LAURENTIAN GREAT LAKES ICE COVER TELECONNECTIONS

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1. INTRODUCTION

An earlier study (Assel, 1992) provided the motivation for this present research on Great Lakes ice cover teleconnections. Here, annual maximal ice cover for winters 1963-1990 are analyzed to define much-above and much-below average ice cover based on the 7 years with the highest and 7 years with the lowest annual maximum ice coverage. Composite anomaly maps of 700 hPa geopotential height for the lowest (highest) quartile ice cover reveal a zonal (meridional) flow pattern. The difference between the 700 hPa composite anomaly maps and maps of correlations between all 28 winters of annual maximum ice cover and 700 hPa geopotential heights provide evidence of teleconnectivity for annual maximum Great Lakes ice cover.

2. STUDY OBJECTIVES

- o Development of an improved understanding of Great Lakes ice cover teleconnections.
- o Identification of likely useful teleconnections for modeling and forecasting ice cover.

3. DATA AND ANALYSIS METHODS

ANNUAL MAXIMUM ICE COVER. The Laurentian Great Lakes do not form a 100% ice cover (freeze-over completely), because of their large depth and associated large heat storage capacity and because of relatively mild winter air temperatures. Estimates of the annual maximum ice extent (the greatest percent of a lake's surface area that will be covered by ice each winter) for each Great Lake were abstracted from published reports For some winters they were estimated using an electronic digitizer and ice charts produced by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration and by the Canadian Ice Service, Environment, Canada.

700 hPa GEOPOTENTIAL HEIGHTS. The 700 hPa heights used in this study are from the National Meteorological Center's Northern Hemisphere monthly grided dataset described by Jenne (1975). Winter average (DJF) 700 hPa geopotential heights were calculated for each winter: 1963 (December 1962, January 1963, February 1963), 1964 (December 1963, January 1964, February 1964)...and so on to 1990 (December 1989, January 1990, February 1990). These winter averages for the 7 years of the highest quartile ice cover for each Great Lake were used to calculate the composite maps for the high ice cover winters - and similarly for the lowest quartile ice cover winters at each Great Lake. Anomalies were calculated as deviations from the 28-winter mean 700 hPa (DJF) geopotential height for the period 1963-1990. Correlations of annual maximum ice cover for all Northern Hemisphere grid points of the winter average 700 hPa height fields were also made.

4. LOWEST QUARTILE ICE COMPOSITE CIRCULATION PATTERNS

The composite map for the lowest quartile for Lake Huron (Fig. 1) is characterized by a wave-train in the middle and high latitudes, with positive anomalies over the central North Pacific and to the north of the Great Lakes (a third center is located in the North Atlantic for Lake Ontario and in northwest Europe for Lake Superior) and negative anomalies centered just off shore of the west coast of North America and in the mid Atlantic. The distribution of 700 hPa anomalies implies a weakening of the quasi-permanent ridge over the west coast and a weakening of the trough over eastern North America that results in a strengthened zonal flow bringing moderate winter air temperatures to the Great Lakes. A weakening of the Baffin Island low, and to a lesser degree the Islandic low, indicates less frequent invasion of Arctic and Polar air into the Great Lakes region.

5. HIGHEST QUARTILE ICE COMPOSITE CIRCULATION PATTERNS

The 700 hPa composite anomaly pattern for highest quartile ice cover of Lakes Michigan, Ontario, and Erie is similar to that of Lake Huron. The pattern of Lake Huron (Fig. 2) has centers of below-average 700 hPa heights in the central Pacific Ocean, over and to the southeast of the Great Lakes, and over western Europe and the adjacent North Atlantic. Above-average 700 hPa heights are located along the west coast of North America and north of 50°N they extend eastward from Alaska to Greenland, with the major center of positive anomalies over southern Greenland. The combined effect of these patterns produces a strengthening of the troughs in the mid Pacific Ocean and over the eastern third of North America and a strengthening of the ridge over the west coast of North America, resulting in a meridional flow regime with increased advection of cold Arctic and Polar air masses into the mid-section and eastern portion of North America.

6. ANOMALY DIFFERENCE MAP

A map of the difference between the composite 700 hPa anomaly of highest quartile minus the composite 700 hPa of lowest quartile ice cover (Fig. 3) shows that significant negative anomaly difference centers occur in the central North Pacific, in the vicinity of the Great Lakes, in the central Atlantic, and in Europe; the area of negative differences for the Great Lakes is largest for Lake Michigan and smallest for Lakes Superior and Ontario. Centers of significant positive differences are located over Alaska, over northern Mexico - southwestern United States, over central Asia, and over the North Atlantic between Greenland and northern Norway. The areas of significant positive and negative differences taken together form patterns that resemble elements of the PNA, the NAO, and TNH teleconnection patterns.

7. ICE COVER 700 hPa CORRELATIONS

Correlations between annual maximum ice cover for individual Great Lakes and 700 hPa geopotential heights over the 1963-1990 winters and correlations of the first difference of annual maximum ice cover (year t+1 minus year t) with the first difference average winter 700 hPa geopotential heights, portray teleconnection centers. The first difference is used to emphasize the interannual variability. Areas locally significant have centers in the subtropical Pacific, Alaska, the Gulf of Alaska, Mexico east to the Gulf of Mexico, the vicinity of the Great Lakes, the mid Atlantic Ocean, Greenland, and western Europe and the adjacent Atlantic Ocean. Correlation coefficients in the Pacific are significant for three of the five Great Lakes (Superior, Huron, and Erie), and Alaskan centers are significant for all five Great Lakes, with the largest area of highest correlation coefficient for Lake Superior. The correlation coefficients in the vicinity of the Great Lakes are significant for Lakes Superior, Michigan, and Erie for the original maps and for all the Great Lakes on the first difference maps. The Mexico center has significant correlations for Lakes Superior, Huron, and Erie. These four correlation centers (Pacific Ocean, Alaska, Great Lakes, and Mexico) appear to be somewhat similar in appearance to distorted PNA teleconnection patterns, with similar signs. Lake Superior has the strongest, and Lake Ontario has the weakest correlation to these four centers.

Correlation coefficients in the western European center are significant for Lakes Michigan and Lake Ontario on the original maps and for Lakes Superior, Michigan, Huron, and Ontario on the first difference time series. The correlation maps for Lakes Michigan, Erie, and Ontario have an entire belt of negative correlation coefficients in the middle latitudes; Lakes Michigan and Ontario maps also have a major area of positive correlation coefficients in the Atlantic and North America. This western Europe - North Atlantic pattern suggests a NAO-like teleconnection with annual maximum ice cover in Lakes Michigan, Ontario, and possibly Huron. A negative mode of the NAO [van Loon and Rogers (1978) "Greenland above" mode] is associated with above-average ice cover on the Great Lakes. "Greenland above" mode refers to above-normal temperature anomalies west of Greenland that are typically observed during this mode of circulation and accompanied by negative temperature anomalies in northwestern Europe. Alternatively, when the NAO mode is positive ("Greenland below" mode), that is, strong westerly winds in the mid-latitude belt, negative temperature anomalies west of Greenland, and positive temperature anomalies in northwestern Europe, ice cover in Lakes Michigan, Huron, and Ontario will tend to be below average.

8. FUTURE WORK

Here we summarized preliminary results of our study, additional analysis and details of our study will be published as a journal article (Assel and Rodionov, submitted). Results given here may lead to development of models of Great Lakes ice formation on monthly, seasonal, and interannual time scales with application to Great Lakes studies related to regional climate and climate change, the winter lake ecosystem, lake hydrology, winter navigation, and hydropower generation.

9. ACKNOWLEDGMENTS

This is GLERL contribution number 1026.

10. REFERENCES

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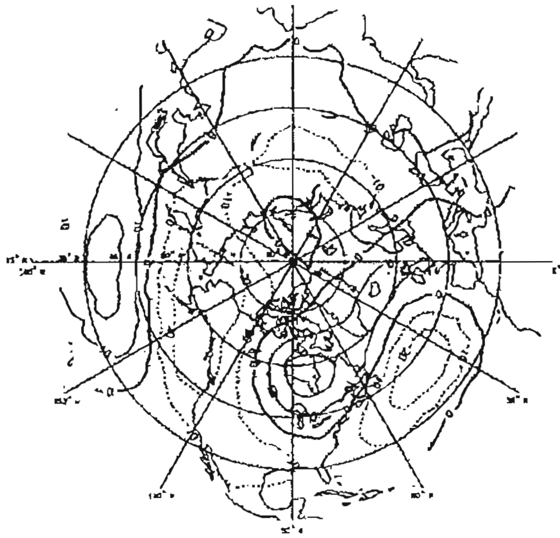

Fig. 1 700 hPa Composite anomaly for lowest quartile ice cover on Lake Huron

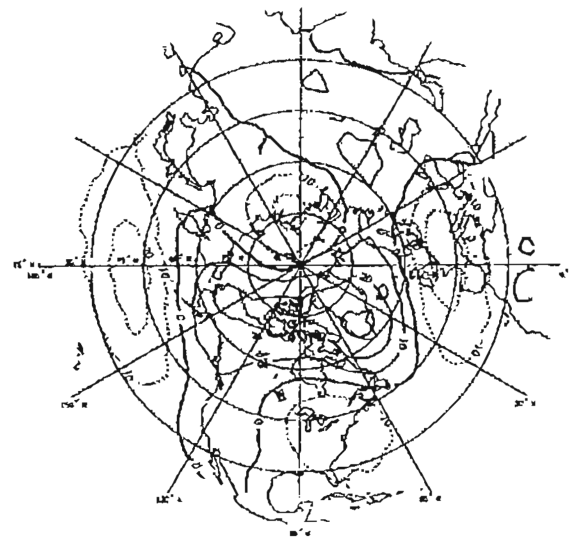

Fig. 2 700 hPa Composite anomaly for highest quartile ice cover on Lake Huron

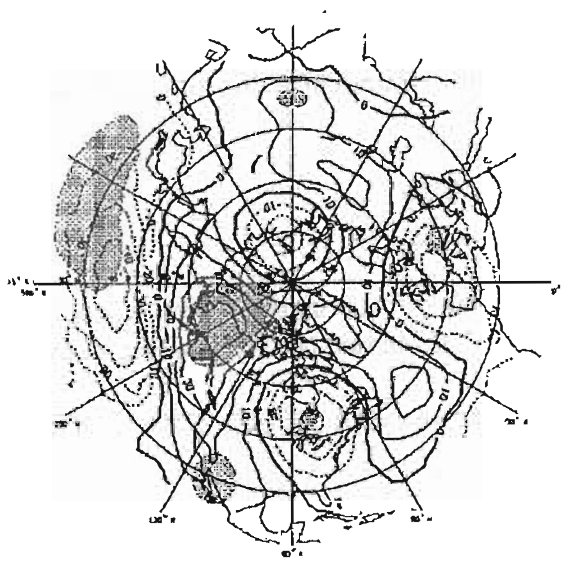

Fig. 3. 700 hPa Anomaly Difference Map for Lake Huron (highest minus lowest quartile ice cover). Dashed lines indicated negative anomaly differences. Shaded areas are significant at the 5% level.

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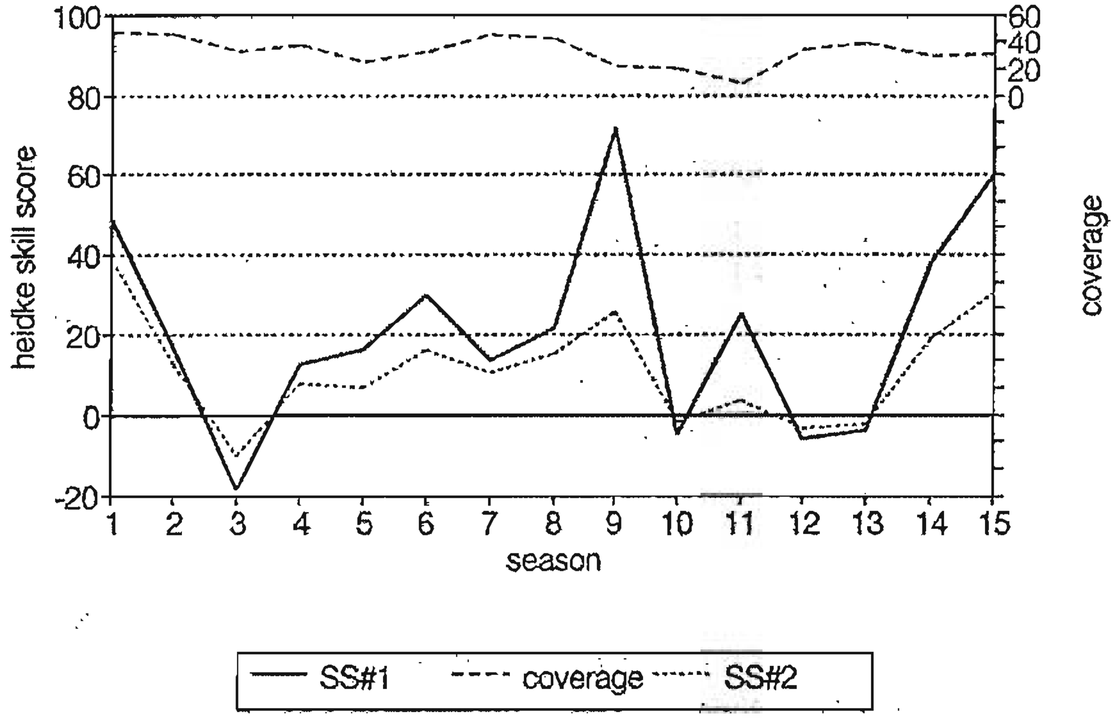

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