of how oscillations play into climate variance at Lake Okoboji.

3. Data

This study utilizes monthly oscillation indices obtained from the National Oceanic and Atmospheric Administration (NOAA) (2017). Oscillation data spans from December 1980 to January 2011. A thirty-year period, 1981-2010, denotes the effective testing period.

Three dependent variables represent atmospheric conditions: monthly mean temperature [Fahrenheit] and precipitation [inches], as well as the total number of snowy days per month for four near-lake weather stations. The four weather stations used in this study are: Estherville, IA (IA2724), Sibley, IA (IA7664), Milford, IA (IA5493), and Windom, MN (MN9033). The Iowa Environmental Mesonet (IEM) publically provides this data (2017). The data spans the same time interval as the oscillations.

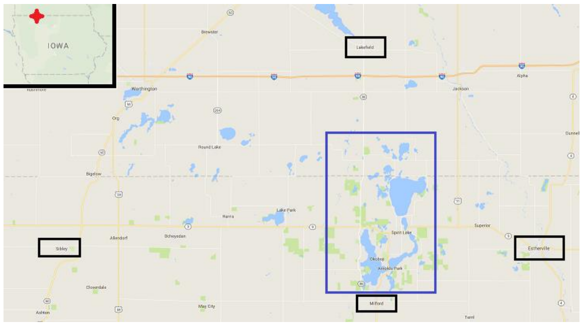


Figure 1. Top/left: Red mark plots Lake Okoboji, IA. Center: Lake Okoboji located in blue box. Weather stations are indicated by black boxes.

Two variables, lake gauge level and lake-ice residence time, represent the hydrological conditions of Lake Okoboji. The United States Geological Survey (USGS) publically makes available lake gauge data. USGS gauge 06604200 is used in this study and is positioned near Milford, IA on the Southern (outlet) edge of Lake Okoboji. The acquired data matches the time interval of previous data and is represented as a monthly mean of water depth [feet] at the gauge location. The Iowa Department of Natural Resources (DNR) provides observational records of lake-ice residence time [days] for this study. A separate record maintained for each lake reports the number of days the ice resides on West Okoboji, East Okoboji, and Spirit Lake.

4. Methods

This study examines correlations of several dependent variables to oscillations by defining three zones within each oscillation. A positive, neutral, and negative zone distinguishes the analysis of each oscillation, with the neutral zone being bound (Table

1.b.). One standard deviation of oscillation index values defines each oscillation's neutral zone centered at a value of zero; effectively, this nearly equates to plus or minus one-half the deviation. These values (Table 1.a.) are used as neutral zones in this study.

Table 1. Defined Neutral Zones for oscillation indices of the SOI, AO, NAO, PNA, & PDO and standard deviation of monthly oscillation indices 1981-2010.

a.) Defined Oscillation Neutral Zones				
SOI	AO	NAO	PNA	PDO
±1.0	±0.5	±0.5	±0.5	±0.5
b.) Oscillation Record Standard Deviation				
SOI	AO	NAO	PNA	PDO
1.6	1.0	1.0	1.0	1.1

Inverse distance weighting from a centrally located point at Lake Okoboji is used to calculate temperature, precipitation and number of snowy days. A constant gradient is assumed. Weighted differences (Table 2) are calculated for both East/West and North/South, then averaged to determine the value of a given parameter at Lake Okoboji.

Correlations are calculated seasonally for temperature, precipitation, number of snowy days and lake gauge level. Defined seasons include: [1] December – February (DJF), [2] March – May (MAM), [3] June – August (JJA), and [4] September – November (SON).

Table 2. Contribution Percentile of Lake Okoboji assigned to measured variables at a given weather observation site. Percentages calculated using inverse differencing over the Lake Okoboji region and are only valid over linear distributions. Distances calculated to nearest tenth. Percentiles rounded to nearest tenth. East/West gradient calculated using Estherville, IA and Sibley, IA. North/South gradient calculated using Milford, IA and Windom, MN.

Observation Site	Distance (km)	Percent of Contribution
Estherville, IA	23.4	68.20%
Sibley, IA	50.2	31.80%
Milford, IA	11.3	81.30%
Windom, MN	49.2	18.70%

Each dependent variable is statistically correlated with each oscillation, which varies in phase. Because this correlation is erratic in signal due to loss of time-series structure, the study utilizes the Spearman correlation to test the relationship between such variables. In such, both linear and monotonic relationships are correlated.

Ice residence time is a single quantity [number of days] per year. Annual oscillation indices (a mean of monthly oscillation indices over a twelve month time interval) were produced to provide a per-year quantity to correlate with the ice residence time variable. The signal grows weaker in amplitude and attenuates in the process. Since both the variable and oscillation signals attenuate equally, a Spearman correlation test is able to identify a relationship. Due to a substantial difference in thermal inertia between the hydrosphere and the atmosphere, seasonal correlations with ice residence likely fall outside of the study's seasonal window. The Spearman Correlation test cannot compute lag intervals due to a lack of time series structure. Moreover, any correlation outside of a zero lag scenario (greater than 1.5 months in this study) will not show up in the results due to the method used.

This study defines statistically significant correlations as those with correlation coefficients ≥ 0.6 and p-scores ≤ 0.1. In context, a 0.6 to 0.8 correlation coefficient is referred to as strong correlation and > 0.8 as very strong correlation.

Each atmosphere and hydrosphere variable undergoes multiple linear regression testing to explain how much each oscillation is impacting said variable. Multiple linear regression accounts for the amount of variance explained in a given dependent variable by each independent variable. For this procedure, monthly means over the thirty-year interval for each variable and all five oscillation indices are used. Due to the single annual observation of ice residence, the annual oscillation mean is substituted for monthly mean in the ice cover variation analysis. The R^2 value of the multiple regression models provides some indication as to the amount of variance explained in one variable by the five oscillations. Multiple regression beta coefficients (β) of each oscillation contribute to some overall percentage of variance explained. Determining the fraction of a whole for all beta coefficients explains the total variance attributed by any one oscillation.

4. Results

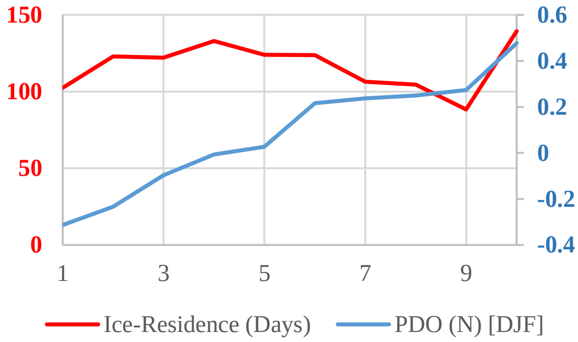
a.) Correlations

Of a total 210 correlations tested, thirteen return significant values with correlation coefficients greater than or equal to 0.6 and p-scores less than or equal to 0.1 (Figure 2). Twelve additional correlations meet the study's correlation coefficient standard, but fail to meet the p-score threshold. In eight of these twelve cases, p-scores likely increase due to a sample size of five or fewer years. The small number of samples natively yields a higher correlation p-score in Spearman correlation testing.

Of the thirteen statistically significant correlations, seven suggest links between oscillations and variables over the DJF period. An additional four correlations indicate links during the MAM mean. Given a single statistically significant correlation, a link may exist between test categories for both the JJA and SON time periods. These results suggest that links between any one oscillations and a single climate variable is more likely to exist for the DJF and MAM time intervals rather than the JJA or SON time intervals.

The positive PNA index (> 0.5) accounts for five of thirteen significant correlations and more than twice as many as any of the 15 oscillatory phases analyzed in this study. The negative AO (< 0.5) and negative NAO (< 0.5) each correlate with two variables analyzed. Various oscillations show evidence of a link to just one variable; they are the: neutral PDO (0.5 to -0.5), negative SOI (< 1.0), positive NAO (> 0.5), and positive SOI (> 0.5). The categorical results of oscillations returning significant correlations suggests that during the positive PNA (> 0.5), negative AO (<0.5), and negative NAO (< 0.5) phases, the forcing attributed to each oscillation overpowers the forcing effects of other oscillations. Alternatively, these results could suggest that the effects of other elements or oscillations parallels the inherent forcing of these three oscillatory phases. With certainty, the most correlations occur during three of the fifteen oscillatory phases in this study.

a.)



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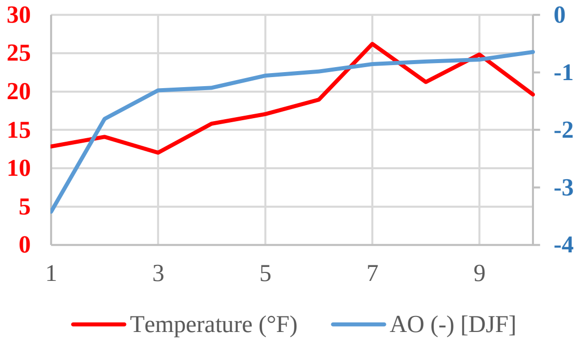

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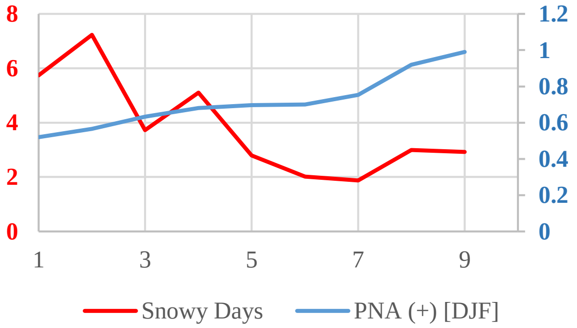

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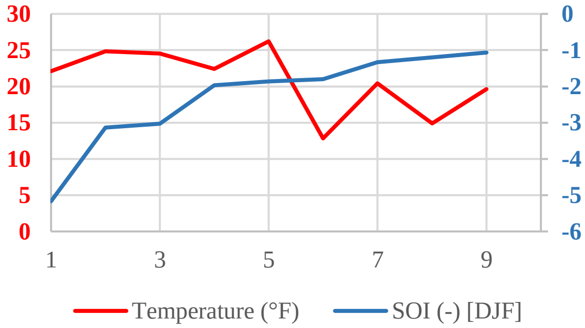

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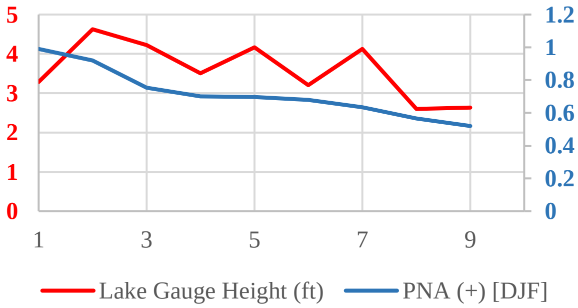

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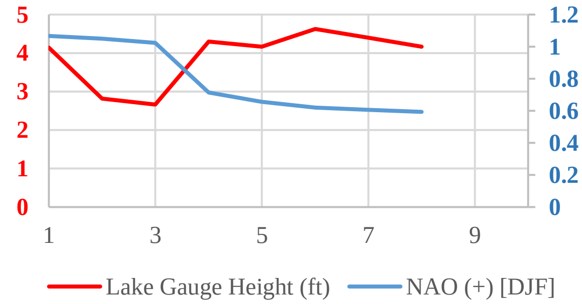

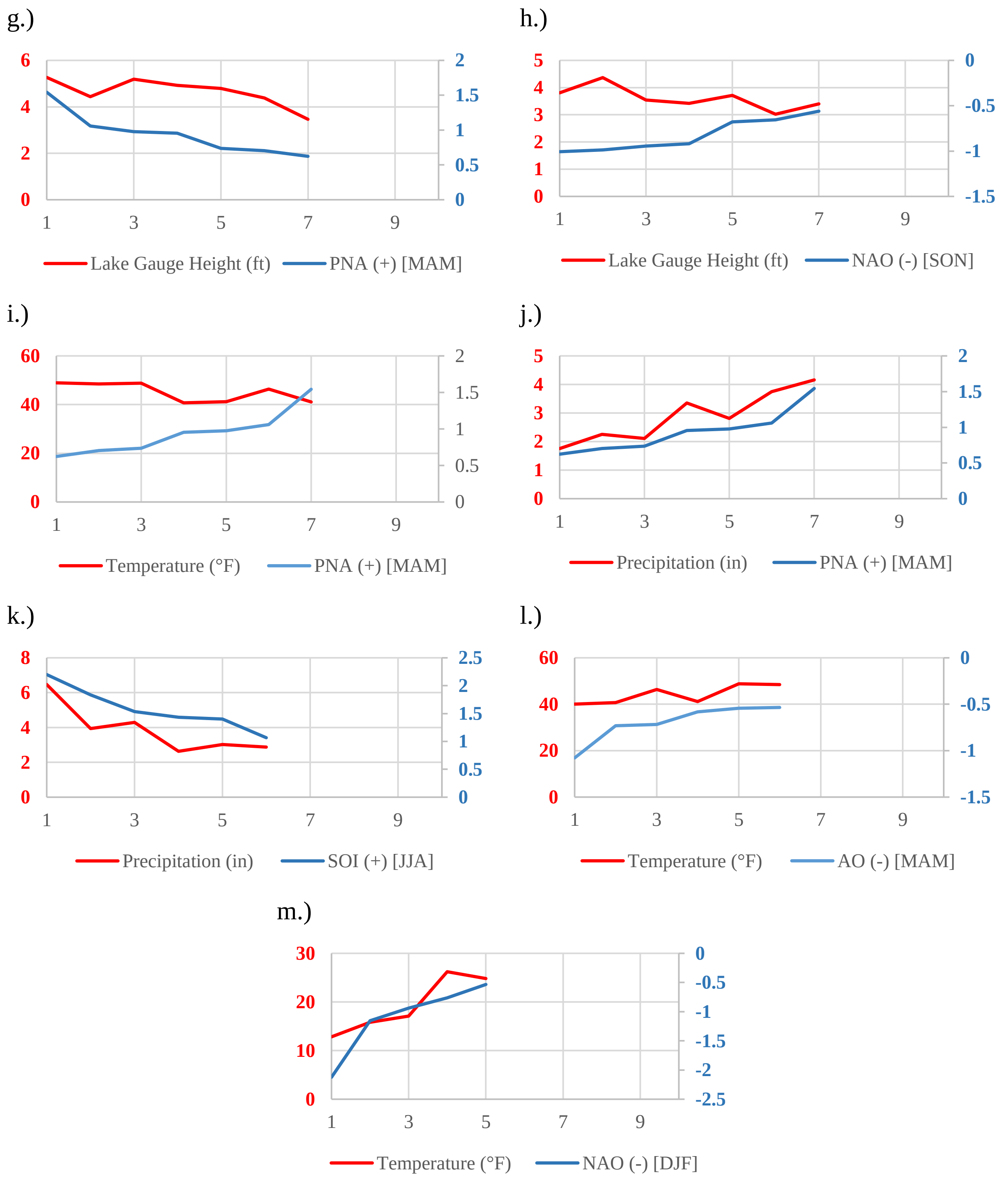

Figure 2: Correlations returning correlation coefficients ≥ 0.6 and p-scores ≤ 0.1. Oscillation index in blue. Paired variable in red. Number of years along x-axis. Season of mean located next to oscillation in legend.

Temperature and lake gauge height correlate more often than the other three variables with five and four correlations, respectively. Precipitation variability returns two statistically significant correlations. Variability in the number of Snowy Days and number of days where ice resided on the lake each yielded one significant correlation.

Categorical analysis of variables and the number of returned significant correlations offers some indication of the response time of each variable to atmospheric or hydrological feedback time. This study utilizes a three-month mean for correlations. That is, any correlation that may exist outside of a given three month mean exceeds the reach of this study.

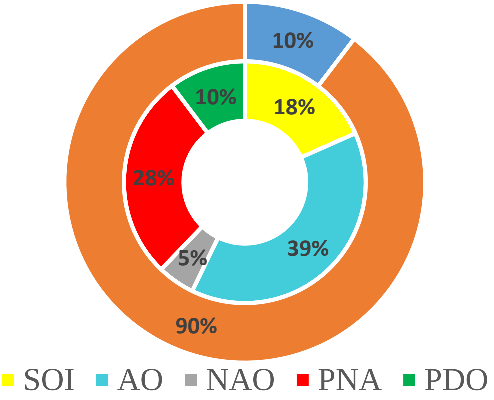

Figure 3. Outer ring: percentiles of explained (blue) and unexplained (brown) variance in Lake Okoboji's temperature attributed to the SOI, AO, NAO, PNA, and PDO. Inner ring: Partial contributions of each oscillation to overall explained variance.

b.)Variance

Multiple regression analysis testing reveals the overall explained variance of any one dependent variable. Additionally, regression delivers statistics relating the percentile of variance explained per oscillation. In such, it is seen that changes in oscillation indices explains up to 10% of variance in Lake Okoboji temperatures (Figure 3). The largest variance is explained by examining the AO and PNA.

Likewise, just one percent of the variance in precipitation and two percent of the variance in lake gauge height (Figures 4 & 5). Because these two quantities directly relate, the similarity in results for both gives strength to the testing method. In other words, both precipitation and lake gauge height reflect low percentiles of explained variance with respect to the five oscillations analyzed.

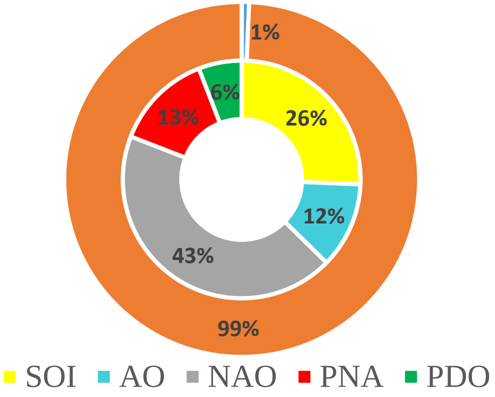

Figure 4. Outer ring: percentiles of explained (blue) and unexplained (brown) variance in Lake Okoboji's precipitation attributed to the SOI, AO, NAO, PNA, and PDO. Inner ring: Partial contributions of each oscillation to overall explained variance.

Of the 1% of precipitation variance explained by the oscillations, the NAO accounts for nearly half. Of the 2% of the lake gauge height variance, the PDO accounts for almost two-thirds.

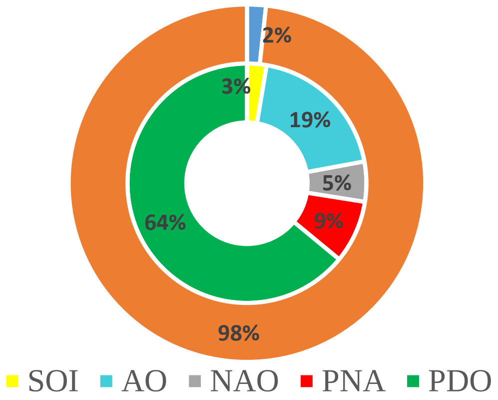

Figure 5. Outer ring: percentiles of explained (blue) and unexplained (brown) variance in Lake Okoboji's lake gauge height attributed to the SOI, AO, NAO, PNA, and PDO. Inner ring: Partial contributions of each oscillation to overall explained variance.

By comparison, the oscillations account for a larger portion of Lake Okoboji's ice-residence time with twelve percent explained variance. The 12% is fairly equally explained by the five oscillations, with NAO contributing slightly more than any other oscillation (Figure 6).

The snowy days regression returns the largest explained variance of any tested variable (Figure 7); the five oscillations explain up to twenty-two percent. Over two-thirds of the 22% explained variance comes from the PDO and AO.

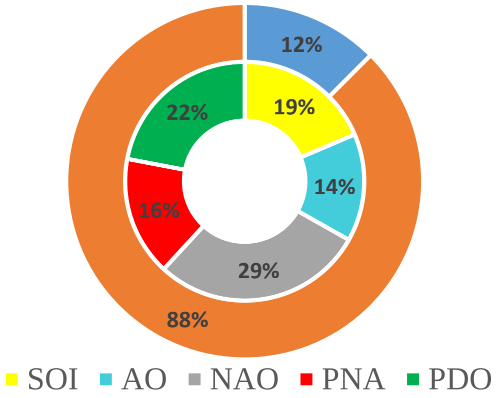

Figure 6. Outer ring: percentiles of explained (blue) and unexplained (brown) variance in Lake Okoboji's ice-residence days attributed to the SOI, AO, NAO, PNA, and PDO. Inner ring: Partial contributions of each oscillation to overall explained variance.

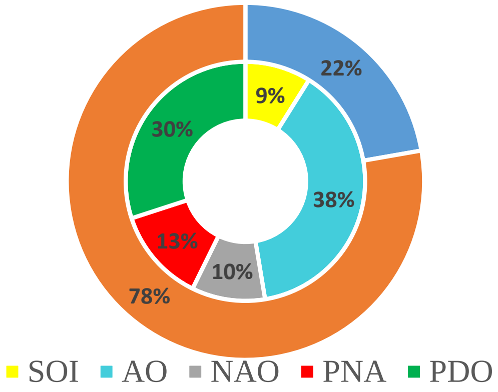

Figure 7. Outer ring: percentiles of explained (blue) and unexplained (brown) variance in Lake Okoboji's snowy days attributed to the SOI, AO, NAO, PNA, and PDO. Inner ring: Partial contributions of each oscillation to overall explained variance.

By examining connected influences between correlations and explained variance, a more robust conclusion develops regarding each oscillation and the overall effect on a given variable. The PDO (N) phase correlated to ice-residence days; the three-phase PDO oscillation contributed twenty-two percent of all explained variance of ice-residence days. Therefore, an inference draws the possible result that the greater portion of the PDO's twenty-two percent contribution comes from the neutral phase. The same reasoning infers certain connection between the remaining twelve correlations. However, the resulting statistics are not overly relevant due to the large unexplained variance of each variable. For this implied result to be of significant value, the unexplained variance must be less than the fraction of explained variance per oscillation.

5. Discussion

Possibly the most important aspect of this study presents itself in understanding why the results returned in the way they have. Seven of thirteen statistically significant correlations occurred during the DJF mean spanning six different oscillations. Therefore, no clear connection exists between DJF correlations and any one oscillation. However, there lies an implication within that during the DJF time interval one oscillation tends to dominate over others. Certainly over the 30-year DJF mean from 1981-2010, this trend prevails. Further testing over previous or future climatic intervals could further validate such a claim.

Similarly, the positive phase of the PNA appeared in four of thirteen statistically significant correlations. The negative AO phase and the negative NAO phase each returned in two correlations. Observing the proximity to the area of study from where these oscillations are calculated may offer some explanation as to why they more frequently showed up in correlations over the other two oscillations. The positive PNA, for example, accounts for two weather patterns; one pattern exists over the central Pacific Ocean and the other over the North American Continent. The variation in these two weather patterns alters the location of the East Asian Jet stream (CPC, 2010). The positive phase of the PNA, returning four correlations in this study, enhances the East Asian Jet stream and an eastward shift of the jet toward North America. Furthermore, an intensification in upper level winds brings more energy and turbulence into the region west of Lake Okoboji. The opposite is true for the negative PNA. This not only explains why the PNA correlates with multiple variables, but also reasons why, specifically, the positive phase influences Lake Okoboji. The negative AO, returning two significant correlations, accounts for how easily cold air can sweep southward. Specifically, the AO index accounts for wind patterns around the 55° N Latitude (NOAA, 2017). In a positive AO index, this pattern restricts cold air from plunging south. When the AO is negative, the circulation strengthens and cold air in the north plunges southward over much of the central and eastern United States. The profound influence of the negative AO, specifically, explains why it correlates more often than many other oscillatory phases. Additionally, both correlations involving the negative AO returned a direct relationship to temperature; as the AO index became more negative, temperature declined. Though the correlations alone are not proof, the theoretical explanation matches observations and further strengthens the study's methodology and results.

Proximity from where the oscillations are calculated to Lake Okoboji helps to explain the PNA and AO, but does not explain the NAO. The NAO index calculation accounts for differences in pressure over Greenland and the North Atlantic Oscillation (CPC, 2012). The NAO highly influences parts of Europe, Scandanavia, Russia and even the east coast of the United States. The correlation results reveal the opposite of what research has shown to be true for the east coast of the United States. That is, in the positive phase of the NAO the east coast generally experiences warm temperature and more precipitation. The opposite is true for negative NAO phase. In this study, the NAO correlations act to oppose what would typically be seen in the eastern United States. Several dynamical explanations outside the scope of this study may offer explanations to this.

One goal of this study focuses on explaining the variance in a given variable due to the five oscillations analyzed. Unquestionably, correlations in the study provide a qualitative indication of thirteen links between variables and oscillatory phases. However, simply understanding how one variable reacts to a change in oscillation index gives no indication of how strongly any one oscillation influences changes in a given variable. Deseasonalized temperature values varied by up to forty-three degrees Fahrenheit from the central mean. Utilizing the temperature regression, ten percent of this value can be explained by the oscillations analyzed, or about four degrees Fahrenheit. Of the explained ten percent variance, one-third comes from the AO and about another third from the PNA. Assuming this standard distribution, the most that any one oscillation contributes to variation in the temperature record at Lake Okoboji is slightly more than plus or minus one degree Fahrenheit. The same logic can be applied to the number of ice-residence days and number of snowy days. Snowy days varied by up to fourteen days during 1981-2010. Linear regression attributed twenty-two percent of the variance to oscillatory effects; the variance explains just over three snowy days as a result of the five oscillations. A near equal two-thirds split between two oscillations, the AO and PDO, explains about plus or minus one and a half days of variance in the snowy days record. The ice-residence day record shows a variance of about 60 days from 1981 to 2010. Twelve percent of all variance within the ice-residence record could be explained by this study's chosen oscillations. Therefore, variance amounting to no more than seven days of ice-residence can be attributed to the SOI, AO, NAO, PNA, and PDO. All five oscillations contribute to this variance in fairly even proportions, with the greatest being twenty-nine percent (NAO) and the least being fourteen percent (AO). Assuming an equal distribution of days over all percentages, any given oscillation accounts for roughly one and a half days of ice-residence.

6. Conclusion

This study aims to [1] correlate Lake Okoboji variables, both hydrologic and atmospheric, to natural oscillations in the climate system and [2] determine the amount of climate variability that can be explained by natural oscillations at Lake Okoboji. The study found thirteen significant correlations and an overall attribution of five oscillations to five dependent climate and hydrologic variables. No discernable link was found between hydrological and atmospheric variables.

On the order of one to two units per measurement could be explained in a given variable due to a certain oscillation index value. This, in and of itself, would most likely not be significant information to a governing agency. However, in the case of ice-residence days, if all oscillations contributed with the same influence, this could mean another, or one less, week of ice cover on Lake Okoboji.

The variability within Lake Okoboji's climate and hydrology that can be attributed to the region's most dominant natural oscillations appears negligible. Variability due to oscillations accounts for minor portions in all tested variables. Likely, major variability comes from somewhere other than an oscillatory link.

7. Acknowledgements

I would like to thank my mentor, Dr. Kristie Franz for her guidance during my research and Dr. Raymond Arritt for his preparatory lessons on climate research. Additionally, I'd like to thank Dr. Mary Skopec & the Iowa DNR for Lake Okoboji, IA ice-residence data and Rachindra Mawalagedara for her constructive editorial feedback.

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Appendix I.

Table 1. Complete inventory of correlations in the study. Seasonal means derived from years 1981-2010. Sample size (n), correlation coefficient (c), and p-score (p) provided for all Spearman correlations.

Temperature															
	SOI (+)	SOI (N)	SOI (-)	AO (+)	AO (N)	AO (-)	NAO (+)	NAO (N)	NAO (-)	PNA (+)	PNA (N)	PNA (-)	PDO (+)	PDO (N)	PDO (-)
DJF	n=8/8	n=13/13	n=9/9	n=9/9	n=11/11	n=10/10	n=8/8	n=17/17	n=5/5	n=9/9	n=15/15	n=6/6	n=10/10	n=10/10	n=10/10
	c=0.524	c=-0.088	c=-0.617	c=-0.183	c=0.564	c=0.855	c=-0.048	c=0.309	c=0.9	c=0.533	c=0.039	c=-0.371	c=0.524	c=-0.139	c=0.333
	p=0.184	p=0.775	p=0.086	p=0.644	p=0.071	p=0.002	p=0.935	p=0.228	p=0.083	p=0.140	p=0.889	p=0.497	p=0.120	p=0.701	p=0.347
MAM	n=7/7	n=15/15	n=8/8	n=10/10	n=14/14	n=6/6	n=-8/8	n=15/15	n=7/7	n=7/7	n=17/17	n=6/6	n=10/10	n=7/7	n=13/13
	c=0.364	c=0.308	c=-0.452	c=0.442	c=0.319	c=0.886	c=-0.357	c=-0.077	c=0.071	c=-0.714	c=0.190	c=0.657	c=-0.083	c=-0.653	c=0.478
	p=0.429	p=0.265	p=0.267	p=0.200	p=0.267	p=0.033	p=0.389	p=0.785	p=0.873	p=0.089	p=0.465	p=0.156	p=0.819	p=0.112	p=0.098
JJA	n=6/6	n=18/18	n=6/6	n=-3/3	n=25/25	n=2/2	n=6/6	n=17/17	n=7/7	n=6/6	n=19/19	n=5/5	n=6/6	n=14/14	n=10/10
	c=0.2	c=0.007	c=0.257	c=-1	c=0.389	c=(n<3)	c=0.429	c=0.262	c=0.643	c=0.371	c=-0.172	c=-0.6	c=0.257	c=-0.314	c=-0.442
	p=0.686	p=0.977	p=0.658	p=0.333	p=0.054	p=(n<3)	p=0.419	p=0.309	p=0.124	p=0.497	p=0.482	p=0.292	p=0.658	p=0.274	p=0.200
SON	n=6/6	n=17/17	n=7/7	n=3/3	n=22/22	n=5/5	n=7/7	n=16/16	n=7/7	n=7/7	n=19/19	n=4/4	n=6/6	n=10/10	n=14/14
	c=-0.429	c=0.092	c=-0.321	c=-0.5	c=0.519	c=0.3	c=-0.393	c=0.097	c=0.179	c=0	c=0.391	c=0.2	c=-0.2	c=-0.285	c=-0.437
	p=0.419	p=0.725	p=0.498	p=1	p=0.013	p=0.683	p=0.396	p=0.720	p=0.713	p=1	p=0.097	p=0.917	p=0.714	p=0.425	p=0.118

Precipitation															
	SOI (+)	SOI (N)	SOI (-)	AO (+)	AO (N)	AO (-)	NAO (+)	NAO (N)	NAO (-)	PNA (+)	PNA (N)	PNA (-)	PDO (+)	PDO (N)	PDO (-)
DJF	n=8/8	n=13/13	n=9/9	n=9/9	n=11/11	n=10/10	n=8/8	n=17/17	n=5/5	n=9/9	n=15/15	n=6/6	n=10/10	n=10/10	n=10/10
	c=-0.262	c=0.341	c=-0.317	c=-0.133	c=-0.064	c=-0.430	c=-0.595	c=-0.360	c=-0.3	c=-0.55	c=0.246	c=0.371	c=-0.323	c=0.152	c=-0.309
	p=0.536	p=0.255	p=0.410	p=0.744	p=0.853	p=0.214	p=0.132	p=0.155	p=0.6	p=0.133	p=0.376	p=0.497	p=0.362	p=0.676	p=0.385
MAM	n=7/7	n=15/15	n=8/8	n=10/10	n=14/14	n=6/6	n=8/8	n=15/15	n=7/7	n=7/7	n=17/17	n=6/6	n=10/10	n=7/7	n=13/13
	c=-0.200	c=-0.143	c=0.286	c=0.539	c=-0.086	c=-0.026	c=-0.095	c=0.109	c=0	c=0.929	c=-0.190	c=-0.486	c=-0.189	c=0.199	c=0.148

	p=0.676	p=0.61	p=0.481	p=0.108	p=0.771	p=1	p=0.840	p=0.699	p=1	p=0.005	p=0.465	p=0.356	p=0.6	p=0.668	p=0.629
JJA	n=6/6	n=18/18	n=6/6	n=3/3	n=25/25	n=2/2	n=6/6	n=17/17	n=7/7	n=6/6	n=19/19	n=5/5	n=6/6	n=14/14	n=10/10
	c=0.771	c=0.010	c=0.257	c=0.5	c=-0.002	c=(n<3)	c=-0.257	c=0.208	c=0.321	c=0.143	c=0.330	c=-0.3	c=-0.486	c=-0.029	c=0.406
	p=0.081	p=0.968	p=0.658	p=1	p=0.994	p=(n<3)	p=0.658	p=0.422	p=0.471	p=0.758	p=0.168	p=0.6	p=0.356	p=0.923	p=0.244
SON	n=6/6	n=17/17	n=7/7	n=3/3	n=22/22	n=5/5	n=7/7	n=16/16	n=7/7	n=7/7	n=19/19	n=4/4	n=6/6	n=10/10	n=14/14
	c=0.6	c=0.060	c=-0.321	c=1	c=0.182	c=0.7	c=0.571	c=0.140	c=-0.5	c=0	c=-0.242	c=-0.8	c=-0.943	c=-0.273	c=-0.231
	p=0.208	p=-0.091	p=0.498	p=0.333	p=0.417	p=0.233	p=0.2	p=0.606	p=0.267	p=1	p=0.318	p=0.333	p=0.017	p=0.446	p=0.427
Lake Gauge Height															
	SOI (+)	SOI (N)	SOI (-)	AO (+)	AO (N)	AO (-)	NAO (+)	NAO (N)	NAO (-)	PNA (+)	PNA (N)	PNA (-)	PDO (+)	PDO (N)	PDO (-)
DJF	n=8/8	n=13/13	n=8/9	n=8/9	n=11/11	n=10/10	n=8/8	n=16/17	n=5/5	n=9/9	n=15/15	n=5/6	n=10/10	n=10/10	n=9/10
	c=0.405	c=0.121	c=-0.024	c=-0.167	c=-0.318	c=-0.212	c=-0.690	c=0.109	c=-.07	c=0.633	c=0.186	c=0.6	c=-0.226	c=0.248	c=0.412
	p=0.313	p=0.694	p=0.977	p=0.703	p=0.340	p=0.556	p=0.069	p=0.688	p=0.183	p=0.076	p=0.508	p=0.35	p=0.531	p=0.489	p=0.270
MAM	n=7/7	n=15/15	n=8/8	n=10/10	n=14/14	n=6/6	n=8/8	n=15/15	n=7/7	n=7/7	n=17/17	n=6/6	n=10/10	n=7/7	n=13/13
	c=-0.509	c=0.122	c=0.286	c=0.030	c=-0.503	c=0.143	c=0.286	c=-0.104	c=-0.286	c=0.786	c=0.269	c=0.2	c=-0.087	c=0.093	c=0.055
	p=0.249	p=0.666	p=0.481	p=0.934	p=0.067	p=0.758	p=0.481	p=0.713	p=0.556	p=0.041	p=0.297	p=0.686	p=0.812	p=0.843	p=0.859
JJA	n=6/6	n=18/18	n=6/6	n=3/3	n=25/25	n=2/2	n=6/6	n=17/17	n=7/7	n=6/6	n=19/19	n=5/5	n=6/6	n=14/14	n=10/10
	c=0.029	c=-0.104	c=0.2	c=-0.5	c=0.071	c=(n<3)	c=0.086	c=0.221	c=-0.25	c=0.257	c=-0.021	c=0.1	c=0.257	c=0.350	c=-0.297
	p=0.960	p=0.680	p=0.686	p=1	p=0.737	p=(n<3)	p=0.861	p=0.395	p=0.595	p=0.658	p=0.932	p=0.95	p=0.658	p=0.221	p=0.405
SON	n=6/6	n=17/17	n=7/7	n=3/3	n=22/22	n=5/5	n=7/7	n=16/16	n=7/7	n=7/7	n=19/19	n=4/4	n=6/6	n=10/10	n=14/14
	c=0.257	c=-0.091	c=0.143	c=1	c=-0.149	c=0.8	c=0.357	c=-0.362	c=-0.821	c=0.357	c=-0.220	c=-0.8	c=-0.029	c=0.018	c=-0.297
	p=0.658	p=0.729	p=0.748	p=0.333	p=0.510	p=0.133	p=0.420	p=0.168	p=0.034	p=0.420	p=0.365	p=0.333	p=1	p=0.960	p=0.303
Number of Snowy Days															
	SOI (+)	SOI (N)	SOI (-)	AO (+)	AO (N)	AO (-)	NAO (+)	NAO (N)	NAO (-)	PNA (+)	PNA (N)	PNA (-)	PDO (+)	PDO (N)	PDO (-)
DJF	n=8/8	n=13/13	n=9/9	n=9/9	n=11/11	n=10/10	n=8/8	n=17/17	n=5/5	n=9/9	n=15/15	n=6/6	n=10/10	n=10/10	n=10/10
	c=0.143	c=0.335	c=0.033	c=-0.233	c=-0.127	c=-0.297	c=-0.262	c=-0.272	c=-0.3	c=-0.717	c=-0.039	c=0.543	c=-0.421	c=-0.152	c=-0.394
	p=0.727	p=0.263	p=0.930	p=0.552	p=0.709	p=0.405	p=0.536	p=0.291	p=0.6	p=0.037	p=0.889	p=0.269	p=0.226	p=0.676	p=0.260

Number of Ice-Residence Days															
	SOI (+)	SOI (N)	SOI (-)	AO (+)	AO (N)	AO (-)	NAO (+)	NAO (N)	NAO (-)	PNA (+)	PNA (N)	PNA (-)	PDO (+)	PDO (N)	PDO (-)
	n=7/7	n=14/15	n=7/7	n=3/3	n=23/24	n=3/3	n=4/4	n=23/24	n=2/2	n=4/4	n=21/22	n=4/4	n=9/9	n=10/10	n=10/11
1981-2010	c=-0.321	c=0.152	c=0.378	c=1	c=0.122	c=0.5	c=-0.4	c=0.108	c=(n<3)	c=0.8	c=-0.185	c=0.4	c=-0.218	c=0.778	c=-0.055
	p=0.498	p=0.589	p=0.406	p=0.333	p=0.579	p=1	p=0.583	p=0.625	p=(n<3)	p=0.333	p=0.422	p=0.75	p=0.572	p=0.008	p=0.881