A Historical Perspective of the 1976–77 Lake Michigan Ice Cover

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ABSTRACT

The formation of ice cover on the Great Lakes during the 1976–77 winter was unusual because of the early onset and continuation of below normal air temperatures. The severe winter produced a particularly extensive ice cover in the southern half of Lake Michigan. During the height of the winter, in early February 1977, the lake was almost entirely frozen over. To put the winter in its proper perspective, temperature records starting in 1897 and ice-cover records beginning in the 1962–63 winter were analyzed to classify winter severity and to examine the relationship between winter severity and maximum ice extent on Lake Michigan. The winters were classified by freezing degree-days into five categories: severe, severer than normal, normal, milder than normal and mild. The classification indicates that the winter of 1976–77 was one of the four coldest in the past 80 years. The analysis also shows that the past 15–20 winters have been colder than the normal established by the 80-year data base. As well-documented ice-cover records of Lake Michigan have only been collected during the past 15 years, existing ice-cover normals based on these records are probably biased toward the severe condition. The analysis also shows that extensive ice cover (in excess of 50% of the total lake's surface area) develops on Lake Michigan only when the southern subregion of the lake experiences a severe winter.

1. Introduction

The winter of 1976–77 was remarkable for Lake Michigan because of the extensive ice cover that formed in the southern half of the lake. During the height of the winter, in early February 1977, the lake was almost completely frozen, in excess of 90% ice cover. This was the most extensive ice cover in the memory of many shoreline residents of the area, making it desirable to understand the winter in its historical context. The winter was analyzed by the use of a 15-year ice-cover climatology and an 80-year data base of freezing degree-days. The progression of the ice cover is also compared with the normals presented by Rondy (1971).

2. Comparison of 1976–77 ice cover with normal winter

Rondy (1971) described the normal progression of Lake Michigan ice cover as follows:

"Green Bay and the Bays de Noc in the northwest portion of the lake are the areas first to form an extensive ice cover. The Straits of Mackinac and the shallow areas to the north of Beaver Island are the next areas to become ice covered. The ice accumulates in a southerly direction, with a rapid buildup in the relatively shallow area east of the Manitou and Fox Islands and a slower accumulation around the southern perimeter. The unique circular current patterns of southern Lake Michigan distribute drifting floes along the shore and even during a mild ice season these floes can be consolidated and extend from shore out into the lake a distance of 10 to 15 miles (16 to 24 km)."

The normal dates of occurrence of the four periods of the ice cycle as given by Rondy (1971) are summarized in Table 1. During the 1976–77 winter, ice configurations similar to the normal early winter, mid-winter and maximum ice extent periods occurred 30, 42 and 58 days earlier than normal. In addition, the maximum ice cover on the lake was more extensive than Rondy's illustration for a severe winter, as evidenced by a comparison of the normal severe winter with an ice chart of Lake Michigan for 6 February 1977 showing the entire lake virtually covered (Fig. 1). Thus, the 1976–77 Lake Michigan ice cover deviated from normal in that the ice formed much earlier and was more extensive than normal, particularly on the southern half of the lake. Further details on the characteristics of the 1976–77 ice cover are given in Quinn *et al.* (1978). However, the maximum extent of the 1976–77 Lake Michigan ice cover can be placed in a historical perspective by the use of air temperature and ice-cover data.

TABLE 1. Comparison of winter ice periods, 1976–77, and normals given by Rondy (1971) for Lake Michigan.

Winter period	Ice-cover (%)	Occurrence	1976–77 Occurrence	Deviation from normal* (days)
Early winter	10	25 Jan–5 Feb	26 Dec	+30
Mid-winter	25	20–28 Feb	9 Jan	+42
Maximum extent	40	15–25 Mar	16 Jan	+58
Early decay	15	20–30 Mar	3 Apr	−4

* Deviation = normal minus 1976–77 winter.

3. Historical perspective

A historical perspective is obtained by comparing the 1976–77 maximum percent ice cover with a 15-year ice-cover data base for each of the years from 1962–63 through 1976–77 (Table 2). It is seen that in only one other year, 1962–63 with 80% ice cover, did the maximum ice extent exceed 50%. Further analysis shows that in a normal winter the maximum ice cover in the lake north of Green Bay, Wisconsin, is approximately 80%, while the remainder of the lake remains about 10% covered. Thus, as described later in the text, a record Lake Michigan ice cover occurs primarily in winters in which the southern portion of the lake develops extensive ice.

A second means of extending the historical analysis is through the use of maximum freezing degree-days (FDD's) accumulations. Freezing degree-days are defined as the departure of the mean daily air temperature from 0°C. Departures below 0°C are given positive algebraic signs (i.e., a day with a mean temperature of −4°C would have 4 FDD's assigned to it). Also a day with 6°C would have −6 FDD's assigned to it. A running sum of freezing degree-days was started in October and continued to the following April each year. If the running sum became negative on a given date, a new running sum was started the next day. Similarly thawing degree-days (TDD's) are defined as the departure of the mean daily air temperature above 0°C.

Accumulated freezing degree-days have long been used to classify winter severity and to estimate ice extent on the Great Lakes. Richards (1964) was one of the first investigators to do so. He developed regression equations between freezing degree-days, thawing degree-days, and percent of the lake's surface that was ice covered. Later Rogers (1976), using a similar approach, developed regression equations for predicting maximum ice extent on each of the Great Lakes. Rondy (1971) also used FDD's to classify winter severity as mild, normal or severe and related the FDD's to four periods in the ice cycle. Snider (1974) used FDD's to predict navigationally significant ice on the Great Lakes. Assel and Quinn (1977), using the same technique as Rondy but with a 10-year greater data base, revised Rondy's (1971) winter severity classification. In this analysis temperature records starting from 1897 obtained from the National Climatic Center, and ice-cover records beginning with the 1962–63 winter from the Great Lakes Environmental Research Laboratories data base, are used to classify winter severity and to examine the relationship between winter severity and maximum ice extent on Lake Michigan.

Eighty winters of daily minimum and maximum temperatures were used to calculate a running sum of FDD's for each winter at the six stations on the perimeter of Lake Michigan (Fig. 1). The maximum FDD value for each winter was then used to define winter severity classes. The classes are defined as

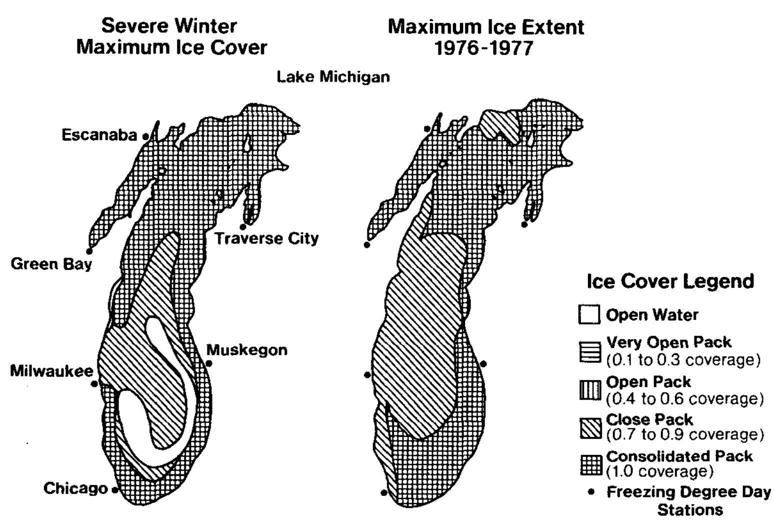

FIG. 1. Maximum extent of Lake Michigan ice cover for severe winter and for winter 1976–77.

TABLE 2. Maximum ice extent, 1963–1977.

Year	Ice cover (%)
1963	80
1964	13
1965	40
1966	15
1967	46
1968	30
1969	15
1970	30
1971	27
1972	45
1973	20
1974	20
1975	25
1976	20
1977	90+
Mean	34
Standard deviation	23

follows: the lower and upper 5% of the maximum FDD values for the 80 winters at each station are used to define severe and mild winters; the next 15% interval at either end of the scale is used to define severer and milder than normal winter classes; the remaining 60% in the mid-range of the maximum FDD values are used to define the normal winter class. This definition of winter severity classes was used instead of the one used by Rondy (1971) and Assel and Quinn (1977); they used the mean plus and minus one standard deviation to define the normal range. An investigation showed that the maximum FDD's were not evenly distributed about their mean value so that using the mean and standard deviation to define winter severity class would introduce a bias into the classification. The lower limit of FDD values for each winter severity category is given in Table 3 for the six stations. The severe and mild winter categories can be expected to occur about once every 20 years. The distribution of these winters for the six stations is given in Table 4. The data may be viewed in two ways: (1) the majority of occurrences for a given winter can be used to identify a lake-wide or regional trend and (2) the majority of occurrences for a given winter at the three southern stations or at the three northern stations can be used to identify subregional trends for the southern and northern halves of Lake Michigan.

The winter severity class of the three southern stations is a prime indicator of ice-cover extent as is shown by the fact that, of the 15 winters for which reliable ice-cover data are available, the winter severity class for the southern stations was severe in both winters with ice covers of over 50%. Extensive ice cover may form on Lake Michigan during winters falling into the severer than normal category of winter severity for the three southern stations, but evidence to this effect, based on the 15-winter ice-cover record, is inconclusive (Table 5).

Fig. 2a shows the variation of the mean maximum freezing degree-days for the three southern stations. Only 4 of the 80 winters fall into the severe category that implies extensive lake-wide ice cover. Ranked in decreasing severity, these are the winters of 1903–04, 1962–63, 1976–77 and 1911–12. It is also interesting to note that none of these severe winters and all of the mild winters occurred between 1919 and 1932.

On a lake-wide basis, Table 4 and Fig. 2b show that the severest winter since 1897 was the winter of 1903–04, which fell within the severe category in all six stations. Following this winter, the winters of 1898–99, 1911–12 and 1962–63 were next in overall severity. The winter of 1976–77 was the fifth severest winter in the last 80 years.

Considering the mild winters since 1897, the winter of 1920–21 was the mildest lake-wide, followed closely by the winters of 1931–32 and 1918–19, when five or six stations had mild winters. Lastly, the winter of 1930–31 was also mild on a lake-wide scale. Minimum total ice coverage is most likely to occur when the three northern stations have a mild winter. Fig. 2c shows this type of winter to have happened in the northern portion of the lake during

TABLE 3. Lower limit of freezing degree-day values for winter severity category.

Station	M	MN	N	SN	S
Chicago*	0	104	198	479	620
Muskegon*	0	166	258	462	681
Milwaukee*	0	245	367	677	827
Traverse City*	0	335	408	706	899
Green Bay*	0	418	639	977	1163
Escanaba*	0	506	690	974	1193
South half	0	179	280	529	718
North half	0	449	586	878	1057
Total lake	0	306	447	699	899
Observations in each category					
Number	4	12	48	12	4
Percent	5	15	60	15	5

South half** = Average of Chicago, Muskegon and Milwaukee
North half** = Average of Traverse City, Green Bay and Escanaba
Total lake** = Average of all six stations

M = Mild, MN = Milder than normal, N = Normal, SN = Severer than normal, S = Severe.

* Lower limits were calculated by averaging the value of ith and the ith + 1 observation where the ith observation is the lowest value in a category. In this way discontinuities between categories are avoided.

** Area averages were calculated by season. These seasonal averages for all stations within an area were then used to define severity category as indicated above.

TABLE 4. Distribution of severe and mild winters during the last 80 winters.

Rank	Chi	Msk	Mil	TVC	GB	Esc	S-H	N-H	T-L
Severe winters									
1	1963	1904	1904	1904	1904	1904	1904	1904	1904
2	1904	1912	1963	1899	1977	1912	1963	1899	1899
3	1977	1977	1977	1963	1959	1899	1977	1912	1963
4	1936	1899	1959	1965	1912	1917	1912	1959	1912
Mild winters									
1	1921	1931	1932	1932	1921	1919	1932	1919	1921
2	1932	1932	1921	1921	1919	1921	1931	1921	1932
3	1909	1921	1931	1919	1931	1953	1921	1932	1919
4	1953	1937	1919	1931	1924	1932	1919	1931	1931

Chi = Chicago, TVC = Traverse City, S-H = Southern half, Msk = Muskegon, GB = Green Bay, N-H = Northern half, Mil = Milwaukee, Esc = Escanaba, T-L = Total lake.

1918–19, 1920–21, 1930–31 and 1931–32. As none of these winters fall into the period of well-documented ice conditions, little can be said about possible ice conditions other than to say that even during normal winters ice covers can be as low as 15% (Table 5). This, however, does imply that during a mild winter it would be expected that the open areas of the lake remain ice free. As an indication of trend in maximum ice extent on Lake Michigan during the past 80 years, an 11-year running mean of the mean FDD accumulations for the three southern stations was made (Fig. 3). It shows that from 1898 to 1936 ice formation potential was generally on the decline. During the next 40 years (1937–77) the potential for ice formation was increasing and reached a maximum in the 11-year period centered around 1964 (1959–69). Ice potential declined after that due to mild winters in the early 1970's, but shows signs of another upward trend in the late 1970's. Thus using the degree-day analysis, during the greater portion of the period of well-documented ice covers the potential for ice formation has been normal or above normal. A regression of maximum ice extent with maximum FDD's averaged for all six stations was developed for a base period of 15 winters (1962–63 to 1976–77); see Fig. 4. The regression was used to hindcast maximum ice extent for the 80-winter FDD data base. Most of the FDD values for the 15-winter base period ranged from 440 to 740 FDD's. For the two winters of extensive ice cover FDD values were near 900 FDD's. A linear regression was calculated but was found to be deficient in the respect that it underestimated the ice extent for the winters of extensive ice cover and it predicted negative ice covers for mild winters. These deficiencies were overcome by forcing a parabolic regression through the point 85%, 900 FDD. The regression, given in Fig. 4, will apply for FDD values between 151 and 963. For FDD's equal or greater than 963 the surface is considered to be 100% ice covered and for FDD's less than 151 the surface is considered to be ice free. Applying the regres-

TABLE 5. Winter severity category and maximum ice extent on Lake Michigan.

Winter	Chi	Msk	Mil	TVC	GB	Esc	S-H	N-H	T-L	Ice cover (%)
1962–63	S	SN	S	S	SN	SN	S	SN	S	80
1963–64	SN					MN				13
1964–65	SN		SN	S		SN	SN	SN	SN	40
1965–66						MN		MN		15
1966–67										46
1967–68										30
1968–69						MN				15
1969–70		SN		SN	SN		SN		SN	30
1970–71		SN	SN		SN		SN			27
1971–72					SN	SN				45
1972–73					MN	MN		MN		20
1973–74										20
1974–75		MN		MN					MN	25
1975–76		MN								20
1976–77	S	S	S	SN	S	SN	S	SN	SN	90

S-H = Average for Chicago, Muskegon and Milwaukee, N-H = Average for Traverse City, Green Bay and Escanaba, T-L = Average for all six stations, S = Severe, SN = Severer than normal, MN = Milder than normal, M = Mild.

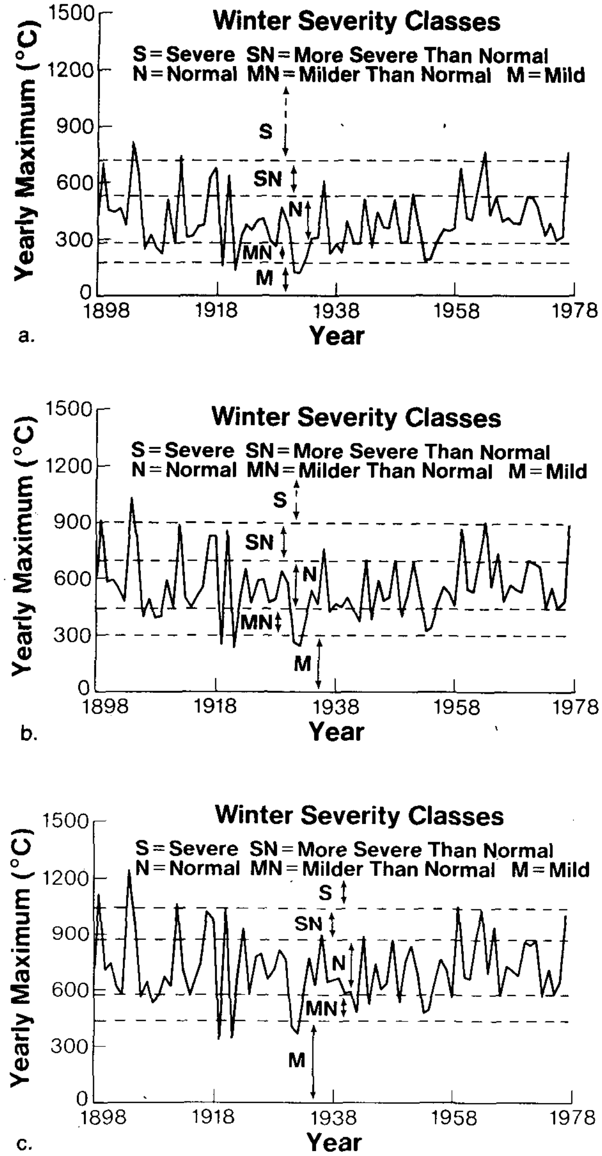

FIG. 2. Maximum freezing degree-days averaged for Chicago, Muskegon and Milwaukee (a), for all six Lake Michigan stations (b), and for Traverse City, Green Bay and Escanaba (c), all for the period 1898–1977.

sion to the 80 winter data base the four winters of greatest ice extent were found to be 1903–04 (100%), 1898–99 (88%), 1962–63 (88%) and 1911–12 (86%). This compares with the 90% measured ice cover for 1976–77. The regression indicates 84% for that winter. The winters with the minimum ice extents were found to be 1920–21 (1%), 1918–19 (2%), 1930–31 (2%) and 1931–32 (2%). The mean ice extent for the 80 winters was 30%, the standard deviation 23%. The actual mean value for the 15 winter base period was 34% and the standard deviation was 23%.

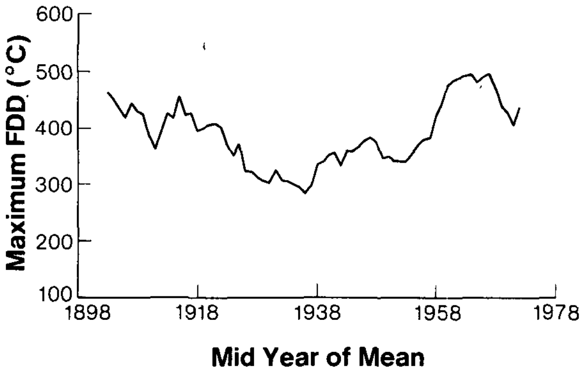

FIG. 3. Eleven-year running mean of averaged freezing degree-days (1898–1977) for the southern half Lake Michigan.

4. Conclusions

From the winter severity classification developed in this paper, it appears that the 1976–77 winter was one of the severest in the past 80 winters relative to ice extent. Ice-cover records for the past 15 years show that extensive ice cover (in excess of 50%) only develops on Lake Michigan when low air temperatures penetrate to the southern half of the lake. Such air temperatures, indicated by the winter severity category of severe for the southern three stations, occurred in the winters of 1903–04, 1911–12 and 1962–63. The 1962–63 winter and probably the winters of 1903–04 and 1911–12 are those of the last 80 years that had ice cover comparable to the 1976–77 winter. The fact that a greater ice cover formed in 1976–77 (90%+) compared to 1962–63 (80%), even though 1962–63 ranked above 1976–77 in severity, can be attributed to the greater heat storage in Lake Michigan during the late fall or early

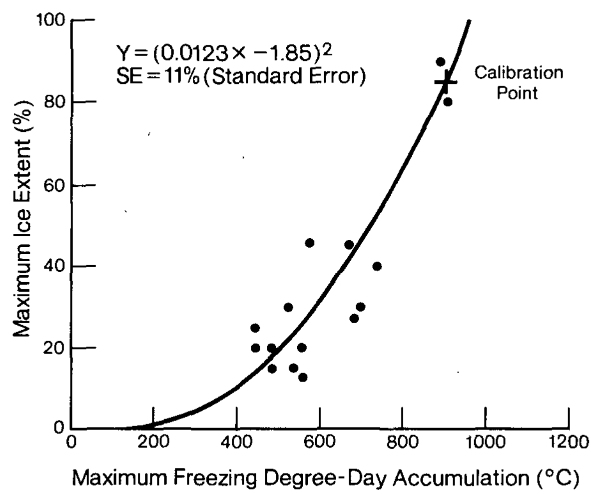

FIG. 4. Correlation of maximum ice extent with maximum freezing degree-days.

winter of the 1962–63 ice cycle. The exception to the above discussion occurred during the winter of 1898–99 when the lake is hindcast to be 88% ice covered even though the winter was not classified as severe for the southern three stations. However on a total lake basis this winter was the second coldest on record. The hindcast ice extent also indicated that mean ice cover during the past 15 winters has been greater than mean ice cover for the 80 winter data base.

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