A Comparison of Great Lakes Winter Severity and Ice Cover Winter 1990 vs. the Historical Record

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ABSTRACT

The large temperature anomaly reversal from December 1989 to January 1990 is described along with its associated impact on early winter snowfall and ice formation. Winter temperature severity is evaluated in terms of magnitude and date of occurrence of the annual maximal freezing degree-day accumulations at several locations on the perimeter of the Great Lakes. Winter severity from the turn of the century to the early 1980s is compared with the 1990 winter severity. The extent and date of occurrence of maximal ice cover for the 1990 winter is placed in a historical perspective by comparing it with the annual maximal ice covers of the preceding three decades.

INTRODUCTION

The winter of 1989-90 in the Great Lakes was notable because of severe temperatures in December followed by unusually mild temperatures in January and February. In this paper we present a descriptive analysis of this winter, early winter monthly air temperature and snowfall, results of a preliminary analysis of winter severity, and an analysis of the annual maximal ice cover on the Great Lakes. These contemporary values are compared with both short-term (28 year) and long-term (86 year and 93 year) variations to place the winter of 1990 in a historical perspective.

WINTER 1990 HIGHLIGHTS

December 1989 and January 1990 Air Temperature Anomalies

Winter 1990 (December to February) ranked as the 20th warmest and the 27th driest over the contiguous United States since 1895; it also had the coldest December and the warmest January of this century (Weekly Weather and Crop Bulletin 1990, vol.77,no.10). In this study, regional average temperature was defined using the stations given in Figure 1. Preliminary analysis of these temperatures shows that during winter 1990 the Great Lakes region experienced the largest reversal in regional December to January departure from monthly normal temperature over 92 previous winter seasons (Figure 2a). Regional December 1989 temperature (-10.5°C) was the lowest (Figure 2b) in the past 93 years, and January temperature (-2.0°C) was the third highest (Figure 2c) during the past 93 years.

Figure 1. Location map of snowfall stations and air temperature stations listed in Table 1 and Table 2

Ice Cover and the Great Lakes - St. Lawrence Seaway Navigation Season

The severe December temperature brought above-normal ice cover to the Great Lakes and severe ice conditions on the St. Lawrence Seaway (Climate Perspectives 1989, vol.11, no.'s 49, 51, 52a). The navigation lift locks at Sault Ste. Marie, Michigan closed on December 28 and the St. Lambert Lock on the St. Lawrence Seaway closed on December 22, 1989. Mild January and February temperatures resulted in below-normal ice covers on the southern portion of the Great Lakes. The St. Lawrence Seaway opened March 28, and ice cover was virtually gone from the southern portion of the Great Lakes by the end of March.

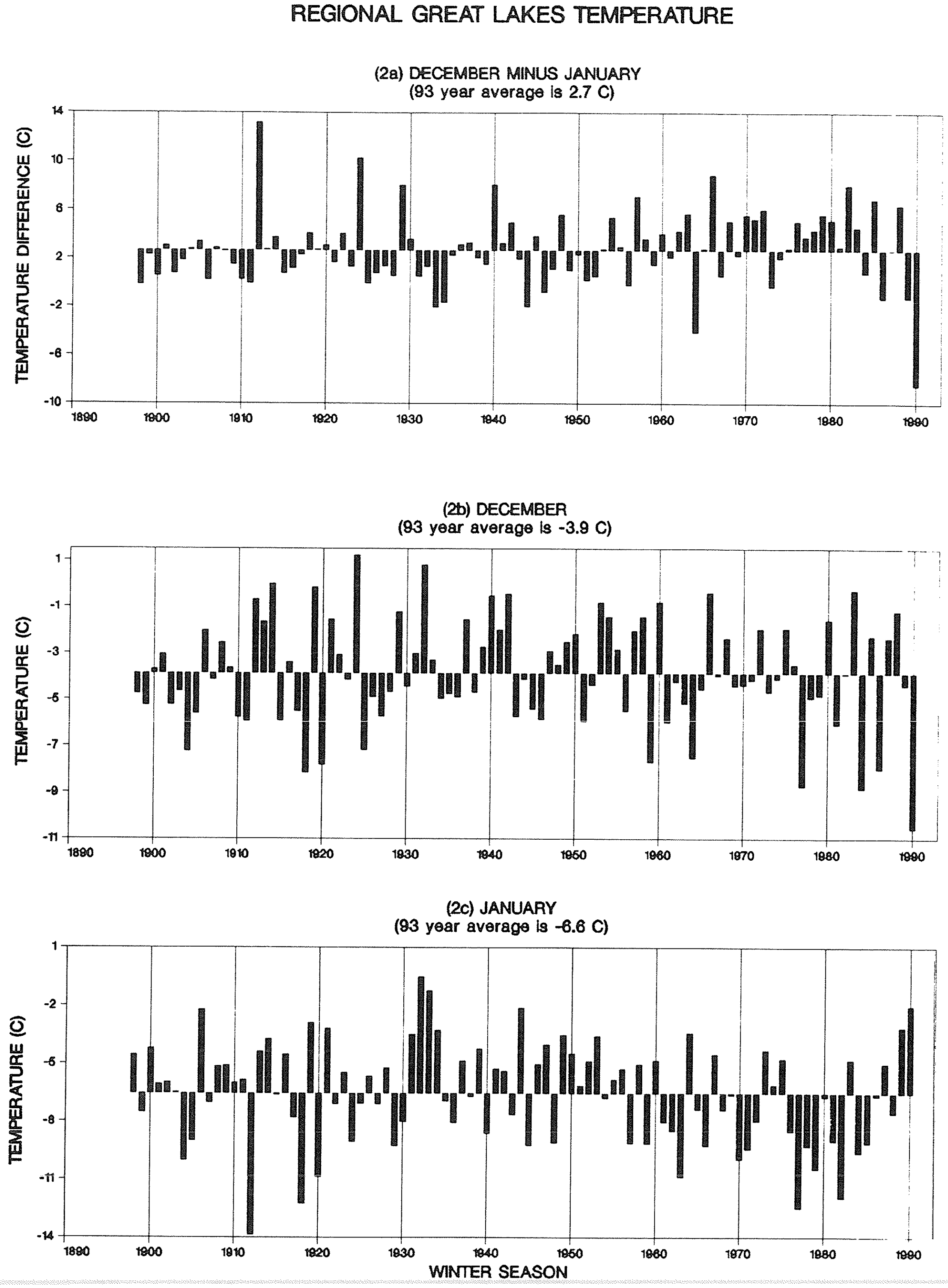


Figure 2. Regional Great Lakes temperature (°C) for the winter seasons 1898 to 1990 (a) December minus January difference, (b) December, and (c) January. Temperatures are plotted as bar graphs above or below the 93 year average.

Precipitation, Temperature, Lake Levels, and Flooding

The below average December 1989 air temperature also brought above average snowfall to the Great Lakes, particularly in the lake-effect regions along the south and east shores of Lakes Superior, Michigan, Erie, and Ontario (Table 1, Figures 3a - 3b). December 1983 regional temperature (-8.8°C) was the second lowest December temperature in the 93 year record, (Figure 2b) and lake-effect snowfall accumulations were also much above-normal (Figure 3c). Average January 1990 temperatures were above freezing in the southern portion of the Great Lakes, bringing rain and below average snowfall with large anomalies in the lake-effect snowfall regions in the Great Lakes (Figures 4a - 4b, Table 1). January 1989 regional temperature (-3.3°C) was second only to January 1990 in above-normal temperatures over the past 40 years. With the exception of Lake Superior where temperatures were 1.5°C to 2.5°C lower in January 1989 compared to January 1990, the January 1989 snowfall pattern over the Great Lakes south of Lake Superior was quite similar to January 1990 (Figure 4c). The large difference in the average rank of lake-effect stations (Table 1) from December 1989 to January 1990 is a measure of the influence of air temperature on snowfall in the shore zone of the Great Lakes. Note this influence is greatly attenuated by land along windward shores as evidenced by the much smaller difference between average rank of December and January snowfall. The mild January 1990 temperatures continued into February, resulting in periods of above freezing temperatures, rain, and snowfall across the southern Great Lakes Basin. Lake Erie had over 200 percent of normal precipitation in February (Weekly Weather and Crop Bulletin 1990, vol.77, no. 9). Notable storms occurred on February 3-4, 15-16, and 22-23. These storms brought freezing rain and snow causing hazardous traveling conditions and loss of electric power in some communities in the southern portion of the Great Lakes Basin (Climate Perspectives 1990, vol.12). The mild February temperatures also resulted in rising and above-normal lake levels for Lake Erie. Lake Erie levels normally decline in February to its minimal annual value (Figure 5). Temperatures were above-average for the third straight month in March, and precipitation was below-normal east of Lake Michigan (Weekly Weather and Crop Bulletin, 1990, vol.77, no. 14). Temperature anomalies of +15°F to +24°F (+8.3°C to +15.3°C) (Weekly Weather and Crop Bulletin, 1990 vol.77, no.11) occurred the week of March 11-17 resulting in rapid snow melt, rapid run-off, and flooding in some rivers and creeks (Climate Perspectives, 1990 vol.12, no.11) marking the end to one of the most atypical winters in decades.

Table 1. 1990 Monthly Snowfall Rank* For The 30 Winters from 1961 to 1990

Lake-Effect Shore	Dec. 89	Jan. 90	Windward Shore	Dec. 89	Jan. 90
Houghton, MI.	2	27	Duluth, MN.	18	27
Marquette, MI.	3	19	Thunder Bay, Ont.	16	10
Sault Ste. Marie, MI.	16	17	Green Bay, WI.	10	14
Traverse City, MI.	2	15	Milwuakee, WI.	21	8
Muskegon, MI.	2	30	Chigago, IL.	21	27
Cleveland, OH.	4	18	Alpena, MI.	3	8
Erie, PA.	1	23	Detroit, MI.	12	26
Buffalo, N.Y.	5	23	Toledo, OH.	21	28
Rochester, N.Y.	6	23	Toronto, Ont.	13	25
Oswego, N.Y.	1	23			
Average	4	22		16	19

* Rank 1 is the greatest monthly snowfall of the 30 winters, rank 30 is the least.

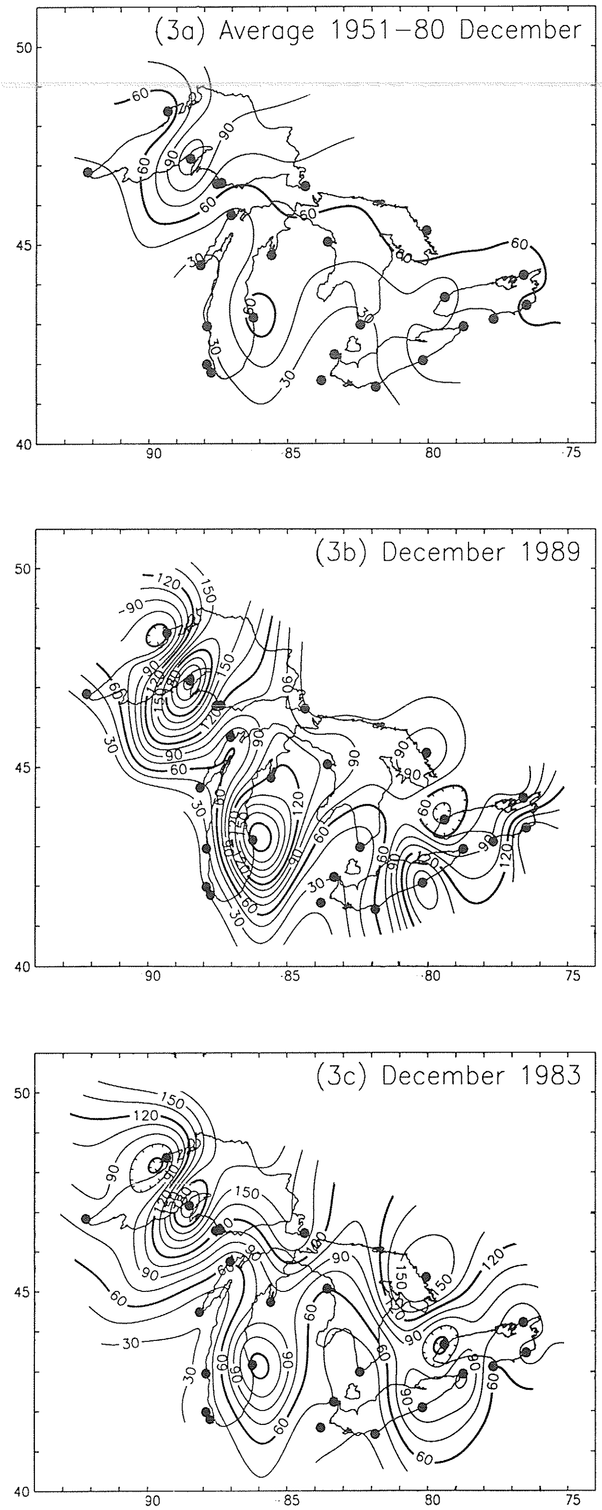


Figure 3. December snowfall (cm)
(a) 1951-80 Average, (b) December 1989,
(c) December 1983, contour interval
is 15 cm.

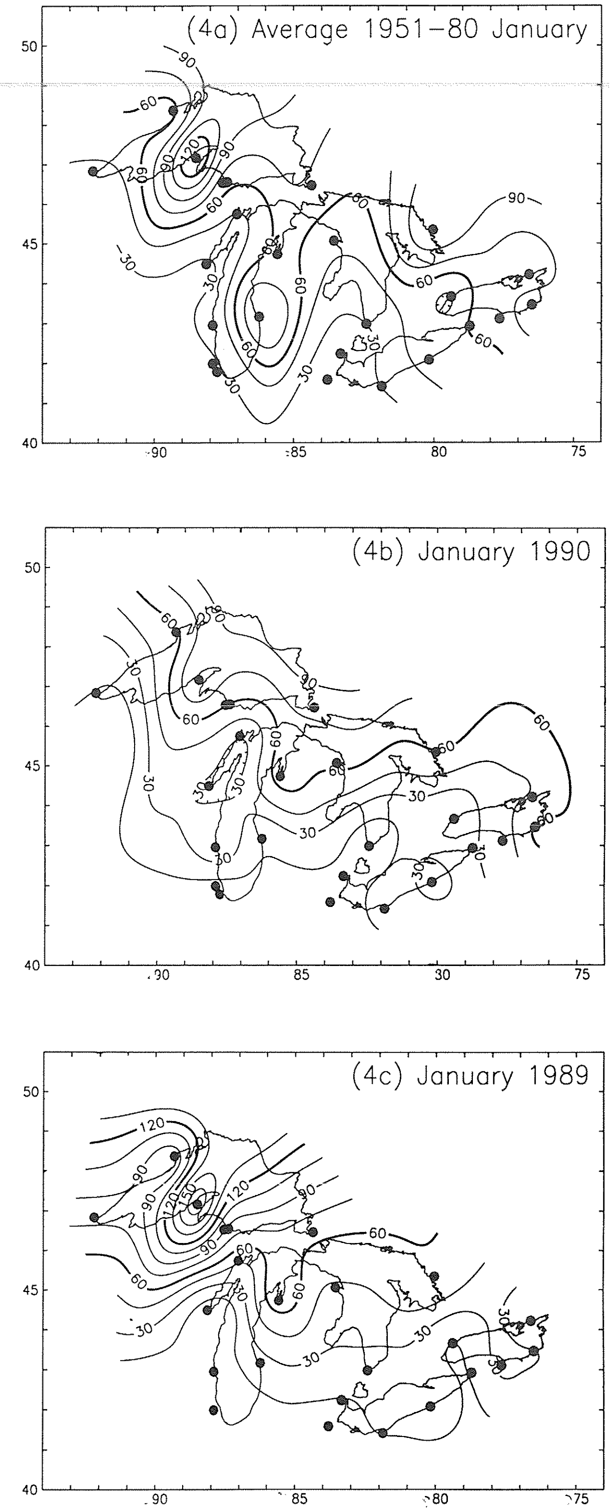


Figure 4. January snowfall (cm)
(a) 1951-80 Average, (b) January 1990
(c) January 1989, contour interval
is 15 cm.

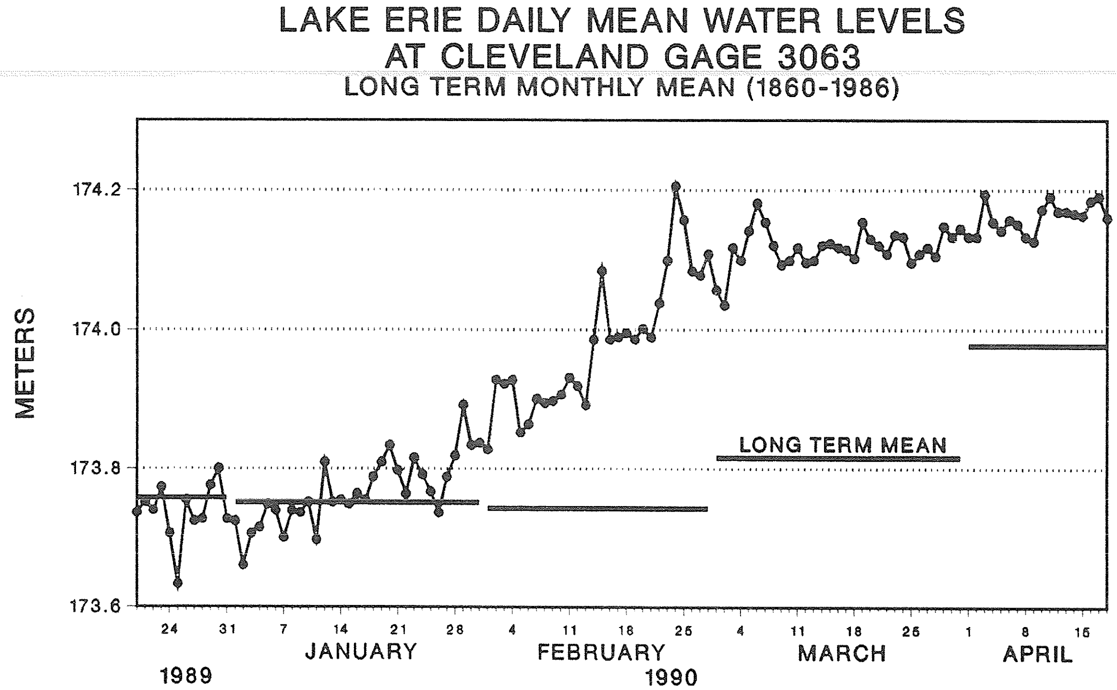


Figure 5. Lake Erie January to April 1990 daily mean water levels at Cleveland, Ohio and the long term monthly mean.

WINTER SEVERITY

Departure of the daily mean air temperature from 0°C is used to calculate freezing degree-days (FDD). If the daily mean air temperature is 3°C, then -3 FDD accumulate for that date; and if the daily mean air temperature is -3°C, then +3 FDD accumulate for that date. Assel (1980) calculated a running sum of daily accumulated FDD over a winter season starting in October and continuing to the end of April. If the running sum became negative it was reset to zero and a new running sum was started the next day. The running FDD sum usually reaches its maximum value (MFDD) in late winter or early spring and then declines as daily air temperatures rise above 0°C. The MFDD value is used as a measure of winter severity. Assel (1980) calculated MFDDs for 80 winters at 25 stations on the perimeter of the Great Lakes and used the MFDD to classify winter severity as normal, above-normal, or below-normal at each station for each of the 80 winters. If the MFDD was between the upper and lower 20 percent of the cumulative frequency distribution (cfd) of the 80 annual MFDD values, winter severity was normal. Winters with MFDD in the upper 20 percent of the cfd were classified as above-normal severity, and winters with MFDD in the lowest 20 percent of the cfd were classified as below-normal severity

In this study we calculated the MFDDs for 17 of Assel's (1983) original 25 Great Lakes stations for winter 1990 and ranked these MFDDs relative to a 86-winter base period (Table 2). Winter severity for 1990 is classified as normal at all but two Great Lakes stations. Milwaukee and Muskegon in the southern half of Lake Michigan had below-normal winter severity.

Table 2. Summary of MFDD - 86 winter average and 1990

Station	1990 MFDD	1990 RANK	86 WINTER AVE MFDD	DATE OF MFDD 1990	DATE OF MFDD 86 AVE
Lake Superior					
*Duluth, MN.	1214	52	1270	Apr 12	Apr 1
Thunder Bay, Ont.	1533	30	1429	Apr 1	Apr 5
Marquette, MI.	969	25	844	Apr 12	Mar 30
*Sault Ste. Marie, MI.	968	49	1013	Apr 7	Apr 2
Lake Michigan					
Green Bay, WI.	687	56	794	Mar 8	Mar 21
Escanaba, MI.	816	39	814	Mar 28	Mar 29
*Milwaukee, WI.	346	74	507	Mar 7	Mar 11
Chicago, IL.	258	54	351	Jan 1	Feb 28
Muskegon, MI.	257	70	378	Mar 8	Mar 12
Lake Huron					
*Alpena, MI.	688	37	675	Mar 8	Mar 26
Lakes Erie & St. Clair					
Detroit, MI.	246	64	328	Mar 7	Mar 7
Cleveland, OH.	227	46	254	Dec 28	Feb 24
*Toledo, OH.	263	49	320	Dec 30	Mar 1
*Buffalo, N.Y.	308	59	365	Mar 8	Mar 11
Lake Ontario					
Toronto, Ont.	511	21	403	Mar 11	Mar 12
*Rochester, N.Y.	331	49	370	Mar 10	Mar 11
Kingston, Ont.	718	33	677	Mar 9	Mar 21

rank = relative to 86 winters between 1897/98 - 1982/83
rank 1 = coldest rank 86 = warmest
winter severity classification:
rank 1 - 17 = above-normal severity
rank 18 - 69 = normal severity
rank 70 - 86 = below-normal severity
* Seasonal progression of daily FDD accumulations at these stations are portrayed in Figure 7. The daily FDDs given in Figure 7 are the average of Sault Ste. Marie and Duluth for Lake Superior and the average of Toledo and Buffalo for Lake Erie.

Winter 1990 was anomalous in terms of the seasonal progression of FDD accumulation because of the severe temperatures in December 1989 followed by the mild temperatures in January and February. These temperature anomalies produced much above-normal FDD accumulations in December and much below-normal FDD accumulations in January and February. Lake Erie and the southern portions of Lakes Michigan, Huron, and Ontario were virtually at their MFDD value by the end of December 1989, and FDD accumulations were in excess of 50 percent of their 1990 MFDD values at most other stations by the end of December 1989 (Figure 6). FDD accumulations actually decreased in January and part of February in the southern Great Lakes region due to above freezing air temperatures. A cold spell near the end of February and in early March resulted in the 1990 MFDD occurring near their long-term dates at most stations (Table 2). However, the much above-normal January and February temperatures at Chicago on the southern end of Lake Michigan and at Cleveland and Toledo along the southern shore of Lake Erie resulted in their MFDDs occurring in late December and early January, some two months earlier than the long-term average date.

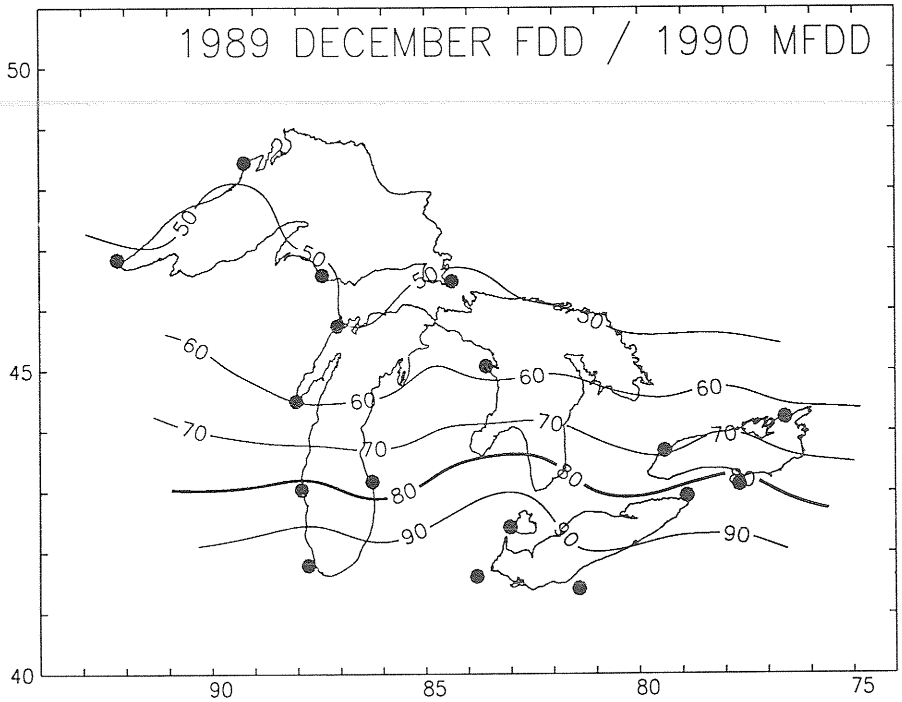


Figure 6. December 31, 1989 FDD accumulations expressed as a percentage of 1990 MFDD.

MAXIMAL ICE COVER CLIMATOLOGY - WINTERS 1963 TO 1990

Regular aerial ice reconnaissance observations of Great Lakes ice cover started in the early 1960s. The distribution of ice concentration and extent over the Great Lakes were recorded on lake outline base maps called ice charts. Source data for ice charts also included satellite imagery and side looking air-borne radar imagery starting in the late 1960s and early 1970s respectively. The 28-winter average of the annual maximal ice cover and its variation are based on analysis of these historic ice charts. Annual maximal ice covers for the Great Lake were obtained from DeWitt et al., (1980) for winters 1963-1979 and from Assel (1986, 1987, 1989) for winters 1986, 1987, and 1980-82 respectively. Annual maximal ice cover was estimated for winters 1984, 1985, 1988, 1989, and 1990 using an electronic digitizer to measure ice concentrations from historic ice charts produced by the National Oceanic and Atmospheric Administration of the United States Department of Commerce and by the Ice Branch of Atmospheric Environment Service, Canada.

Winter 1990 Maximal Ice Cover

The seasonal progression of ice formation starts in the shallow bays and along the lake perimeter in December and January and progresses toward the deeper midlake areas in February and March. The maximal ice cover extent usually occurs in the last half of February or in early March (Assel et al., 1983). Winter 1990 maximal ice cover was within one standard deviation of the 28-winter average for all five Great Lakes (Table 3). Ice cover on Lakes Superior, Huron and Ontario was a little greater than the 28-winter average. Ice cover on Lakes Erie and Michigan was less than the average. This is in good agreement with winter severity which was milder on southern Lake Michigan and Lake Erie relative to its long-term average.

Table 3. Maximal Ice Cover on the Great Lakes

Lake	Percent Ice Sd.	Avg.	1990	Date of Maximal Sd.	Avg.	1990
Superior	25	69	75	14	Mar 1	Mar 5
Michigan	23	37	23	15	Feb 21	Dec 29, Jan 17-22, Mar 5-9
Huron	20	64	70	16	Feb 27	Mar 7
Erie	14	90	83	14	Feb 12	Dec 25, Jan 3, Mar 7-9
Ontario	19	25	26	13	Feb 23	Jan 17-22, Feb 4-7, Feb 26-Mar 9

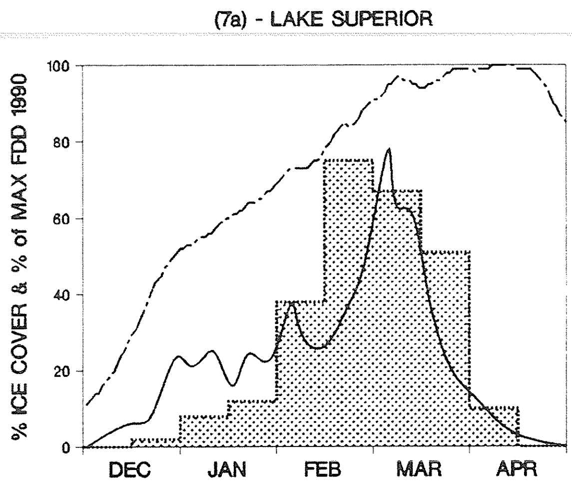
Percent ice is the percentage of the total surface area of the lake covered with ice. Avg. is the 1963-1990 average of the maximal ice cover and Sd is the standard deviation of that average.

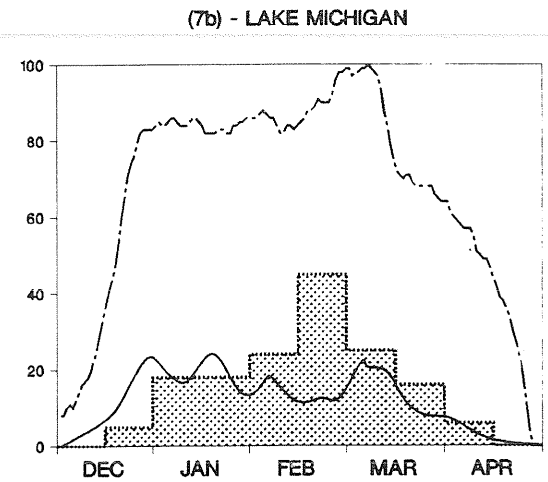
Date of 1990 Maximal Ice Cover

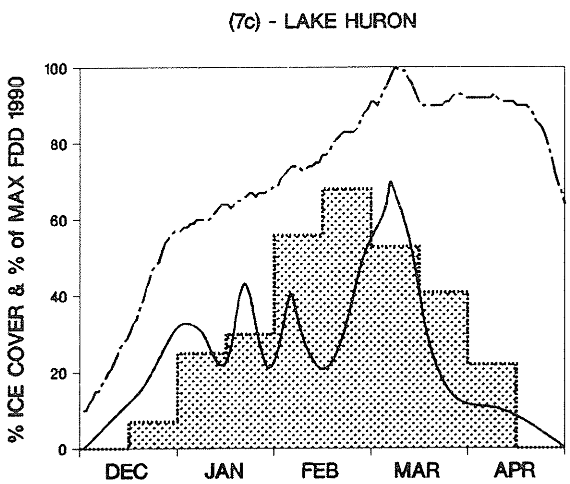
Maximal ice cover on Lakes Superior and Huron for 1990 occurred near the end of the first week in March, which is near the 28-winter average date. Lakes Erie, Michigan and Ontario were near their maximal ice cover several times during the winter (Table 3 and Figure 7), so it is difficult to say with certainty on which of these dates the actual date of maximal ice cover occurred. Lake Erie was near its maximal ice cover the last week in December, in early January, and near the end of the first week in March. Lake Michigan was near its maximal ice cover the end of December, in mid January and in early March. Lake Ontario was near its maximal ice cover during the third week of January, during the first week of February and from the end of February to March 9. These ice cover trends correspond to the 1990 anomalies in FDD accumulations. FDD accumulations were much above-average in early winter when they were near their MFDD value at the end of December for the southern Great Lakes. In January and part of February FDD accumulations on portions of the southern Great Lakes actually decreased (Figure 7), as did the ice covers on Lake Erie (starting in early January) and ice cover on Lakes Ontario and Michigan (in late January and again the second week of February). More seasonable temperatures from the last half of February to the first week of March brought both FDD and ice cover extent on the Great Lakes close to their seasonal maximal values.

Maximal Ice Cover - FDD Correlations

Previous studies have shown that ice formation and maximal ice cover on the Great Lakes is correlated with FDD (Richards 1963, Snider 1974, Rogers 1976). In this study a simple regression model was constructed where annual maximal ice cover was equal to MFDD times a coefficient. The model was calibrated using MFDD and maximal ice cover data for each of the Great Lakes over the 28-winters 1963 - 1990 (Table 4). The Lake Erie ice cover model was not as good as climatology, that is using the 28 winter average as a predictor of maximal ice cover, because of the low annual variation in maximal ice cover for that lake. The MFDD ice cover models showed modest improvement over climatology for the other four Great Lakes.







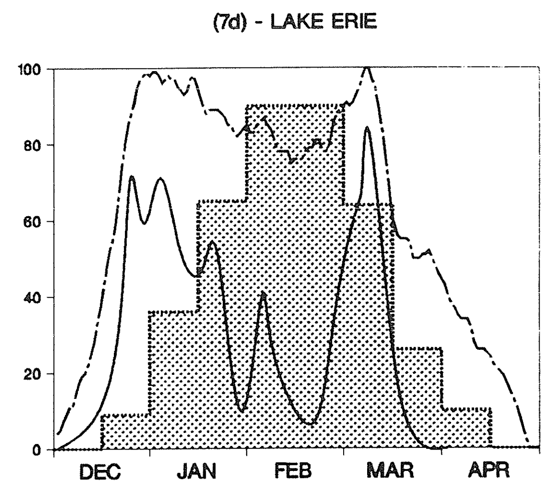
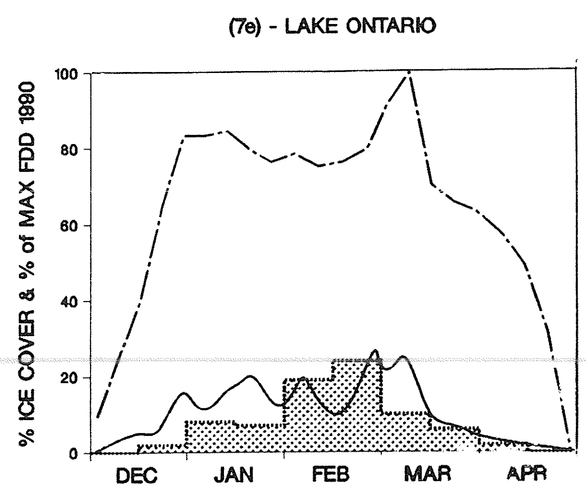


Figure 7. The seasonal progression of winter 1990 ice cover (**solid line**), 1990 FDD accumulations expressed as a percentage of the MFDD (**dashed line**), and the normal ice cover (**bar graph**) for half month periods (Assel et al., 1983) for (a) Lake Superior, (b) Lake Michigan, (c) Lake Huron, (d) Lake Erie, and (e) Lake Ontario. The FDD sites used here for each Great Lake are given in Table 2.



SUMMARY AND CONCLUSIONS

Table 4. MFDD ice cover model*

Lake	R^2	RMSE	Sd	C1
Superior	.93	19	25	.06024664
Michigan	.88	15	23	.06986341
Huron	.94	15	20	.08809692
Erie	.90	29	14	.20900114
Ontario	.76	16	19	.06993296

* ice cover = C1 x MFDD
R^2 = (correlation coefficient)^2
RMSE = root mean square error
Sd = standard deviation of observed ice cover

The 1990 winter was remarkable because of the large temperature anomaly reversal from December to January which was the largest reversal of its kind in the 93 year record. This large reversal in air temperatures and the above freezing average January temperatures in the southern portion of the Great Lakes Basin was reflected in much above-normal snowfall in December, much below-normal snowfall in January, and a virtual lack of lake-effect snowfall in January in the southern portion of the Great Lakes Basin. Mild temperatures continued into February, and several rain and freezing rain events occurred in the southern portion of the Great Lakes Basin. Record precipitation fell on the Lake Erie drainage Basin, reversing the normal seasonal decline of lake levels on that lake during February. December ice cover was much above-normal on the Great Lakes and the St. Lawrence Seaway. Lakes Erie, Michigan, and Ontario were near their seasonal maximal ice cover several times during the winter making it difficult to identify a single date of maximal ice cover. February ice cover on Lakes Erie, Michigan, and Ontario declined from their early season values at a time when they are usually increasing in extent. Lakes Huron and Superior reached their maximal extent near the end of the first week of March. Record breaking high temperatures near mid March brought rapid melting of snow cover, some flooding in the southern half of the Great Lakes and an end to one of the most unusual winter seasons in the past 30 years.

ACKNOWLEDGEMENT

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