LAKE ICE RECORDS USED TO DETECT HISTORICAL AND FUTURE CLIMATIC CHANGES

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Abstract. Historical ice records, such as freeze and breakup dates and the total duration of ice cover, can be used as a quantitative indicator of climatic change if long homogeneous records exist and if the records can be calibrated in terms of climatic changes. Lake Mendota, Wisconsin, has the longest uninterrupted ice records available for any lake in North America dating back to 1855. These records extend back prior to any reliable air temperature data in the midwestern region of the U.S. and demonstrate significant warming of approximately 1.5 °C in fall and early winter temperatures and 2.5 °C in winter and spring temperatures during the past 135 years. These changes are not completely monotonic, but rather appear as two shorter periods of climatic change in the longer record. The first change was between 1875 and 1890, when fall, winter, and spring air temperatures increased by approximately 1.5 °C. The second change, earlier ice breakup dates since 1979, was caused by a significant increase in winter and early spring air temperatures of approximately 1.3 °C. This change may be indicative of shifts in regional climatic patterns associated with global warming, possibly associated with the 'Greenhouse Effect'.

With the relationships between air temperature and freeze and breakup dates, we can project how the ice cover of Lake Mendota should respond to future climatic changes. If warming occurs, the ice cover for Lake Mendota should decrease approximately 11 days per 1 °C increase. With a warming of 4 to 5 °C, years with no ice cover should occur in approximately 1 out of 15 to 30 years.

1. Introduction

Interest in past and future climatic changes has been renewed with the possibility of global climatic warming associated with the 'Greenhouse Effect' (Liss and Crane, 1983; Ramanathan, 1988). Many indicators have been used to try to detect and quantify climatic changes. The most obvious but often the most deceiving indicators have been the weather records themselves. Changes in techniques for monitoring meteorological parameters have often produced data which appear to show climatic changes; these changes can be significantly larger than the subtle, actual climatic changes (Schaal and Dale, 1977; Karl and Williams, 1987). Techniques have been developed to remove most systematic biases introduced into the meteorological data for a specific location by comparing the data with that of a nearby station(s) (Gaskill, 1981; Karl and Williams, 1987). Early weather data do not exist for some locations or are of questionable quality and have no nearby unbiased data

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for comparison; therefore, other phenological data, such as ice cover records, have been used as climatic indicators (Tramoni et al., 1985; Palecki and Barry, 1986).

Ice cover information, such as freeze and break up dates and the total days of ice cover (ice duration) represent an integration of local weather conditions, primarily air temperature (McFadden, 1965; Tramoni, 1985; Palecki and Barry, 1986). The exact timing of freezing and break up for a particular season are dependent upon daily and often hourly weather conditions including air temperature and wind speed. Ice conditions on rivers, in addition, are also dependent on the amount of runoff and river flow. However, changes in the general timing or mean date of freezing or break up depend on changes in the state of the regional climate. For most locations there have been no precise definitions of what constitutes complete freezing or break up; therefore, the recorded dates were not free of observer bias. However, some lakes experience rapid transition periods where freeze and break up dates can usually be resolved to one or two days. For these systems, annual freeze and break up dates can be accurately documented.

Three techniques have been used to determine the relationship between lake ice cover records and air temperature: fixed period regression analyses (Rannie, 1983; Tramoni et al., 1985; Palecki and Barry, 1986), variable length air temperature integration (McFadden, 1965), and dynamic freeze and break up models (Bilello, 1964). Regression analyses have been used to calibrate ice records of specific lakes having many years of data by regressing specific air temperature summary parameters, such as a monthly or bi-monthly average air temperature, on the coinciding freeze or break up dates and total ice duration. Variable length integration techniques involve using a moving index which accumulates through time, such as a moving average air temperature (McFadden, 1965). The lake is estimated to freeze or break up when the index reaches a certain threshold. A third technique involves developing dynamic models to simulate the physical processes occurring in the lake leading to the particular freeze or break up events. Rodhe (1952) and Bilello (1964) approximated the heat exchange between the water surface and air using solely sensible heat transfer and developed lake ice formation models.

Freeze and break up dates and ice duration for Lake Mendota, Wisconsin from 1855 to present are the longest uninterrupted ice data available for any lake in North America (Tramoni, 1985). These data are used to: (1) develop mean freeze and break up dates for Lake Mendota into quantitative indices of seasonal air temperatures using the coinciding meteorological records, (2) determine if significant changes have occurred in mean values of each ice cover parameter since 1855, (3) estimate historical changes in air temperature suggested by the changes in mean ice cover using the quantitative relationships between the ice cover parameters and seasonal air temperatures, and (4) project how the mean ice cover should respond to future climatic change.