Is the Relationship between Great Lakes Ice Cover and Climate Patterns Statistically Significant?

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Overview

This work is based on previous projects titled “Great Lakes Ice Cycle” conducted by Rau Assel. This proposed study will use generalized statistical analyses of the NCEP/NCAR reanalysis and climate GCM products along with historical sea ice observations including recent satellite measurements to analyze the statistical relationship between lake ice cover and climate indices in both spatial and temporal spaces. First, the EOF analysis will be applied to SLP, SAT, and 700 hPa geopotential height fields to reveal the AO/NAO (first mode) and PNA (second mode). The time series of these two modes can be used to conduct linear regression to sea ice cover. The lake ice composite analyses will be conducted based on the indices. Then the difference between the AO/NAO+ and AO/NAO- phases will be tested by student t-test. The similar ice composite analysis is applied to the El Nino and La Nina phases. Furthermore, a linear regression of the AO/NAO and ENSO indices will be applied to sea ice concentration to map the spatial correlation. Generalized relationship between the lake ice cover, lake levels, and atmospheric circulation patterns will be concluded.

Proposed Work

The CILER (postdoc) researcher will participate in the statistical data analysis of both ice data and atmospheric data. We will conduct the lake ice analysis in all five lakes, including in situ observations and satellite measurements for ice area, EOF, and linear regression analyses between the atmospheric forcing and ice cover. We also plan to measure ice thickness in Lake Erie using a USCG helicopter in February 2008 (ice max period), and in Lake Superior using a USCG icebreaker in March 2008 (Leshkevich and Wang).

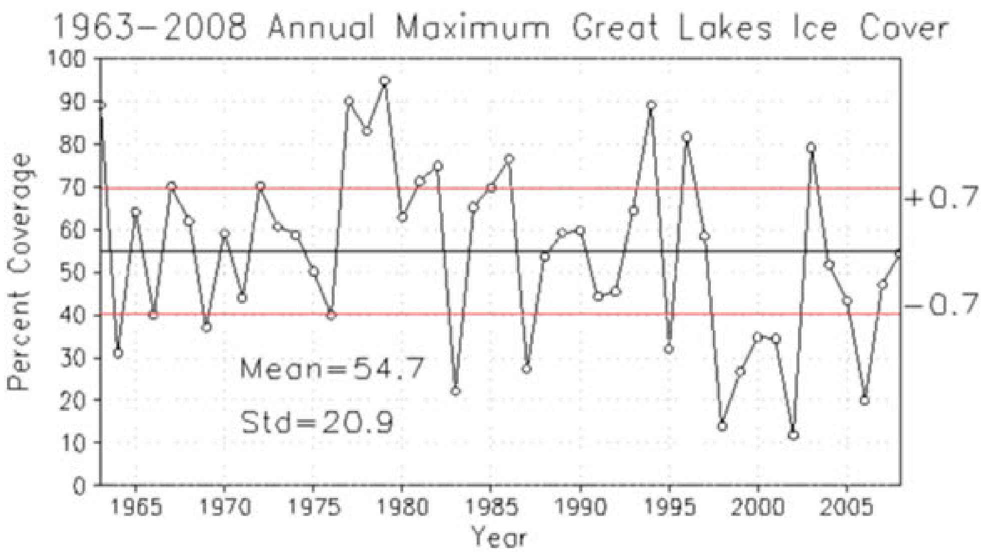

Figure 1: *Great Lakes ice cover record reveals 13 winters with anomalous low ice cover and 13 winters with anomalous high ice cover. – AO signal found in the high ice cover winters and El Nino signal in the low ice cover winters.*

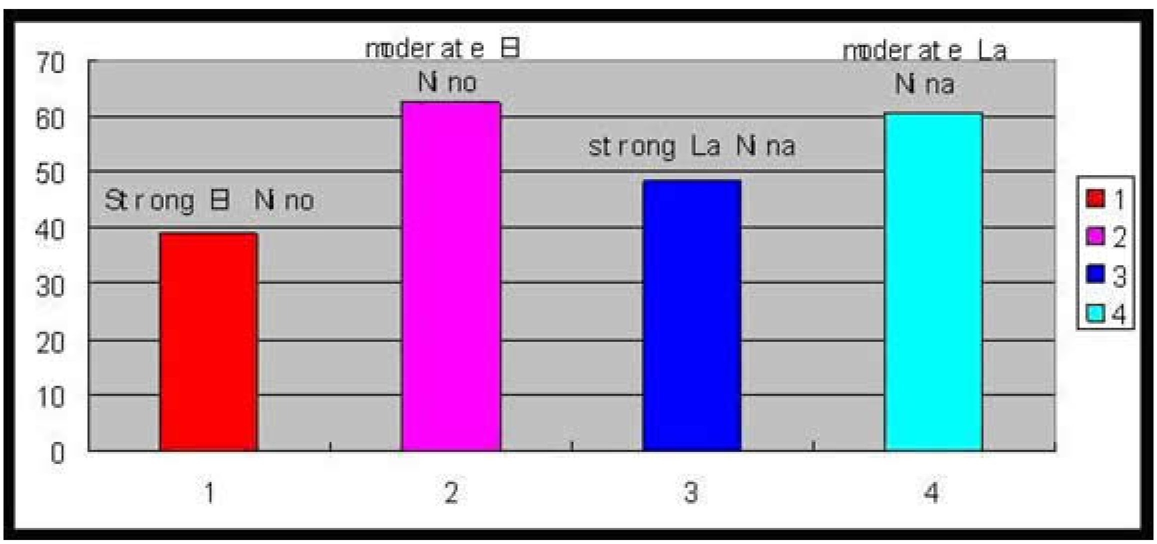

Figure 2: *ENSO and Ice Cover. Average percentages of ice cover in both El Nino andLa Nina Years. Only strong El Nino events are associated with significant low ice cover.Effects of weak El Nino and La Nina events on Great Lakes ice are not remarkable.*

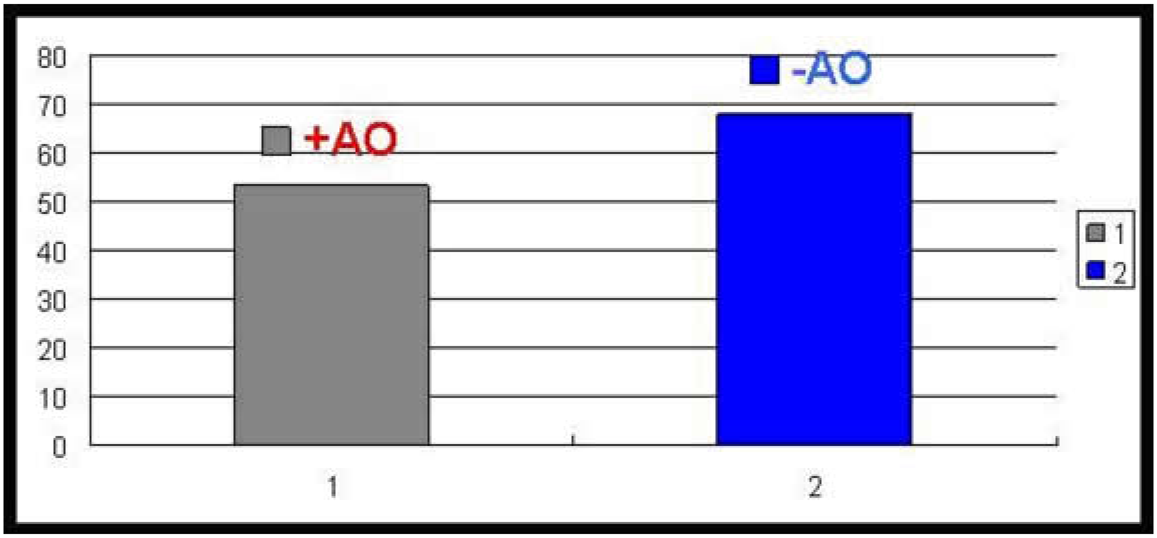

Figure 3: *Arctic Oscillation (AO) and Ice Cover. Average percentage of ice cover for winters with +/- AO. The impact of –AO on the Great Lakes is more remarkable than that of + AO.*

	+AO/NAO (warm)	-AO/NAO (cold)
El Nino (warm)	Extremely warm 1973,1983,1992,1995,2007	Normal 1966,1969
La Nina (cold)	Normal 1975 1976 1989 2000 2008	Extremely cold 1965 1985 2001

Figure 4: *Combination effects of ENSO and AO.*

Scientific Rationale

Summary of Previous Research Results

Correlations between average winter 700 mb heights at grid points in the northern hemisphere and annual maximum ice extent provided evidence of ice cover teleconnections (Assel and Rodionov, 1998). Teleconnections were further investigated using Classification and Regression Trees (CART) methodology (Rodionov and Assel 1999; Rodionov and Assel, 2000; Rodionov, Assel, and Herche, 2001). In general warm winters and below average ice covers were associated with zonal (west - east) atmospheric circulation while cold winters and above average ice covers were associated with a meridianal (north - south) circulation. Combinations of threshold values (both positive and negative) of the Polar/Eurasian Index, the Pacific/North

American index (PNA) and Tropical Northern Hemisphere (TNH) index accounted for much of the inter-annual variation of winter severity while threshold values of the Multivariate ENSO index and the TNH index were found to be useful in modeling Great Lakes annual maximum ice cover variations. The positive PNA index was found to have a nonlinear relationship with Great Lakes winter severity and ice cover (Rodionov and Assel 2001). Two types of atmospheric circulation over North America are associated with a high positive Pacific/North American (PNA) index. The first type is the true PNA pattern (amplified ridge-trough system). The second type, which is associated with strong warm ENSO events, is characterized by a flattening of the Polar jet stream and southward shift of the Subtropical jet. These nonlinear teleconnections with winter severity and annual maximum ice cover make their use in models and forecasts of ice cover (winter severity) a much greater challenge. In a subsequent study of the nonlinear affects of ENSO and the Pacific Decadal Oscillation (PDO) on winter severity the PDO is found to modulate the effect of the El Niño Southern Oscillation (ENSO) on a Great Lakes Winter Severity Index (WSI) (Rodionov and Assel, 2003). The correlation between ENSO and the WSI is weak [-.13] during the cold PDO phase and strong [.70] during the warm phase of the PDO. During the warm phase PDO w/o a strong ENSO, winters are colder. This occurred in the late 1970s and early 1980s and was responsible for the high ice cover regime during those years.

An analysis was made to develop long-range (30-day) prediction models of ice cover on Beginning Of Month (BOM) date for the Great Lakes (Assel, Drobrot, and Croley, 2004). Lake averaged ice covers were calculated for each Great Lake for BOM dates in January, February, March, and April for winters 1973 to 2002 and statistics for these data were analyzed (average, median, maximum, minimum, standard deviation). Predictor variable data sets were assembled and four types of statistical models were developed for lake averaged BOM ice concentration on each Great Lake: 1) the climatological model, 2) the anomaly propagation model, 3) the observational linear regression model, and 4) the Perfect AFDD linear regression model. Predictor variables included Freezing Degree Day (FDD) accumulations and indices of atmospheric circulation. It was also shown that parameters output from GLERL's lake evaporation model also have high correlations with BOM lake-averaged ice cover. The Perfect AFDD model has the highest overall forecast skill but it requires an accurate 30 day air temperature forecast.

The Generalization of Impacts of Multiple Atmospheric Patterns on GL Ice

The Great Lakes ice severity conditions are determined by air temperature, water temperature, heat flux, and water heat storage that is directly proportional to water depth. These factors are associated with global (hemisphere) and regional climate patterns, such as the Arctic Oscillation (AO) or the North Atlantic Oscillation (NAO), and El Nino and Southern Oscillation (ENSO) pattern (note that the PDO-Pacific Decadal Oscillation is thought to be a similar phenomenon of ENSO, although the definition differs from ENSO). Nevertheless, the Great Lakes are located at the edge of the Icelandic Low, far away from the action center (see Fig. 5). Thus, although being influenced by the Icelandic Low whose intensity is associated with AO/NAO (AO+/- means a stronger/weaker Icelandic Low), ice cover may not be statistically significant relationship with AO/NAO.

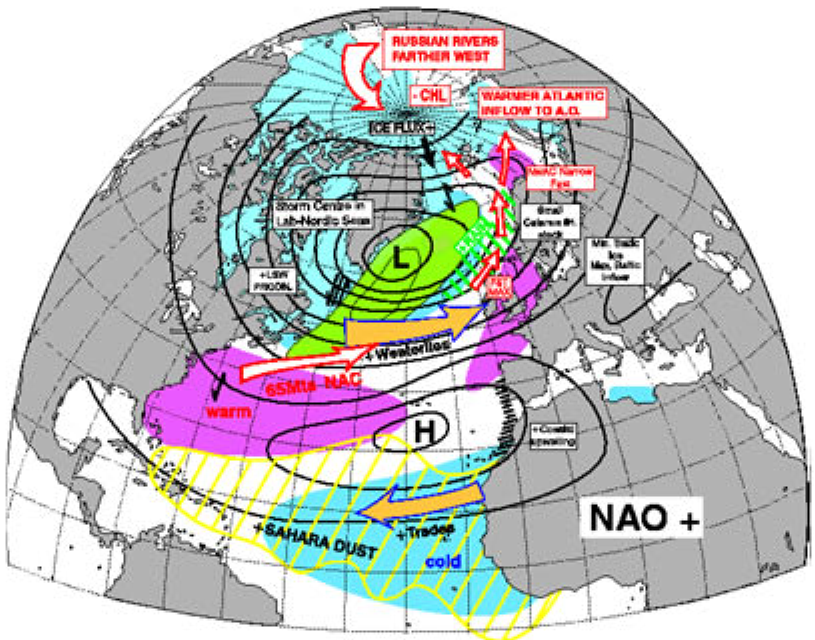

Figure 5*: The AO/NAO pattern during its positive phase in terms of SLP anomaly. L mean Icelandic Low is intensified, H means Azores High is also intensified. Vice versa during the negative AO/NAO phase. The intensified Icelandic Low associated with AO/NAO+ advects warm, moist Atlantic air to the European sector, while brings down Arctic dry, cold air to the eastern Canada, including Hudson Bay and the Great Lakes. Nevertheless, the Great Lake is far away from the Icelandic Low, which is hypothesized to be marginally statistically significant.*

The similar doubt/hypothesis is also applied to the ENSO pattern (see Fig. 6). Based on previous research (Wang et al. 1994; Mysak et al. 1996), ENSO pattern may have a significant impact on ice cover in the Great Lakes. Thus, we propose to conduct climate research to test the above hypotheses. If a statistically significant linkage between ice conditions and one or more climate patterns can be verified, then a generalized statistical hindcast model can be developed to predict ice conditions based on climate pattern indices. Otherwise, we have to 1) study lake ice cover and its linkage to the atmospheric circulation patterns on a case-to-case and/or an extreme event basis, and 2) rely heavily on numerical ice model forecast.

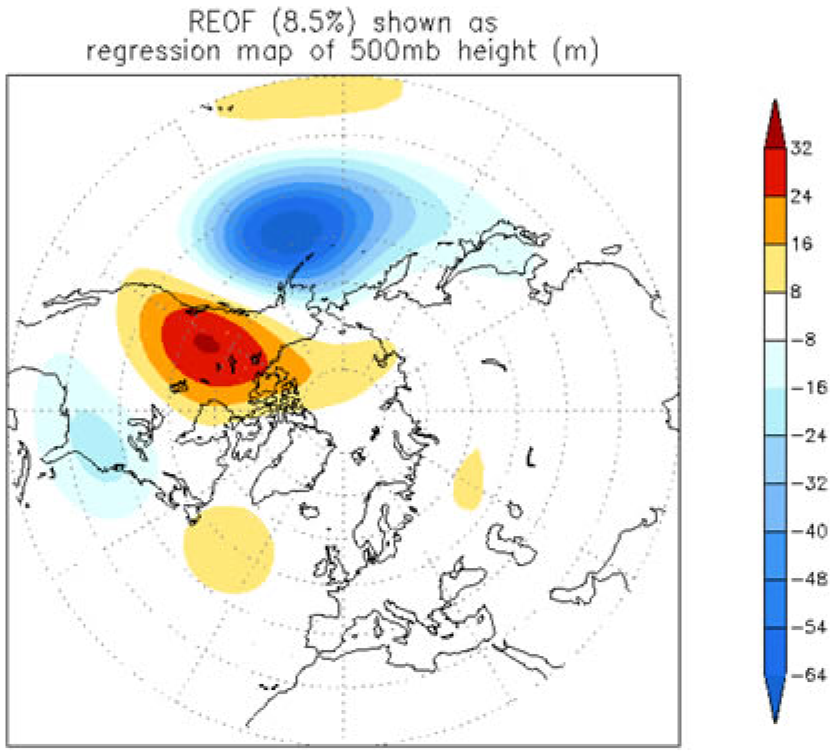

Figure 6: *The ENSO pattern in terms of 500 hPa height anomaly. Red means positive (anticyclonic) anomaly, blue means negative (cyclonic) anomaly. Vice versa during the negative ENSO pattern. During the El Nino event, the intensified low center in the southeastern US would advect warm, moist Atlantic air to northeastern US including the Great Lakes region, while the Alberta High brings down the Arctic dry, cold air to the eastern Canada, including Hudson Bay and the Great Lakes. These two different air masses encounter in the Great Lakes area and the northeastern US would result in heavy precipitation (snow) and winter snow storms. Nevertheless, during the La Nino event, an opposite scenario occurs, i.e., the Great Lakes area would have less precipitation. The Great Lake is located between these two action centers, which is hypothesized to be statistically significant linkage between the lakes ice and PNA pattern.*

Governmental/Societal Relevance

Knowledge of the lake ice dynamics and thermodynamics in the Great Lakes associated with climate patterns is important not only to wintertime navigation and rescue efforts, but also to prediction of precipitation, lake water level variability, and environmental preconditioning for phytoplankton and zooplankton blooms.

Products

Presentations

Wang, J. 2008. Projections *of the Great Lakes climate in the 21st century and coupled lake - ice modeling*, Workshop of Impact of Climate Change on the Great Lakes Ecosystems. July 19-22, Ann Arbor, MI (invited)

Bai, X. and J. Wang, 2008. *Interannual variability of lake ice and internal climate teleconnection patterns*. Workshop of Impact of Climate Change on the Great Lakes Ecosystems. July 19-22, Ann Arbor, MI

Publications

Bai, X., J. Wang, C. Sellinger, A. Clites, and R. Assel. 2008. Relationship of the Great Lakes ice cover to AO and ENSO (in preparation., to be submitted to *J. Climate* or *J. Great Lakes Res*.)

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