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Influence of El Niño on lake and river ice cover in the Northern Hemisphere from 1900 to 1995

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Introduction

Large-scale interactions between the ocean and atmosphere contribute to climate fluctuations over a broad range of time and geographic scales. The interaction between the anomalous warming (El Niño) and cooling (La Niña) of the equatorial Pacific Ocean with the Southern Oscillation (the seesawing of atmospheric pressure between the southeastern and western tropical Pacific Ocean) has driven climatic variability throughout the world with a periodicity of 2–7 years (MYSAK 1986). During El Niños, consistent climatic anomalies occur near the tropics, for example Ecuador and Peru are warmer and wetter than normal and Australia and Indonesia are drier than normal (QUINN et al. 1978, MYSAK 1986). The anomalous atmospheric conditions in the Pacific Ocean during El Niños propagate unusual atmospheric conditions into extra-tropical areas which, in turn, lead to unusual climatic conditions far from the Pacific Ocean (ROGERS 1984, KILADIS & DIAZ 1989). These teleconnections between the Pacific Ocean and the extra-tropical areas in the Northern Hemisphere are strongest during winter (HOREL & WALLACE 1981). KILADIS & DIAZ (1989) used weather data from 1854 to 1979 from 1,045 stations to describe changes in air temperature and precipitation around the world during different phases of the Southern Oscillation.

Ice-cover records for lakes and rivers represent an integration of local winter weather, primarily air temperature (ROBERTSON 1989). Because winter has been hypothesized to have the strongest teleconnections, interannual variability in ice-cover dates for lakes and rivers may be affected by El Niño/Southern Oscillation (ENSO) events, especially in the areas demonstrated by KILADIS & DIAZ (1989) to be strongly affected. Since 1940, ice cover on lakes in Wisconsin, U.S.A. breaks up significantly earlier in years with strong to moderate El Niños than in other years (ROBERTSON 1989, ANDERSON et al. 1996); this is consistent with the warming in these areas as noted by KILADIS & DIAZ (1989). During the most recent strong El Niño (1998), the earliest breakup on record was documented for several lakes in Wisconsin, and one lake (Lake Geneva) did not freeze for the first time in its 137-year record.

We examine the freeze and breakup dates throughout the Northern Hemisphere from 62 lakes and rivers with extensive ice records to determine whether (1) El Niños are associated with consistently earlier or later than normal freeze and (or) breakup dates, (2) the relations between ice cover and El Niños are consistent throughout the 1900s, and (3) the anomalies in ice cover during El Niños are consistent with those estimated for air temperature by KILADIS & DIAZ (1989).

Data and methods

Freeze and breakup records throughout the Northern Hemisphere from the 62 lakes and rivers with extensive records (locations are shown on Figs. 1 and 2) were assembled as part of a 1996 International Ice Workshop (MAGNUSON et al. 2000). Most of the sites are in North America (Canada, Minnesota, Wisconsin, harbors in the Great Lakes, and eastern U.S.), Europe (Finland), and Asia (Russia and Japan). For all years when a site did not freeze, the freeze date was set to the latest observed freeze date for that particular site and breakup date was set to the earliest observed breakup date. Annual departures from the long-term average (1884–1996) were then computed for all years for each site.

Years of strong or moderate El Niños between 1900 and 1987 were obtained from QUINN et al. (1987). Additional strong events were added in 1992 and 1998 and a moderate event in 1993. The specific year of each event was chosen by examining the intensity of the Southern Oscillation Index (SOI), as defined by ROPELEWSKI & JONES (1987). Years of strong El Niños included: 1900, 12, 19, 26, 32, 41, 58, 73, 83, 92, and 98. Years of moderate El Niños included: 1903, 07, 14, 31, 40, 42, 52, 53, 66, 77, 78, 87, and 93.

Composite event or superposed epoch analyses

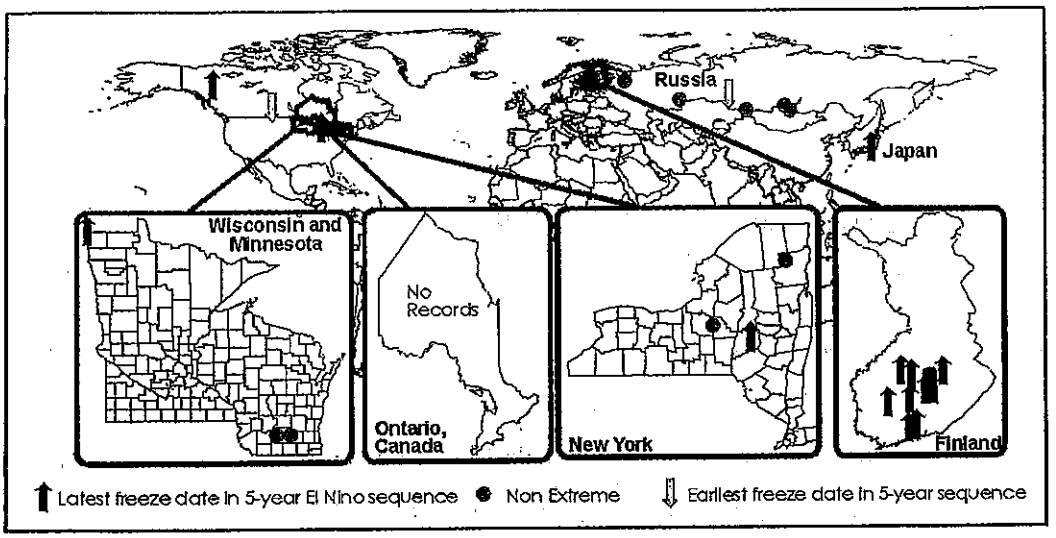

Fig. 1. Anomalies in freeze dates (latest or earliest freeze date in the 5-year El Niño sequence) for selected sites during strong El Niño events between 1940 and 1992. Dark shaded arrows indicate anomalously late freeze dates and warmer early winter air temperatures. Light shaded arrows indicate anomalously early freeze dates and cooler early winter air temperatures.

were used to determine the average departure in ice cover for years just prior to (Years −2 and −1), during (Year 0), and after (Years +1 and +2) an El Niño (ROBERTSON, 1989). To determine whether ice cover during the years with El Niños (Year 0) was significantly different from other years for certain geographical areas, the Kruskal–Wallis rank analysis of variance test was used and followed by a Tukey-multiple comparison procedure. Relations between ice cover and El Niños (Year 0) for individual lakes were divided into three categories: latest departure from average in the 5-year El Niño sequence, earliest departure, and non-extreme in the sequence. Relations between ice cover and El Niños (Year 0) for broad geographic areas were divided into seven categories: earliest or latest departure in the 5-year El Niño sequence and Year 0 being statistically different from the other 4 years ($P < 0.1$), earliest or latest departure and statistically different from that of 2 or 3 other years, earliest or latest departure, but not statistically different from any other year, and not the extreme year in the sequence.

Results

ROBERTSON (1989) found the relationship between El Niños and ice cover for Lake Mendota, Wisconsin, to be different before and after about 1940. This change in the relationship between El Niños and ice cover was visually observed in the time series for several of the sites investigated here, and that relationship appeared to change depending on whether strong or moderate El Niños were examined. Therefore, freeze and breakup dates were examined before and after 1940 and by strong and moderate El Niño intensity. Ice-cover data for the recent strong 1998 El Niño were not included in the analyses.

Freeze dates

Anomalies in freeze dates during strong El Niños after 1940 are demonstrated for all of the lakes and rivers with data in Fig. 1. In general, freeze dates were later in years with strong El Niños than in other years; this was observed throughout Finland and for a few selected lakes in Japan, Minnesota and Canada, but little difference in years was apparent in other areas. Statistical patterns were examined by compositing records from general areas (Table 1). After compositing the records, only lakes in Finland had significantly later freeze dates during El Niños than in other years, indicative of warmer air temperatures in early winter.

Anomalies in freeze dates occurred more fre-

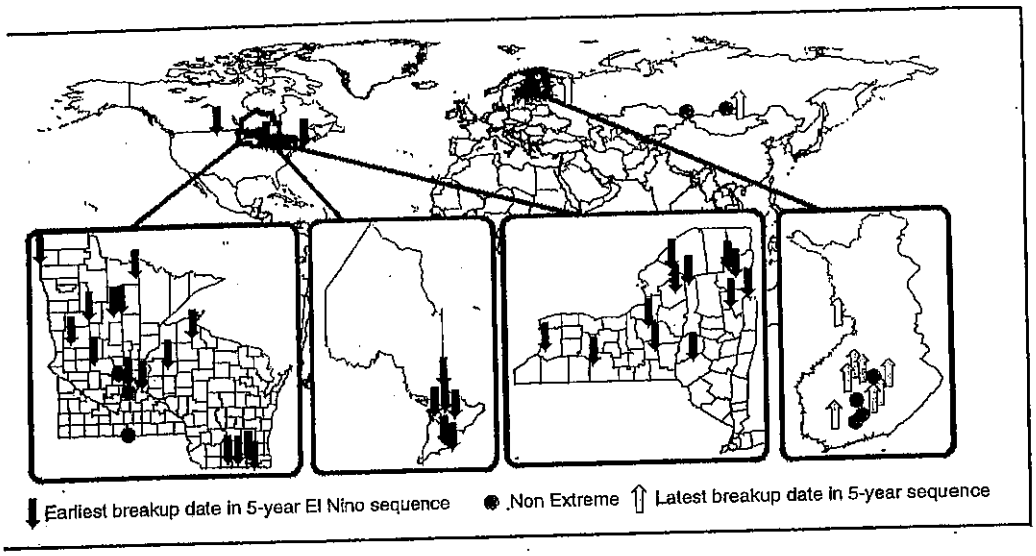

Fig. 2. Anomalies in breakup dates (latest or earliest breakup date in the 5-year El Niño sequence) for selected sites during strong El Niño events between 1940 and 1992. Dark shaded arrows indicate anomalously early breakup dates and warmer late winter air temperatures. Light shaded arrows indicate anomalously late breakup dates and cooler late winter air temperatures.

Table 1. Anomalies in ice cover (earliest or latest freeze or breakup dates in the 5-year El Niño sequence) during strong El Niño events.

Area	Freeze dates		Breakup dates	
	Pre 1940	Post 1940	Pre 1940	Post 1940
North America	+ +	0	+ + +	− − −
Canada	+	0	+ +	− −
Minnesota	+	+	0	− − −
Wisconsin	+ +	0	+ +	− −
Harbors	+	0	0	−
Eastern U.S.	0	0	+ + +	− − −
Europe				
Finland	0	+ + +	+ + +	+
Asia				
Russia	0	0	−	+
Japan	0	+		

\+ Latest median in 5-year El Niño sequence but not statistically different from other years.
\+ + Latest median in sequence, statistically different from at least two other years
\+ + + Latest median in sequence, statistically different from all other years.
0 Non-extreme in 5-year El Niño sequence
− Earliest median in sequence, but not statistically different from other years.
− − Earliest median in sequence, statistically different from at least two other years
− − − Earliest median in sequence, statistically different from all other years.

quently during strong El Niños before 1940 than after 1940. During El Niños before 1940, freeze dates were later than normal at every site in North America except one lake in New York; they were about the same as in other years in Finland, Russia, and Japan. By compositing data for sites throughout North America, a moderately significant relation was found (freeze dates during El Niños prior to 1940 had the latest mean and were significantly different ($P < 0.1$) than all other years except Year –2) (Table 1).

Breakup dates

Anomalies in breakup dates during strong El Niños after 1940 are shown for all the sites with data in Fig. 2. Consistent anomalies in breakup dates were related more strongly to El Niños than were anomalies in freeze dates. Almost all areas had extreme conditions occurring during El Niños. In general, breakup dates were earlier in years with strong El Niños throughout North America and slightly later than in other years in Finland and Russia. After compositing the records, sites in North America had significantly earlier breakup dates during El Niños, indicative of warmer air temperatures in late winter and spring. Breakup dates in Finland and Russia were later than in other years, but not significantly different.

Anomalies in breakup dates during strong El Niños before 1940 were different than those after 1940. Breakup dates during El Niños before 1940 were later at most sites in North America (except in some Minnesota lakes and Great Lake harbors) and Finland, and earlier at sites in Russia. With composited data, anomalies were significant ($P < 0.1$) for North America and Finland; both demonstrated later breakup dates during El Niños before 1940, indicative of cooler air temperatures in late winter and early spring. In North America, later breakup dates during El Niños before 1940 contrasted with their earlier breakup dates after 1940.

Moderate El Niño events

Ice cover during moderate El Niños had no statistically significant anomalies ($P < 0.1$) anywhere in the Northern Hemisphere. In general, trends in the timing of ice cover events during moderate El Niños were similar but smaller in magnitude to that observed during strong El Niños. Exceptions were for breakup dates in Wisconsin lakes before 1940, which had stronger effects, and freeze dates in Finland, which demonstrated smaller changes in the opposite direction.

Discussion

Climatic anomalies inferred from weather stations versus ice cover

Anomalies in freeze dates were compared with anomalies in November through January air temperatures during the warm phase of ENSO events as estimated by KILADIS & DIAZ (1989) and anomalies in breakup dates were compared with those of February through April air temperatures to determine if the anomalies in ice cover during El Niños were consistent with those estimated from weather records. Both data sets demonstrated relatively similar extratropical climatic anomalies during El Niños when just the ice records after 1940 were examined. Both data sets indicated that during El Niños, winter air temperatures were warmer than in other years in Canada and northern parts of the U.S., especially in late winter, and that late winter air temperatures in Europe (Finland) and Russia were colder than in other years. However, ice records in Finland and Japan did indicate warmer air temperatures in early winter than in other years, whereas weather data indicated these areas should have had minimal responses. Therefore, the ice records indicate that for the entire winter, air temperatures in North America during El Niños were warmer than in other years. In Finland, winter air temperatures were about the same as in other years, but the entire winter season was slightly shifted forward in time.

The major difference in the relation between El Niños and anomalies in ice cover before and after 1940 is in the breakup records for North America. Here, anomalies in breakup dates during El Niños indicate air temperatures in late winter were cooler during El Niños before 1940, but were warmer than in other years after

1940.

Conclusion

Freeze and breakup dates from lakes and rivers throughout the Northern Hemisphere indicate that large-scale interactions between the ocean and atmosphere, such as El Niño/Southern Oscillation events, contribute to relatively consistent extra-tropical climatic fluctuations and that these teleconnections may change through time.

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