Great Lakes Ice Cycle

Primary Investigator: Raymond Assel - NOAA GLERL (Emeritus)

Co-Investigators: Thomas E. Croley - NOAA GLERL (Emeritus). Sheldon Drobot - National Academy of Science, Polar Research Board

The formation, duration, and extent of ice cover on the Great Lakes has a major impact on the economy of the region by impeding commercial navigation, interfering with hydropower production and cooling water intakes, and damaging shoreline structures. The ice cover also has an impact on the water balance of the lake, by affecting lake evaporation, heat, and momentum transfers, and on the biology and chemistry of the lakes. The significance of reduced ice cover on the biota of the Great Lakes includes: greater over winter mortality of whitefish eggs (and thus potentially lower year class size), lower diatom production, both due to loss of the stable environment afforded by formation of a continuous ice cover, and perhaps a temporal displacement of both physical and biological processes in the Great Lakes, such as the recurrent springtime plume in southern Lake Michigan and associated offshore and longshore sediment transport and increased biological activity within the plume.

Objectives

- To document and analyze lake ice cycles for climate and climate change, lake hydrology, lake ecosystems, and ice modeling and forecasting applications.
- To provide ice cover information useful for placing the ice cover of the 1980s, 1990s, and beyond into a historical perspective.

2005 Plans

I will respond to reviewer comments for two manuscripts submitted for journal publication in CY 04 and make any needed changes to address reviewer criticisms. Empirical freezing degree day models of ice cover will be develop for specific regions of each Great Lakes. This will be done in consultation with a forecaster at the National Weather Service Office in Cleveland, Ohio who has expressed a need for such models for operational applications. The development of a grid-cell (2-D) model of 30-day ice forecasts for the Great Lakes will be explored as a potential improvement over the current lake averaged (1-D) model developed last year. As was the case in the development of the 1-D model, Thomas Croley and Sheldon Drobot (Univ. of Colorado at Boulder) will be collaborators in the development of the 2-D 30-day ice forecast models.

2004 Accomplishments

In 2004 we responded to reviewer comments of: "Improving 30-day Great Lakes Ice Cover Outlooks", made changes and further analysis as appropriate, and published the manuscript in the Journal of Hydrometeorology. Since these changes resulted in a considerable shortening of the manuscript, a technical memorandum version of this study was written for those interested in a more detailed description of study results (Assel et al, 2004b). The Canadian Ice Service expressed an interest in consulting with GLERL to explore operational implementation of the 30-day ice forecast methodology.

An analysis of basin average ice cover was made for the east, central, and west basins of Lake Erie for the 105 winters from 1898 to 2002. Ice cover data for 1973 to 2002 is based on data from the NOAA Great Lakes Ice Atlas. Ice cover data from 1898 to 1983 is based on modeled ice cover data.

An analysis of the annual ice cycles for each Great Lake was made. Integrated seasonal ice cover was calculated for each lake each of 30 winters and used to classify ice cycles as mild, typical, and severe. Ancillary data included dates of first/last ice, and ice duration. Seasonal ice cover spatial patterns are shown for each ice cycle class. The classification scheme will be useful in comparing past and future Great Lakes ice cycles relative to the current ice cover climatology.

The contemporary ice cover climatology for Lake Superior ice cycles was reviewed within the context of lake bathymetry as part of a larger study of the state of Lake Superior. Long-term averages of date of first ice, date of last ice, and ice duration were portrayed and discussed. The seasonal progression of lake-averaged ice cover for discrete depth ranges and the spatial patterns of ice cover for early, mid, and late winter and for early spring for mild, typical, and severe winters were also described and discussed.

2003 Accomplishments

Two journal papers, one on trends in annual maximum ice cover and the other on winter severity teleconnections were published in 2003. Preliminary results of the annual maximum ice cover trends paper was presented at a scientific meeting in December 2002 and published as a paper in the meeting proceeding.

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. 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. A manuscript that documents methods, results, and conclusions of this study was submitted for publication.

An ice cover data set for the Lake Erie Integrated Program was prepared. Using data from the NOAA Great Lakes Ice Atlas (Assel 2003) daily spatial average ice concentrations for the west, center, and eastern basins of Lake Erie were calculated for the winters 1973 through 2002. Daily basin averaged ice concentration was also modeled for these three basins for winters from 1898 to 1972 using a statistical FDD model developed in an earlier study. Daily basin averaged ice cover concentration for each basin for each winter and statistics (maximum, minimum, median, first quartile, third quartile), dates of first ice, dates of last ice, ice season duration, were also calculated. Analysis results were recorded as plots and tabulations.

2002 Accomplishments

Teleconnections: The Pacific Decadal Oscillation (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.

Climate Variations/Changes: Three ice cover regimes were identified over the past 40 winters: a low regime (1963 -1976), high regime (1977-1982), and a second low regime (1983 to 2001), details of the characteristics of spatial patterns of annual maximum ice cover for winters with above average and below average ice cover are given in Assel, Cronk, Norton (2003).

A study of the trend in annual maximum ice covers of the combined area of the Great Lakes was continued in 2002 by adding the winter of 2002 to the analysis. The annual maximum ice cover averaged over the most recent 5 winters of that study (1998, 1999, 2000, 2001, and 2002) is the lowest on record and is a unique 5-winter average of low ice cover relative to the past century (Assel and Norton, 2002), lending credence to the possibility of the beginning of a lower ice cover regime.

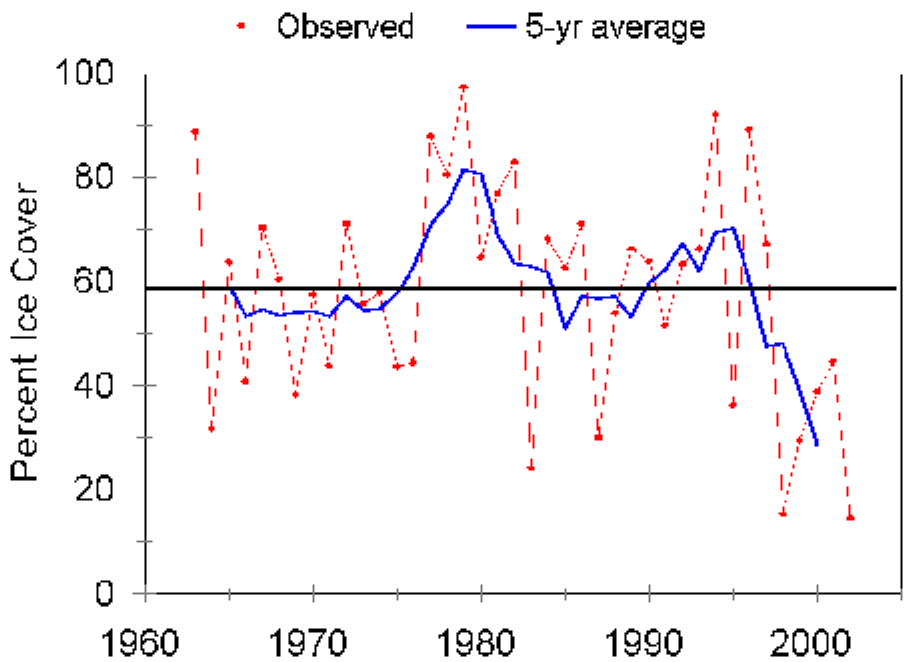

***Figure 1:** Annual Maximum Great Lakes Ice Cover for Winters 1963 - 2002. Figure 1 portrays annual maximum Great Lakes ice cover for winters 1963-2002. The y axis = percent ice cover. The x axis = years starting from 1960 - 2002. Observed and a 5-yr average lines are depicted.*

Accomplishments prior to 2002

Teleconnection: A teleconnection is a linkage between weather changes occurring in widely separated regions of the globe. Identification and models of Great Lakes ice cover and winter severity teleconnections may lead to improved long-range forecasts of ice cover and insight into regional (Great Lakes) impact of variations in large scale atmospheric circulation.

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 in 1999 (Rodionov and Assel 1999), 2000 (Rodionov and Assel, 2000), and 2001 (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. Details are given in the publications cited above. 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. This work is continuing with a study of the nonlinear affects of ENSO and the PDO on winter severity (see 2002 accomplishments above).

Climate Variation/Changes:. The annual ice cycle is an index of the regional winter climate and climate change. Changes in the ice cover regime have the potential to affect the flora and fauna of the Great Lakes and the regional economy.

A synthesis of Laurentian Great Lakes ice cover climatology, temporal trends (over the past century), possible changes due to global warming, and affects on the lake ecosystem was published (Assel 1999) in "Climate Change Effects on Lake Hydrodynamics and Water Quality". That book provides a state of the art review of the climate change effects on lake hydrodynamics and water quality and it is useful for engineers and scientists working on water resources and environmental problems for lakes and impoundments.

Long-term freeze-up, breakup, and ice duration records for sites in North America, Europe, and Asia were analyzed for spatial and temporal trends and for coherence of freeze-up and break-up dates over the northern hemisphere. This work was accomplished under the auspices of a National Science Foundation project: North Temperate Lakes: Global Generalization and Analyses of Lakescapes, Biodiversity and Ice Phenology. Over a 150 year period (1846-1995), freeze dates averaged 5.8 days per century later, breakup dates averaged 6.5 days per century earlier, and inter-annual variability in freeze and breakup dates has increased since 1950. These trends are in agreement with the long-term ice record of Grand Traverse Bay, Lake Michigan (Assel 2001). Additional analysis results are given in: Assel and Herche (1998), Magnuson et al. (2000), and Assel and Herche (2001).

There has been a high frequency of warm winters starting with winter 1998. The maximum ice cover of the combined area of the five Great Lakes for the 4 winters 1998,1999, 2000 and 2001 was compared to the previous 35 winters to place these recent warm winters into a historical perspective. The 4-winter average was found to be the lowest average over the 39 winters of record (see presentations: Assel, Herche, and Cronk 2001). These results are noteworthy as they may be a harbinger of global warming in the Great Lakes. This analysis is continuing (see accomplishments 2002).

Products

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