Ohio Sea Grant

A SPRING-SUMMER (APRIL-SEPTEMBER) CLIMATOLOGY OF THE LAKE ERIE BASIN

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ABSTRACT

The effects of Lake Erie upon the meteorology and climatology of the lake basin during the spring and summer months are investigated. The major driving force behind these effects is seen to be the temperature difference between lake and land, the lake surface being cooler than the mean land temperature for all months during the period except September. Specific climatic variables are examined as well as any possible lake influence upon them. The report, therefore, constitutes a climatology of the Lake Erie region from the months of April through September.

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CHAPTER 1

INTRODUCTION

While the effects of the Great Lakes on the meteorology of the region during the cold season are reasonably well known [Petterssen and Calabrese (1979), Danard and Rao (1972), among others], comparatively little is known about their effects during the spring and summer months. This report surveys the current body of knowledge concerning the meteorology and climatology of the Lake Erie basin, in particular, during the months of April through September; it, therefore, constitutes a spring-summer climatology of this region. Such a survey is important in order to better understand the weather in the region and as a basis for possible future research studies which might lead to improved understanding of Lake Erie-related weather during this time of year. Consideration of the period from October through March will be treated in a later report.

1.1. General Description

Anyone living near the shoreline of Lake Erie can attest to the fact that its water can exert a marked cooling effect on the local climate, especially during the spring months. Trees and shrubs bloom one to two weeks later than they do inland and the lake breeze is a common occurrence. On a larger scale, Lake Erie also significantly influences the weather of northern Ohio, northwestern Pennsylvania, western New York, extreme southern Ontario, and southeastern Michigan.

There are a number of reasons why the study of "Lake Erie meteorology" is of practical importance. It is useful in agriculture for classifying areas suitable for certain crops and in deciding planting schedules.

Vineyards along the south shore of Lake Erie are examples of the benefits of Lake Erie in extending the frost-free period over that inland. Secondly, the large cities of Toledo, Cleveland (Ohio), Erie (Pennsylvania), Buffalo (New York), and Detroit (Michigan) are located on or near the shore of Lake Erie. Thirdly, the shoreline area is a popular holiday area. Finally, knowledge of lake winds is important to boating and shipping.

Figure 1 depicts the Lake Erie basin, while Table 1 lists some of the dimensions of Lake Erie. Covering an area of 9930 square miles, Lake Erie is only the fourth largest of the Great Lakes. It is the most southerly of the Great Lakes and also the shallowest with a mean depth of 58 feet. The western end of the lake is the shallowest part, averaging 30-40 feet in depth. Lake Erie comprises 30% of its water basin.

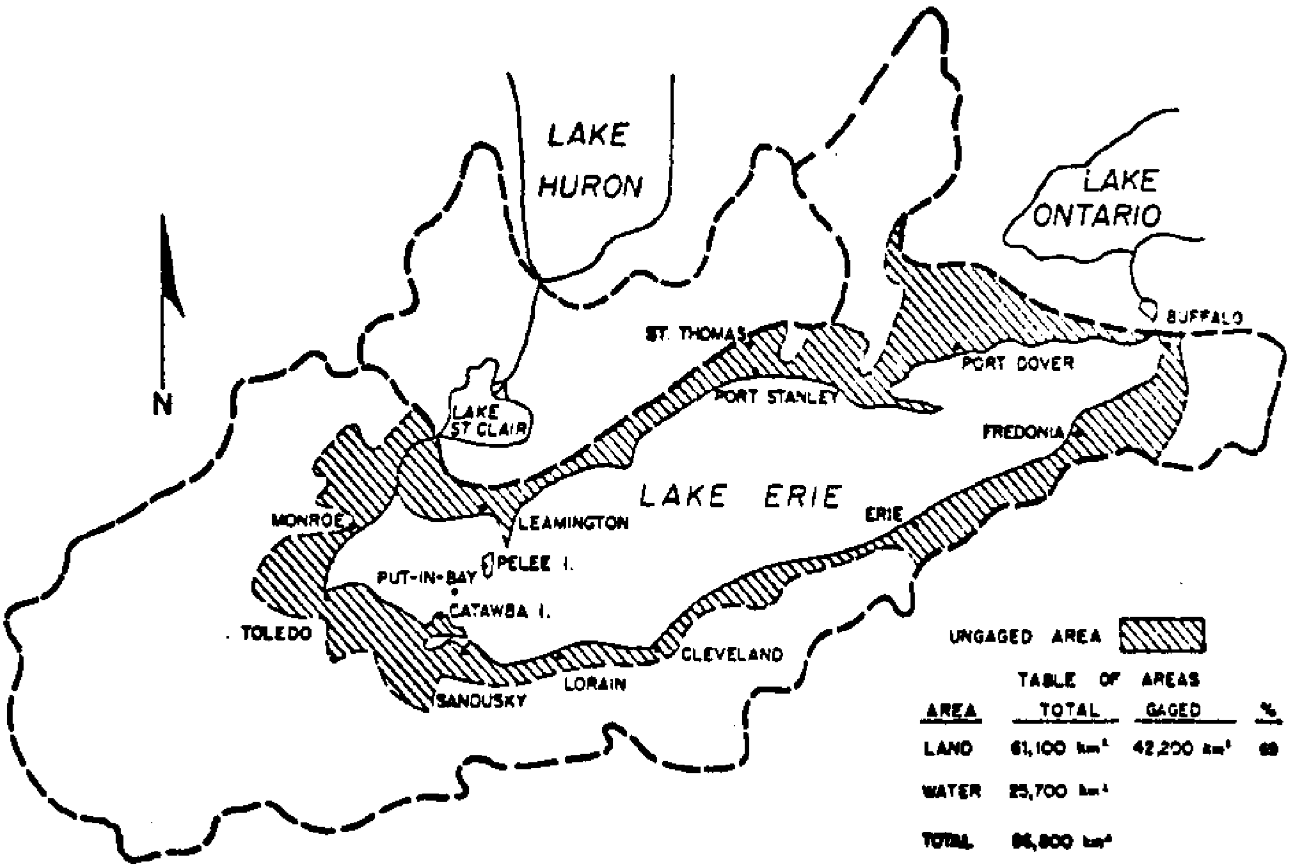


TABLE OF AREAS

AREA	TOTAL	GAGED	%
LAND	61,100 km²	42,200 km²	69
WATER	25,700 km²		
TOTAL	86,800 km²		

Figure 1. Lake Erie basin.
[Derecki (1964)]

TABLE 1. Dimensions of the Great Lakes.
[Jones and Meredith (1972)]

Lake	Length[a] (mi)[c]	Breadth[a] (mi)[c]	Area[a] Water Surface (mi^2)[d]	Area[a] Drainage (ft^3/sec)[e]	Average discharge 1946-1965[b] (ft^3/sec)[e]	Maximum depth[a] (ft)[f]	Mean depth[a] (ft)[f]
Superior	350	160	31,820	80,000	78,000	1,333	487
Michigan	307	118	22,400	67,860		923	276
Huron	206	183	23,010	72,620	St. Clair 182,000	750	195
St. Clair	26	24	490	7430	Detroit 186,000	21	10
Erie	241	57	9930	32,490	Niagara 198,000	210	58
Ontario	193	53	7520	34,800	St. Lawrence 239,000	802	283

[a] Source: U.S. Army Engineer Division, North Central (1965a).
[b] Source: From data supplied by U.S. Department of Commerce, Lake Survey Center (personal communication).
[c] 1 mile (mi) = 1.61 kilometers (km).
[d] 1 square mile (mi^2) = 2.59 square kilometers (km^2).
[e] 1 cubic foot per second (ft^3/sec) = 0.028 cubic meters per second (m^3/sec).
[f] 1 foot (ft) = 0.305 meters (m).

1.2. Order of Investigation

Chapter 2 examines the physical basis behind the effects of Lake Erie on the meteorology during the spring and summer months. The thermal properties of water versus soil are looked at with a view to better understanding the lake-land temperature differences, which are the primary driving forces behind the lake effects.

Chapter 3 presents the general effects of Lake Erie on the meteorology and climate. The chapter first discusses the most local effects in horizontal scale, the lake and land breezes. Then, geostrophic flow across the lake is examined and, finally, the climatological effect of the lake on the large-scale pressure patterns is presented.

Chapter 4 looks at the various climatic variables and how Lake Erie affects them. Temperature, humidity, solar radiation, wind, evaporation, precipitation, and severe weather are each examined in turn.

Finally, Chapter 5 provides a brief summary of the report.

CHAPTER 2

PHYSICAL BASIS BEHIND THE METEOROLOGICAL INFLUENCE OF LAKE ERIE

Any discussion of the physical causes behind any effects of Lake Erie on the region's meteorology must of necessity focus on the differences between the surface boundaries of lake versus land. In other words, one must understand the physical properties of both water and soil.

2.1. Surface Roughness

A fixed land surface provides a different lower boundary condition for the atmosphere than does a changing water surface. Roughness length z_0 is a rough measure of the friction exerted by the surface on the atmosphere and is mainly a function of the type of surface. For land, z_0 varies from 1 cm for short grass to 165 cm for a large city to 283 cm for a fir forest [Sellers (1965]. For water, z_0 ranges from 1×10^{-4} cm to 50 cm [Munn (1966)]. Hence, the generally smoother lake surface means there is less friction to slow a given air flow. Accordingly, winds might be expected to be stronger over the lake. That this occurrence is not always true will be seen later in this report, where it is seen that the thermal structure over the lake plays a governing role as well.

2.2. Moisture Supply

A lake surface obviously provides a greater amount of water per surface area for evaporation than does land. In the winter this fact leads to greater evaporation over Lake Erie, resulting in lake-effect snow squalls on the lee side of the lake. During other seasons of the year, however, the greater availability of water on the lake surface does not necessarily lead to greater evaporation over the lake. As will be seen later, the thermal stratification over the lake is again important and during the spring months the cooler lake suppresses evaporation and in April, may actually cause a net condensation.

2.3. Surface Temperature

2.3.1. Thermal Properties. Table 2 presents values of two physical properties for different types of soil and water. *Heat capacity* C is the amount of heat, in calories, needed to raise the temperature of one cubic centimeter of substance by 1°C. As can be seen in the table, the heat capacity of water is 1.00 whereas that of soil varies from 0.23 to 0.67 for the types listed. Thus land heats more rapidly than does water. This fact accounts for some of the observed temperature differences between the lake and land.

TABLE 2. Thermal properties of soil and water [Adapted from Sellers (1965)].

Soil	Heat Capacity C (cal/°C cm^3)	Thermal Diffusivity κ (cm^2/s)
Dry quartz sand	0.23	.0030
Quartz sand, 40% moisture	0.65	.0090
Sandy clay, 40% moisture	0.67	.0066
Peat, 40% moisture	0.50	.0010
Water		
Still	1.00	.0014
Stirred (stable)	1.00	50.
Stirred (neutral)	1.00	300.

The other property is the *thermal diffusivity* κ, which is an inverse measure of the time it takes for surface temperature changes to penetrate to lower depths. For still water the κ values are of the same order as those of soil. However, the water in Lake Erie is not still and for such water the heat transfer occurs through turbulence and values for κ (now representing "eddy" diffusivities) are thousands of times that for land. Hence, heat flux downward within water occurs much faster than within soil. Accordingly, temperatures at the surface (the level of meteorological interaction) exhibit greater extremes in soil than in water, both diurnally and annually.

2.3.2. Lake-Land Temperature Differences. These two properties combine to make the average monthly Lake Erie surface temperature lower in summer and higher in winter than over land. Greater mixing within the lake also causes the surface temperature of Lake Erie to lag behind that of the land by about a month. These temperature differences are presented in Table 3, where Cleveland is chosen as the land station.

The meteorological and climatic controls exerted by Lake Erie on the region during the spring-summer months are due largely to such lake-land temperature differences. Since these differences are crucial, consider also Figure 2, which is a graph of the average maximum, mean, and minimum temperatures for Sandusky, Ohio, for the months of April through September. Also plotted is the average Lake Erie surface temperature for these months.

Note that the average daily high over land is greater than the lake temperature throughout the entire period, the greatest difference occurring in May (+19.3°F). The average mean temperature over land also exceeds that of the lake for all months except September; the greatest positive difference also occurs in May (+10.3°F). The average minimum

TABLE 3. Average monthly temperatures (°F) of Lake Erie and Cleveland, Ohio. [Adapted from Climates of the States (1974) and Richards & Irbe (1969)]

	Cleveland	Lake Erie
JAN	28.5	34
FEB	28.6	33
MAR	36.8	33
APR	47.3	38
MAY	59.1	49
JUN	69.4	63
JUL	73.7	70
AUG	71.9	72
SEP	65.5	67
OCT	54.4	59
NOV	41.7	49
DEC	30.9	39

temperature over land is lower than the lake temperature for all months except April and May.

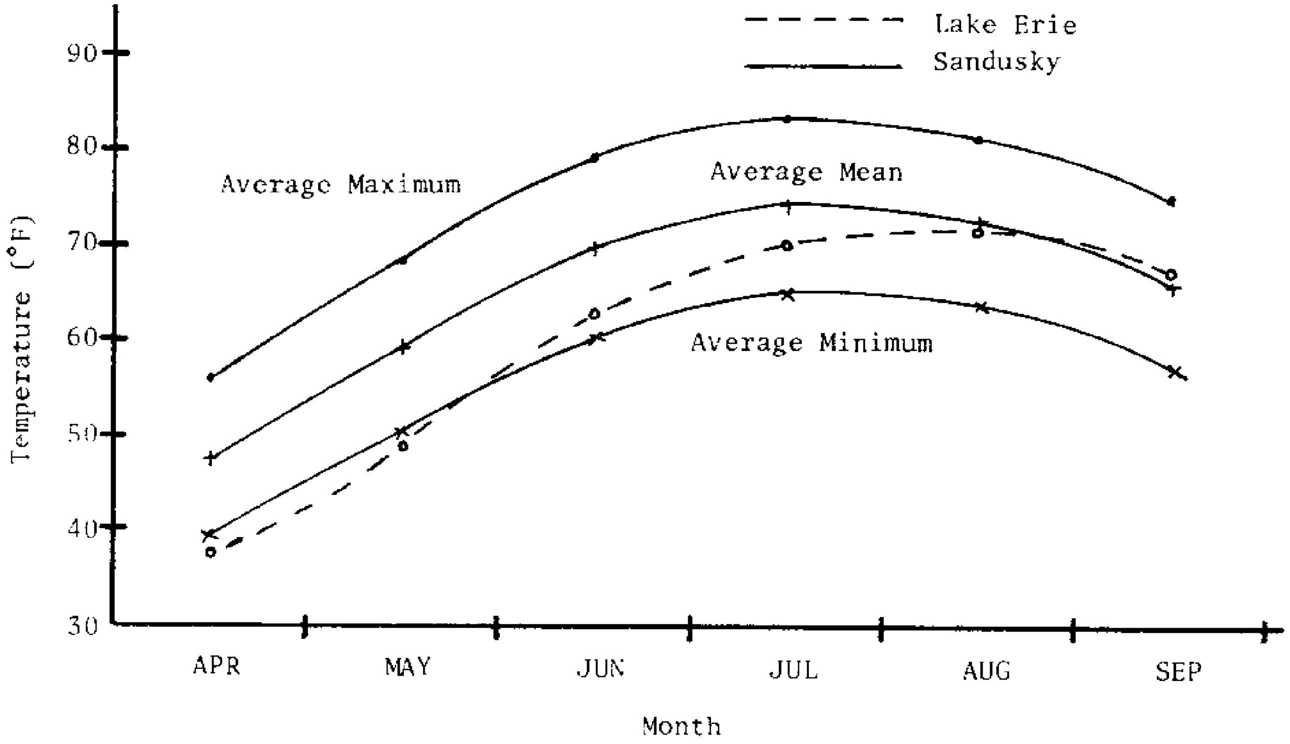


Figure 2. Lake-land temperatures for the spring and summer months. [Data from Climates of the States (1974) and Richards and Irbe (1969).]

CHAPTER 3

GENERAL METEOROLOGICAL EFFECTS OF LAKE ERIE UPON THE REGION

In this chapter some of the observed effects of Lake Erie upon the meteorology and climatology of the region are presented. Local winds are examined first. Then, effects of a greater horizontal scale are discussed.

3.1. The Lake and Land Breezes

During periods of light geostrophic winds, the lake-land temperature differences may lead to mesoscale circulation cells. Warmer temperatures over land cause the lake breeze phenomenon, with surface winds blowing from lake to land. Cooler land temperatures may induce a weaker land breeze, with surface winds blowing toward the warmer lake. From Figure 2, one can infer that, on the average, lake breezes are possible during the daytime of all the months studied, being strongest and most probable in the spring months. A land breeze may develop during the night hours in the summer.

An excellent observational study of the Chicago lake breeze was conducted by Lyons (1972). Analyzing mesoscale data from ten summer months (1966-68), Lyons found the lake breeze to occur on 36% of all days. Time of onset averaged from 0800-0900 LST and the lake breeze front was found to push inland anywhere from one block to over 40 km. The typical circulation pattern (see Figure 3) is seen to have an inflow layer depth of 500 m and a return layer aloft twice as deep. Surface inflow speeds average about $6 \mathrm{~m~s^{-1}}$ with return speeds aloft half as large.

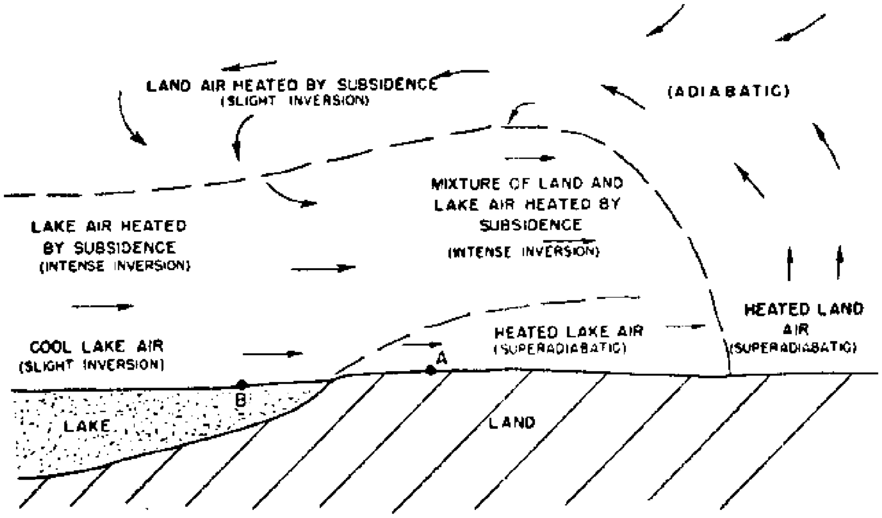


Figure 3. Schematic representation of a lake breeze with light geostrophic wind. [Munn and Richards (1964)]

The lake breeze front is a 1 - 2 km wide band of convergence with updrafts of more than 1 m s^{-1}, often accompanied by cloud bands due to the uplifting. Subsidence occurs over the lake, resulting in clear skies there and over the shoreline. A mesoscale high pressure cell develops over the lake. Lyons also found the lake breeze to veer with time in response to Coriolis accelerations, so that by evening the breeze is parallel to the shoreline.

Munn and Richards (1964), in a survey article on the lake breeze, indicated that passage of the lake breeze front is accompanied by a sharp fall in temperature and rise in relative humidity (due to the cooler temperature). They also observed "surges" of the lake breeze along the north shore of Lake Erie.

Numerical models have also been developed to study the lake breeze, among which are those of Estoque (1962), Moroz (1967), Mahrer and Pielke (1977), and Danard (1978).

3.2. Geostrophic Flow Over the Lake

During periods of substantive geostrophic winds, modification of the air being advected over the lake occurs. During the spring and early summer, such air is usually warmer than the underlying lake water.

Bellaire (1965) presents an observational study of a warm air mass moving directly northward over Lake Michigan in May of 1964. Wiresonde soundings from a ship were taken from the southern tip of Lake Michigan to a point 70 miles north. Figure 4 depicts the thermal cross-section observed. Air leaving the south shore is cooled, forming a temperature inversion whose top rises in height to an equilibrium value of about 350 feet at 50 miles downwind. Winds were observed to rapidly decrease over the lake; beyond 20 miles the water surface was rippled to smooth. Hence, warm air advection leads to a shallow dome of cold, stable air over the lake.

Lyons (1970), in another similar study, studied warm air advection over Lake Michigan in June of 1966. This time the air flow was southwesterly and wiresonde soundings were made along a line from Waukegan, Illinois, to Saugatuck, Michigan. Figure 5 presents the thermal cross-section. The inversion top in this case gradually increased to 150 m near the eastern shore in the afternoon. Vertical temperature gradients as large as $+9^{\circ}C/30m$ over the middle of the lake were observed between ship deck and the lake surface. Once ashore, the lake air undergoes remodification and an internal boundary layer characterized by convergence and uplift occurs.

Clouds moving over the lake were observed by Lyons to dissipate within 15 km of the windward lake shore and the air over the lake was cloud-free. Over the lake, surface wind speeds decreased due to the

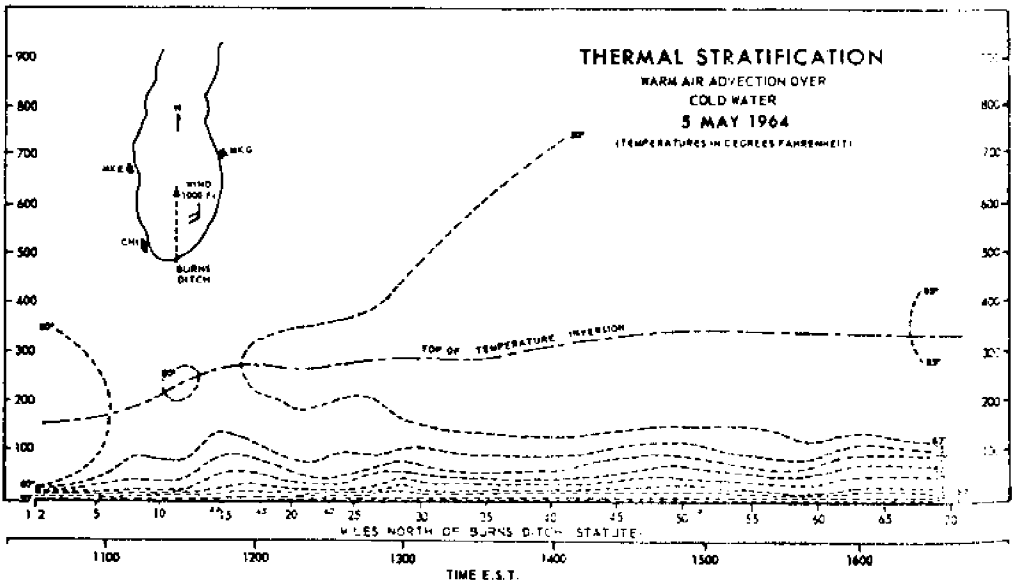


Figure 4. Temperature cross-section obtained from wiresonde soundings, May 5, 1964. [Bellaire (1965)]

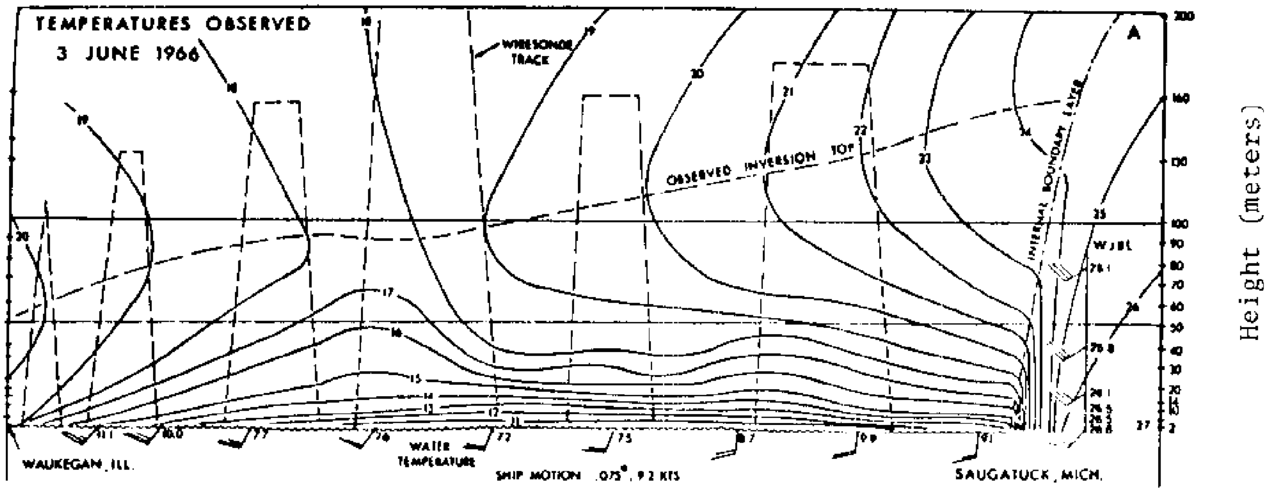


Figure 5. Temperature cross-section obtained from wiresonde soundings on June 3, 1966. One wind barb equals 5 knots; temperature is in °C. [Lyons (1970)]

greater stability of surface air. The wind also backed in direction over the lake due to the development of a lake mesohigh having a pressure excess of 2 - 4 millibars over the prevailing synoptic value.

The lake mesohigh is the subject of an article by Strong (1972). In an observational study over Lake Michigan, he found the warm offshore wind to experience a pronounced upward lifting as it approached the windward shoreline and then to undergo strong subsidence (as large as $-1\ \mathrm{m\ s^{-1}}$) as it moved over the lake. The most intense lake high observed during the study was one having a pressure excess of 2 mb. He also found the winds to back in direction as air moved over the lake.

3.3. Lake Effect on Climatological Pressure Patterns

From the discussion thus far it might be inferred that, on the average, the Great Lakes should be a region with higher pressure than surrounding areas during the spring and early summer months. Such is indeed the case. Charts from Klein's (1957) paper show local maxima over the Great Lakes during these months for the number of anticyclone centers observed in a 20-year period. Also, major tracks of anticyclones cross the region.

Carlson (1974) produced a quantitative argument for the existence of these high pressure zones during the months of April through June. Using surface heat budget models, he established the surface sensible heating fields over the Great Lakes region and from them calculated the thermally induced vertical motion fields at 900 mb. Figure 6 presents the results. In the absence of any synoptic systems, the surface heating fields cause subsidence over the cooler lake waters on the order of -0.1 to $-0.4\ \mathrm{cm\ s^{-1}}$, the same order as that observed within actual anticyclones. Such subsidence encourages anticyclones to develop and maintain themselves over the lakes.

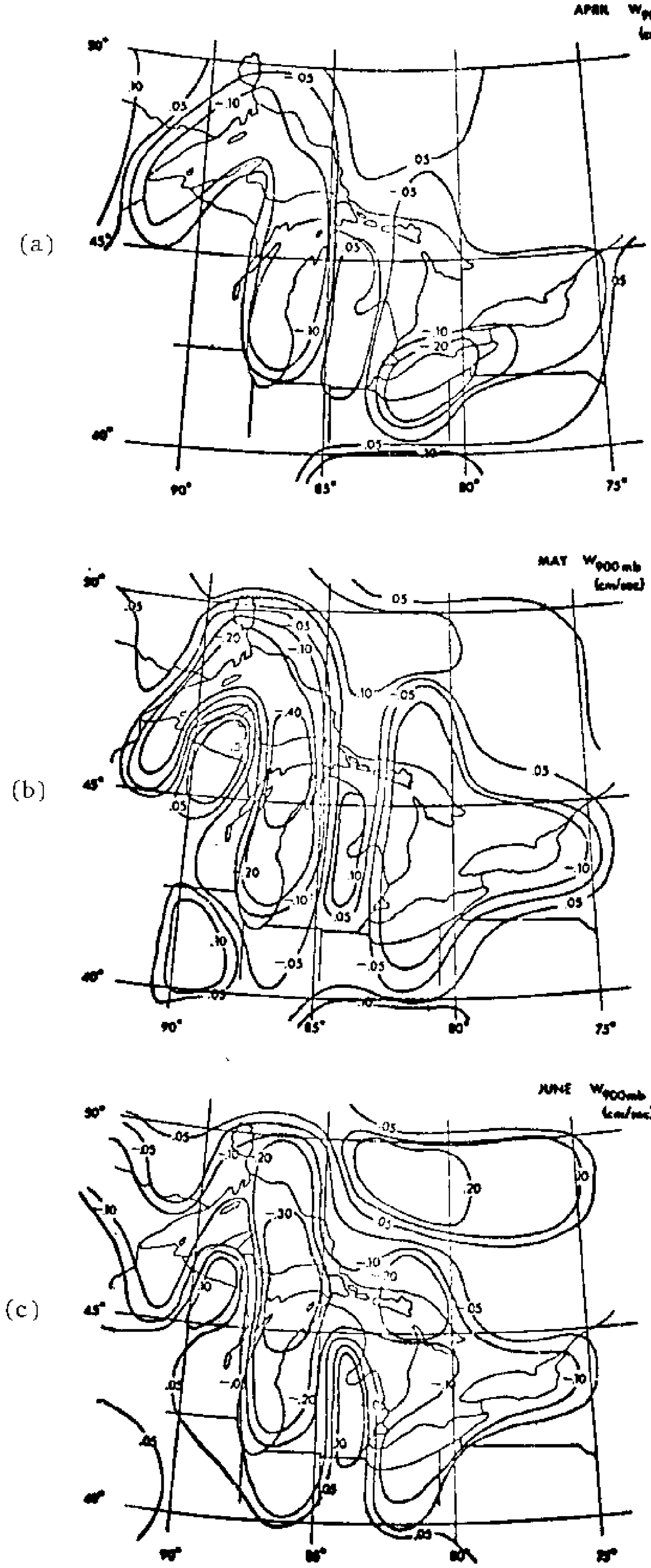


Figure 6. Mean induced vertical motions at 900 mb height over the Great Lakes area for April (a), May (b), and June (c). [Carlson (1974)]

CHAPTER 4

CLIMATIC VARIABLES IN THE LAKE ERIE BASIN

At the beginning of this section are presented the climatic data tables for Toledo, Sandusky, and Cleveland, Ohio, for Erie, Pennsylvania, for Buffalo, New York, and for Detroit, Michigan. These tables, Tables 4 - 9, respectively, are taken from Climates of the States (1974).

4.1. Temperature

Tables 4 - 9 give the average daily maximum, mean, and minimum temperatures for each month for each of the six cities mentioned above.

To see the effect of Lake Erie on temperatures near the shoreline, consider Figures 7 - 10, which are maps of the average daily maximum and minimum temperatures for April and July for the Great Lakes region [Phillips and McCulloch (1972)]. In April and July (see Figure 2) Lake Erie is cooler than the average maximum temperatures over land. Accordingly (Figures 7 and 9), the temperature contours reflect large gradients as Lake Erie is approached, with cooler shoreline temperatures during the daytime than further inland. At night in April (Figure 2), the nearly equal temperatures of lake and land result in negligible lake influence in April (Figure 8) on nighttime temperatures. In July, however, lake temperatures are warmer at night (Figure 2) and the temperature contours (Figure 10) reflect this fact, with shoreline night temperatures being warmer than further inland.

The influence of Lake Erie on temperatures can also be seen from Table 10, which lists the 1893-1921 monthly averages of temperature and precipitation for April through September for Cleveland and North Royalton,

TABLE 4. Climatic data for Toledo, Ohio. [Climates of the States (1974)]

LATITUDE 41° 36' N
LONGITUDE 83° 48' W
ELEVATION (ground) 676 Feet

TOLEDO, OHIO
EXPRESS AIRPORT

	Temperature							Normal degree days	Precipitation												Relative humidity				Wind					Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days										
	Normal			Extremes												Snow, Sleet											Fastest mile					Sunrise to sunset							Temperatures Max.		Min.	
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	1:00 a.m., EST	7:00 a.m., EST	1:00 p.m., EST	7:00 p.m., EST	Mean hourly speed	Prevailing direction	Speed	Direction	Year			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	90° and above	32° and below	32° and below	0° and below
(a)	(b)	(b)	(b)	87		87		(b)	(b)	87		87		87		73	73		73		17	29	27	29	77	9	46			58	87	87	87	87	87	67	67	86	84	84	84	84
J	34.7	18.0	26.4	71	1950+	-16	1887	1197	2.25	6.67	1913	0.52	1943	1.58	1948	8.0	26.2	1918	9.8	1885	80	80	72	76	12.6	WSW	66	SW	1940	33	7.0	6	8	17	13	3	*	1	0	14	27	2
F	36.0	18.6	27.3	71	1944	-16	1885	1056	1.80	6.04	1887	0.09	1877	2.28	1883	6.9	25.1	1900	19.0	1900	80	78	68	73	12.5	SW	63	SW	1919	40	6.5	6	8	14	11	2	*	1	0	12	25	2
M	45.6	25.0	35.8	83	1910	-10	1943	905	2.88	7.99	1913	0.05	1910	2.89	1913	5.1	17.1	1916	8.4	1888	79	78	62	70	13.0	SW	87	SW	1948	47	6.2	6	9	14	13	2	2	1	0	5	22	*
A	58.0	35.0	46.5	89	1942+	12	1875	555	3.25	7.13	1929	0.55	1876	2.93	1920	1.3	12.0	1957	9.8	1957	78	78	56	64	12.8	WSW	72	SW	1956	50	5.7	9	9	12	12	*	3	*	0	*	7	0
M	70.4	46.0	58.2	95	1911	28	1945	245	2.95	8.04	1943	0.45	1881	3.57	1913	0.1	4.0	1923	4.0	1923	81	75	55	63	11.0	ENE	58	SW	1917	59	5.2	10	11	10	12	*	5	*	*	0	*	0
J	80.7	56.5	68.6	101	1934	36	1945+	60	3.55	7.88	1911	0.12	1952	3.44	1944	0.0	0.0		0.0		83	78	54	63	9.8	SW	56	W	1930	63	4.8	11	12	7	11	0	7	*	3	0	0	0
J	85.3	60.9	73.1	105	1936	44	1945	0	2.65	6.65	1896	0.35	1916	2.47	1929	0.0	0.0		0.0		83	76	52	58	9.1	SW	78	SW	1922	71	4.1	14	12	5	9	0	7	*	5	0	0	0
A	83.0	59.9	71.0	103	1918	41	1965	12	2.69	7.84	1926	0.60	1894	4.56	1920	0.0	0.0		0.0		85	86	54	63	8.8	SW	76	W	1924	67	4.2	14	11	6	9	0	5	*	4	0	0	0
S	75.8	52.5	64.2	104	1953+	28	1942	102	3.02	8.07	1926	0.37	1945	5.98	1918	0.0	0.0		0.0		84	82	55	67	8.7	SW	62	S	1919	62	4.4	13	10	7	9	0	3	1	1	0	0	0
O	63.9	41.5	52.7	92	1951	21	1952+	387	2.33	8.49	1881	0.32	1892	3.10	1881	T	1.2	1925	1.1	1925	83	83	56	66	10.5	SW	57	SW	1916	55	5.1	12	8	11	9	*	2	1	*	0	2	0
N	48.9	30.7	39.8	80	1950	2	1947+	756	2.18	5.58	1927	0.04	1904	2.68	1871	2.0	12.0	1932	11.5	1932	81	81	66	73	12.4	SW	78	SW	1919	36	6.8	7	8	15	11	1	1	1	0	2	14	0
D	36.9	20.9	28.9	70	1889	-15	1872	1119	2.29	5.74	1923	0.33	1919	2.04	1885	7.0	25.5	1951	10.8	1909	81	82	73	76	12.3	SW	69	SW	1920	30	7.1	5	8	18	12	2	*	1	0	10	24	1
Year	59.9	38.8	49.4	105	July 1936	-16	Jan. 1887+	6394	31.84	8.49	Oct. 1881	0.04	Nov. 1904	5.98	Sept. 1918	30.4	26.2	Jan. 1918	19.0	Feb. 1900	82	79	60	66	11.2	SW	87	SW	Mar. 1948	53	5.6	115	114	136	131	10	35	7	13	43	121	5

TABLE 5. Climatic data for Sandusky, Ohio. [Climates of the States (1974)]

LATITUDE 41° 27' N
LONGITUDE 82° 43' W
ELEVATION (ground) 603 feet

SANDUSKY, OHIO
POST OFFICE BUILDING

Month	Temperature							Normal degree days	Precipitation												Relative humidity			Wind					Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days										
	Normal			Extremes												Snow, Sleet										Fastest mile					Sunrise to sunset							Temperatures			
																																						Max.		Min.	
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	7:00 a.m., EST	1:00 p.m., EST	7:00 p.m., EST	Mean hourly speed	Prevailing direction	Speed	Direction	Year			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	90° and above	32° and below	32° and below	0° and below
(a)	(b)	(b)	(b)	80		80		(b)	(b)	81		81		81		73	73		73		53	25	20	80	80	80	80		47	69	80	80	80	81	66	74	74	80	80	80	80
J	35.7	21.8	28.8	73	1950	-16	1879	1122	2.29	6.58	1937	0.60	1902	1.71	1937	8.2	29.8	1893	11.8	1910	81	68	78	10.8	SW	56	SW	1952	35	7.4	5	8	18	14	4	0	1	0	13	28	2
F	36.4	22.4	29.4	72	1944	-15	1899	997	1.92	8.53	1887	0.27	1920	2.98	1887	6.5	22.1	1893	10.1	1900	81	70	76	10.9	SW	64	NE	1881	41	7.0	5	8	15	12	3	0	1	0	11	24	1
M	45.2	29.8	37.5	85	1910	- 3	1885	833	2.89	8.69	1913	0.28	1910	2.96	1913	4.5	16.1	1915	8.7	1955	79	64	74	11.3	SW	56	NW	1918	49	6.7	6	9	16	13	2	2	1	0	5	21	0
A	56.3	39.4	47.9	90	1942	14	1923	513	2.96	6.24	1910	0.35	1915	2.21	1929	1.2	12.0	1957	9.0	1886	73	61	68	10.6	SW	58	SW	1919	52	6.3	7	9	14	12	0	3	0	0	0	5	0
M	68.3	50.2	59.3	93	1941+	32	1923+	217	3.32	9.04	1943	0.64	1934	3.83	1938	0.0	0.0		0.0		72	59	67	9.0	SW	48	SW	1917	62	5.8	8	11	12	13	0	5	0	0	0	0	0
J	79.0	60.7	69.9	104	1934	40	1894	41	3.73	12.51	1937	0.91	1919	5.95	1937	0.0	0.0		0.0		73	58	68	8.1	SW	77	NW	1924	69	5.3	9	13	8	11	0	7	0	3	0	0	0
J	83.7	65.5	74.6	105	1936	50	1918	0	3.45	9.71	1943	0.26	1916	3.87	1935	0.0	0.0		0.0		72	56	65	7.6	SW	69	N	1879	71	4.7	11	14	6	10	0	7	0	5	0	0	0
A	81.7	63.9	72.8	105	1918	45	1946	0	2.81	8.02	1882	0.23	1894	4.20	1906	0.0	0.0		0.0		74	57	67	7.6	SW	63	NE	1885	68	4.8	11	13	7	9	0	5	0	3	0	0	0
S	75.4	57.5	66.5	99	1953+	34	1956+	66	3.26	7.77	1950	0.73	1928	4.28	1950	0.0	0.0		0.0		74	58	68	8.4	SW	52	NW	1897	63	5.0	11	11	8	9	0	3	0	2	0	0	0
O	63.5	46.5	55.0	93	1953	22	1925	327	2.10	6.22	1917	0.43	1897	2.76	1920	T	1.6	1917	1.5	1917	77	59	70	9.3	SW	54	N	1885	55	5.5	10	9	12	10	0	1	1	0	0	1	0
N	49.2	35.2	42.2	82	1950	0	1880	684	2.27	6.43	1927	0.09	1904	2.23	1927	1.9	12.3	1950	12.3	1950	79	66	73	10.9	SW	66	SW	1919	37	7.1	5	8	17	12	1	1	1	0	2	11	0
D	37.6	25.3	31.5	70	1899	-13	1880	1039	2.16	6.27	1881	0.63	1934	1.74	1927	6.1	20.2	1951	9.0	1886	81	71	75	10.8	SW	56	NW	1895	29	7.7	3	8	20	13	3	0	1	0	10	23	0
Year	59.3	43.2	51.3	105	July 1936+	-16	Jan. 1879	5859	33.16	12.51	June 1937	0.09	Nov. 1904	5.95	June 1937	28.2	29.8	Jan. 1893	12.3	Nov. 1950	76	62	71	9.6	SW	77	NW	June 1924	53	6.1	91	121	153	138	13	34	6	13	41	111	3

TABLE 6. Climatic data for Cleveland, Ohio.
[Climates of the States (1974)]

LATITUDE 41° 24' N
LONGITUDE 81° 51' W
ELEVATION (ground) 787 feet

CLEVELAND, OHIO
CLEVELAND HOPKINS AIRPORT

Month	Temperature							Normal degree days
	Normal			Extremes				
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	
(a)	(b)	(b)	(b)	17		17		(b)
J	36.0	20.9	28.5	73	1950	- 9	1942	1132
F	36.4	20.8	28.6	69	1957	- 8	1951+	1019
M	45.3	28.3	36.8	83	1945	- 5	1948	874
A	57.1	37.5	47.3	88	1942	19	1954	531
M	69.9	48.2	59.1	92	1944	29	1947	223
J	80.4	58.3	69.4	101	1944	38	1945	46
J	84.7	62.8	73.7	103	1941	46	1946+	0
A	82.7	61.1	71.9	102	1948	44	1952	10
S	75.8	55.1	65.5	101	1953	32	1942	75
O	64.3	44.5	54.4	90	1946	25	1942	340
N	49.2	34.2	41.7	82	1950	7	1950	699
D	37.5	24.3	30.9	69	1941	- 9	1951	1057
Year	59.9	41.3	50.6	103	July 1941	- 9	Dec. 1951+	6006

Month	Precipitation												
								Snow, Sleet					
	Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)	(b)	16		16		16		16	16		16	
J	2.38	7.01	1950	0.79	1946	1.74	1952	10.6	18.7	1945	9.3	1952
F	2.12	4.64	1950	0.75	1947	1.77	1950	9.7	20.7	1942	7.5	1944
M	2.89	6.07	1954	1.50	1957	2.78	1948	10.9	26.3	1954	14.9	1954
A	2.73	5.90	1950	1.18	1946	1.82	1950	3.1	14.3	1943	7.8	1957
M	2.73	6.04	1947	1.04	1954	3.73	1955	0.0	T	1957+	T	1957+
J	3.05	6.07	1947	1.38	1954	2.79	1946	0.0	0.0		0.0	
J	3.04	5.37	1943	1.23	1952	2.73	1950	0.0	0.0		0.0	
A	2.64	5.19	1947	1.61	1943	3.07	1947	0.0	0.0		0.0	
S	3.13	6.37	1945	1.57	1953	1.85	1945	0.0	0.0		0.0	
O	2.42	9.50	1954	0.61	1952	3.44	1954	0.8	8.4	1954	6.1	1954
N	2.66	6.44	1950	1.14	1956	1.94	1950	6.5	22.3	1950	15.0	1950
D	2.29	5.60	1951	0.96	1955	1.26	1957	11.1	28.9	1944	8.7	1944
Year	32.08	9.50	Oct. 1954	0.61	Oct. 1952	3.73	May 1955	52.5	28.9	Dec. 1944	15.0	Nov. 1950

Month	Relative humidity				Wind					Pct of possible sunshine	Mean sky cover sunrise to sunset
							Fastest mile				
	1:00 a.m., EST	7:00 a.m., EST	1:00 p.m., EST	7:00 p.m., EST	Mean hourly speed	Prevailing direction	Speed	Direction	Year		
(a)	16	16	16	16	16	8	16	16		16	16
J	80	82	73	79	12.5	S	59	SW	1950	27	8.1
F	79	81	69	76	12.5	S	65	W	1956+	34	7.7
M	77	80	62	72	13.0	WNW	74	W	1948	43	7.1
A	77	78	56	63	12.0	S	65	W	1951	50	6.9
M	79	76	55	66	10.5	S	68	SW	1957	57	6.6
J	82	78	54	61	9.5	S	56	S	1953+	64	6.0
J	81	79	52	58	8.9	S	65	W	1956	69	5.3
A	83	82	53	63	8.5	S	61	W	1956	67	5.2
S	81	83	53	67	9.5	S	45	S	1953+	63	5.3
O	78	82	55	70	10.2	S	43	W	1946	56	5.6
N	77	80	64	73	12.8	S	59	W	1948	33	7.7
D	78	80	70	77	12.9	S	49	W	1949	28	8.0
Year	79	80	60	69	11.1	S	74	W	Mar. 1948	49	6.6

Month	Mean number of days										
	Sunrise to sunset							Temperatures			
								Max.		Min.	
	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	90° and above	32° and below	32° and below	0° and below
(a)	16	16	16	16	16	16	16	16	16	16	16
J	3	5	23	16	4	*	2	0	12	27	2
F	3	6	19	15	4	*	2	0	9	24	1
M	6	7	18	16	4	2	1	0	5	21	*
A	5	8	17	15	1	4	2	0	*	8	0
M	5	11	15	14	0	6	1	*	0	*	0
J	6	13	11	11	0	8	1	5	0	0	0
J	10	12	9	10	0	7	1	7	0	0	0
A	10	13	8	9	0	5	1	6	0	0	0
S	10	10	10	9	0	3	*	2	0	*	0
O	11	8	12	10	*	2	1	*	0	1	0
N	3	7	20	15	2	1	1	0	2	13	0
D	3	6	22	16	5	*	1	0	10	25	1
Year	75	106	184	166	20	38	14	20	38	119	4

Means and extremes in the above table are from the existing or comparable location(s). Annual extremes have been exceeded at prior locations as follows: Lowest temperature -17 in January 1873; maximum monthly precipitation 9.77 in January 1902; minimum monthly precipitation 0.17 in August 1881; maximum precipitation in 24 hours 4.97 in September 1901; maximum monthly snowfall 30.5 in February 1908; maximum snowfall in 24 hours 17.4 in November 1913; fastest mile of wind 78 from Southwest in May 1940.

TABLE 7. Climatic data for Erie, Pennsylvania. [Climates of the States (1974)]

Station: ERIE, PENNSYLVANIA ERIE INTERNATIONAL AIRPORT Standard time used: EASTERN Latitude: 42° 05' N Longitude: 80° 11' W Elevation (ground): 731 feet Year: 1970

Month	Temperature							Normal heating degree days (Base 65°)	Precipitation												Relative humidity				Wind &					Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days											Average daily solar radiation - langleys
	Normal			Extremes												Snow, Ice pellets											Fastest mile					Sunrise to sunset							Temperatures Max		Temperatures Min		
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs	Year	Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Mean speed	Prevailing direction	Speed	Direction	Year			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	90° and above ‡	32° and below	32° and below	0° and below	
(a)	(b)	(b)	(b)	5		5		(b)	(b)	17		17		15		16	16		16		5	5	5	5	17	8	13	13			15	15	15	15	17	15	15	15	5	5	5	5	
J	34.0	20.5	27.3	64	1967	-13	1970	1169	2.67	4.59	1959	0.90	1967	1.51	1959	19.3	29.9	1966	10.0	1958	73	74	71	73	13.1	WSW	42	32	1959		8.4	3	4	24	17	7	*	2	0	17	28	3	
F	34.0	18.8	26.4	54	1967	-5	1970	1081	2.32	4.03	1961	0.73	1969	2.16	1961	13.8	24.6	1968	7.7	1960	74	77	69	73	12.3	WSW	43	16	1963		7.9	2	7	19	14	5	*	1	0	15	26	2	
M	41.5	25.6	33.6	79	1967	0	1967	973	2.88	4.32	1954	0.63	1960	1.87	1965	11.2	26.8	1965	12.0	1965	74	76	65	69	12.1	NNE	55	14	1960		7.3	5	7	19	14	4	1	3	0	9	24	*	
A	54.7	36.3	45.5	80	1969+	21	1969	585	3.56	7.11	1961	1.66	1965	2.42	1961	3.1	17.2	1957	10.0	1957	72	73	60	67	11.7	WSW	46	21	1965		6.8	6	8	16	14	1	4	2	0	0	11	0	
M	66.1	46.7	56.4	85	1970	26	1970	288	3.54	5.59	1956	1.45	1962	2.23	1969	T	0.1	1963	0.2	1963	74	75	62	63	10.2	WSW	37	25	1964		6.4	6	12	13	11	0	5	2	0	0	2	0	
J	76.1	57.2	66.7	91	1969+	37	1966	60	3.05	7.74	1957	0.85	1963	2.80	1957	0.0	0.0		0.0		77	77	62	62	9.4	S	35	27	1969+		5.5	9	11	10	9	0	6	1	1	0	0	0	
J	80.1	62.0	71.1	94	1968	47	1970+	0	3.67	7.70	1970	1.51	1954	3.22	1970	0.0	0.0		0.0		80	81	64	65	9.0	S	46	32	1959		5.5	9	13	9	9	0	7	1	*	0	0	0	
A	78.5	61.1	69.8	89	1968	45	1968	25	2.98	6.61	1956	0.58	1959	2.79	1964	0.0	0.0		0.0		81	82	62	66	9.2	S	35	24	1970		5.4	10	11	10	11	0	7	*	0	0	0	0	
S	72.1	54.5	63.3	86	1970+	35	1969	102	3.56	7.08	1970	1.45	1960	4.84	1959	0.0	0.0		0.0		79	81	63	72	10.3	S	45	17	1965		6.1	8	9	13	10	0	4	1	0	0	0	0	
O	61.0	44.2	52.6	82	1969+	26	1969	391	3.20	9.87	1954	1.13	1963	4.35	1954	0.3	4.0	1954	2.1	1962	72	75	61	70	11.5	SSE	39	21	1967		6.3	8	8	15	12	*	3	*	0	0	2	0	
N	48.0	34.3	41.2	73	1968	15	1970	714	3.36	5.91	1963	1.95	1954	2.86	1956	13.5	36.3	1967	23.0	1956	74	75	70	73	13.2	SSW	39	30	1968		8.4	2	5	23	17	3	2	1	0	3	12	0	
D	36.8	24.5	30.7	68	1966	2	1969	1063	2.61	4.32	1966	1.36	1960	1.86	1968	20.9	56.0	1963	12.9	1966	73	74	71	73	13.7	SSW	38	17	1964		8.9	1	4	26	18	7	1	1	0	13	26	0	
YR	56.9	40.5	48.7	94	JUL. 1968	-13	JAN. 1970	6451	37.50	9.87	OCT. 1954	0.58	AUG. 1959	4.84	SEP. 1959	82.1	56.0	DEC. 1963	23.0	NOV. 1956	75	77	65	69	11.2	S	55	14	MAR. 1960		6.9	69	99	197	157	26	39	15	1	56	130	5	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 99 in September 1953; lowest temperature -16 in February 1875; maximum monthly precipitation 13.27 in July 1947; minimum monthly precipitation 0.02 in October 1924; maximum precipitation in 24 hours 10.42 in July 1947; maximum snowfall in 24 hours 26.5 in December 1944.

TABLE 8. Climatic data for Buffalo, New York.
[Climates of the States (1974)]

Station BUFFALO, NEW YORK GREATER BUFFALO INTL AIRPORT Standard time used: EASTERN Latitude: 42° 56' N Longitude: 78° 44' W Elevation (ground) 705 feet

Month	Temperature							Normal heating degree days (Base 65°)	Precipitation												Relative humidity				Wind #					Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days											Average daily solar radiation - langleys
	Normal			Extremes												Snow, Ice pellets					Hour 01	Hour 07	Hour 13	Hour 19			Fastest mile					Sunrise to sunset							Temperatures Max		Temperatures Min		
	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	(Local time)				Mean speed	Prevailing direction	Speed	Direction #	Year			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	90° and above ‡	32° and below	32° and below	0° and below	
(a)	(b)	(b)	(b)	11		11		(b)	(b)	28		28		28		28	28		28		11	11	11	11	32	14	28	28		28	28	28	28	28	28	28	28	28	11	11	11	11	
J	30.8	18.2	24.5	61	1967	-11	1968+	1256	2.84	6.47	1959	1.03	1946	2.40	1957	22.3	50.6	1945	18.2	1966	75	77	72	75	14.4	WSW	91	SW	1950+	33	8.3	2	6	23	20	7	*	2	0	18	29	3	
F	31.0	17.2	24.1	60	1965	-20	1961	1145	2.72	5.80	1960	0.81	1968	2.31	1954	17.8	54.2	1958	14.5	1958	78	79	71	74	14.2	SW	70	SW	1946	40	8.1	2	6	20	17	5	*	2	0	16	26	2	
M	38.6	24.4	31.5	78	1966	-4	1967	1039	3.24	5.25	1956	1.20	1967	2.14	1954	12.1	29.2	1959	15.8	1954	80	81	68	74	13.9	SW	68	W	1959	47	7.5	4	8	19	16	4	1	3	0	8	26	*	
A	52.9	34.0	43.5	83	1970+	17	1969	645	3.01	5.90	1961	1.27	1946	1.49	1944	2.6	13.1	1961	5.1	1961	75	76	58	65	13.1	SW	67	W	1957	52	7.1	5	8	17	15	1	2	3	0	*	12	0	
M	65.5	44.1	54.8	88	1962	29	1970+	329	2.95	6.39	1953	1.21	1965	2.03	1957	0.2	2.0	1945	2.0	1945	76	75	56	62	12.0	SW	63	SW	1950	59	6.7	6	10	15	12	*	3	2	0	0	1	0	
J	75.1	54.5	64.8	94	1963	38	1964	78	2.54	4.48	1951	0.11	1955	3.04	1968	0.0	0.0		0.0		78	77	57	61	11.4	SW	56	NW	1954	67	6.1	6	13	11	10	0	5	1	1	0	0	0	
J	80.1	59.4	69.8	94	1968+	46	1965	19	2.57	6.43	1963	1.04	1944	3.38	1963	0.0	0.0		0.0		60	79	56	61	10.7	SW	59	NW	1953	69	5.8	7	14	10	10	0	6	1	1	0	0	0	
A	78.6	58.1	68.4	93	1962	38	1965	37	3.05	8.04	1963	1.10	1948	3.88	1963	0.0	0.0		0.0		83	83	59	67	10.2	SW	56	SW	1944	67	5.8	8	12	11	10	0	6	1	*	0	0	0	
S	71.5	51.2	61.4	90	1960	32	1963	141	3.13	6.36	1967	0.77	1964	3.63	1967	T	T	1956+	T	1956+	81	83	60	72	10.7	S	59	SW	1954	61	6.2	7	10	13	10	0	4	1	0	0	*	0	
O	60.1	41.4	50.8	82	1971+	20	1965	440	3.00	9.13	1954	0.30	1963	3.49	1945	0.2	2.0	1962	2.0	1962	80	62	61	74	11.5	S	63	SW	1954	54	6.3	8	8	15	11	*	2	1	0	0	3	0	
N	46.5	31.7	39.1	80	1961	9	1971+	777	3.60	6.37	1949	1.44	1944	2.51	1949	12.6	28.6	1949	19.9	1955	81	82	71	78	13.1	S	66	SW	1948	30	8.3	2	6	22	16	3	1	1	0	2	14	0	
D	34.3	21.1	27.7	66	1966	-4	1962	1156	3.00	5.83	1954	0.69	1943	2.16	1945	20.2	51.1	1945	24.3	1945	79	81	73	77	13.6	WSW	60	S	1945	29	8.4	1	7	23	19	6	*	1	0	14	26	*	
YR	55.4	37.9	46.7	94	JUL. 1968+	-20	FEB. 1961	7062	35.65	9.13	OCT. 1954	0.11	JUN. 1955	3.88	AUG. 1963	88.0	54.2	FEB. 1958	24.3	DEC. 1945	79	80	63	70	12.4	SW	91	SW	JAN. 1950+	53	7.1	58	108	199	165	26	30	20	3	58	137	5	

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 99 in August 1948; lowest temperature -21 in February 1934; maximum monthly precipitation 10.63 in August 1885; minimum monthly precipitation .05 in August 1876; maximum precipitation in 24 hours 4.28 in August 1893.

TABLE 9. Climatic data for Detroit, Michigan.

[Climates of the States (1974)]

LATITUDE 42° 14' N
LONGITUDE 83° 20' W
ELEVATION (ground) 633 Feet

DETROIT, MICHIGAN
METROPOLITAN AIRPORT

	Temperature							Normal degree days	Precipitation												Relative humidity				Wind					Ø Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days											
	Normal			Extremes												Snow, Sleet											Fastest mile					Sunrise to sunset							Temperatures			
																																							Max.		Min.	
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year		Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	1:00 A.M. EST	7:00 A.M. EST	1:00 P.M. EST	7:00 P.M. EST	Mean hourly speed	Prevailing direction	Speed	Direction	Year			Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Sleet 1.0 inch or more	Thunderstorms	Heavy fog	90 and above	32 and below	32 and below	0 and below
(a)	(b)	(b)	(b)	8		8		(b)	(b)	8		8		8		8	8		8		8	8	8	8	8	5				1	8	8	8	8	8	8	8	8	8	8	8	8
J	33.9	19.1	26.5	62	1965	-13	1963	1194	1.93	3.63	1965	0.27	1961	1.40	1960	7.7	13.4	1959	5.3	1965	76	77	68	72	11.2	WSW				44	7.3	5	7	19	12	3	*	3	0	17	30	4
F	35.0	19.2	27.1	58	1966	- 6	1963	1061	1.95	2.54	1965	0.67	1963	1.23	1965	9.4	17.4	1962	10.3	1965	77	79	66	71	10.9	WSW				34	7.5	4	7	17	12	3	*	3	0	13	27	2
M	43.6	76.1	34.9	77	1963	1	1963	933	2.41	3.59	1965	0.92	1960	1.13	1965	6.6	16.1	1965	5.5	1965	76	80	63	67	11.4	WSW				50	7.4	4	8	19	14	2	2	3	0	6	24	0
A	57.7	36.6	47.2	85	1962+	17	1964	534	3.05	5.40	1961	1.80	1960	1.97	1965	1.6	7.4	1961	4.2	1961	77	81	57	62	11.1	WSW				45	7.2	4	8	18	14	1	4	1	0	0	11	0
M	69.7	47.1	58.4	92	1962	25	1966	239	3.54	4.09	1963	1.15	1965	1.72	1966	T	T	1963+	T	1963+	77	78	54	58	9.9	WSW				65	6.4	6	11	14	10	0	4	1	1	0	1	0
J	79.9	56.8	68.4	94	1965+	36	1966	57	3.31	6.60	1960	2.12	1959	2.62	1960	0.0	0.0		0.0		80	80	52	57	8.5	SW				81	5.4	9	11	10	10	0	6	1	4	0	0	0
J	84.7	61.1	72.9	98	1966	41	1965	0	2.69	5.24	1966	1.11	1964	3.19	1966	0.0	0.0		0.0		81	82	51	57	8.3	SW				66	5.3	9	14	8	9	0	5	1	5	0	0	0
A	83.8	60.0	71.9	97	1964	40	1964	0	2.84	7.70	1964	1.44	1963	3.21	1964	0.0	0.0		0.0		86	88	58	67	8.2	SW				67	5.8	8	12	11	11	0	7	3	3	0	0	0
S	76.1	52.5	64.3	94	1960	33	1959	96	2.32	5.83	1962	0.43	1960	2.07	1961	0.0	0.0		0.0		84	88	57	68	8.5	SW				61	6.3	10	8	12	10	0	4	2	1	0	0	0
O	64.8	43.1	54.0	91	1963	18	1965	353	2.57	4.14	1959	0.35	1964	2.11	1959	T	T	1965+	T	1965+	80	84	54	67	9.1	WSW				67	5.7	9	10	12	8	0	2	3	*	0	6	0
N	48.9	31.8	40.4	72	1964	9	1964	738	2.27	3.13	1966	0.30	1964	1.28	1961	3.4	11.8	1956	5.2	1966+	80	83	65	73	10.4	SW				22	7.5	4	8	18	9	1	1	3	0	1	18	0
D	36.5	23.2	29.9	66	1966	- 9	1960	1088	1.92	6.00	1965	0.46	1960	3.71	1965	8.3	17.3	1962	5.7	1966	79	80	70	75	10.4	SW				24	7.6	5	6	20	12	3	0	3	0	14	27	2
YR	59.6	39.7	49.7	98	JUL. 1966	-13	JAN. 1963	6293	30.80	7.70	AUG. 1964	0.27	JAN. 1961	3.71	DEC. 1965	37.0	17.4	FEB. 1962	10.3	FEB. 1965	80	82	60	66	9.8	SW				52	6.6	77	110	178	130	13	34	26	13	50	143	7

Ø Data from Detroit City Airport through April 1966.

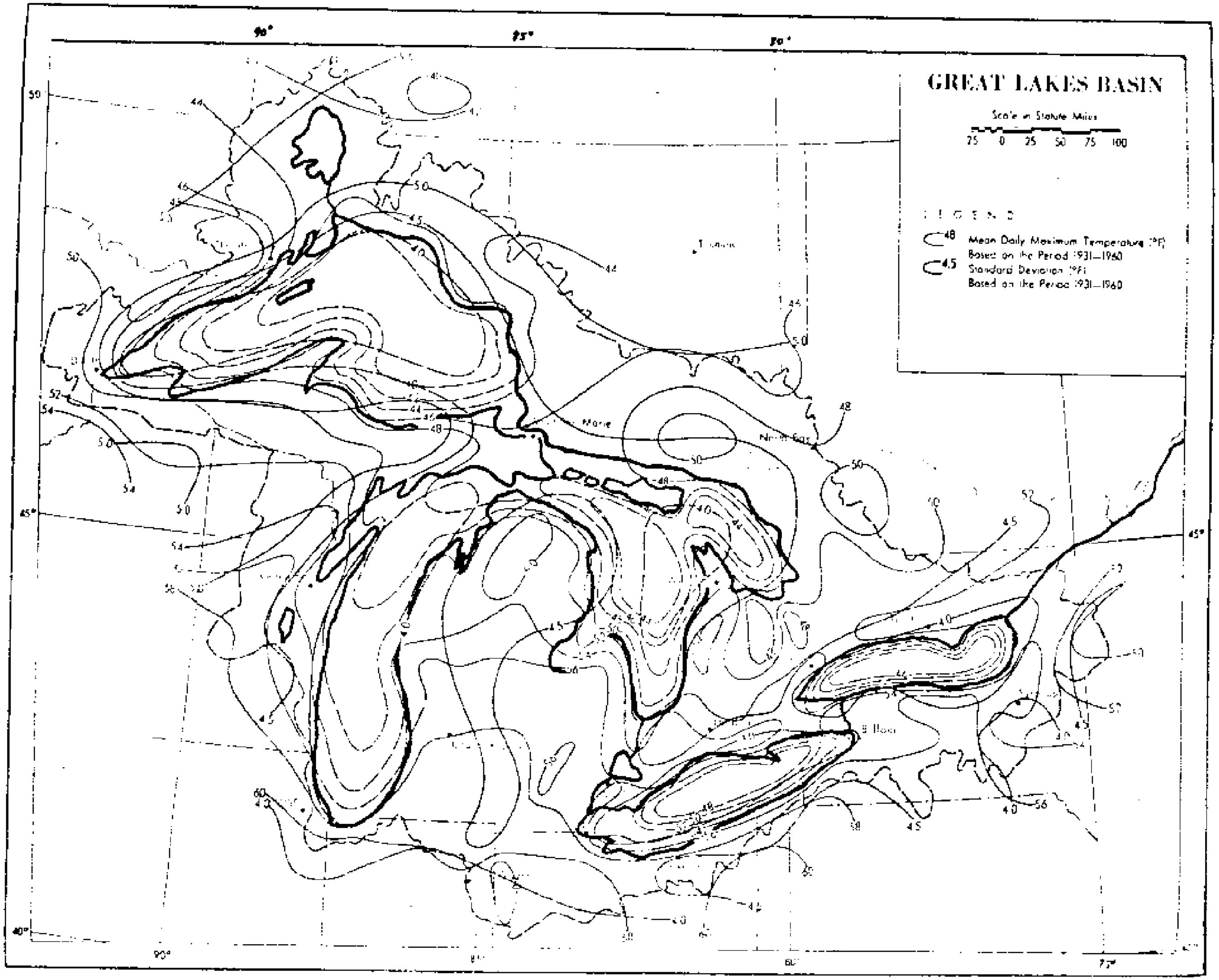


Figure 7. April mean daily maximum temperature and its standard deviation (°F). [Phillips and McCulloch (1972)]

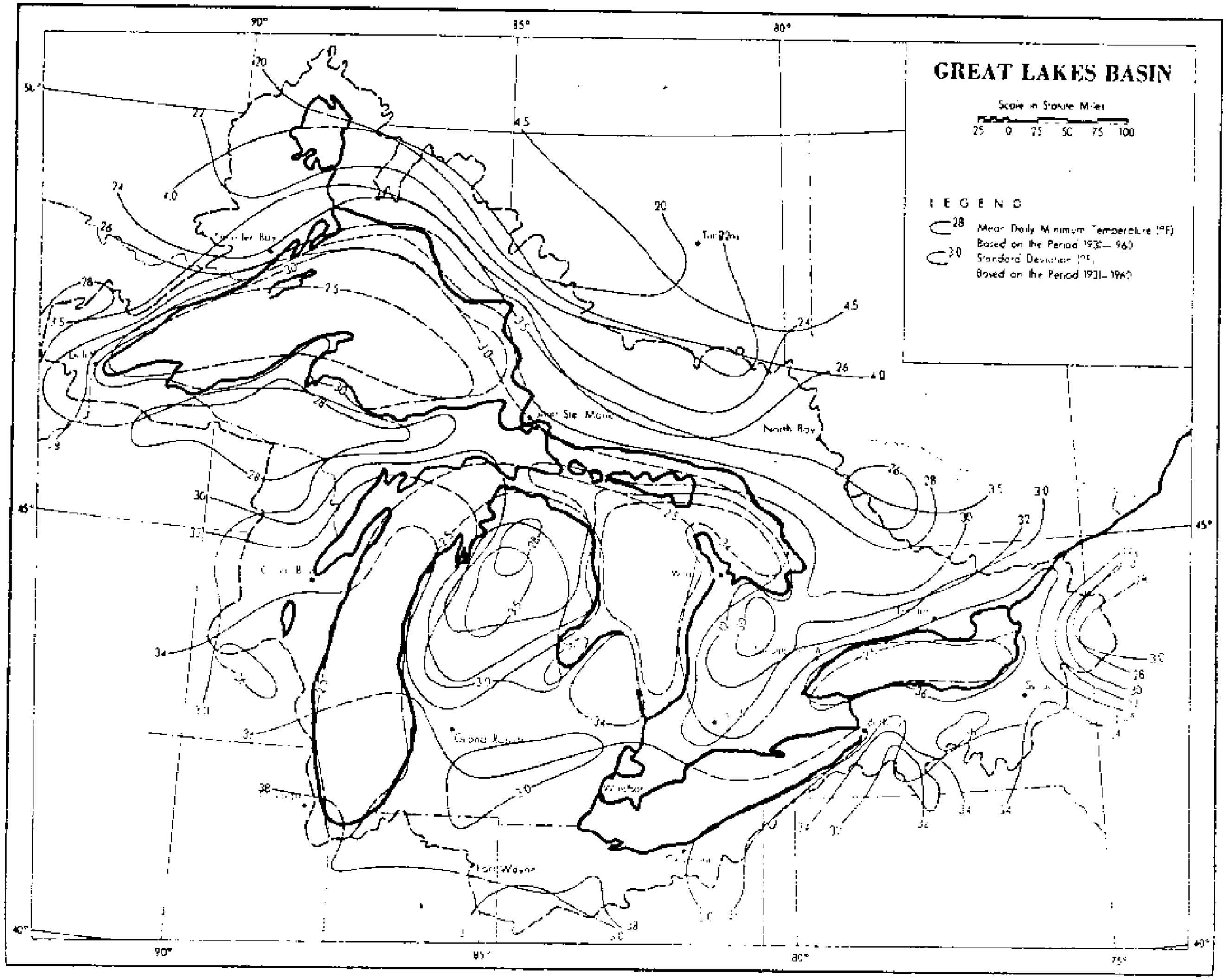


Figure 8. April mean daily minimum temperature and its standard deviation (°F). [Phillips and McCulloch (1972)]

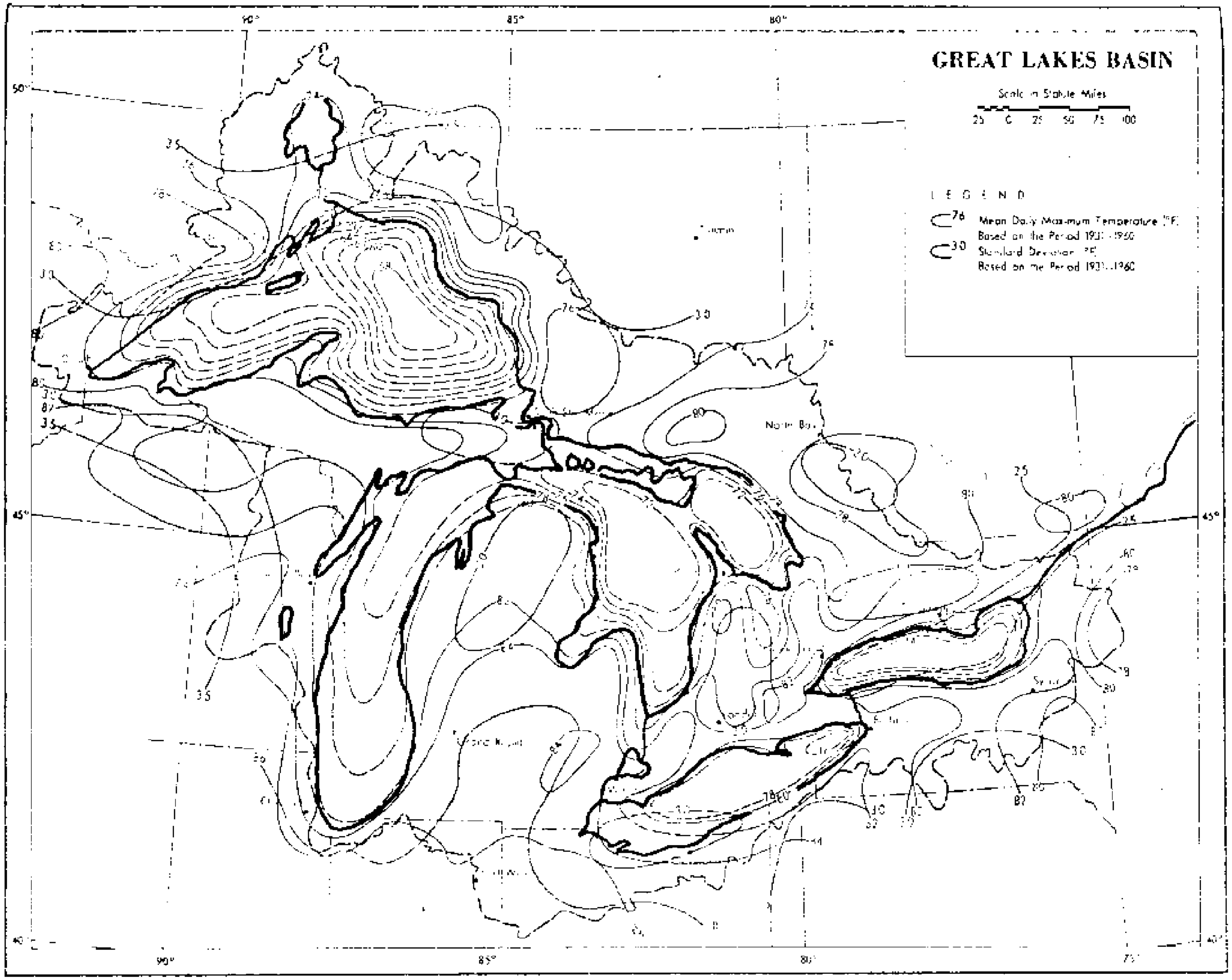


Figure 9. July mean daily maximum temperature and its standard deviation (°F). [Phillips and McCulloch (1972)]

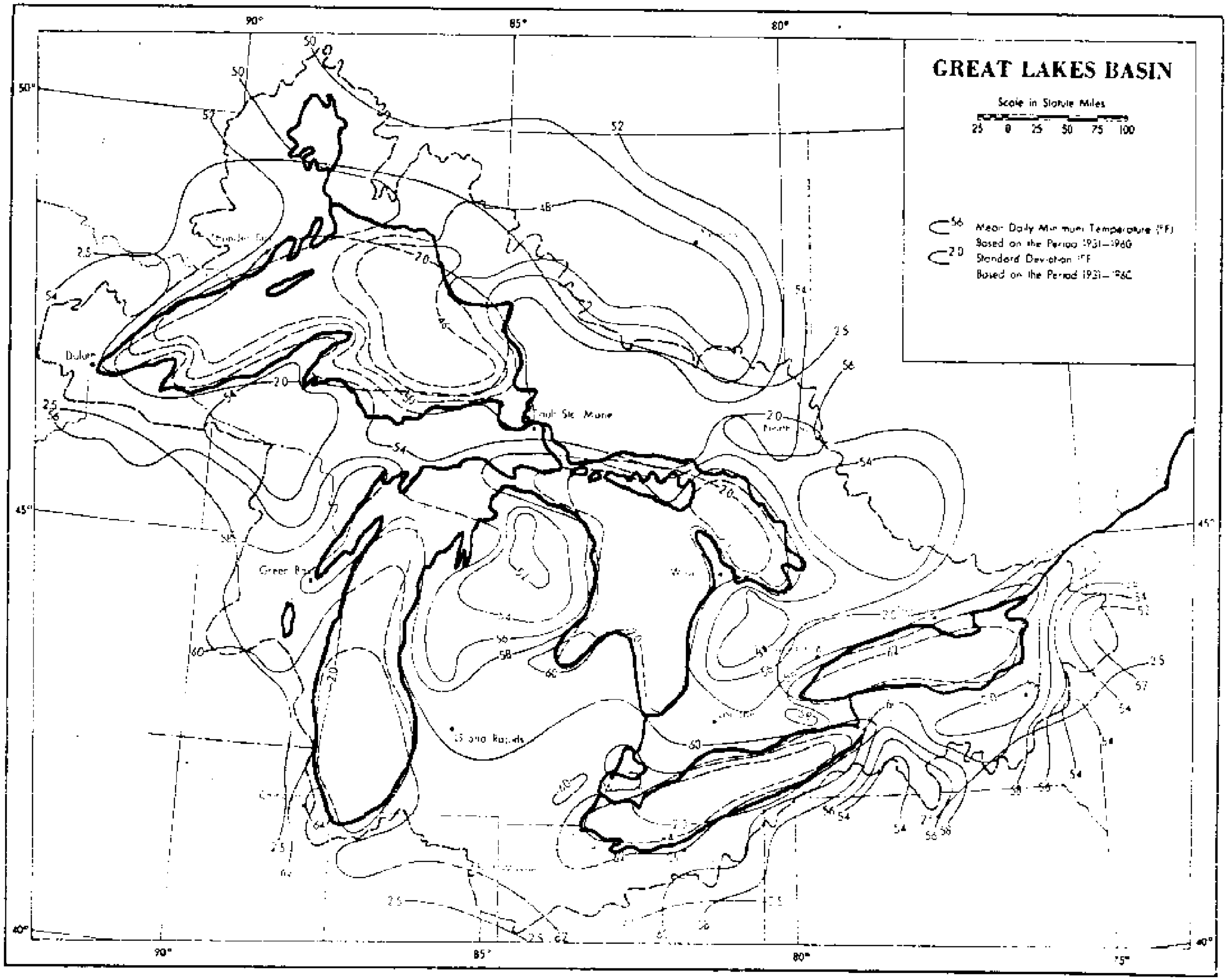


Figure 10. July mean daily minimum temperature and its standard deviation (°F). [Phillips and McCulloch (1972)]

TABLE 10. Average monthly values of temperature and precipitation for Cleveland and North Royalton, Ohio (1893-1921 means). Means are calculated from yearly values given in Alexander (1923).

Temperature (°F)

	APR	MAY	JUN	JUL	AUG	SEP
Cleveland	46.6	58.0	66.9	72.0	70.0	64.6
N. Royalton	47.2	58.5	67.3	72.2	70.3	64.5

Precipitation (inches)

	APR	MAY	JUN	JUL	AUG	SEP
Cleveland	2.59	2.92	2.72	3.34	2.93	2.80
N. Royalton	3.10	3.87	3.44	4.29	3.68	3.33

Ohio. Both cities are located in Cuyahoga County, but Cleveland is on the lakeshore while North Royalton is in the southern part of the county, about 12 miles inland. Note Cleveland's mean monthly temperatures are cooler than those of North Royalton from April through August; in September, the slightly warmer lake (Table 3) gives Cleveland a warmer mean temperature.

To see the lake effect on an island station, consider Table 11, which lists the 1921-1950 mean monthly temperatures and precipitation for Gibraltar Island and Sandusky, Ohio. Sandusky is a shoreline station whereas Gibraltar is a small island on Lake Erie. From April through June the mean temperature on Gibraltar Island is lower, but from July through September it is higher, presumably due to the greater solar radiation received over the lake versus shoreline and inland stations.

TABLE 11. Average monthly values of temperature and precipitation for Gibraltar Island and Sandusky, Ohio (1921-1950 means). [Ref. (8)]

Temperature (°F)

	APR	MAY	JUN	JUL	AUG	SEP
Gibraltar I.	45.7	57.9	69.3	74.7	74.2	67.4
Sandusky	47.9	59.3	69.9	74.6	72.8	66.5

Precipitation (inches)

	APR	MAY	JUN	JUL	AUG	SEP
Gibraltar I.	2.98	3.19	3.11	2.46	2.88	2.66
Sandusky	2.96	3.32	3.73	3.45	2.81	3.26

4.2. Humidity

The amount of moisture in the air is important in determining the rate of evaporation and also for determining the convective stability or instability of air, an important factor in precipitation development.

Vapor pressure e is one measure of the amount of water vapor in the air. To see the lake effect on vapor pressure, consider Figure 11, which is a graph of the mean vapor pressure at Wiarton and Killaloe, Ontario. Wiarton is virtually surrounded by lakes (Georgian Bay and Lake Huron) while Killaloe is 150 miles inland. Note that vapor pressures are virtually the same at both locations from May through July, but higher beginning in August. Hence, in spring and early summer, the cooler lake waters have little effect on the relative amount of water vapor in the air, but beginning about mid-summer, evaporation over the lakes supplies more atmospheric moisture than does evaporation over land.

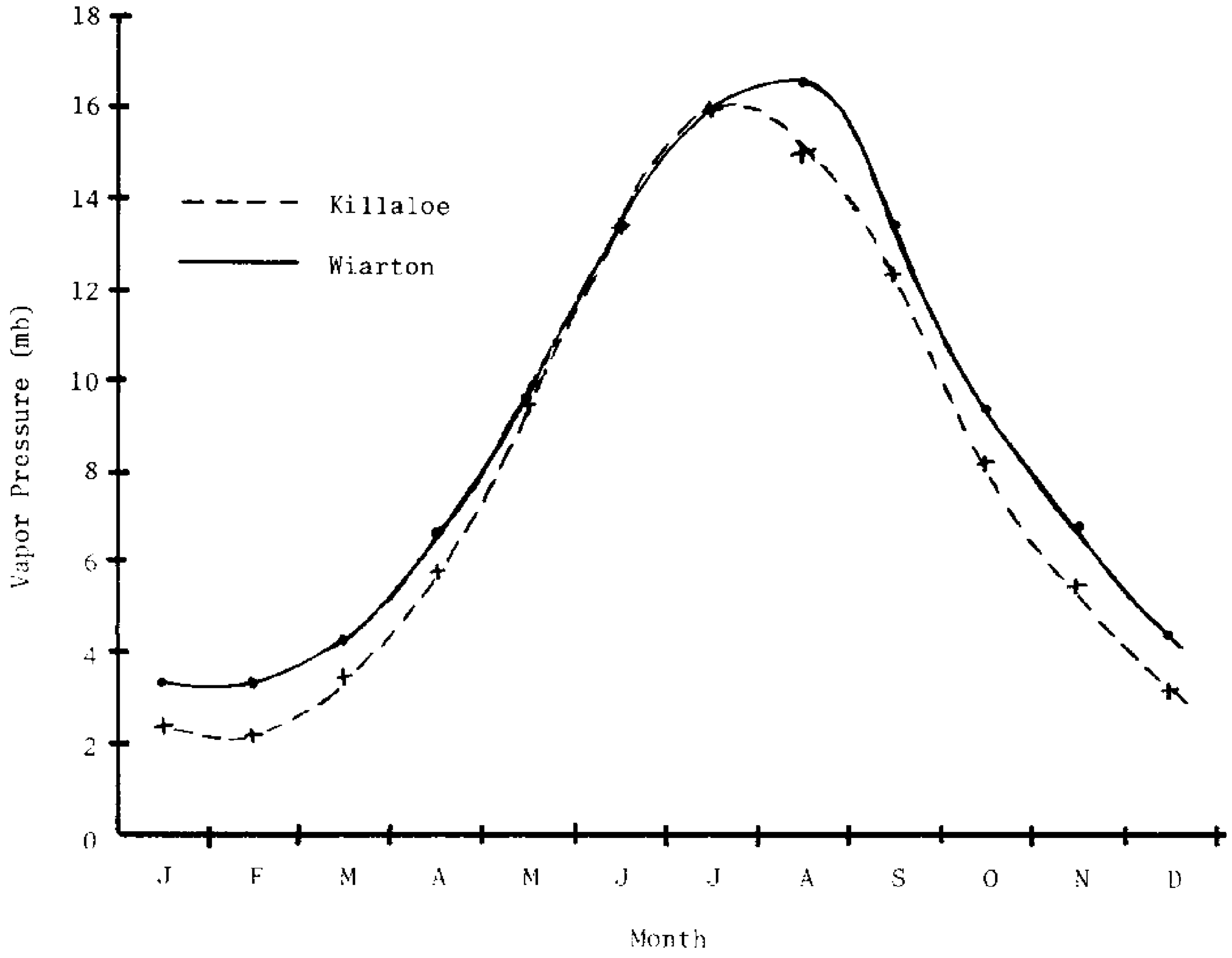


Figure 11. Mean Monthly vapor pressures at Wiarton and Killaloe, Ontario. [Adapted from Phillips and McCulloch (1972)]

In contrast to vapor pressure, *relative humidity* r, defined as

$$r \equiv e/e_s ,$$

where e_s is the saturation vapor pressure, may in the spring be greater over Lake Erie than over land, since the overlying lake air, being cooler, has a lower e_s value than over land. That such is the case is confirmed by relative humidity increases after passage of a lake-breeze front [Munn and Richards (1964]. Tables 4 - 9 give the average monthly relative humidity at four times of the day for the six major cities surrounding Lake Erie.

4.3. Solar Radiation

Due to frequent subsidence over Lake Erie in the spring and early summer (see Chapter 3), it might be inferred that areas over and near the lake should have more sunshine than areas further inland.

Figure 12 depicts the mean number of hours of sunshine for July in the Great Lakes region. Note the local maximum over Lake Erie. In addition, Tables 4 - 9 list the mean monthly percentage of possible sunshine for the six cities around the lake.

Figure 13 shows the mean monthly daily solar radiation at Sault Ste. Marie, Michigan, and Ottawa, Ontario. Ottawa is an inland station, only 1° of latitude further south. Note the greater daily amounts at Sault Ste. Marie during April through August, when the cooler Great Lakes which surround that city encourage subsidence and cloud dissipation.

4.4. Wind

The mean monthly wind speed and prevailing wind direction for the six major cities surrounding Lake Erie are given in Tables 4 - 9.

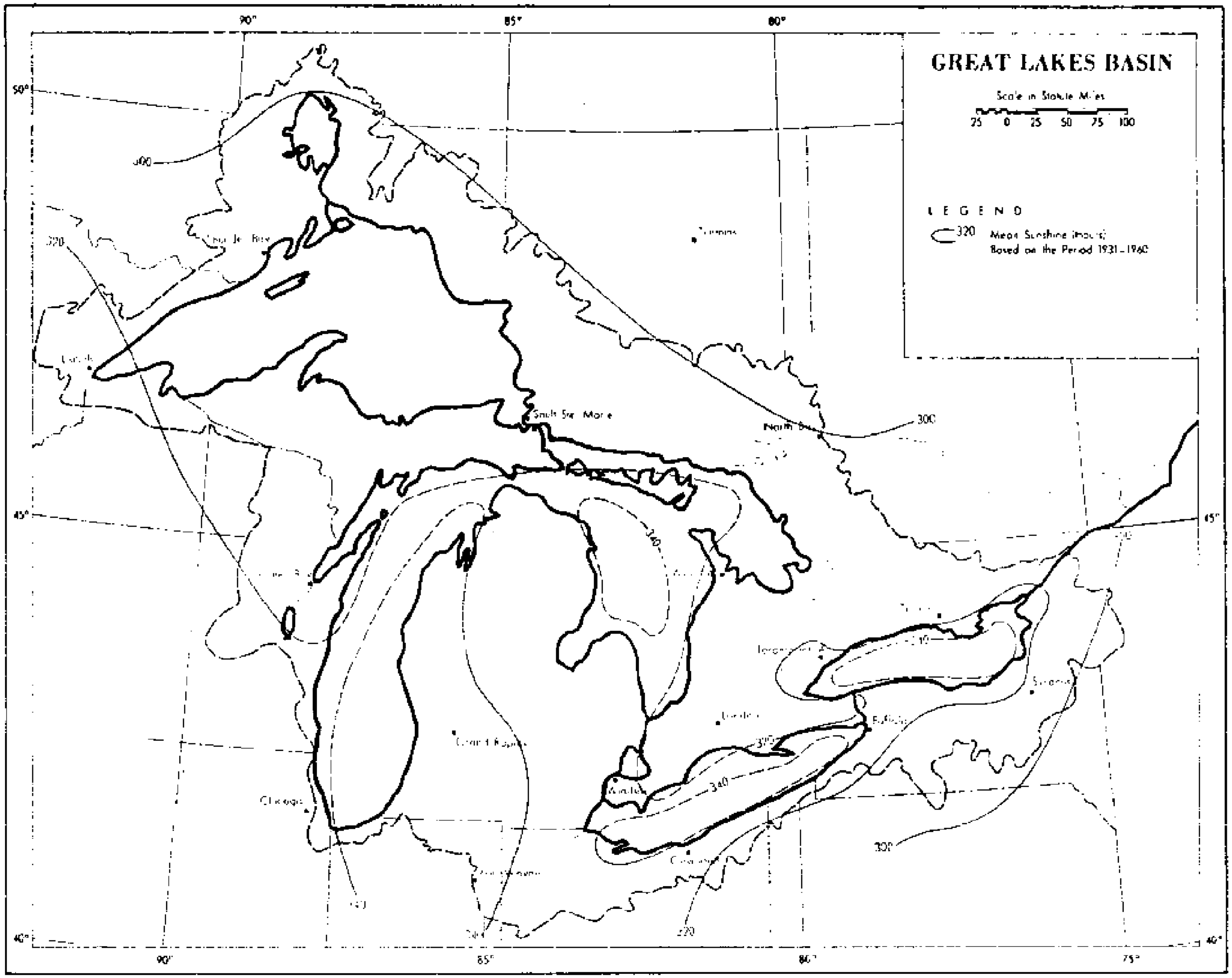


Figure 12. Mean number of hours of sunshine for July. [Phillips and McCulloch (1972)]

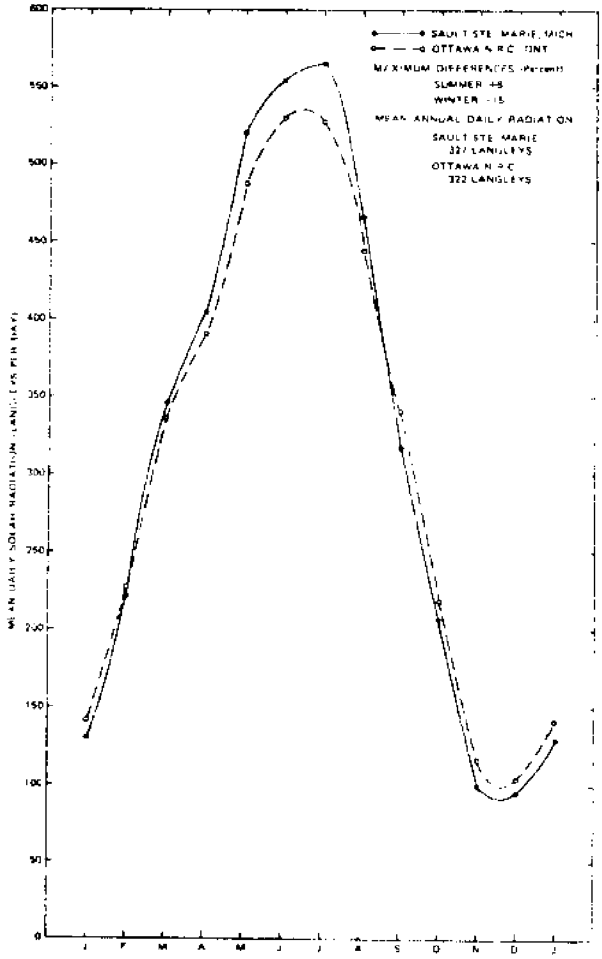


Figure 13. Mean daily solar radiation at Ottawa NRC, Ontario, and Sault Ste. Marie, Michigan. [Phillips and McCulloch (1972)]

April and July wind roses for the Great Lakes region are shown in Figures 14 and 15, respectively. The prevailing synoptic flow is out of the southwest during these months but lake breezes during these months lead to maxima in directions perpendicular to the shoreline as well (e.g., north wind at Cleveland, etc.).

Figure 16 depicts wind roses for April through September based on ship observations over western Lake Erie. Note the prevalence of southerly and southwesterly flows during May through August. The mean wind speed falls to a minimum during the summer months, as might be expected.

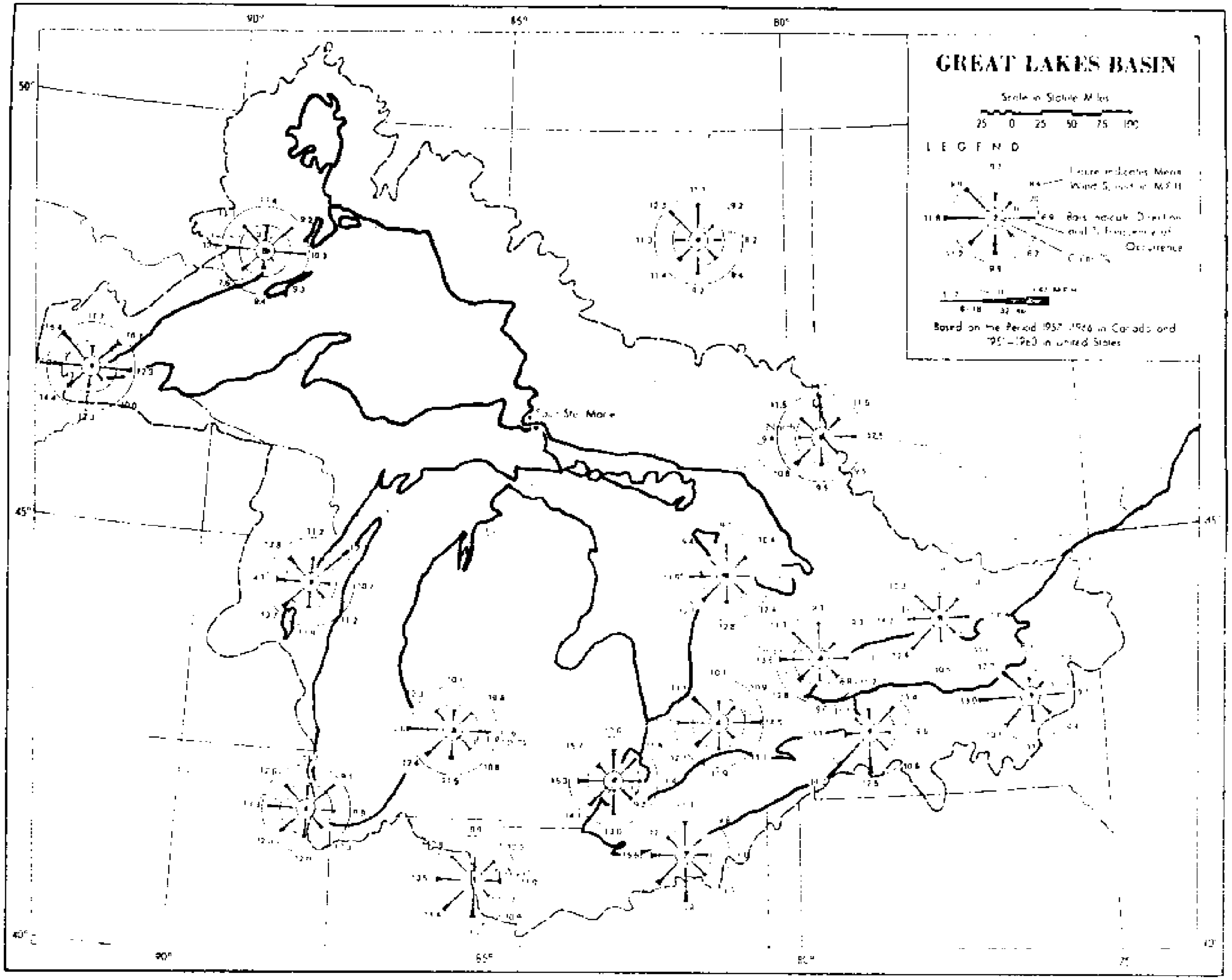


Figure 14. April wind roses for selected airport stations.
[Phillips and McCulloch (1972)]

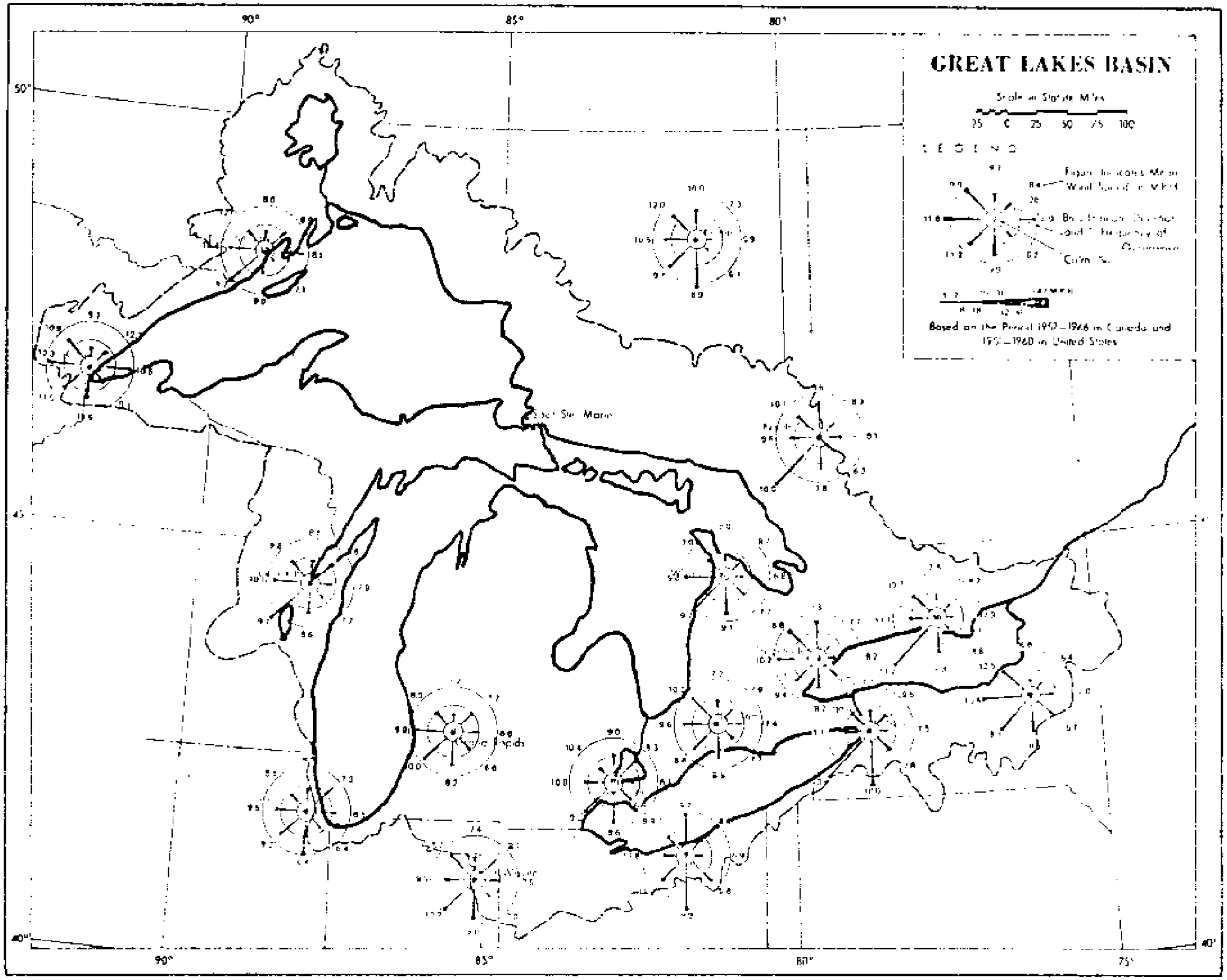
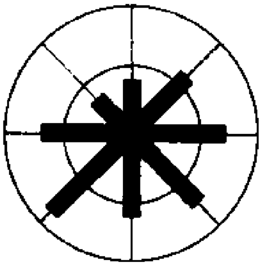
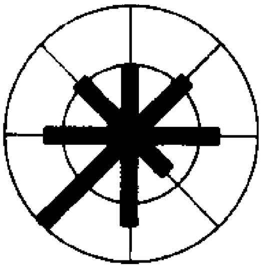


Figure 15. July wind roses for selected airport stations.
[Phillips and McCulloch (1972)]



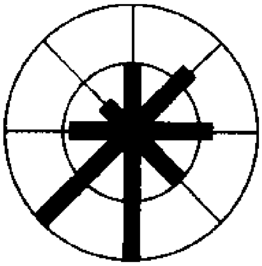
APR

(Mean Speed =
15.1 knots)



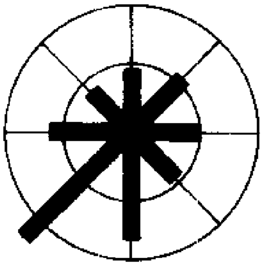
MAY

(Mean Speed =
14 knots)



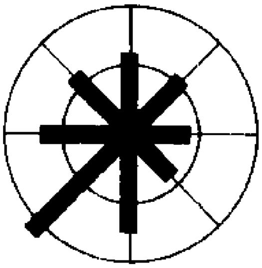
JUN

(Mean Speed =
12.6 knots)



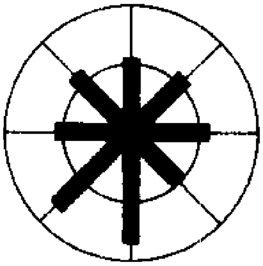
JUL

(Mean Speed =
12.1 knots)



AUG

(Mean Speed =
12.5 knots)



SEP

(Mean Speed =
14.3 knots)

Figure 16. Wind roses for western Lake Erie. Data from 1963-1973 (June-September), 1964-1973 (May), and 1965-1973 (April). Contour interval is 10% frequency. [Adapted from Ref. (33)]

What is the lake effect on wind? Because the surface of a lake is much smoother than land and therefore exerts a lower stress on the atmosphere, one at first might expect speeds to increase as air flows over water. However, Lyons (1970) and Bellaire (1965), in their case studies, observed speeds to decrease because of the stable thermal stratification over the water. One might also expect winds to be more gradient in direction due to less friction (to veer over the water). Lyons (1972), as noted earlier, found the reverse because of wind adjustment to the lake mesohigh. However, with neutral or unstable lapse rates over the surface of the lake, one might indeed expect stronger winds over the lake due to reduced friction; winds should also be more nearly gradient in direction.

Richards et al. (1966) performed an observational study on the influence of atmospheric stability on winds over Lakes Erie and Ontario. Using five years of ship data, they found wind speeds to decrease over water during stable stratification over the lakes and speeds to increase during unstable stratification. The greatest changes (in speeds over land to those over water) are experienced at lower wind speeds and occur over an over-water fetch of up to 25 miles, beyond which winds remain nearly constant.

Looking at Figure 2, one might, on the basis of these studies, make the following predictions for winds over Lake Erie during spring and summer. During the daytime with light synoptic winds, winds will decrease over Lake Erie. At nighttime with light synoptic winds, speeds will increase during the months of July through September.

4.5. Evaporation

Various investigators have provided estimates of the mean monthly and annual evaporation from Lake Erie. The two most common techniques used are the water budget and mass transfer methods; these are well known and will not be discussed here.

Table 12 provides a summary of the evaporation estimates of the more comprehensive studies of Lake Erie. Monthly values for April through September and annual means are given. Note that the cooler lake suppresses evaporation in the spring months (in April, condensation is even indicated in three of the five studies); beginning in July, however, evaporation increases, reaching a maximum in early fall. Annual evaporation of around 35 inches occurs. These numbers should be regarded only as estimates, however, since both techniques involve the uncertain extrapolation of either precipitation or wind speeds over the lake.

Over the land surrounding Lake Erie, annual evaporation is much less, as might be expected. Phillips and McCulloch (1972) estimate a value of 22 inches. As inferred from Carlson (1974), average monthly land evaporation around Lake Erie for April through June is approximately 2.5 inches in April, 3.4 inches in May, and 3.9 inches in June. The comparisons in Table 12 clearly show that, in contrast to the annual results, more evaporation occurs over land than over Lake Erie in the spring months.

4.6. Precipitation

Tables 4 - 9 present the average monthly precipitation amounts for the six major cities surrounding Lake Erie. Figure 17 presents the monthly averages for Sandusky in histogram format. Amounts are rather evenly distributed with higher amounts in March through September.

TABLE 12. Estimates of evaporation for Lake Erie (inches).

Investigator(s)	Derecki (1964)	Richards & Irbe (1969)	Jones & Meredith (1972)	Derecki (1975)	
Years of Data Used	1937-59 (23)	1950-68 (19)	1946-65 (20)	1937-68 (32)	
Technique	Water Budget	Mass Transfer	Mass Transfer	Water Budget	Mass Transfer
APRIL	0.00	-1.10	-1.08	0.31	-0.63
MAY	0.39	2.31	2.31	0.63	2.36
JUNE	1.18	2.91	2.86	1.14	2.24
JULY	3.54	2.65	2.50	3.78	2.20
AUGUST	5.51	4.45	4.46	5.35	4.21
SEPTEMBER	6.30	5.59	5.67	6.38	5.55
Annual	33.46	35.88	35.52	35.79	35.35

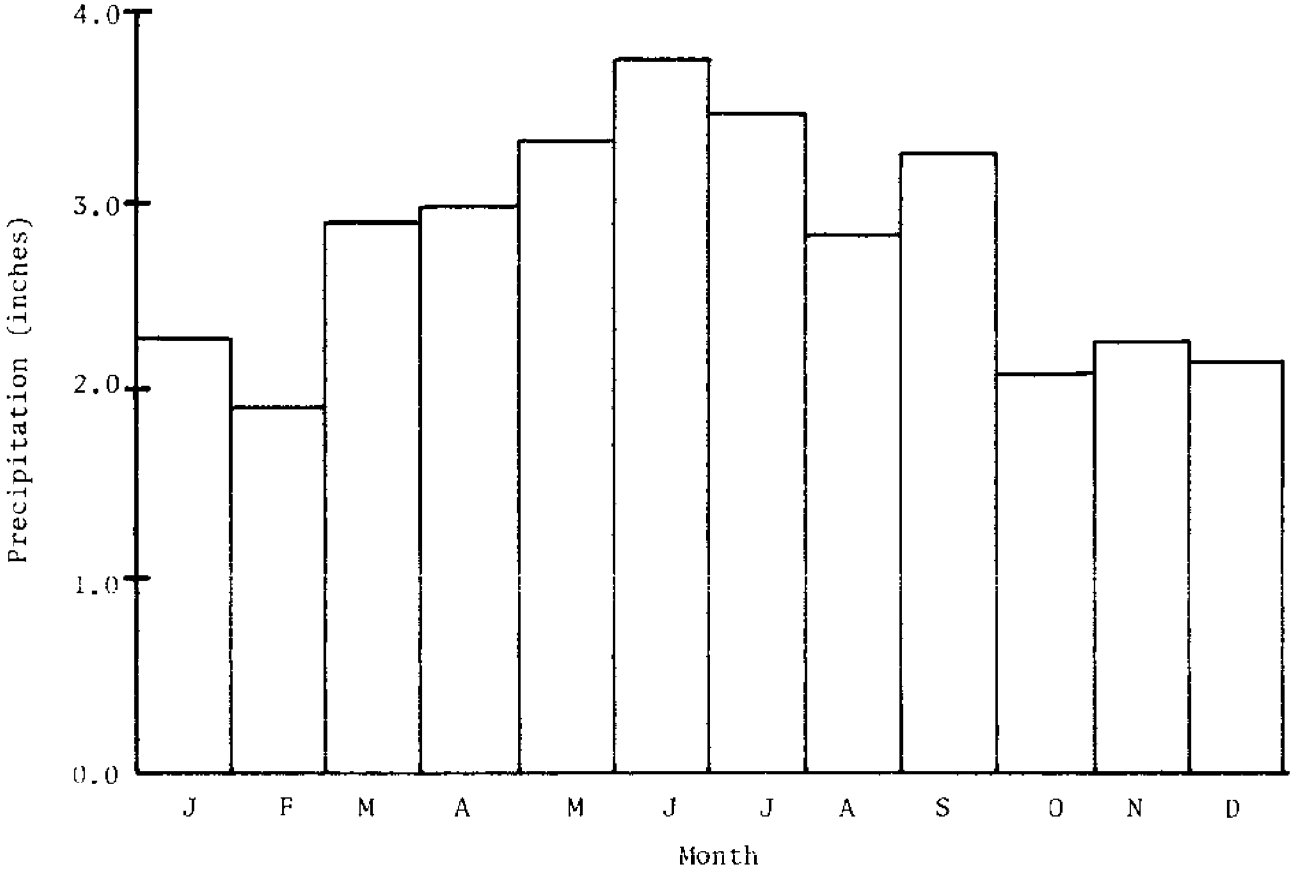


Figure 17. Histogram of average monthly precipitation amounts at Sandusky, Ohio. [Data from Climates of the States (1974)]

4.6.1. Long-Term Lake Effect. What is the effect of Lake Erie on precipitation during the spring and summer? On a long-term basis (average of many years) the cooler waters of Lake Erie during this period definitely reduce precipitation over the lake and shoreline areas as compared to further inland. Consider Table 10 again, this time with respect to precipitation. Monthly amounts at Cleveland are lower by 0.5 to 0.95 inches over those at North Royalton. Also, consider Table 11. During May through September, with the exception of August, monthly amounts are lower out over the lake (Gibraltar Island) than at the shore. Figure 18 depicts the mean July precipitation over the Great Lakes region. The lower amounts as Lake Erie is approached are clearly seen.

Blust and DeCooke (1960) made a comparison of precipitation over the islands of northeastern Lake Michigan with that over the lake perimeter. Their study covered the years 1952-1959. They found a decrease in precipitation of 6.2% over the islands as compared with over the lake perimeter during the summer months.

Using climatological data from land stations surrounding Lake Michigan, Changnon (1966) inferred that during the summer the lake reduces thunderstorms by more than 20% over and to the lee of the southern half of the lake. At night the warmer lake actually increases thunderstorm activity, but 30-50% reductions during the day cause a net summer reduction.

4.6.2. Short-Term Lake Effect. In any given year, however, it is unclear what effect a large cold lake will have on precipitation. For example, consider Table 13, which lists the observed monthly precipitation amounts from May through September 1916 for North Bass Island and Danbury, Ohio, a station on Sandusky Bay. North Bass is well out into Lake Erie and should reflect any lake effect. However, for this year, North Bass

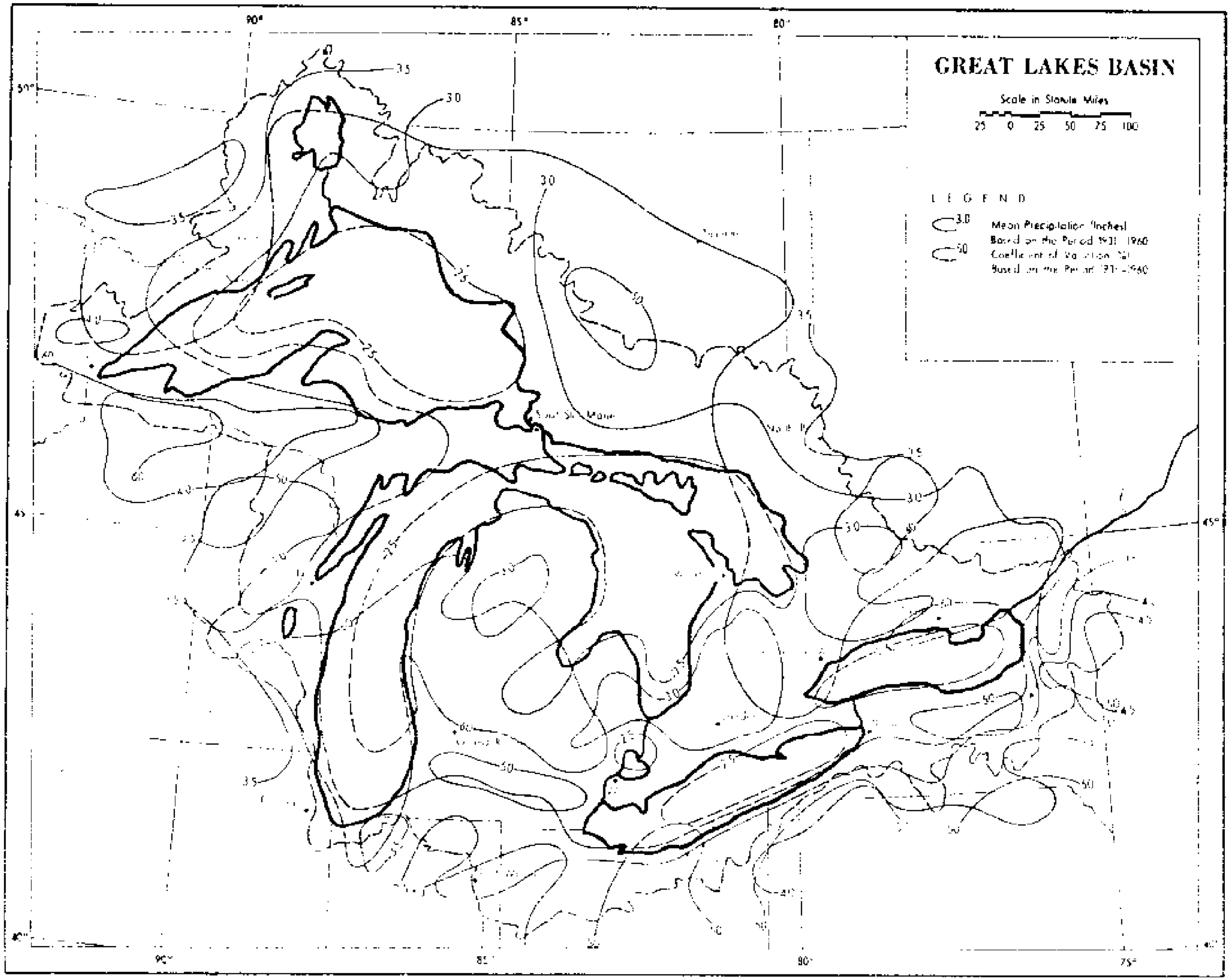


Figure 18. Mean July precipitation (inches) and its coefficient of variation (%). [Phillips and McCulloch (1972)]

shows greater precipitation than Danbury in all months except July. Also, consider Table 14, which gives the 1873-75 averages of monthly precipitation over Kelly's Island and Margaretta, Ohio, an inland station in Erie County. Note the island station has greater precipitation during June and July than does the inland station, the reverse of that expected.

TABLE 13. 1916 monthly precipitation amounts for North Bass Island and Danbury, Ohio (inches). [Data from Alexander (1923)]

	MAY	JUN	JUL	AUG	SEP
North Bass	5.67	4.58	0.63	2.08	2.08
Danbury	4.49	3.89	0.73	1.91	1.62

TABLE 14. Three-year (1873-1875) monthly precipitation averages for Kelly's Island and Margaretta, Ohio (inches). [Data from Alexander (1923)]

	APR	MAY	JUN	JUL	AUG	SEP
Kelly's Island	3.19	2.40	4.08	5.12	2.46	3.15
Margaretta	3.55	3.16	3.98	3.53	3.96	3.81

Why the discrepancy between what occurs in a given year or several year period and what occurs in long-term averages? One possibility is that over the long term the cooling effect of Lake Erie in spring and summer does encourage subsidence and inhibit precipitation, certainly the local summer convective type. However, in the short term the prevailing synoptic systems most likely override this "climatological" effect and may produce more rain over the lake. Lyons (1966) believes in some cases that the large lake may even intensify the precipitation, as the systems experience uplift over the cold air dome as they move out over the lake. In other cases the lake may induce no effect at all, as the storms and advection move right over the cold dome, which serves to reduce friction. It may also be that the uplift associated with the lake breeze front encourages more precipitation over shoreline areas than over inland areas.

4.6.3. Over-Lake Precipitation. Using ratio techniques (based on long-term precipitation averages over island versus shoreline stations) to extrapolate precipitation amounts from shoreline stations to areas over Lake Erie, various investigators have estimated precipitation over Lake Erie. Some of these estimates appear in Table 15 for April through September and also for the annual amount. Such techniques are highly suspect, however, because of the large geographical area involved in the extrapolation, and the numbers should be regarded merely as estimates.

TABLE 15. Estimates of precipitation over Lake Erie (inches).

Investigator(s)	Derecki (1964)	Jones & Meredith (1972)	Derecki (1975)
Years of Data Used	1937-59 (23)	1946-65 (20)	1937-68 (32)
APRIL	3.46	3.40	3.38
MAY	3.58	3.04	3.11
JUNE	3.11	2.89	3.03
JULY	3.19	2.89	2.91
AUGUST	3.19	3.14	3.23
SEPTEMBER	2.76	2.45	2.56
Annual	34.64	32.79	32.83

4.6.4. Intensive Precipitation. The Climatological Data--National Summary annual series provides a data base for examining intensive rainfall in the Lake Erie region during the spring and summer months.

Tables 16-21 summarize the findings for the six major cities surrounding the lake. In each table are listed the number of years (of the period studied) when precipitation greater than or equal to the given hourly intensity was observed at least once within that month. The results show that the peak months for intensive rainfall are June through August. The months with the greatest intensity (≥ 1 in h^{-1}) are July and August; these months, although past the severe weather peak, are months with much humidity and, therefore, water vapor supply. Also, remnants of tropical hurricanes occasionally influence the area.

Table 22, inferred from Hershfield (1961), presents the annual probabilities of intense rainfall (of the given amount) for the Lake Erie region for April through September. As can be seen, the greatest probabilities occur in June through August, which agrees with the results deduced from Tables 16-21.

4.7. Severe Weather

Tables 4-9 give the average monthly number of thunderstorm days for the six cities around Lake Erie. At most stations the number peaks during June and July with approximately 5 to 7 such days per month. During the six-month spring-summer period, the average number of thunderstorm days for the six stations is 30.3.

Information on Ohio tornadoes was obtained from the National Weather Service at Columbus. Table 23 presents the monthly tornado frequency. The peak month is May, with April having a nearly equal number of occurrences. Figures 19 and 20 depict the number of tornadoes reported in each county (1900-1975) and number of deaths (1916-1975), respectively. The Lake Erie region is by no means immune; in fact, some of Ohio's worst tornadoes (those of 1924, 1953, and 1965) have tracked through counties bordering on the lake.

TABLE 16. TOLEDO: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Twenty-five years of data were used (1950-1972, 1976, 1978). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	2	2	1		
MAY	10	7	4		
JUN	18	16	9	6	3
JUL	17	14	10	5	1
AUG	18	13	8	8	4
SEP	10	8	7	3	1

TABLE 17. SANDUSKY: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Fourteen years of data were used (1950-1963). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	3	3	1		
MAY	7	6	4	2	
JUN	8	6	4	2	
JUL	7	6	3	2	1
AUG	8	7	3	3	1
SEP	6	3	2	2	1

TABLE 18. CLEVELAND: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Twenty-five years of data were used (1950-1972, 1976, 1978). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	6	5	1		
MAY	13	11	8	2	1
JUN	18	15	6	2	
JUL	19	17	15	10	1
AUG	16	13	10	7	1
SEP	11	9	5	2	1

TABLE 19. ERIE: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Twenty years of data were used (1950-1952, 1958-1972, 1976, 1978). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	3	1			
MAY	6	6	5	2	
JUN	17	17	6	2	
JUL	15	13	8	2	
AUG	14	10	9	5	1
SEP	8	6	3	1	

TABLE 20. BUFFALO: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Twenty-five years of data were used (1950-1972, 1976, 1978). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	3	2	1		
MAY	6	5	1		
JUN	12	9	4	1	
JUL	15	12	7	5	1
AUG	19	15	8	6	2
SEP	11	9	7	4	1

TABLE 21. DETROIT: Number of years with at least one hourly precipitation occurrence per month greater than or equal to given intensity. Twenty-five years of data were used (1950-1972, 1976, 1978). [Ref. (7)]

	Number of years with precipitation greater than or equal to				
	.25 in/h	.5 in/h	.75 in/h	1.0 in/h	1.5 in/h
APR	3	2	2	2	
MAY	12	8	5		
JUN	15	12	7	5	1
JUL	18	13	10	3	2
AUG	21	19	13	10	3
SEP	11	8	3	2	2

TABLE 22. Annual probabilities for rainfall of specified intensity over the Lake Erie region. [Inferred from Hershfield (1961)]

Intense 1-hour rainfall (≥ 1 in.)

APR	MAY	JUN	JUL	AUG	SEP
5%	10%	22%	26%	22%	13%

Intense 6-hour rainfall (≥ 1.5 in.)

APR	MAY	JUN	JUL	AUG	SEP
5%	10%	17%	20%	22%	17%

Intense 24-hour rainfall (≥ 2.1 in.)

APR	MAY	JUN	JUL	AUG	SEP
7%	12%	16%	16%	17%	15%

TABLE 23. Tornado frequency by month and year for Ohio. [Ref. (25)]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1950	1	0	0	0	0	0	2	0	0	0	0	0	3
1951	0	0	0	1	0	2	0	0	0	0	0	0	3
1952	0	0	0	1	1	0	0	0	0	0	0	0	2
1953	0	0	0	1	0	2	0	0	0	0	0	0	3
1954	0	0	1	1	5	2	0	2	1	1	0	0	13
1955	0	0	5	0	0	0	0	0	0	0	1	0	6
1956	0	3	1	1	0	1	2	1	0	0	0	0	9
1957	0	0	0	0	1	2	1	0	0	0	0	0	4
1958	0	0	0	1	1	3	6	1	0	0	0	0	12
1959	0	1	0	2	4	0	1	1	0	1	0	0	10
1960	0	0	0	1	2	3	0	1	0	0	0	0	7
1961	0	1	1	4	4	2	4	3	0	0	0	0	19
1962	0	0	0	0	2	0	1	1	0	0	0	0	4
1963	0	0	0	10	2	2	2	0	3	0	0	0	19
1964	0	0	1	0	1	4	0	3	0	0	0	0	9
1965	0	0	1	15	4	0	2	2	0	0	8	0	32
1966	0	0	0	0	0	0	1	0	1	1	0	0	3
1967	0	0	1	0	0	3	2	0	0	0	0	0	6
1968	0	0	0	6	3	4	0	1	0	0	0	0	14
1969	0	0	1	1	8	2	4	1	0	0	0	0	17
1970	0	0	0	4	6	3	2	1	7	0	0	0	23
1971	0	3	0	0	4	2	3	1	1	1	0	0	15
1972	0	0	0	0	0	1	3	6	0	0	0	0	10
1973	0	0	0	0	13	15	10	3	0	0	0	2	43
1974	1	0	0	15	5	0	0	2	0	0	0	0	23
1975	0	0	0	1	0	2	1	4	3	0	1	0	12
1953-75	1	8	12	63	65	53	45	34	16	4	10	2	313
MEAN	+	0.4	0.5	2.8	3.0	2.3	2.0	1.4	0.6	0.2	0.4	0.1	13.7
MEDIAN	0	0	0	1	2	2	2	1	0	0	0	0	12
MOST	1	3	5	15	13	15	10	6	7	1	8	2	43

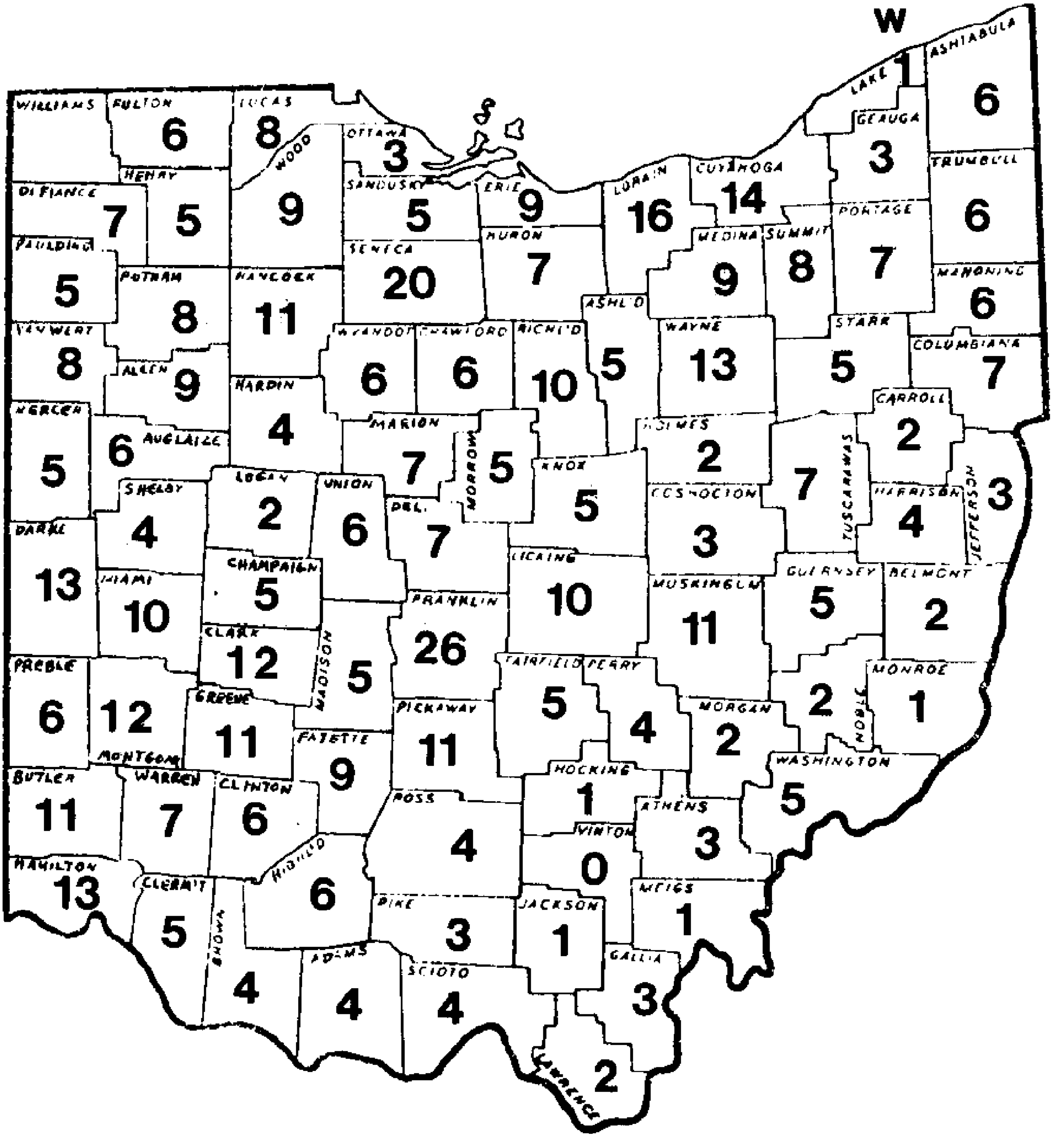


Figure 19. Number of tornadoes reported in each county of Ohio, 1900-1975. [Ref. (25)]

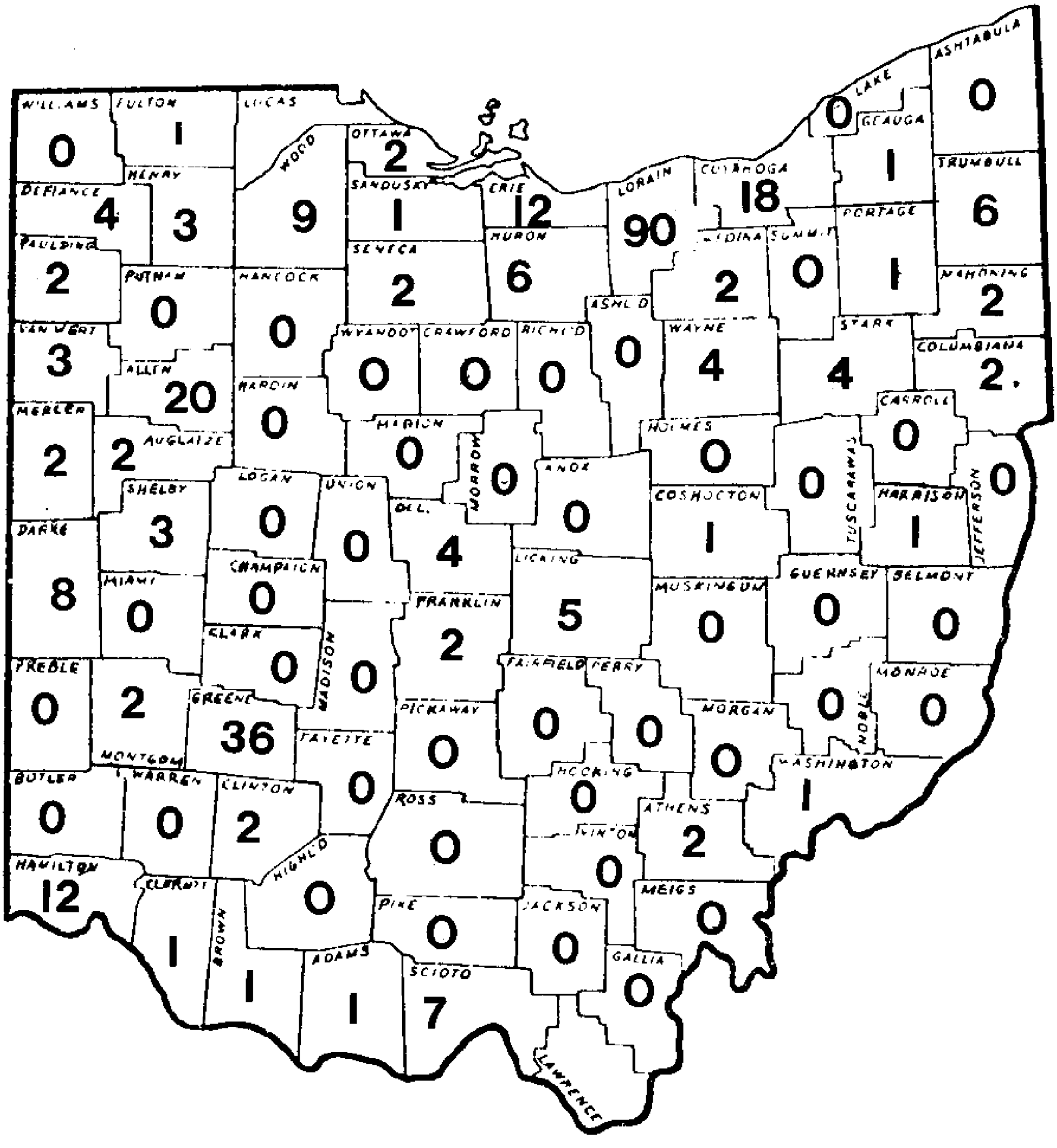


Figure 20. Number of deaths from tornadoes in each county of Ohio, 1916-1975. [Ref. (25)]

CHAPTER 5

SUMMARY

This report summarizes the climate of the Lake Erie region during the months from April through September and, as such, will provide the basis for future meteorological research in the lake basin. The major physical factors influencing the climate are identified in Chapter 2 and include the surface roughness, moisture supply, and temperatures of the lake versus the land surface. Chapter 3 examines some meteorological effects of Lake Erie: the lake and land breezes, the influence exerted by the lake on geostrophic flow, and its effect on pressure patterns, including the lake mesohigh and the climatological high. Lastly, Chapter 4 discusses the specific climatic variables and any possible lake influence upon them. They include temperature, humidity, solar radiation, wind, evaporation, precipitation, and severe weather. Results were obtained from a variety of sources and are frequently presented in both graphical and tabular form.

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