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Climatic-change implications from long-term (1823–1994) ice records for the Laurentian Great Lakes

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ABSTRACT. Long-term ice records (1823–1994) from six sites in different parts of the Laurentian Great Lakes region were used to show the type and general timing of climatic changes throughout the region. The general timing of both freeze-up and ice loss varies and is driven by local air temperatures, adjacent water bodies and mixing, and site morphometry. Grand Traverse Bay and Buffalo Harbor represent deeper-water environments affected by mixing of off-shore waters; Chequamegon Bay, Menominee, Lake Mendota, and Toronto Harbor represent relatively shallow-water, protected environments. Freeze-up dates gradually became later and ice-loss dates gradually earlier from the start of records to the 1890s in both environments, marking the end of the "Little Ice Age". After this, freeze-up dates remained relatively constant, suggesting little change in early-winter air temperatures during the 20th century. Ice-loss dates at Grand Traverse Bay and Buffalo Harbor (but not at the other sites) became earlier during the 1940s and 1970s and became later during the 1960s. The global warming of the 1980s was marked by a trend toward earlier ice-loss dates in both environments.

INTRODUCTION

Past studies have shown that freeze-up and ice-loss dates are useful indices of climate and climatic change (Palecki and Barry, 1986; Robertson, 1989; Schindler and others, 1990; Skinner, 1993). Long-term freeze-up and ice-loss records at Grand Traverse Bay and Lake Mendota began in the 1850s and by about 1890 the average dates reveal a shift to later freeze-up and earlier ice loss. A gradual warming during the 20th century was associated with a second shift to earlier ice-loss dates, starting in about 1940 at Grand Traverse Bay (1910–93), and in 1980 at Lake Mendota (Assel and Robertson, in press). Here we expand on this work by examining four additional sites spread throughout the Great Lakes region. The scope of this study is limited to a first exploratory look at the data. We examine long-term averages and variances (standard deviation) and smoothed plots of the annual data. Our objectives are to (a) identify similarities in the changes in ice cover over the past 200 years throughout the Great Lakes region, (b) describe differences in the ice cover among sites, and (c) qualitatively infer changes in the winter climate throughout the region over the past 200 years.

DATA AND SITE DESCRIPTIONS

Ice-event dates, i.e. freeze-up and ice-loss (break-up) dates, are available throughout the Great Lakes region. Freeze-up can be defined as the date of the first skim ice, the date solid ice forms that lasts until the spring, or something in-between. Ice-loss date can be defined as the date the ice cover breaks up, the date of final loss of ice cover, or something in-between. Since a standard definition thus does not exist for freeze-up or ice loss, climatic analysis of these data is problematic. Albeit with this caveat, we found six sites, spanning virtually the entire region (Fig. 1), that had long-term freeze-up and ice-loss date data sets. These locations were (1) Chequamegon Bay (46.67° N, 90.88° W) between Houghton Point and Ashland, (2) Grand Traverse Bay (44.76° N, 85.62° W) from the head of the west arm of the bay to Marion Island, (3) Lake Mendota (43.66° N, 89.40° N), (4) Green Bay in the vicinity of Menominee, Michigan (45.00° N, 87.64° W), (5) Buffalo Harbor (42.88° N, 78.90° W) westward to Long Point, and (6) Toronto Harbor (43.65° N, 79.45° W) between Toronto Island and the mainland. The period of record and the average water depth for the six sites ranged from 64 to

These data suggest there has been warming during the 20th century with the 1980s being the warmest decade on record at many locations. The ice-loss dates for Grand Traverse Bay and Lake Mendota remained similar throughout the early 1940s. However, during the 1940s and 1950s, ice loss at Grand Traverse Bay became earlier in response to milder mid- to late-winter and early-spring temperatures. Assel and Robertson (in press) found that ice-loss dates for Grand Traverse Bay are strongly related to average March air temperatures which started to increase in about the 1940s and 1950s. Lake Mendota's ice-loss dates did not become notably earlier in the 1940s and 1950s because its ice-loss dates are more strongly related to average January–March air temperatures which did not collectively increase until around 1980 (Assel and Robertson, in press).

Changes in ice-loss dates at Buffalo and the east end of Lake Erie were most similar to those at Grand Traverse Bay. These two sites have relatively deep adjacent waters and therefore the potential for mixing with warmer waters. Changes in the ice-loss dates at Menominee and Chequamegon Bay appear to follow the pattern of the ice-loss dates of Lake Mendota more than they do those of Grand Traverse Bay, but each site is also unique in its response to climate and climatic change.

Warming in the 1980s and early 1990s affected the entire winter and is reflected in a trend toward earlier ice-loss dates at all sites. In fact, during the winters of 1983–92, Grand Traverse Bay did not freeze up in 6 out of these 10 years, a record that is unmatched during any other 10 year period in the 144 years of observations for that site.

The changes in ice-loss dates for Lake Mendota and Grand Traverse Bay that occurred around 1890 were quantified in terms of changes in air temperature using ice models by Assel and Robertson (in press). The results suggest that mid- to late-winter air temperatures increased by approximately 1.1°C. However, ice-loss dates were in a period of transition, so the air-temperature change would be expected to be even larger if the period were extended back to the beginning of the Toronto record (1823). The results also suggest that mid- to late-winter air temperatures increased by approximately 1.1°C after 1940.

CONCLUDING REMARKS

Air temperature is the primary climatic variable affecting freeze-up and ice-loss dates, while water depth and mixing with larger adjacent water bodies are also contributory factors affecting ice-event dates. Sites having greater water depth and more exposure to larger bodies of water have later freeze-up dates and greater variance in ice-event dates. The long-term average ice-loss date at such sites can be either about the same (Grand Traverse Bay) or much later (eastern end of Lake Erie) than the long-term average date at less exposed sites (Lake Mendota and Toronto Harbor).

The earliest ice records from Toronto, Grand Traverse Bay and Lake Mendota (1823–90) suggest that the winter climate near the Great Lakes prior to 1890 was warming as indicated by a trend toward later freeze-up and earlier ice-loss dates. This is in good agreement with the suggested timing of the end of the Little Ice Age, around 1850. Since about 1890, the average freeze-up dates have remained relatively steady, indicating little change in early-winter air temperatures. Ice-loss dates, however, have continued to become earlier as demonstrated by changes over relatively short periods (1) after 1940 at Grand Traverse Bay, (2) after 1980 at Lake Mendota. The reason for these changes appears to be that ice-event dates at Grand Traverse Bay represent an integration of air temperatures over different time periods and a different lake environment than at Lake Mendota. Ice records at all six sites indicate the warmest decade over the past 200 year occurred in the 1980s.

A key to quantifying the ice-event information in terms of climate change is to develop an objective and accurate ice-event dates model which relates ice events to air temperature or other climatic variable(s). We plan to explore the development of ice-event–air-temperature models to represent air-temperature integration periods associated with freeze-up and ice-loss dates at the four sites not examined by Assel and Robertson (in press). We also plan to examine possible teleconnections between ice-event dates in the different lake environments represented by the six ice sites and possibly at other sites within the Northern Hemisphere by comparing geopotential heights in upper-air data for the Northern Hemisphere.

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