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LAKE ICE COVER AS A TEMPERATURE INDEX FOR MONITORING CLIMATE PERTURBATIONS

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With 1 figure

SUMMARY

Records of lake freeze-up and break-up in middle and higher latitudes of North America provide a little exploited index of temperatures in the transition seasons. Regression analysis, testing several temperature indices for 27 lakes widely distributed across Canada, shows that in half of the cases freezing degree-day totals for the 50 days prior to freeze-up give the highest correlations. Correlations with break-up are generally lower due to snow cover and other factors. A ±5 day variation in freeze-up date corresponds approximately to a ∓1° C change in temperature for the 30 days preceding this event.

Lake ice formation/decay is readily observed by weather satellites enabling temperature indices as a means of detecting and assessing climatic trends.

SEE-EISDECKEN ALS TEMPERATURINDIKATOREN FÜR KLIMASCHWANKUNGEN

ZUSAMMENFASSUNG

Aufzeichnungen über das Zufrieren und Aufbrechen von Seen in den mittleren und höheren Breiten von Nordamerika bieten einen bisher wenig genützten Indikator für die Temperaturen der Übergangsjahreszeiten. Die Regressionsanalyse verschiedener Temperaturindices zeigte, daß in der Hälfte der Fälle die Summe der negativen Gradtage über die 50 Tage vor dem Zufrieren die besten Korrelationen ergab. Die Korrelation mit dem Aufbrechen der Eisdecke ist allgemein schwächer, vor allem wegen verschiedener Isolierung durch die Schneedecke. Eine Änderung von ±5 Tagen im Datum des Zufrierens bedeutet eine Änderung der Temperatur von ±1° C, gemittelt über die 30 Tage davor.

Die Bildung und Auflösung von See-Eis kann leicht vom Satelliten aus beobachtet werden, so daß große Gebiete der Nordhalbkugel zur Bestimmung des Trends von jahreszeitlichen Temperaturindices zur Verfügung stehen.

1. INTRODUCTION

Recent projections of a potentially significant global temperature rise due to increased atmospheric carbon dioxide concentrations (Manabe 1971, Manabe and Wetherald 1980, and others), have led us to evaluate the usefulness of seasonal lake ice data as a potential indicator for early detection of this warming. From state-of-the-art numerical model experiments, the change in temperature of high latitudes is expected to be amplified over that of low latitudes (Manabe and Wetherald 1975, Manabe and Stouffer 1980, National Academy of Sciences, 1982). We have, therefore, selected data from lakes and meteorological stations between 45°—76° N latitude, as shown in the fig. and table 1.

Table 1: List of Canadian Lakes Used in the Analysis

Number on Map	Lake	Meteorological Station	Latitude (N)	Longitude (W)	Period of Record	Years	Number of Years With Useful Data
1	Goshen Lake	Copper Lake, N. S.	45° 23′	61° 58′	1957—1975	(18)	17
2	Grand Lake	Sydney, N. S.	46° 10′	60° 03′	1940—1980	(40)	38
3	Ramsey Lake	Sudbury, Ont.	46° 37′	80° 48′	1940—1980	(40)	25
4	Un-named lake	Grindstone Island, Que.	47° 23′	61° 52′	1963—1980	(17)	16
5	Blouin Lake	Val D'or, Que.	48° 03′	77° 47′	1954—1980	(26)	24
6	Picnic Lake	White River, Ont.	48° 36′	85° 17′	1952—1975	(23)	20
7	Tookenay Lake	White River, Ont.	48° 36′	85° 17′	1952—1975	(23)	20
8	Plateau Lake	Atitokan, Ont.	48° 45′	91° 37′	1965—1980	(15)	13
9	Nym Lake	Aritokan, Ont.	48° 45′	91° 37′	1965—1980	(15)	13
10	Deadman's Pond	Gander, Nfld.	48° 57′	54° 34′	1956—1980	(24)	23
11	Pelican Lake	Sioux Lookout, Ont.	50° 07′	91° 54′	1956—1980	(24)	23
12	Wascana Lake	Regina, Sask.	50° 26′	104° 40′	1936—1980	(41)	39
13	Big Quill Lake	Wynyard, Sask.	51° 46′	104° 12′	1956—1980	(24)	15
14	Attawa Pisket Lake	Landsdowne House, Ont.	52° 14′	87° 53′	1949—1980	(31)	30
15	Atikameg Lake	The Pas, Man.	53° 58′	101° 06′	1956—1980	(24)	22
16	Knob Lake	Schefferville, Que.	54° 48′	66° 49′	1949—1980	(31)	8
17	Setting Lake	Wabowden, Man.	54° 55′	93° 38′	1955—1970	(15)	14
18	Dease Lake	Dease Lake, B. C.	58° 25′	130° 00′	1956—1980	(24)	23
19	Ennadai Lake	Ennadai Lake, N. W. T.	61° 08′	100° 55′	1954—1979	(25)	24
20	Long Lake	Yellowknife, N. W. T.	62° 28′	114° 27′	1954—1980	(26)	7
21	Frame Lake	Yellowknife, N. W. T.	62° 28′	114° 27′	1949—1980	(31)	23
22	Module Lake	Lady Franklin Point, N. W. T.	68° 30′	113° 13′	1963—1980	(17)	16
23	Dewar Lake	Dewar Lake, N. W. T.	68° 39′	71° 10′	1962—1980	(18)	15
24	Un-named lake	Shepherd Bay, N. W. T.	68° 49′	93° 25′	1962—1980	(18)	10
25	Un-named lake	Clinton Point, N. W. T.	69° 35′	120° 45′	1962—1980	(18)	9
26	Un-named lake	Sachs Harbour, N. W. T.	71° 57′	124° 44′	1958—1980	(22)	17
27	Un-named lake	Mould Bay, N. W. T.	76° 14′	119° 20′	1964—1980	(16)	15

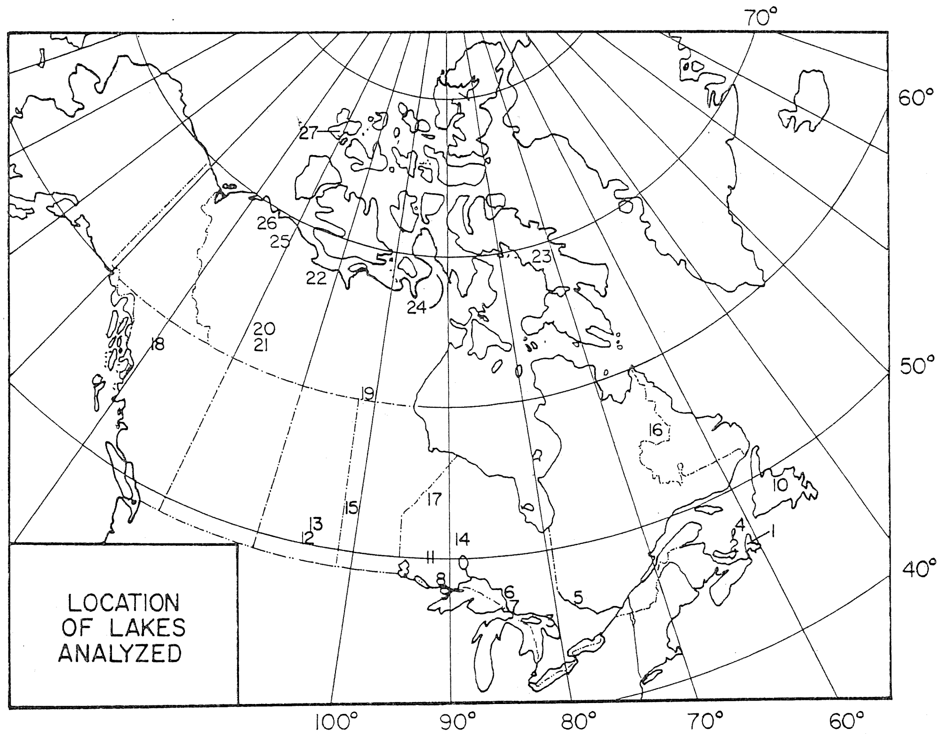

Fig 1: Location of lakes analyzed

2. METHODS

A water body integrates rapid fluctuations of air temperature over a period which is a function of its location, area, and depth, as well as river inflow/outflow. We have examined, on a statistical basis, the relation between freeze-up and break-up records and mean daily temperature data for 27 stations (see reference for sources). The dates analyzed refer to the occurrences of "complete freeze over" and "water clear of ice" (Allen 1971). Several simple temperature indices were derived for the fifty day periods (divided into ten pentads) preceding the freeze-up and break-up events. Some of these include: the average daily temperature for each of the ten individual pentads; the number of freezing (or thawing) degree days during this period; the number of days with mean temperatures below (or above) freezing during this period; the number of days with mean temperatures below (or above) freezing during this period; and the average daily temperature during each successive group of cumulative pentads prior to freeze-up (or break-up).

3. OBSERVED TRENDS IN FREEZE-UP/BREAK-UP PATTERNS

Average freeze-up in Canada takes place in early to mid-September in the Arctic Archipelago and early to mid-November in the south. Break-up is generally around early to mid-May in the south, but not until the end of July to early August in the Arctic Archipelago. Standard deviations for these dates are of the order of 5—15 days.

Break-up is generally more variable than freeze-up due to the presence of a snow-cover, wind effects, and differences in lake depth. Within large-scale climatic regions (e. g. the "Atlantic" region or the "Arctic" region), and for specific years, freeze-up and break-up do not necessarily follow the same pattern of earlier or later occurrence.

A complete analysis of trends has not yet been performed, but freeze-up for the 1970s decade at Wascana Lake, Saskatchewan, and Dewar Lake, N. W. T., was 9 days and 3 days earlier, respectively, than the means for 1940—80 at Wascana Lake and for 1964—79 at Dewar Lake. However, at Atikameg Lake, Manitoba, the mean dates of freeze-up and break-up in the 1970s were unchanged from the 1956—80 averages.

Records for thirteen lakes, widely distributed across Canada were also examined for 1970—80. Seven of the lakes show a trend toward a later freeze-up, and nine lakes show a trend toward an earlier break-up. These findings are indicative of warmer autumns and springs and possibly less severe winters. It is interesting to note that the six lakes which have been experiencing both later freeze-up and earlier break-up are not concentrated in any particular climatic region. Should they become available, it would be of value to obtain and analyze area and depth data for these lakes to determine their similarities. This would provide information as to which types of lake are potentially responding to subtle changes in air temperature.

4. RESULTS OF REGRESSION ANALYSIS

In the pentad analysis for the fifty days before freeze-up, no single pentad (or group of pentads) is more significant in the regression tests. However, pentad 6 (26—30 days before freeze-up) and pentad 8 (36—40 days before freeze-up) are selected most often, and yield the highest correlation coefficients between date of freeze-up and mean daily temperature during the pentad (up to 0.91 at Wascana Lake, Saskatchewan). The greatest number of low correlation coefficients (below 0.6) are loosely centered between approximately 50° —60° N latitude. Results for all lakes are summarized in table 2.

The additive effect of the pre-freeze-up period was incorporated into the regression analysis by choosing successive cumulative pentads as the independent variables. Twenty-two of the twenty-seven lake stations have the highest correlations for the first six pentads before freeze-up (i. e. 30 days) and those beyond (to include all fifty days before freeze-up). This indicates that these lakes respond best to the integrated temperature effect in the period 30 to 50 days before they close. There are no stations for which the last ten days before freeze-up yield high correlations. Only four lakes have high values in the period 15—20 days before freeze-up, and only two more in the pentad 25—30 days before freeze-up.

Wascana Lake and Knob Lake (Quebec) have the highest correlation coefficients overall (0.96 and 0.97, respectively), although not for the same time period (35 days before freeze-up for the former, and 45 days before freeze-up for the latter). The lowest correlations occur in the late period, 15 days before freeze-up at Atikameg and Setting Lakes, Manitoba. The results for all lakes are presented in table 3.

Table 2: Highest correlation coefficient for each lake station between freeze-up and individual pentads. Pentad 1 denotes the five days immediately before freeze-up, pentad 2, days 6—10 before freeze-up, etc.

Lake	Pentad 1	2	3	4	5	6	7	8	9	10
1							0.82			
2										0.72
3						0.53				
4								0.83		
5			0.70							
6						0.62				
7									0.77	
8		0.58								
9						0.56				
10						0.67				
11	0.74									
12								0.91		
13						0:71				
14										0.44
15								0.30		
16							0.85			
17				0.36						
18								0.68		
19										0.63
20						0.74				
21										0.66
22	0.54									
23					0.84					
24			0.90							
25					0.84					
26								0.77		
27								0.81		

Table 3: Highest correlation coefficient between freeze-up and successive cumulative pentads '1—2' represents pentad 1 to 2, or the last 10 days before freeze-up

Lake	1—2	1—3	1—4	1—5	1—6	1—7	1—8	1—9	1—10
1								0.77	
2									0.73
3									0.56
4								0.71	
5				0.76					
6						0.80			
7								0.68	
8								0.57	
9					0.70				
10									0.59
11							0.74		
12								0.96	
13									0.82
14									0.47
15		0.20							
16						0.97			
17		0.36							
18									0.43
19									0.61
20							0.68		
21									0.53
22			0.48						
23						0.82			
24			0.54						
25						0.61			
26							0.78		
27								0.87	

In order to assess the usefulness of trends in lake freeze-up dates as a measure of autumn temperature, the regression of Julian freeze-up date against the temperature departures for cumulative pentads 1—6 has been determined for Wascana Lake, Dewar Lake, a lake near Mould Bay, and Knob Lake. A difference of ± 10 days in freeze-up corresponds to mean temperature anomalies of $\mp 2.8°$ C for the first two stations, and $\mp 4.4°$ C and $\mp 1.7°$ C for the others, respectively.

5. COMPARISON WITH OTHER RESULTS

Relatively little attention has been given to lake freeze-up/break-up data as a climatic indicator in North America, despite considerable attention to process of ice formation/decay and prediction of these events (Michel 1971, Williams 1971). Earlier work on Wisconsin lakes (Wing 1943) recognized the value of lake records as a phenological indicator and McFadden (1965) undertook a large-scale aircraft survey of Canadian lakes, but for a limited time interval. There has been considerable study of lake ice conditions in several European countries. Studies for Finland by Simojoki (1940, 1959) are of particular interest in view of their comparable latitude with the Canadian lakes and we are currently extending our analysis to selected Finnish records.

For Lake Kallavesi, Finland, Simojoki (1959) reported a 10-day advance in break-up date in the 1940—50s compared with the 1960s; this was associated with a 2° C warming. Based on the long record of freeze-up for Lake Suwa, Japan (36° N), Tanaka and Yoshino (1982) indicate that a range of about 60 days in freeze-up corresponds to a 4° C range in December—January mean temperature. Accordingly, it appears that for mid-latitude lakes, a 1° C temperature rise, uniformly distributed over the year, would delay freeze-up and advance break-up by about 5—15 days in each case. The effect appears to be greater in high latitudes (based on the results of Mould Bay) and smaller for Lake Suwa, Japan.

5. CONCLUSIONS

The goal of this research effort has been to determine wheter lake ice conditions can be reliably correlated with daily temperature data. Given the careful selection of meteorological stations with respect to the locations of lakes, it appears that valuable results may be obtained. For several Canadian lakes examined, ± 5 day variation in freeze-up date corresponds approximately to a $\mp 1°$ C change in temperature for the 30 days preceding this event. For one Arctic lake, the effect is about twice as great. The advantage of using lake ice in climatic change studies is that readily available, point observations may be organized in a spatially representative network as a basis for assessing trends in air temperature. Establishment of a global network of lake ice data is already feasible from existing satellite systems.

There are, however, some limitations to the use of lake ice as an integrative climatic index. These include the homogeneity and quality of the data (length of record, missing years) and the general lack of information on lake size and depth, which determines the thermal response of lakes to local climate.

Once the regional relationships between ice patterns and climate are determined for an area, freeze-up and break-up may be used as a proxy for temperature measurements in other similar areas. There remains much uncertainty as to the actual climate changes that can be expected from increasing concentrations of atmospheric carbon dioxide. It must be determined, as longer records become available, whether observed and predicted changes in temperature and ice patterns are within or beyond the range of natural variability and, if the latter is true, whether these changes can be attributed unequivocally to increases in carbon dioxide. It must be recognized that even a high carbon dioxide, warm period may exhibit large regional variability in temperature, and that a temperature increase in subarctic latitudes may not necessarily be construed as signifying a global temperature increase.

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