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AN EVALUATION OF CLIMATIC IMPACT OF THE NIAGARA ICE BOOM RELATIVE TO AIR AND WATER TEMPERATURE AND WINTER SEVERITY

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THE NIAGARA ICE BOOM RELATIVE TO AIR AND WATER TEMPERATURE
AND WINTER SEVERITY

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The objective of this study was to determine if the Niagara River ice boom installed every winter since 1964-65 has prolonged the Lake Erie ice cover at Buffalo, N.Y., resulting in significant changes in the spring warm-up of Lake Erie and longer, colder winters in the area. On the basis of the analysis presented in this report, there is no evidence that the operation of the ice boom has either extended Buffalo winters or made them more severe. statistical analysis of Buffalo temperature series compared with those for Lockport, N.Y., does not reveal any statistically significant cooling in the climate at Buffalo related to the operation of the ice boom. However, because of the distance of the airport from the shore zone, the possibility of a localized effect of small magnitude within the vicinity of the ice boom cannot be ruled out. A comparison of the water temperature at the Buffalo intake as recorded in pre- and post-boom years also indicates that the ice boom has not had an impact on the timing of the spring rise in the Lake Erie water temperature at Buffalo. The analysis of winter temperature trends since 1898 shows that the winter severity at Buffalo follows a general pattern characteristic not only of the region around the eastern end of Lake Erie but also of the Great Lakes Region as a whole. This general pattern has been one of increasing winter severity from 1898 to 1918, decreasing winter severity from 1920 to 1958, and increasing winter severity again from 1958 to the present. Winters have become colder since the installation of the ice boom, but these colder winters are part of a general climatic trend toward more severe winters beginning in 1958. Thus, there is no evidence to suggest that the ice boom has intensified winter severity or duration at Buffalo relative to other areas around the Great Lakes.

1. INTRODUCTION

This study on the impact of the Niagara River ice boom on the local climate at Buffalo, N.Y., was conducted at the request of the Chairman of the U.S Section of the International Niagara Board of Control. The objective was to determine if the installation of the ice boom, beginning in winter of 1964-65, has prolonged the Lake Erie ice cover at Buffalo, resulting in significant changes in the spring warm-up of Lake Erie and longer, colder winters. By

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[1]GLERL Contribution No. 232.

request, the study was specifically designed to address the following questions:

(1) Historically, has the winter-like weather in Buffalo, New York always been extended, relative to areas further inland, by the presence of ice on Lake Erie?

(2) How has the severity of winters in the Buffalo, New York area compared to other localities along the Great Lakes shores as a whole and for pre-boom (prior to 1964) and post-boom periods taken separately?

(3) Is the use of NWS air temperature data invalidated because of the airport location of the instruments or the 1943 relocation of the instruments from downtown Buffalo to the airport?

Four meteorological parameters, monthly air temperatures, maximum seasonal freezing degree-days (FDD's), spring thawing degree-days (TDD's), and the beginning of the seasonal rise in Lake Erie water temperatures, will be analyzed to test the hypothesis that the installation of the ice boom has resulted in a significant cooling of Buffalo air temperatures during winter and spring.

2. BASIC DATA AND STATION HOMOGENEITY ANALYSIS

The basic data used in the study consisted of monthly mean air temperatures recorded at Buffalo and Lockport, N.Y., and obtained from the Climatological Data, Annual Summaries for the State of New York, published by the Environmental Data and Information Service of NOAA; FDD and TDD data for Buffalo and other Great Lakes stations (Assel, 1980); and water temperature and water temperature parameter data for the Buffalo water intake (International Niagara Working Committee, 1979).

The station history of the Buffalo weather station was examined from 1896 to date to determine any changes in station or sensor location that might produce significant discontinuities in the climatic record. The station was first moved in 1913, resulting in a small change in station location in downtown Buffalo (175 feet) but a major change in the height of the thermometer from 178 to 247 feet above the ground. In July 1943 the station was relocated to the Buffalo Airport administration building, a distance of approximately 9 miles. (See figure I). In August 1960 it was moved approximately 0.4 miles to its present NWS site. At this time the temperature sensor was moved from a roof exposure 34 feet above the ground and mean sea level (msl) of 693 feet to an exposure 5 feet above the ground and msl of 705 feet. The impact of these changes on the Buffalo temperature time series is best assessed by comparing the series with a similar time series from a station whose location has remained the same throughout the period in question. The station located in Lockport (figure 1) is the only nearby station meeting this criterion. The station histories of Lockport and Buffalo are summarized in table 1. The parameter used to examine the Buffalo station changes is the difference of

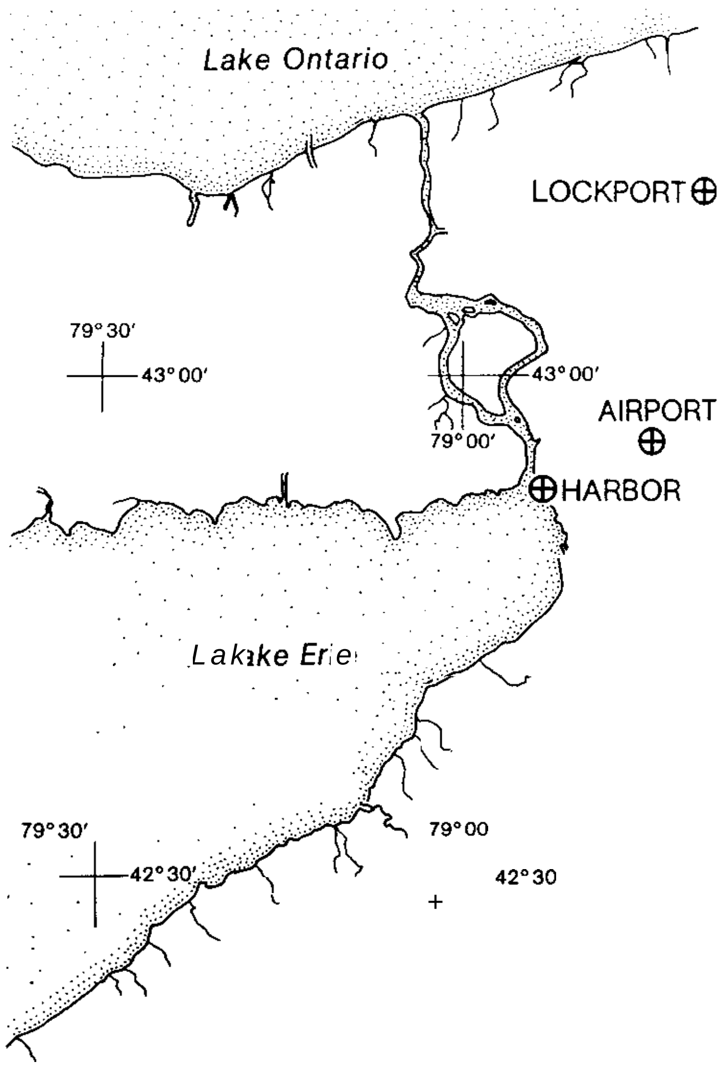

Figure 1.--*Location of Buffalo and Lockport air temperature stations.*

the monthly mean temperature between Buffalo and Lockport (Buffalo minus Lockport).

A comparison shown in figure 2 was first made for the homogeneous period 1914-42. The "lake effect" at Buffalo is very pronounced on the average, with Buffalo being colder than Lockport during spring and early summer and warmer than Lockport during fall and winter. This is because of the large beat

Table 1.--Station *histories of Buffalo and Lockport*

Location	Period	Distance from previous location	MSL	Elevation above ground	Lat. N.	Long. N.
Buffalo						
downtown	Jan. 1, 1914- June 30, 1943		604	247	42°53'	78°53'
Buffalo						
airport	July 1, 1943- Aug. 22, 1960	9 mi NE	693	34	42°56'	78°44'
	Aug. 23, 1960- to date	'4 mi N	705	5		
Lockport						
Lockport 2 NE	Jan. 1, 1914- to date		520		43°11'	78°39'

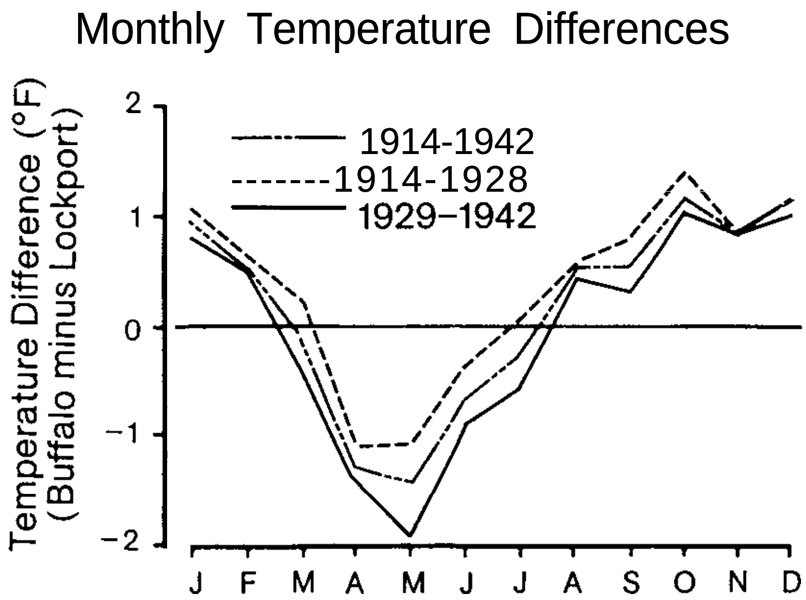

Figure *Z.--Difference of mean monthly temperature between Buffalo and Lockport,* 1914-42, 1914-28, 1929-42.

storage capacity of Lake Erie. During spring the lake heats up more slowly than the inland areas, causing the temperatures of the adjacent land areas to remain cooler than the inland air temperatures. During late summer, fall, and winter, the process is reversed, with the lake losing heat slower than the inland areas, resulting in the adjacent land areas remaining warmer than inland areas. To determine if this relationship remained constant, we broke the base period into the two equal periods 1914-28 and 1929-42. These data are summarized in table 2, with the results shown in figure 2. The lake effect is seen to be continuous throughout the base period but more pronounced during the 1929-42 period.

A temperature comparison was next made for the period 1944-1959, following the station move to the airport. These data are also summarized in table 2. Figure 3 illustrates that the spring lake effect has been essentially eliminated by the move to the airport. The statistical significance of the move was analyzed by use of the one-sided t-test at the YO-percent confidence level to compare the temperature differences for the 1944-59 period with those for the 1914-42 period. The results, shown in table 3, indicate that despite the high variability of the data the station change was significant for March, April, May, June, July, September, October, and December. It is interesting to note that the station shift had no appreciable effect during the colder winter months of January and February.

Table 2.--*Summary of Buffalo minus Lockport temperature differences, degrees Fahrenheit*

Period		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1914-28	M	1.05	0.65	0.23	-1.10	-1.05	-0.33	0.10	0.60	0.60	1.39	0.83	1.13
	SO	0.62	0.85	0.79	1.30	1.30	0.65	0.6	0.53	0.54	0.76	0.44	0.6
	CV	59	131	343	118	124							
	N	15	15	14	15	14	13	13	14	14	14	14	15
1929-42	M	0.80	0.50	-0.45	-1.4	-1.8	-0.90	-0.55	0.42	0.30	1.02	0.85	1.00
	SO	0.55	0.65	0.75	0.90	1.00	1.10	0.43	0.60	0.40	0.55	0.70	0.60
	CV	69	130	167	64	56							
	N	13	14	14	14	13	14	14	14	14	14	14	13
1944-59	M	0.80	0.55	0.46	0.42	0.42	0.35	0.26	0.36	0.36	0.40	0.61	0.74
	SO	0.62	0.61	0.62	0.69	0.5	0.44	0.60	0.55	0.73	0.46	0.48	0.60
	CV	78	111	135	164	126							
	N	16	15	16	16	15	14	16	16	16	15	16	16

M is the mean for the period.

SD is the standard deviation for the period.

CV is the coefficient of variation in percent = | SD/M | *100.

N is the number of months used in the period.

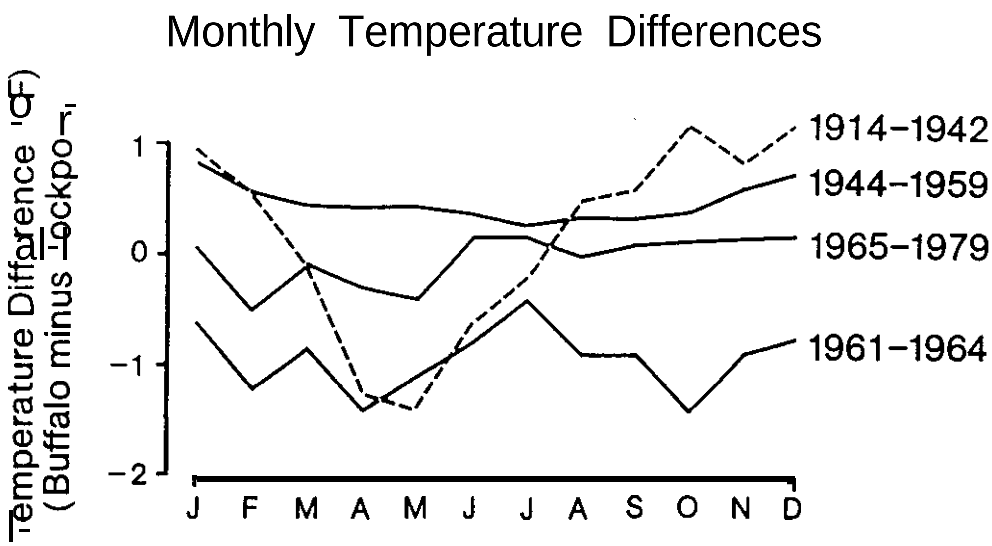

Figure 3.--Difference of mean monthly temperature between Buffalo and Lockport, 1914-42, 1944-59, 1961-64, 1965-79.

The impact of the shift from a roof exposure to a ground level exposure in August 1960 is also shown in figure 3 for the pre-boom years of 1961-64, and the post-boon period of 1965-79. The analysis shown in table 3 indicates that a significant discontinuity exists for each month of the year. This is important because it limits the Buffalo temperature time series for determining the possible impact of the boom to the period 1961-79.

3. CLIMATIC IMPACT USING THE BUFFALO AIK TEMPERATURES

In the preceding analysis, the relocation of the weather station from the waterfront to the airport was found to eliminate the lake effect in the monthly time series. This is further verified by the comparative data for the years 1941 and 1942, when both the waterfront and airport stations were run simultaneously. Table 4 shows the average lake effect as determined from the 2 years of simultaneous measurements and from the homogeneity analysis. The 2 years of measurements show very good agreement with the homogeneity study, with the maximum lake effect being approximately 2°F during May. Thus, the airport temperatures are not representative of the waterfront temperatures during spring and cannot be used to determine the impact of the boom at the waterfront.

The relocation of the air temperature sensor at the Buffalo airport in July 1960 has been shown to have resulted in statistically significant

Table 3. *–Statistical analysis of 1943 Buffalo station move to the airport and 1960 move to National Weather Service Observatory: One-Tailed t-test*

	Jan.	Feb	Mar	Apr	May	June	uly	Aug	Sept	Oct	4	Dec
Periods I and II												
Sp	0.6	0.51	0.58	0.93	.1	0.79	0.6	0.55	0.62	0.62	0.54	0.56
t	0.67	0.06	-2 67	4.9	-4	-3 5	-2.2	0.83	1.7	3. 6	1.22	2.0
Significant	0	0	+	+	+	+	+	0	+	+	0	+
Periods II and II												
SP	0.77	0.6	0.62	0.8	0.53	0.48	0.36	0.58	0.45	0.46	0.48	0.73
t	4.3	7.2	5.0	5.7	7.1	6.8	4.5	5.4	7.0	9.7	7.5	4.9
Significant	+	+	+	+	+	+	+	+	+	+	+	+

Period I = 1914–42

Period II = 1944–59

SP = pooled standard deviation for bothperiods

t = computed t statistic

Significant = + if significant at $\alpha = 0.1$, 0 if not significant at $\alpha = 0.1$

Period III = 1961–79

Table 4.--*Lake effect on Buffalo air temperature between the waterfront and airport locations,* ***waterfront*** *minus airport in degrees Fahrenheit*

Month	Difference in average max. temp. [1]	Difference in average min. temp. [1]	Difference in average mean temp. [1]	Difference [2]
Jan.	-0.15	0.8	+0.4	+0.1
Feb.	0.45	1.7	+0.8	0
Mar.	-1.0	0.9	-0.5	-0.6
Apr.	-4.5	1.3	-1.5	-1.6
May	-4.9	0.8	-2.0	-1.8
June	-5.8	2.7	-1.1	-1.0
July	-4.9	3.2	-0.9	-0.5
Aug.	-3.3	4.2	+0.3	+0.2
Sept.	-2.7	3.7	+0.5	+0.2
Oct.	-1.5	2.5	+0.5	+0.8
NOV.	-0.5	1.3	+0.4	+0.2
Dec.	-0.7	1.2	+0.2	+0.3

[1] From 1941, 1942 simultaneous measurements.

[2] From homogeneity analysis.

differences in mean monthly air temperatures. Thus, the pre-boom period available for comparison with the post-boom period is necessarily limited to the 4 years from 1961 through 1964--the operation of the Niagara ice boom beginning in the 1964-65 winter.

The hypothesis to be tested is that the ice boom has prolonged the winters in the Buffalo area and made them more severe relative to areas further inland. As in the previous section, a statistical test of this hypothesis can be made by comparing the differences in the monthly mean air temperatures at buffalo and Lockport during the pre-boom period with those during the post-boom period. If in fact the Niagara ice boom has extended winter-like conditions at Buffalo and made them more severe, one would expect a change in the difference series (buffalo minus Lockport mean monthly temperatures) that would reflect the increased severity and duration of Buffalo's winters. The ice boom, of course, would not be expected to have any impact on the difference series for summer and fall of the year.

The post-boom period from 1965 to 1979 was divided into two periods of equal length: 1965-72, and 1972-79. (The second period overlaps the first period in 1972.) One-tailed t-tests conducted between these periods and the 1961-64 period to determine if the monthly air temperatures at Buffalo had cooled relative to Lockport in any month indicate no statistically significant cooling in any month.

Thus, there is no evidence in the difference series of Buffalo minus Lockport mean monthly temperatures that would suggest any significant cooling in the local climate at Buffalo relative to Lockport resulting from operation of the ice boom. Therefore, the supposition of *a dramatic* cooling having taken place in the local climate at Buffalo during late winter-early spring as a result of operation of the ice boom is rejected. Since the airport is several miles from the vicinity of the ice boom, these results do not rule out the possibility of an impact of small magnitude occurring in the immediate vicinity of the boom. Such an impact cannot be detected in these data.

It should be pointed out that 'I-year samples are insufficient in length for the purpose of obtaining reliable estimates of the mean and standard deviation of a population. However, even though the statistical estimates may not be highly accurate, they should indicate any local climatic changes of a dramatic nature. The mean temperature differences between Buffalo and Lockport for the 1961-64 period were also compared with the S-year mean differences following the installation. The comparisons are shown in table 5. The comparisons show an interesting pattern. For every period following the boom installation, the Buffalo monthly temperatures are higher relative to Lockport than for the period prior to the installation.

Thus, based on the Buffalo air temperature data, there is no indication of significant lowering of the air temperature at the airport location attributable to the installation of the ice boom.

Table 5.--*Four-year mean temperature differences for the 1961-79 period, Buffalo minus Lockport in degrees Fahrenheit*

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1961-64*	-0.6	-1.2	-0.9	-1.4	-1.1	-0.8	-0.4	-0.9	-0.9	-1.4	-0.9	-0.8
1965-68	0.1	-0.3	-0.3	0.1	0.2	0.3	0.6	0.3	0.2	-0.1	0.1	0.3
1969-72	0.7	0.3	0.1	0.1	-0.2	0.5	0.5	0.3	0.4	0.6	-0.2	0.2
1973-76	0.1	-0.2	-0.1	-0.8	-0.9	0.3	-0.2	-0.4	-0.2	0.0	-0.2	-0.1
1976-79**	-0.5	-1.2	-0.3	-0.6	-1.0	-0.6	0.5	-0.2	0.1	-0.2	0.3	0.2

*Pre-boom.

***Note:* 1-year overlap with previous group.

4. CLIMATIC IMPACT USING WATEK TEMPERATURES

A second climatic indicator used to analyze the impact of the boom on the Buffalo climate is the seasonal rise in the Lake Erie water temperature as measured at the Colonel Ward Filtration Plant, Department of Public Works, City of Buffalo. The temperature sensor is located at a depth of 18 feet and approximately 1,000 feet downstream of the ice boom and 1,000 feet toward the United States side of the United States-Canadian border in Lake Erie. Water temperature is measured daily with a sensor that is calibrated to 1°F.

Water temperature affects the temperature of air passing over it through heating and cooling processes. Thus, a delayed or late rise in the water temperature would tend to retard spring warming in the adjacent land areas. This is one aspect of the lake effect on the adjacent land areas. The parameter that has been used most often to define the onset of the spring rise in water temperatures is the water temperature parameter, which is defined as the number of days past March 15 that it takes the water temperature measured at the Buffalo intake to reach a value 1.7°C greater than the coldest water temperature experienced from January 1 through March 15. For example, if the water temperature measured at the intake reached 1.7°C on March 30 and the coldest water temperature was 0°C, then the water temperature parameter for that year would be 15 days. The data are given in table 6, and are plotted in both raw and standardized form in figure 4. The mean and standard deviation for the pre-boom period of 1927-64 were used to standardize the data. The figure shows the time series to be highly variable, with two relatively high periods in 1927-47 and 1959-72 and two relatively low periods in 1948-58 and 1973-80.

These data were analyzed, to determine if the post-boom period differs significantly from the pre-boom period, by dividing the water temperature parameter time series into three approximately equal periods and testing by analysis of variance statistical tests. The results are summarized in table 7. Testing the hypothesis (at the 90- and 95-percent confidence levels) that the boom has no effect on the water temperature parameter would call for the hypothesis to be rejected only if the probabilities given in table 7 are 10 and 5 percent, respectively, or less. As this is not the case. the boom is considered to have no significant impact on the water temperature parameter and therefore on the spring rise in the Lake Erie water temperature at Buffalo.

The periods were also analyzed to determine how many days the water temperature parameter in the post-boom period would have to be increased before the boom could be said to have a statistically significant impact. The parameter would have to be increased by an additional 4 days to be significant at the YS-percent confidence level and by an additional 2 days to be significant at the 90-percent confidence level. However, even with these increased values, the mean of the post-boom period was found to be nonsignificantly different, at the 95-percent confidence level, from the 1927-45 pre-boom period.

An example of the use of mean values to determine the impact on the water temperature parameter by the ice boom is shown in table 8. The time series was broken into eight periods of similar length and the mean water temperature parameter determined for each period. The periods are arranged in increasing

Table b.--*Calculation of the water temperature parameter, 1927-79**

Year	Date		WT	Year	Date		WT	Year	Date		WT	Year	Date		WT
1927	Apr.	14	30	1941	Apr.	14	30	1955	Apr.	2	18	1969	Apr.	28	44
1928	May	lb	62	1942	Apr.	27	43	1956	Apr.	18	24	1970	Apr.	30	46
1929	Apr.	25	41	1943	May	17	b3	1957	Apr.	11	27	1971	May	25	71
1930	Play	5	51	1944	Apr.	24	40	1958	Apr.	7	23	1972	May	4	50
1931	Apr.	6	22	lY45	Mar.	29	14	1959	May	11	57	1973	Mar.	16	1
1932	Apr.	18	34	1946	Apr.	5	21	1960	May	4	50	1974	Apr.	6	22
1933	Apr.	25	41	1947	May	16	62	1961	Apr.	15	31	1975	Apr.	15	31
1934	Apr.	Y	25	1948	Apr.	2	18	1962	Apr.	30	46	lY76	Apr.	19	35
1935	Apr.	15	31	1949	Mar.	28	13	1963	May	Y	55	1977	Apr.	30	46
1936	May	20	66	1950	May	2	48	1964	Apr.	22	38	1978	May	14	60
1937	Apr.	13	29	1951	Apr.	16	32	1965	May.	13	59	1979	Apr.	22	38
lY38	Apr.	12	28	1952	Mar.	28	13	1966	Apr.	25	41	1980	Apr.	22	38
1939	May	Y	55	1953	Mar.	20	5	lYb7	Apr.	15	31				
1940	Apr.	29	45	1954	Apr.	8	24	1968	Apr.	29	45				

WT = number of days past March 15 that water temperature measured at the Buffalo intake is plus 0.17°C (3°F) or greater than the coldest water temperature ex- experienced from January 1 through March 15.

*After International Niagara Working Committee (1979).

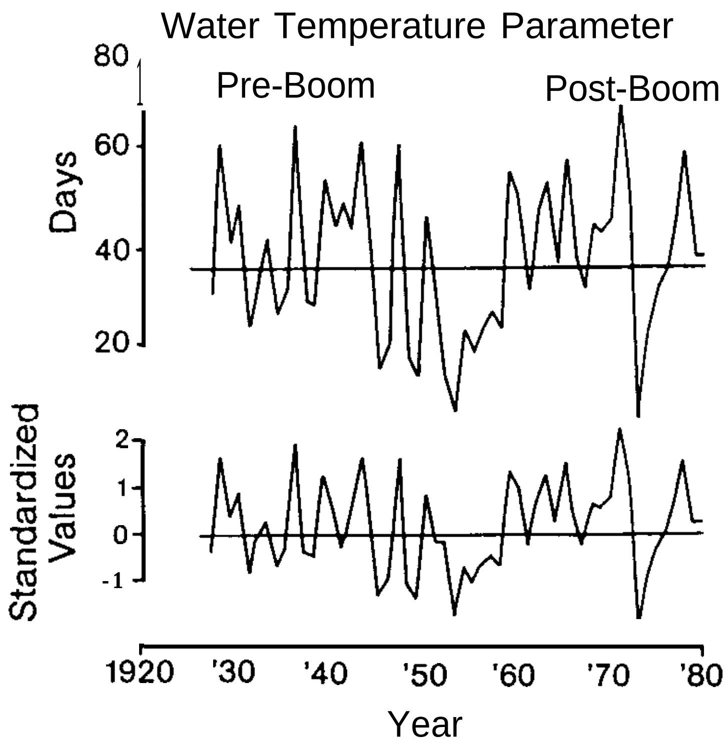

Figure 4.--*Water temperature parameter, 1927-80.*

order of the mean water temperature parameter. Of particular interest is the fact that period eight, comprising the last 8 years after the boom was installed, has the third lowest value of the mean water temperature parameter of the series and is lower than three of the five pre-boom periods. This indicates an earlier spring warming during this particular g-year period than under three of the five pre-boom periods.

5. IMPACT ON WINTER SEVERITY

FDD's are defined as the departure of the mean daily air temperature below 0°C (32°F). FDD accumulations for a given winter season are a measure of the cumulative departure of the average daily air temperature below 0°C and the maximum seasonal value is an Index of the severity of a particular winter season.

Winter severity in the Buffalo area is compared to three stations in the Buffalo region (Toronto, Ont.; Rochester, N.Y.; and Erie, N.Y.) and

Table 7.--*Analysis of variance tests water temperature parameter, three periods*

Period	Years included	Number (days)	Mean	Std. dev.	Coef. var. (%)	95% Conf. int. Mean
1	1927-45	19	39.5	14.7	37	32.4-46.5
2	1946-64	19	31.8	16.8	53	23.8-39.9
3*	1965-80	16	41.1	16.2	39	32.5-49.8

*Post-boom period.

F Probability = 18.2%.

Kruskal-Wallis rank test, F probability = 15.7%.

Tests for homogeneity of variances.
Cochrans test, probability = 66.0%.
Bartlett-box test, probability = 84.6%.

to the Great Lakes shore zone as a whole (figure 5). Port Dover, Ont., was not used in the regional analysis because of a discontinuity in the station temperature records occurring in 1924. A comparison of the maximum FDD time series at Buffalo for the 82 winters between 1897 and 1979 with the 3-station regional average and the 25-station Great Lakes average maximum FDD time series appears on figures 6a and b. All three time series were standardized to a base period extending from 1897 to 1960. This base was used because the 1960 Buffalo instrument move resulted in lower air temperatures in the Buffalo air temperature records relative to the old station location. Figure 6 shows that in general the extremes in winter severity usually occur simultaneously in the three series. The four coldest and four warmest winters at Buffalo, the region, and the Great Lakes shore zone are shown in table 9. With the exception of the 1977 winter for the region, the extreme winters all occurred prior to the installation of the ice boom and two of the four coldest winters and three of the four warmest winters occurred simultaneously for Buffalo, the region, and the Great Lakes. Thus, winters during the post-ice boom years have not been as extreme as in the pi-e-boom years.

Table 8.--*Mean water temperature parameters by periods in ascending order*

Period	Years included	Number of years	Mean (days)
4	1948-53	6	21.5
5	1954-59	6	28.8
8*	1973-80	8	33.9
3	1941-47	7	39.0
2	1934-40	7	39.9
1	1927-33	7	40.1
6	1960-64	5	44.0
7*	1965-72	8	48.4

*Post-boom period.

As a further illustration of trends in winter severity at Buffalo relative to regional and Great Lakes trends, graphs of the cumulative standardized FDD values for these three areas are shown in figures 7a and b. Analysis of the figure indicates the following:

1. All three curves show the same trends.

   a. Winter severity increased from 1898-1918;

   b. Winter severity decreased from 1920-58; and

   c. Winter severity increased from 1958 to present.

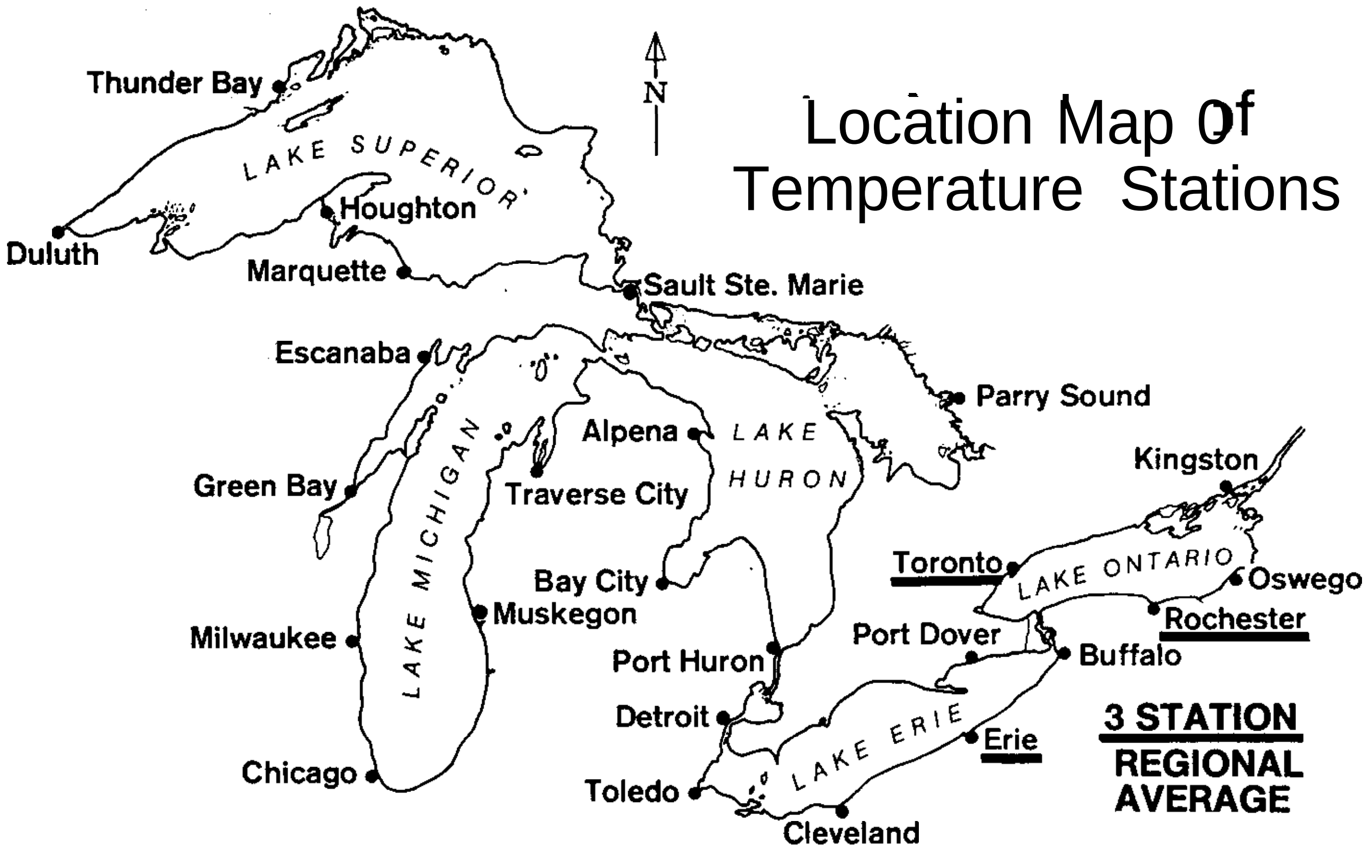

Figure 5.--*Location map of temperature stations.*

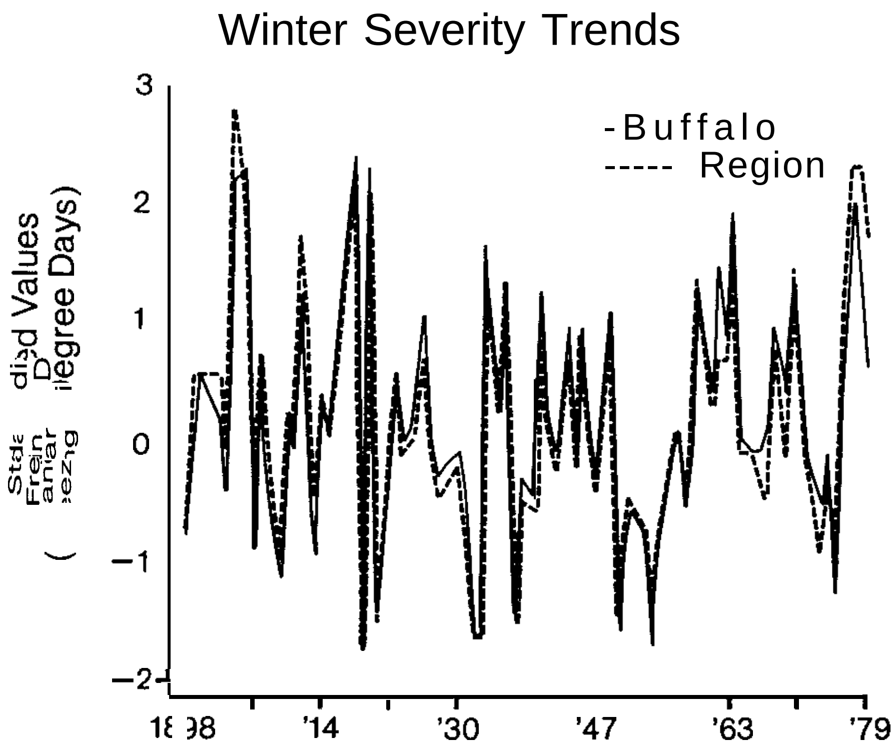

Figure 6a.--*Standardized maximum FDD values for Buffalo and the three-station regional average.*

2. Buffalo winters were relatively less severe than either the regional or the Great Lakes averages for 1898-1938.

3. Buffalo "inters and those for the region were relatively **more** severe than those for the rest of the Great Lakes from 1938-1952.

4. Buffalo winters were relatively cold compared to the regional average and the rest of the Great Lakes from 1958 to 1974 and milder than the Great Lakes average from 1975 to 1979. The winters at Buffalo were relatively cold when compared to the regional average because of the air temperature sensor **move** in 1960, which resulted in lower air temperatures in winter as shown in figure 3.

Thus, **FDD's** at Buffalo have tended to be higher than the mean **(1897-1960)** since the installation of the ice boom, but this trend toward cooler "inters

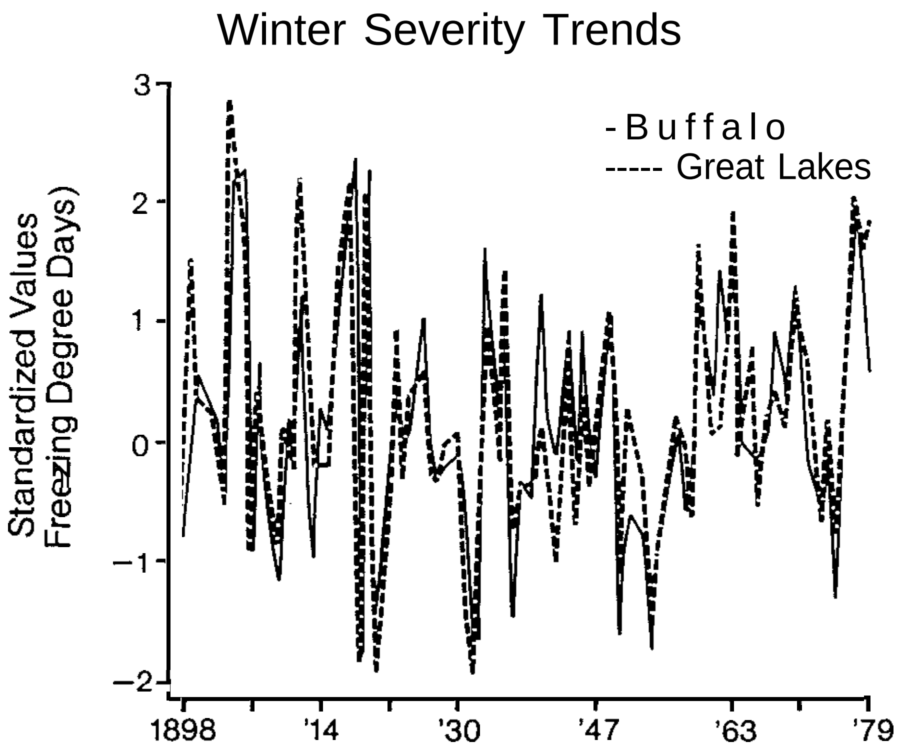

Figure 6b.--*Standardized maximum FDD values for Buffalo and the 25-station Great Lakes average.*

coincides with a general climatic trend toward more severe winters in the Great Lakes shore zone as a whole starting in 1958.

In table 10 the post-ice boom winters are ranked from coldest to warmest. From this table it can be seen that the severity of winters at Buffalo is virtually the same as that for the regional average and is comparable to the Great Lakes as a whole. Dividing the 15 post-ice boom years between 1965-79 into three 5-year periods, coldest, warmest, and intermediate winters, it can be seen that five of the regional and four of the Great Lakes five coldest winters were the same as for Buffalo. Also, four of the regional and three of the Great Lakes five warmest winters were the same as for Buffalo. The intermediate winters, as might be expected, showed the least agreement, with four of the regional winters and two of the Great Lakes intermediate winters occurring in the same years as Buffalo's. Thus, winter severity at Buffalo during post-ice boom years has been very similar to other areas in the shore zone of the Great Lakes.

Table 9.--*Winter severity*

	Four coldest winters				Four warmest winters			
Buffalo	1904	1905	1918	1920	1919	1932	1933	1953
Region	1904	1905	1918	1977	1919	1932	1933	1953
Great Lakes	1904	1912	1918	1920	1919	1921	1932	1953

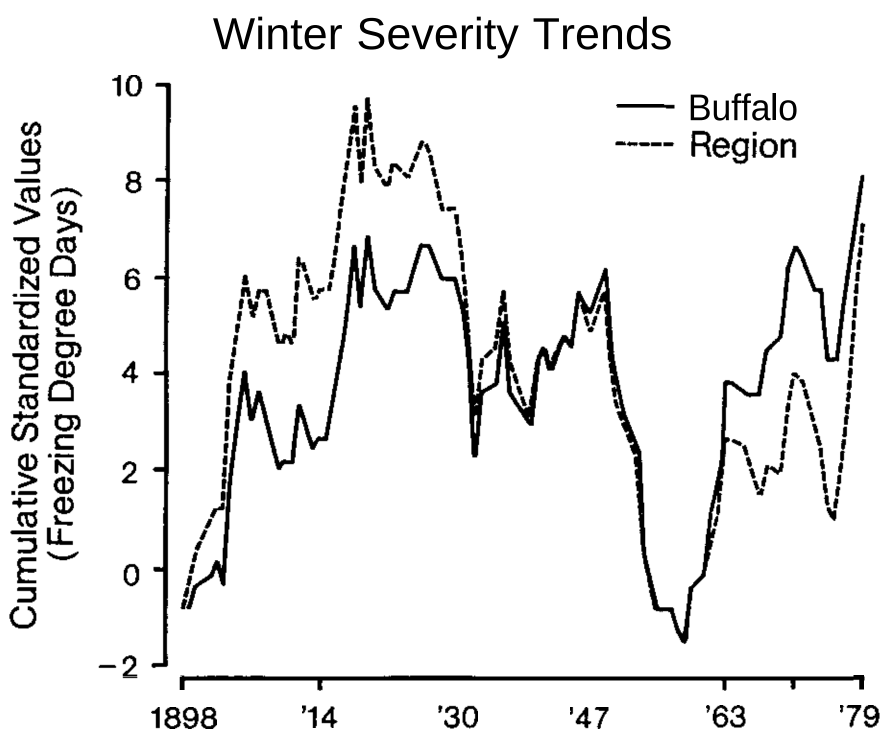

Figure 7a.--Cumulative standardized FDD values for Buffalo and the region.

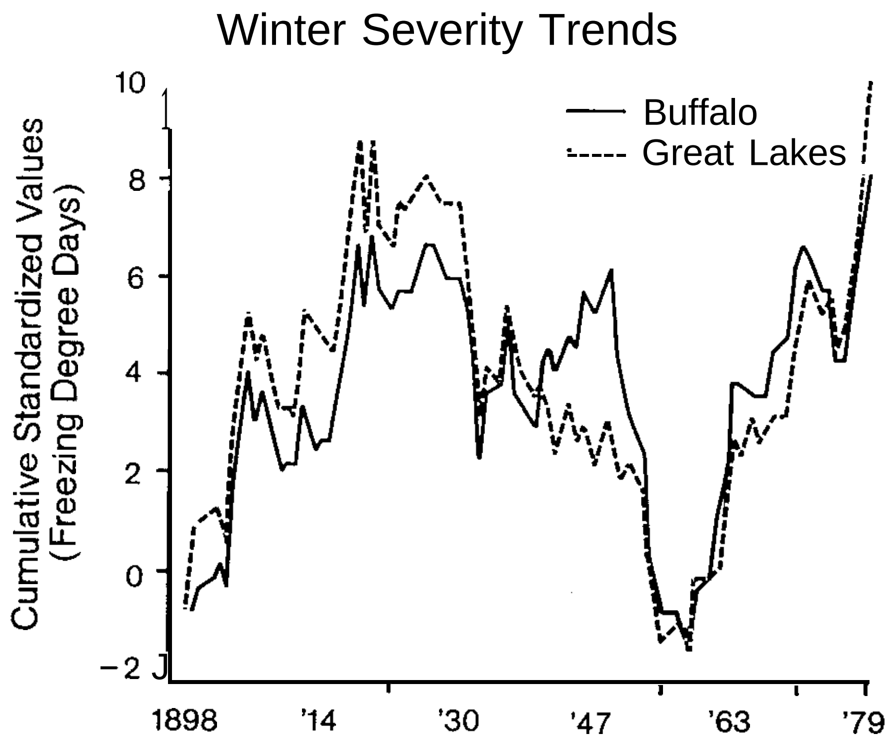

Figure 7b.--*Cumulative standardized FDD values for Buffalo and the Great Lakes.*

Table 11 shows winters in which the standardized maximum FDD value at buffalo is larger than the standardized maximum FDD value for the region. A plus sign indicates that Buffalo's FDD accumulations are greater than the region's. The 15-winter post-ice boom period is compared to four 15-winter pre-ice boom periods to see if Buffalo's post-ice boom winters have been proportionately colder relative to the mean for the base period 1897-1960 and compared to the regional average. Table 11 shows that in 8 of the 15 post-ice boom years, or about 50 percent of the time, Buffalo did experience colder winters relative to the region. Comparing the 15-winter post-ice boom period to four 15 pre-ice boom periods, also given in table 11, one can see that in three of the four pre-ice boom periods Buffalo had a greater number or virtually the same number of relatively cold winters as it did for the post-ice boom period. Thus, for about half of the post-ice boom period Buffalo had relatively colder winters compared to the regional average, but this is not a disproportionately large number when compared to three of four pre-ice boom periods in which the same or a greater number of relatively cold winters occurred compared to the regional average.

Table 10.--Ranking of winter severity for post-ice boom years

Rank	Buffalo	Region	Great Lakes
1	1977	1978	1977
2	1978	1977	1979
3	1970	1979	1978
4	1979	1970	1970
5	1968	1968	1971
6	1971	1971	1965
7	1969	1969	1972
8	1976	1965	1968
9	1967	1972	1967
10	1965	1976	1974
11	1974	1966	1976
12	1966	1974	1969
13	1972	1967	1966
14	1973	1973	1973
15	1975	1975	1975
Five coldest (rank 1-5)		all same as Buffalo	4 out of 5 same as Buffalo
Five warmest (rank 11-15)		4 out of 5 same as Buffalo	3 out of 5 same as Buffalo
Five Intermediate (rank 6-10)		4 out of 5 same as Buffalo	2 out of 5 same as Buffalo

Table 1.--*Difference series of standardized maximum FDD's, Buffalo minus region*

Period	1965	2 1966	3 1967	4	5	6	7	8	9	3	1	12	3	4	15	+'s	-'s
1965-79	-	+	+	+	+	-	-	+	+	+	-	+	-	-	-	8	7
1950 64	+	-	-	-	-	-	-	-	+	-	+	+	+	+	+	7	8
935-49	-	-	+	+	+	+	—	+	+	+	+	+	+	+	-		4
1920-34	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	14	
905-19	+	-	-	-	-	-	-	-	-	-	+	+	+	+	-	5	10

Plus +) indicates Buffalo cooler relative to its mean than region

Since fluctuations in standardized maximum FDD accumulations at Buffalo and the region show similar trends, a regression of Buffalo maximum FDD accumulations on the regional average was used to predict maximum FDD accumulations at Buffalo. The regression was based on the 45-year pre-boom period 1920-64. Deviations of actual FDD accumulation at Buffalo from the predicted values based on the regression are shown in figure 8 (Y-Buff). Positive deviations indicate that buffalo has been warmer than expected, and negative deviations indicate that Buffalo has been colder than expected. If the impact of the ice boom has been to make Buffalo's winters colder, the regression equation should consistently underestimate maximum FDD accumulation at Buffalo. Figure 8 shows that eight of the predictions for the post-boom period are too high and seven are too low, with no consistent temporal pattern to these errors. This implies that the installation of the boom has had no impact on the expected value of FDD accumulations at Buffalo and therefore has not affected the severity of Buffalo winters.

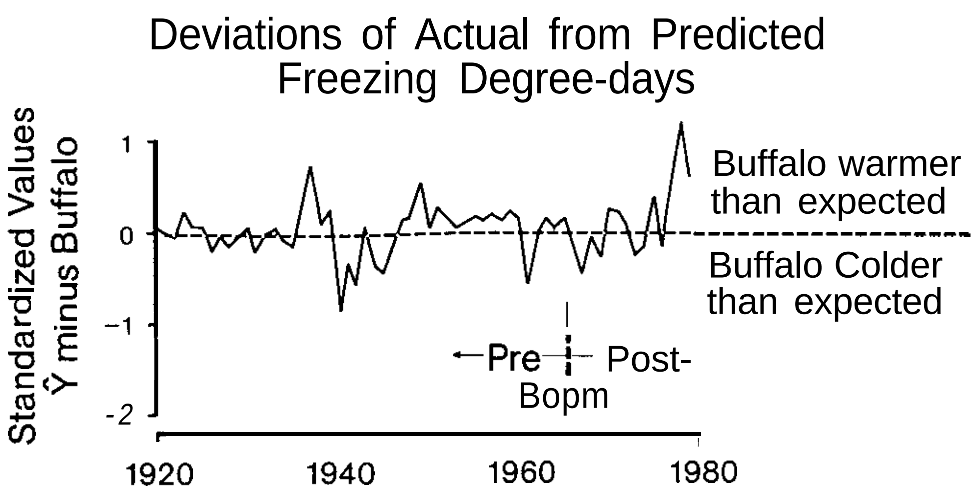

Figure 8.--*Deviations of actual-from predicted FDD accumulations at Buffalo (Y-Buff), 1920-79.*

In addition to investigating the intensity of winter severity, indicated by the maximum FDD accumulation each winter, the duration of Buffalo winters was also investigated through the use of TDD's. TDD's are the deviation of average daily air temperature above 0°C (32°F). Cumulative values of TDD's for March and April represent an index of the duration of the winter season air temperatures: for winter-like weather in spring, smaller TDD values would be accumulated. If the ice boom has had the effect of extending the duration of the winter season at Buffalo, this should be reflected in a marked decrease in TUD accumulations for post-ice boom winters as compared to pre-ice boom winters. A time series of TDD's at Buffalo and the three-station regional average used in the FDD analysis was calculated for TDD accumulations for March and April. The time series was standardized for the base period 1897 to 1960, as was the FDD time series. The TDD time series for Buffalo and the regional average are given in figure 9. Figure 9 shows that the extreme winters, i.e., the longest and the shortest, occurred prior to the ice boom installation and also that the trend at Buffalo is the same as the regional average for almost the entire period of record. Figure 10 shows the cumulative standardized values at Buffalo and the region. From figure 10 it can be seen that the trend in winter duration has been toward longer winters from 1898 to 1943 and then toward shorter winters to 195X. From 1958 to the present winter, duration has also tended to decrease for Buffalo, but has tended to increase for the region. Warmer temperatures at Buffalo in March and especially in April after 1943, and thus in post-ice boom years, can be attributed to the 1943 station move from downtown to the airport location; there warmer recorded temperatures are responsible for the apparent trend toward shorter winters at Buffalo from 1958 to the present.

In order to examine the variability of winter duration during this post-ice boom period in greater detail, we ranked the years of the post-ice boom periods from shortest winter to longest at Buffalo and the region (table 12). From table 12 it can be seen that four of the five shortest and four of the five longest winters were the same at Buffalo and the region, indicating that, regardless of when the ice boom was removed each winter, it is the general weather prevailing in the region that determines the length of the winter season at Buffalo, as reflected by the comparison of winter length at Buffalo and the regional average.

To further investigate the relative length of the winter season at Buffalo compared to the region in the pre- and post-ice boom periods, we calculated a difference series of the standardized TDD (Buffalo region) for the 15 winter post-boom period and four 15-year pre-boom periods (table 13). Plus signs indicate that, compared to the region, Buffalo had shorter winters relative to its mean. Table 13 shows that the only pre-boom period similar to the post-boom period was 1950-64, where in 12 of the 15 winters Buffalo had a relatively early spring compared to the region. In the period 1935-49, the region had earlier winters about as frequently as Buffalo (eight for Buffalo, seven for the region). And in the two earliest pre-boom periods, 1920-34 and 1905-19, the region had relatively shorter winters than Buffalo. Thus, there is no evidence to suggest that Buffalo has had a disproportionate increase in the length of its winters in the post-boom period.

A second method used to examine the relationship between pre- and post-ice boom winter duration relative to the regional trend is regression analysis. Since the standardized TDD series for Buffalo and the region show similar trends, a regression equation of Buffalo TDD's on the regional average was used

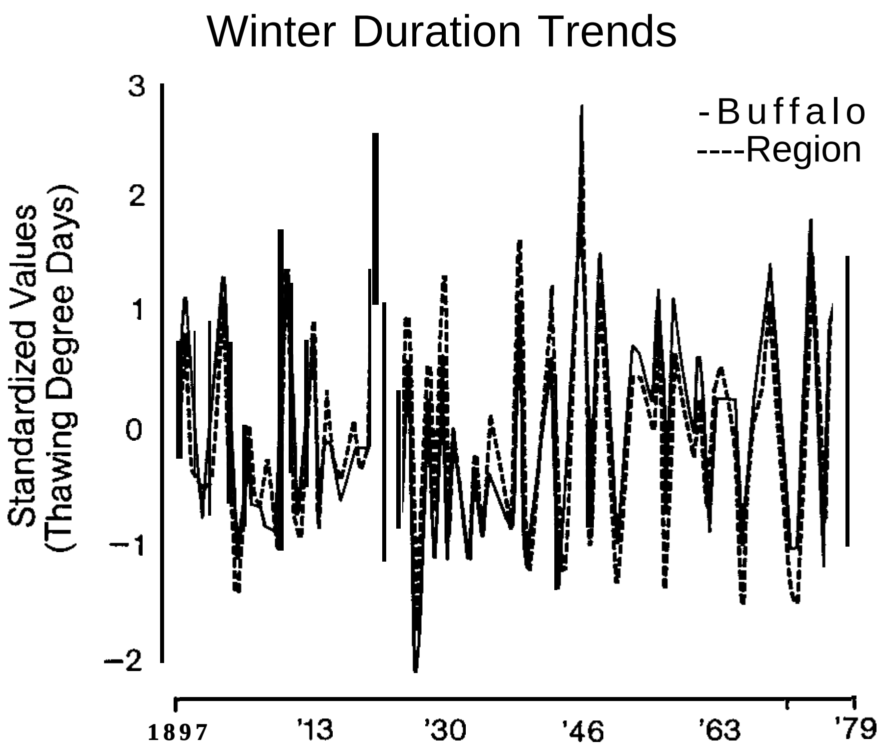

Figure 9.--Standardized TDD values for Buffalo and the three-station regional average for March and April.

to predict TDD's at Buffalo. As with the FDD analysis, the regression was based on 45 pre-boom years (1920-64). Deviations of actual TDD's at Buffalo from the predicted values based on the regression are shown in figure 11 (Y-Buff). Positive deviations indicate that Buffalo had longer than expected winters and negative deviations indicate Buffalo had shorter than expected winters. The regression overestimates the length of winter during the post-ice boom period, but this is related to the station move in 1943 rather than the ice boom as can be seen in figure 11.

6. CONCLUSIONS

Based on our analysis, there is no evidence to suggest that the ice boom has enhanced winter severity at Buffalo relative to other areas around the Great Lakes. Winter severity at Buffalo during the post-boom period is within the range of natural climatic variability identified during the pre-ice boom

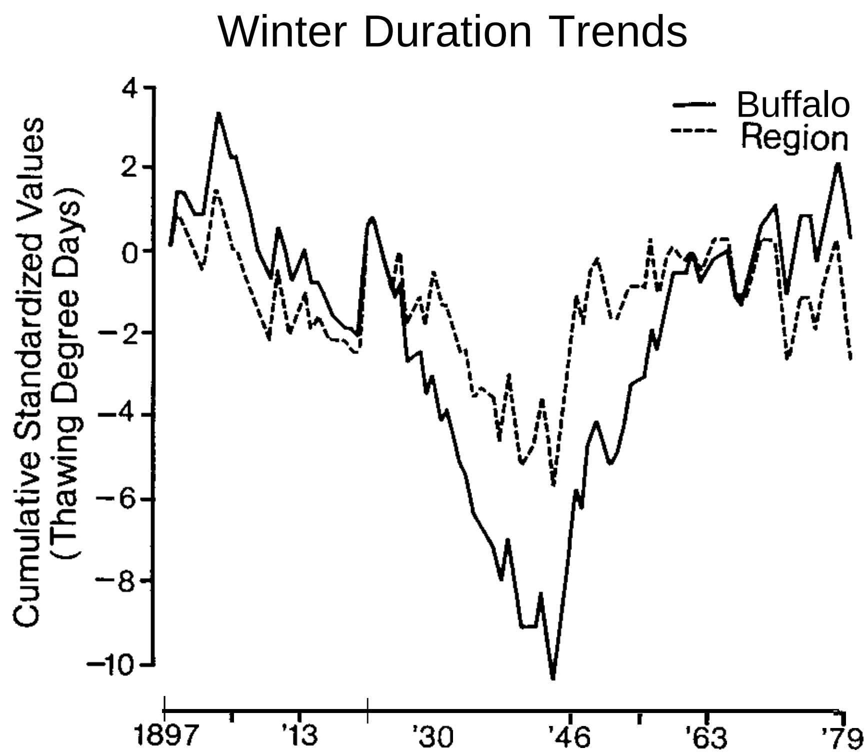

Figure 10.--*Cumulative standardized TDD values for Buffalo and the region.*

winters: the ice boom has not had an identifiable impact on the winter climatic regime at Buffalo.

The analysis showed that there was a statistically significant change in monthly average temperature in March, April, and May, as well as other months, because of the relocation of the instruments from downtown Buffalo to the airport. In addition, the relocation of the instrument from a roof top to a ground exposure in 1960 also caused a difference in the average monthly air temperature record so that the Buffalo air temperature record for determining the possible impact of the boom on a monthly time scale is limited to the period 1961-79. As to the question of the validity of the airport temperature record, if *a dramatic* cooling took place in the local climate at Buffalo during the late winter-early spring months as a result of the ice boom, it should have been observable at the airport. Since our analysis did not show a statistically significant cooling for this period, we conclude a *dramatic* cooling did not take place. These results, however, do not rule out the possibility of an impact of a smaller magnitude occurring in the immediate vicinity of the boom. Thus, the use of the airport temperature record is valid, but it limits the analysis we can make in determining the geographic extent of any cooling that may have occurred.

Table 12.--*Ranking of post-ice boom winter length index, 1965-79*

Rank	Buffalo	Region
1	1973	1973
2	1977	1968
3	1968	1977
4	1976	1976
5	1967	1974
6	1969	1967
7	1970	1969
8	1974	196b
Y	1966	1970
10	1979	1975
11	1971	1979
12	1972	1971
13	1965	1972
14	1978	1965
15	1975	1978

Five shortest (rank 1-5)	4 of 5 same as Buffalo
Five longest (rank 11-15)	4 of 5 same as Buffalo
Five intermediate (rank b-10)	3 of 5 same as Buffalo

Table 13.--*Difference series of standardized TDD's, Buffalo minus region*

Period	1 1965	2 1966	3 1967	4	5	6	7	8	9	10	11	12	13	14	15	+	-
1965-79	+	-	+	+	+	+	+	+	+	+	+	+	+	+	+	14	1
1950-64	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	12	3
1935-49	-	-	+	-	-	+	-	-	-	+	+	+	+	+	+	8	7
1920-34	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	2	13
1905-19	-	-	-	-	+	-	+	+	-	+	-	+	-	-	+	6	9

Plus (+) indicates Buffalo had shorter winter, relative to its mean, than region.

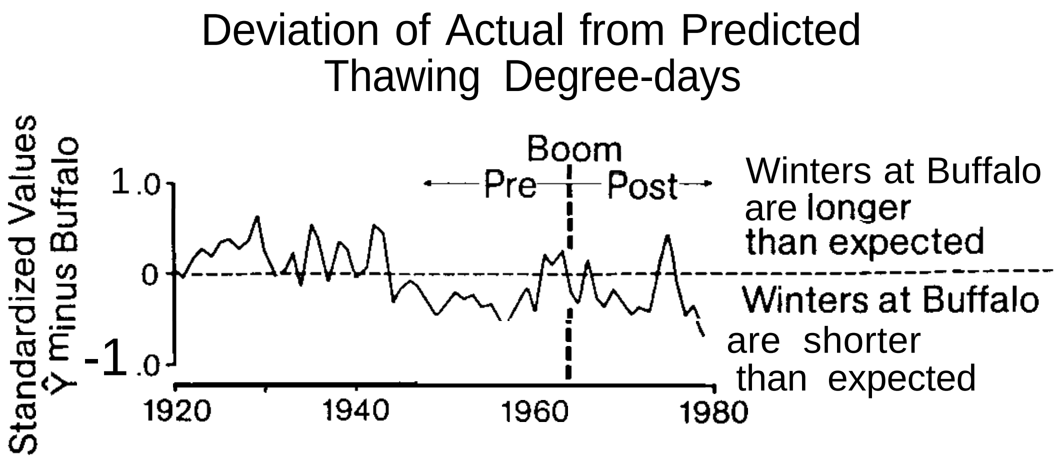

Figure *I1.--Deviation of actual from predicted TDD at Buffalo (Ŷ-Buff), 1920-79.*

The effect of the Lake Erie ice cover and heat storage on extending the winter-like weather at Buffalo can be seen by comparing air temperatures at Buffalo and Lockport. Buffalo temperatures are cooler in spring because of ice cover and because of cooling of the air as it moves over the ice or water after the ice melts. Away from the shore, the magnitude of the cooling decreases as indicated by our comparison of temperature records at the airport and downtown Buffalo for the years of 1941 and 1942; the maximum average monthly temperature difference was 2°F for May.

The severity of winters at Buffalo was examined in terms of FDD's and TDD's as indexes of the severity (coldness) and duration (length) of the winters at Buffalo. Compared to a 62-winter mean (1897-1960) of FDD accumulation, winters at Buffalo during post-boom years are higher (cooler) than the mean, but these cooler winters began in 1958 and are part of a climatic trend toward cooler winters that began that year. This same trend is seen in a 3-station regional average of FDD's and a 25-station Great Lakes average FDD time series. Thus, winter severity at Buffalo is very similar to that of the regional and Great Lakes winter severity trends. A regression equation of the regional and Buffalo FDD's based on the period 1920-64 was used to predict winter severity for the post-boom period. Because the residuals for the post-boom period did not show a marked difference from the residuals of the pre-boom period, it is concluded that post-boom winter severity has not been affected by the ice boom. Winter duration was examined through the "se of TDD accumulations in March and April. Comparison of TDD values for the regional average and for Buffalo for 83 years show that trends in winter TDD's, and thus "inter duration, are the same for Buffalo as for the region for pre-boom years. In addition, the trend in winter duration in post-boom years does not suggest that Buffalo has had longer winters during that period compared to the region or compared to winter duration at Buffalo in pre-boom years. Thus, the ice boom has not increased winter duration.

The analysis of the water temperature parameter is consistent with the results of the TDD analysis in that it has shown that the ice boom has not had an impact on the timing of the spring rise in the Lake Erie water temperature at Buffalo.

7. ACKNOWLEDGMENTS

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