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CLIMATOLOGY OF SURFACE TEMPERATURES OF LAKES SUPERIOR, HURON, ERIE, AND ONTARIO

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INTRODUCTION

The surface temperature of the Great Lakes is a potentially important predictor for many of TDL's products. While this variable can be obtained from at least two sources, satellites and airborne radiometers, it is either available irregularly, as in the case of airborne radiometers, or there is a relatively short record of observation, as in the case of satellites. In either case the observations are not available in the operational system that TDL's products are part of. For those reasons it is useful to have a climatological estimate of this predictor.

Since 1966 the Atmospheric Environment Service of Canada has made airborne radiometer temperature surveys of surface water for Lakes Ontario, Erie, Huron, and Superior (Richards, Irbe, Massey, 1969 and Irbe, 1972)*. These surveys form the basis of a method of estimating lake surface temperatures at the points shown in Fig. 1. The period of record for these locations ranged from 4 to 10 years.

PROCEDURE

Temperatures for the points shown in Fig. 1 were subjectively interpolated from airborne radiometer fields on all available days. A 5- to 10-year record was then constructed by giving days without observations the values obtained by linearly interpolating from days on either side. In this way a temperature was constructed for each point and for each day of the period. Surveys were not always made during periods of maximum or minimum temperatures. Where necessary these maximums and minimums were inferred by subjective extrapolation from temperatures available on either side of these critical points.

The temperatures for all available years were then averaged for each day of the year, for each forecast point, so that climatic graphs of the temperature cycle were obtained for each location. For operational purposes, a six-wave Fourier curve was fitted to each yearly cycle. The curve was based on values from the climatic graph picked off in 5-day intervals. The Fourier equations substitute for a "look up" table.

Since maximum and minimum temperatures did not occur at the same time each year, the climatic peaks and troughs tended to be flattened. In some applications it is important to have an estimate of the unflattened peaks and troughs. This was obtained by examining the climatic graph and subject-

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* Surveys taken after 1970 have been made available to us on a continuing basis.

ively adjusting it. The adjustment was, in all cases, less than .9°C and usually less than .5° C. The Fourier curve reflects the adjusted peaks and troughs. Figures 2-10 illustrate the graphs. Each figure includes the climatic graph and the Fourier curve. The average observed maximum and minimum temperatures, their standard deviations, the average day of year of the maximum temperatures and their standard deviations are also shown.

The traits of the observation records vary. The number of observations per point ranged from 27 to 163; 68 was average. Except for Lake Ontario, no observations were made in 1972. Normally, for a given lake, observations were not taken on the same day of year during the period of record. Few observations were taken between November and March on all the lakes. This problem was greatest at Lake Superior where almost no observations were taken between October and April, hence, on this lake, the temperatures in this time frame are dubious. Since the observations at all of the forecast points were so sparse, these equations are offered as crude approximations of the annual lake temperature cycle.

RESULTS

The generalized Fourier equation is shown below. The nine sets of coefficients are given in Table 1. Surface temperature, for a point, for a given date, can be calculated by inserting the proper constant and coefficients.

$$
\begin{aligned}
\text{Temp (D)} = {} & A_o + \\
& A_1 \mathrm{COS}(2\pi D/365) + B_1 \mathrm{SIN}(2\pi D/365) + \\
& A_2 \mathrm{COS}(4\pi D/365) + B_2 \mathrm{SIN}(4\pi D/365) + \\
& A_3 \mathrm{COS}(6\pi D/365) + B_3 \mathrm{SIN}(6\pi D/365) + \\
& A_4 \mathrm{COS}(8\pi D/365) + B_4 \mathrm{SIN}(8\pi D/365) + \\
& A_5 \mathrm{COS}(10\pi D/365) + B_5 \mathrm{SIN}(10\pi D/365) + \\
& A_6 \mathrm{COS}(12\pi D/365) + B_6 \mathrm{SIN}(12\pi D/365)
\end{aligned}
$$

where D = Day of year
A_o = constant
$A_1 \ldots A_6$, $B_1 \ldots B_6$ = Coefficients

ACKNOWLEDGEMENT

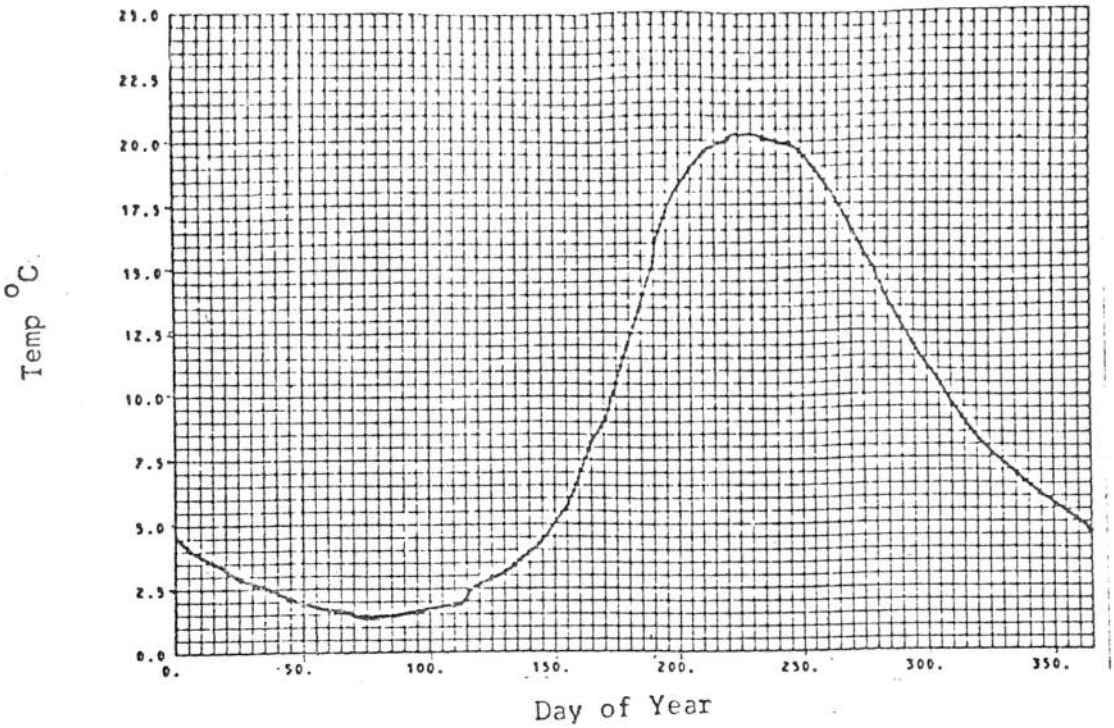
The authors would like to thank the Atmospheric Environment Service of Canada for supplying and continuing to supply us with Great Lakes surface temperature analyses.

REFERENCES

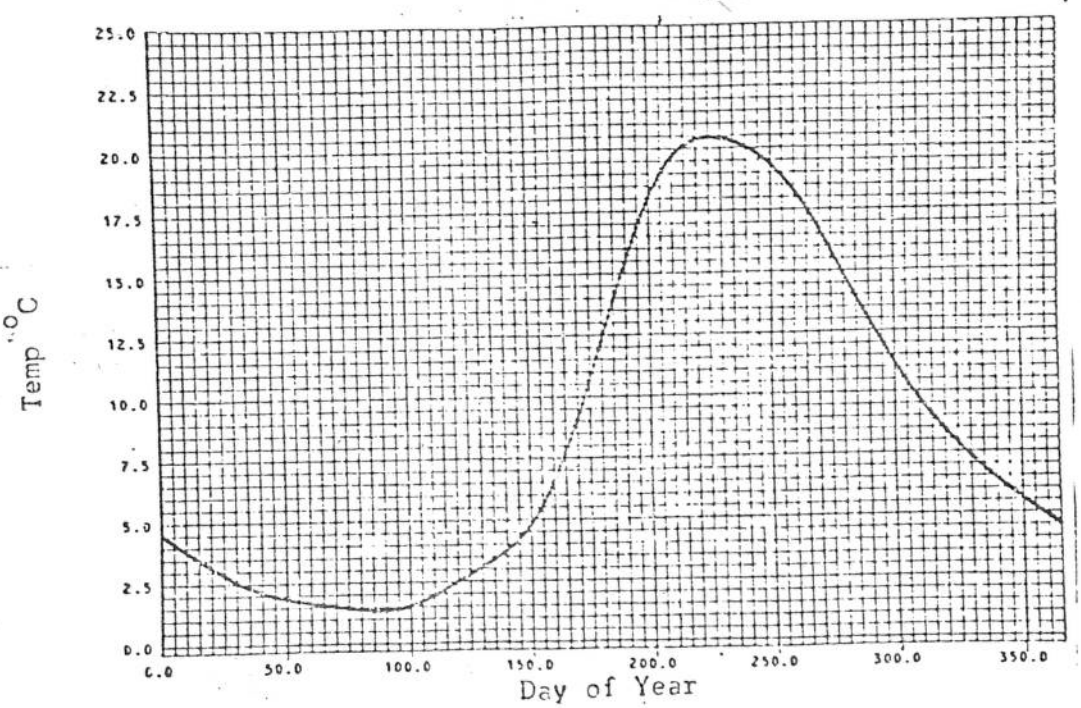
Richards, T. L., J. G. Irbe, and D. G. Massey, 1969: Aerial surveys of Great Lakes water temperatures, April 1966 to March 1968. Climatological Studies, No. 14, Environment Canada, Atmospheric Environment, Toronto, 57 pp.

Irbe, J. G., 1972: Aerial surveys of Great Lakes water temperatures April 1968 to March 1970. Climatological Studies, No. 19, Environment Canada, Atmospheric Environment, Toronto, 57 pp.

Figure 1. Locations of surface temperature estimates.



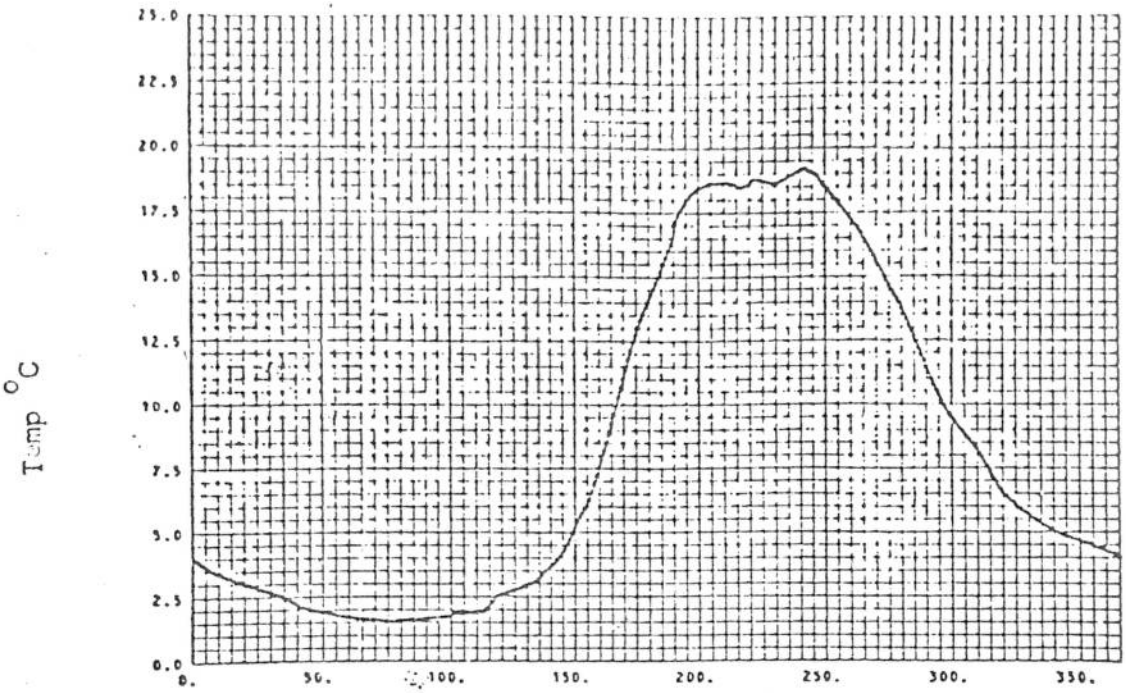
Observed Averages



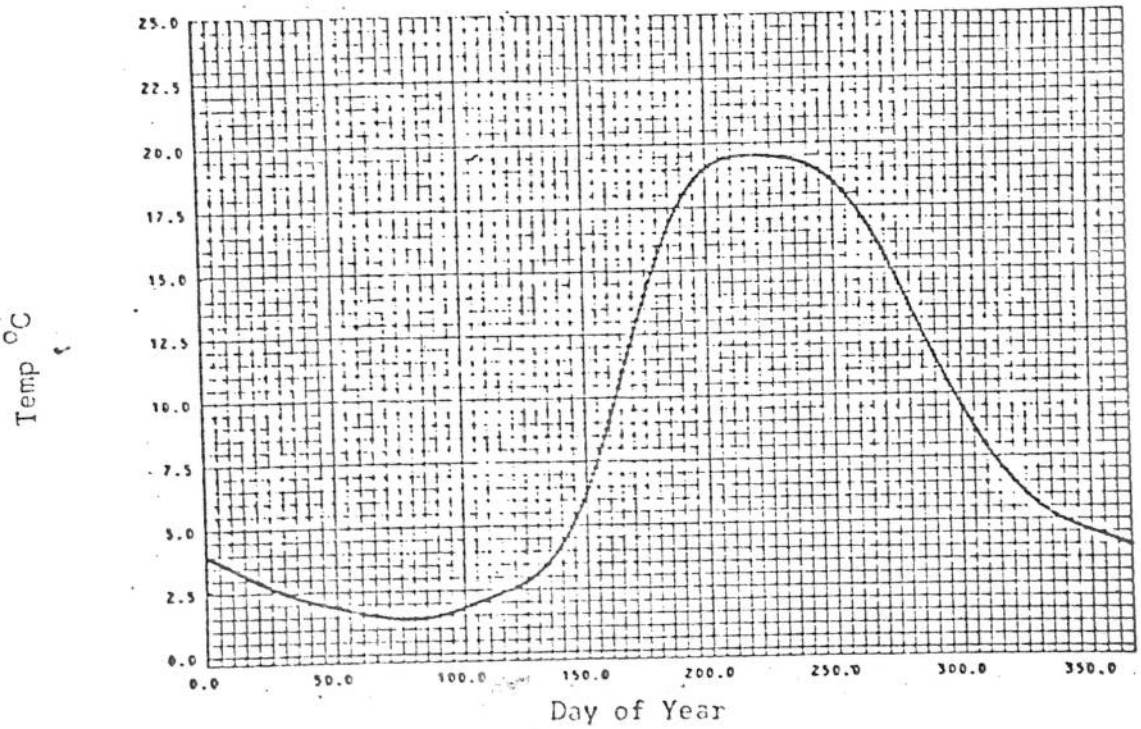
Fourier Curve

Avg. Obs. Max. Temp.	21.5°C	Avg. Obs. Min. Temp.	1.4°C
Std. Dev. of Max.	1.9°C	Std. Dev. of Min.	.6°C
Avg. Day of Year of Obs. Max. Temp.	23	Avg. Day of Year of Obs. Min. Temp.	92
Std. Dev. of Date	19	Std. Dev. of Date	41

Figure 2. Ontario East, climatic graph and Fourier curve based on 10 years of data, 163 observations.



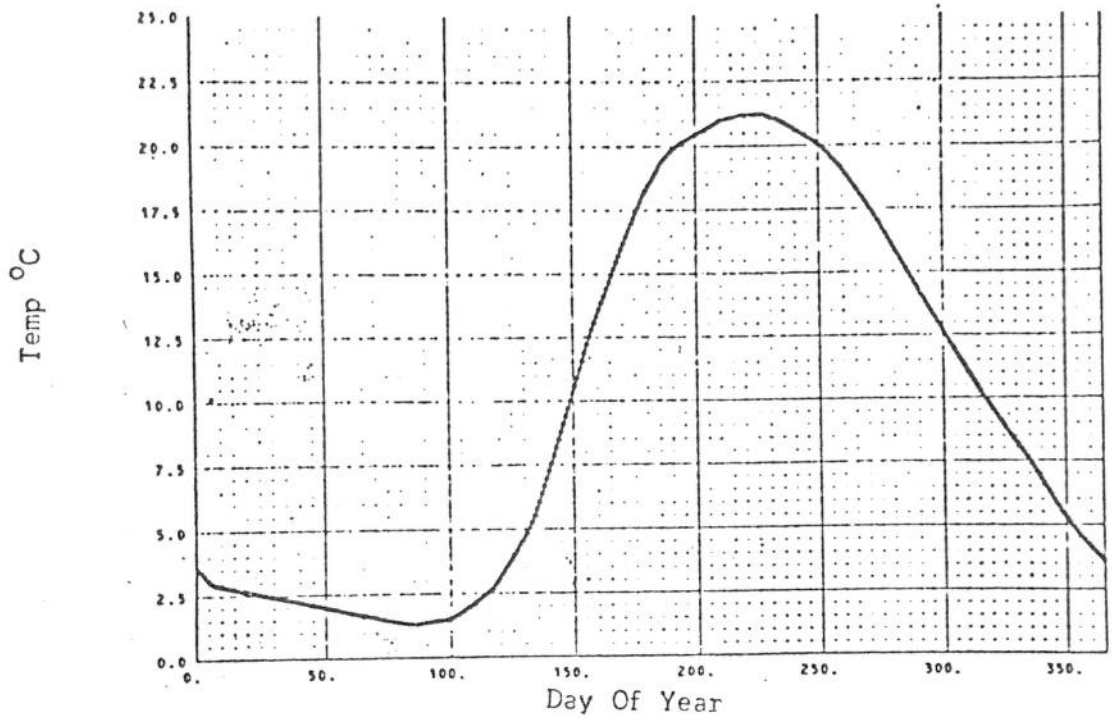
Observed Averages



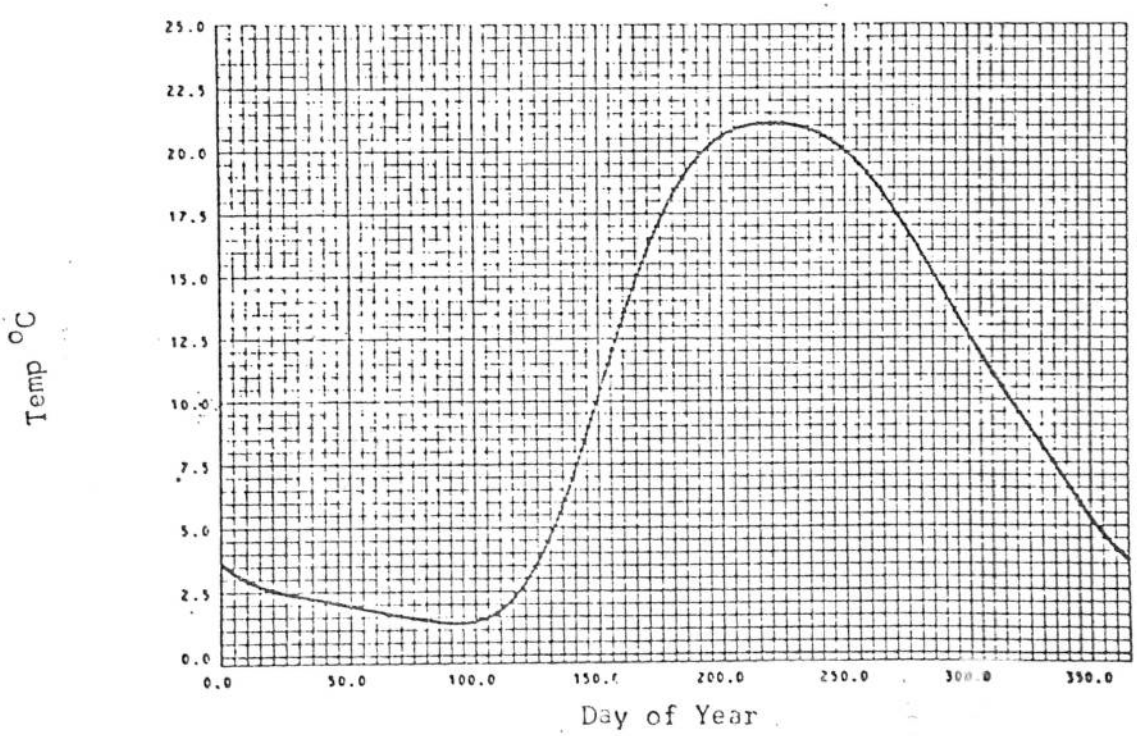
Fourier Curve

Avg. Obs. Max. Temp.	20.8°C	Avg. Obs. Min. Temp.	1.3°C
Std. Dev. of Max.	1.8°C	Std. Dev. of Min.	.5°C
Avg. Day of Year of Obs. Max. Temp.	221	Avg. Day of Year of Obs. Min. Temp.	95
Std. Dev. of Date	21	Std. Dev. of Date	30

Figure 3. Ontario West, climatic graph and Fourier curve based on 10 years of data, 163 observations.



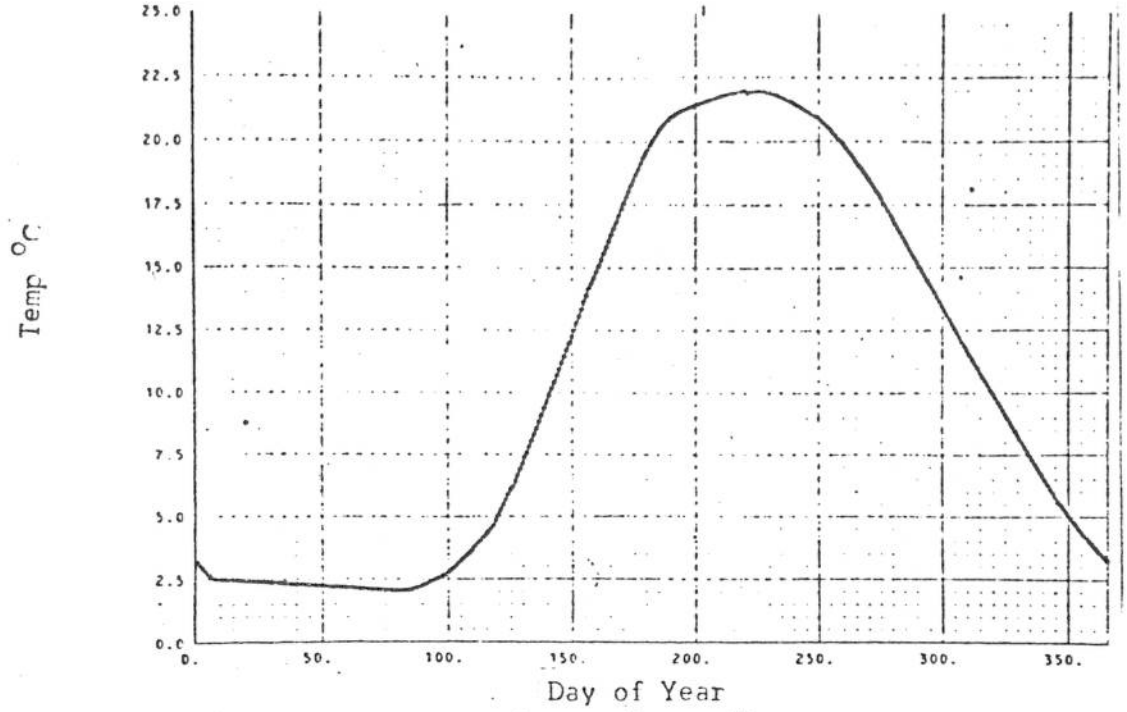
Observed Averages



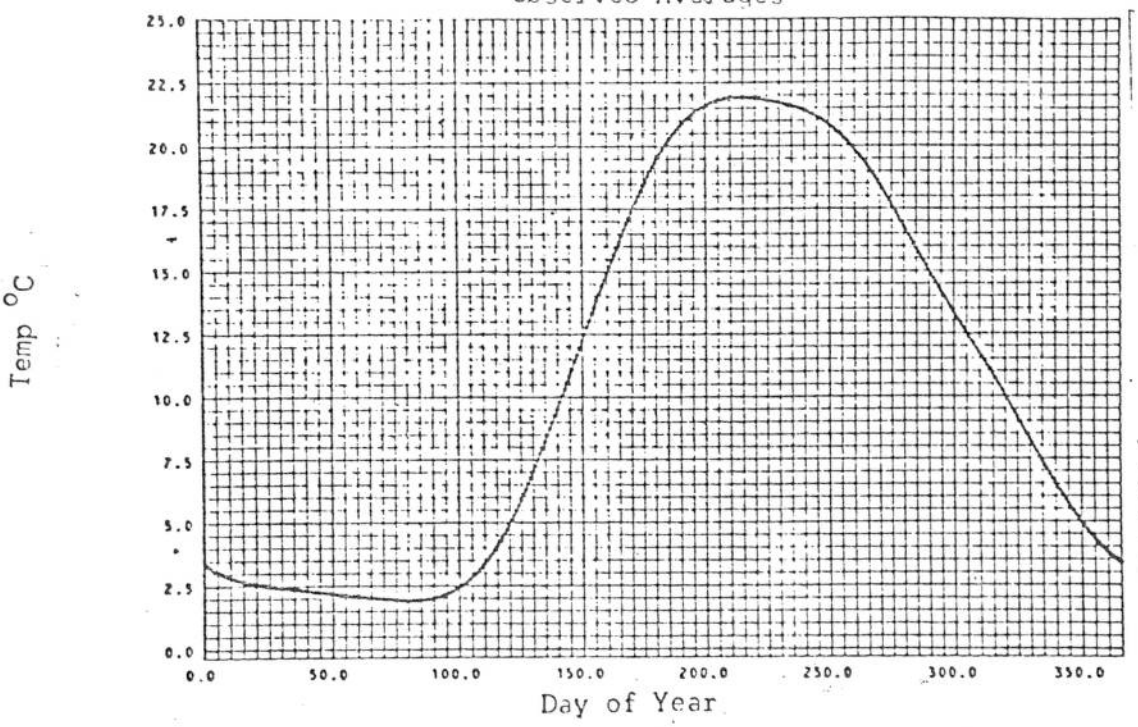
Fourier Curve

Avg. Obs. Max. Temp.	22.0°C	Avg. Obs. Min. Temp.	1.1°C
Std. Dev. of Max.	1.3°C	Std. Dev. of Min.	.8°C
Avg. Day of Year of Obs. Max. Temp.	212	Avg. Day of Year of Obs. Min. Temp.	71
Std. Dev. of Date	23	Std. Dev. of Date	32

Figure 4. Erie East, climatic graph and Fourier curve, based on 9 years of data, 83 observations.



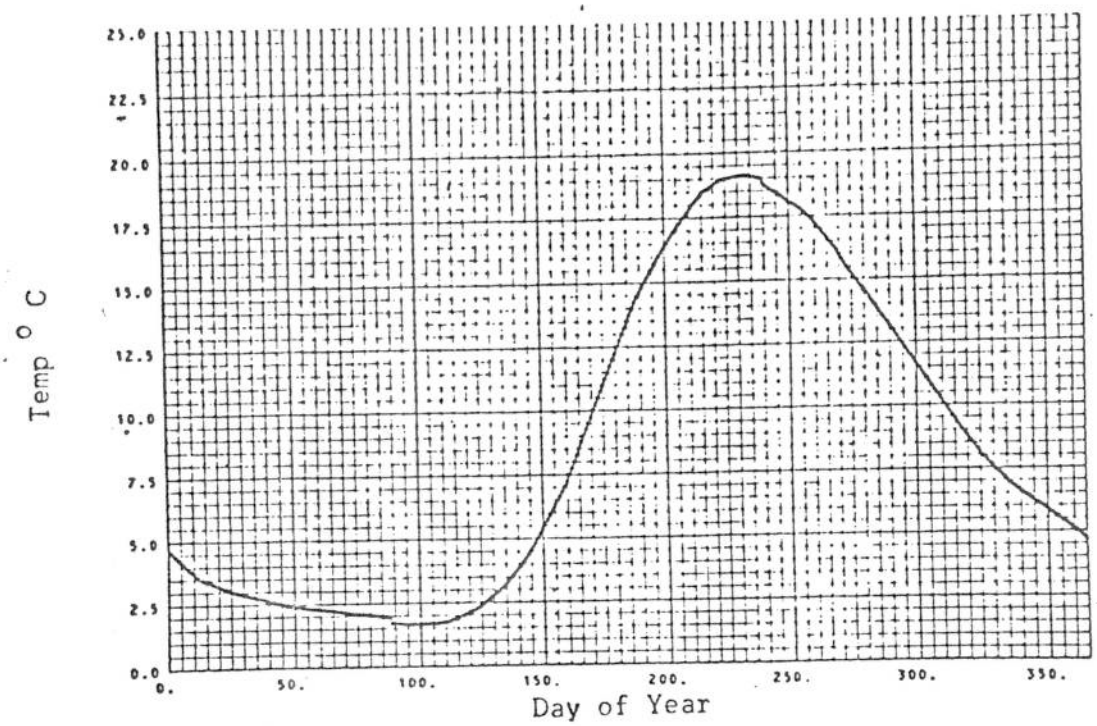
Observed Averages



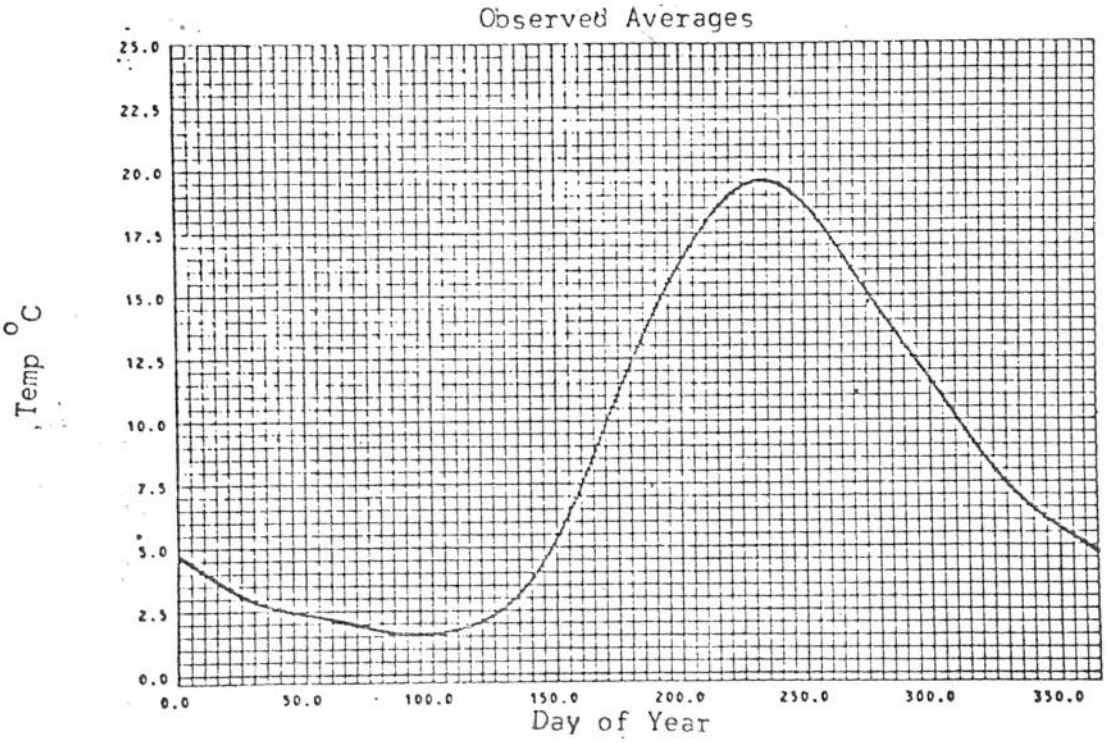
Fourier Curve

Avg. Obs. Max. Temp.	22.8°C	Avg. Obs. Min. Temp.	1.6°C
Std. Dev. of Max.	1.4°C	Std. Dev. of Min.	1.1°C
Avg. Day of Year of Obs. Max. Temp.	207	Avg. Day of Year of Obs. Min. Temp.	59
Std. Dev. of Date	25	Std. Dev. of Date	44

Figure 5. Erie West, climatic graph and Fourier curve, based on 9 years of data, 83 observations.



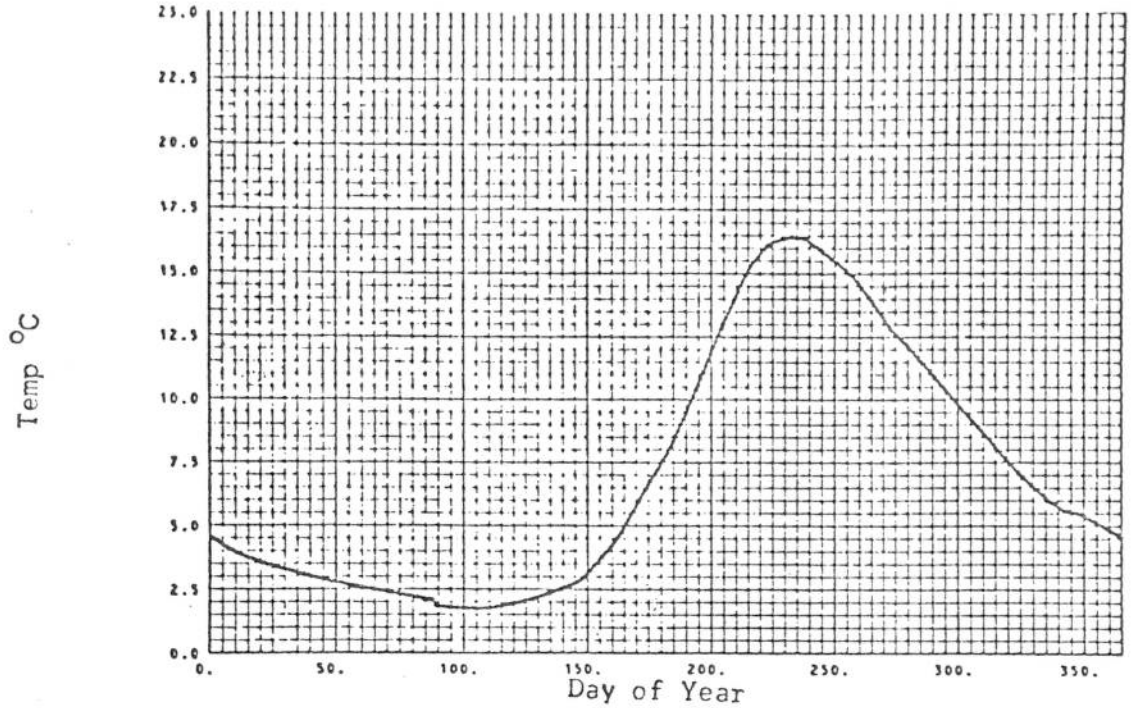
Observed Averages



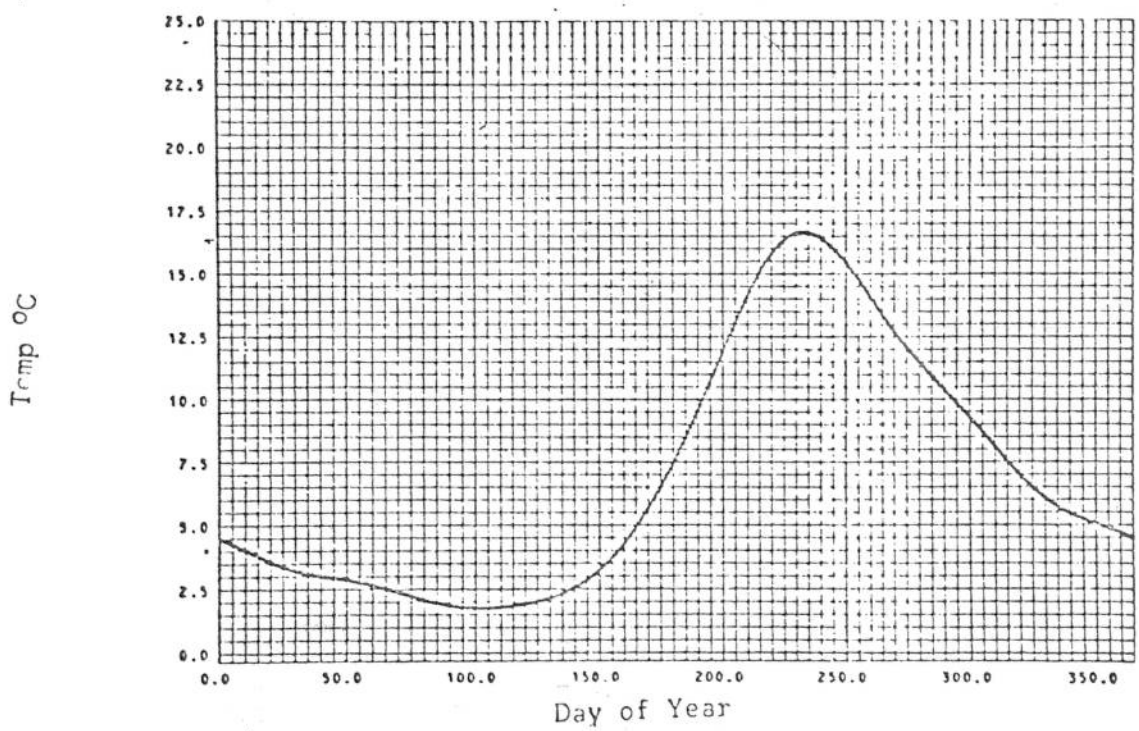
Fourier Curve

Avg. Obs. Max. Temp.	15.5°C	Avg. Obs. Min. Temp.	1.5°C
Std. Dev. of Max.	1.2°C	Std. Dev. of Min.	.9°C
Avg. Day of Year of Obs. Max. Temp.	236	Avg. Day of Year of Obs. Min. Temp.	98
Std. Dev. of Date	22	Std. Dev. of Date	23

Figure 6. Huron South, climatic graph and Fourier curve based on 8 years of data, 67 observations.



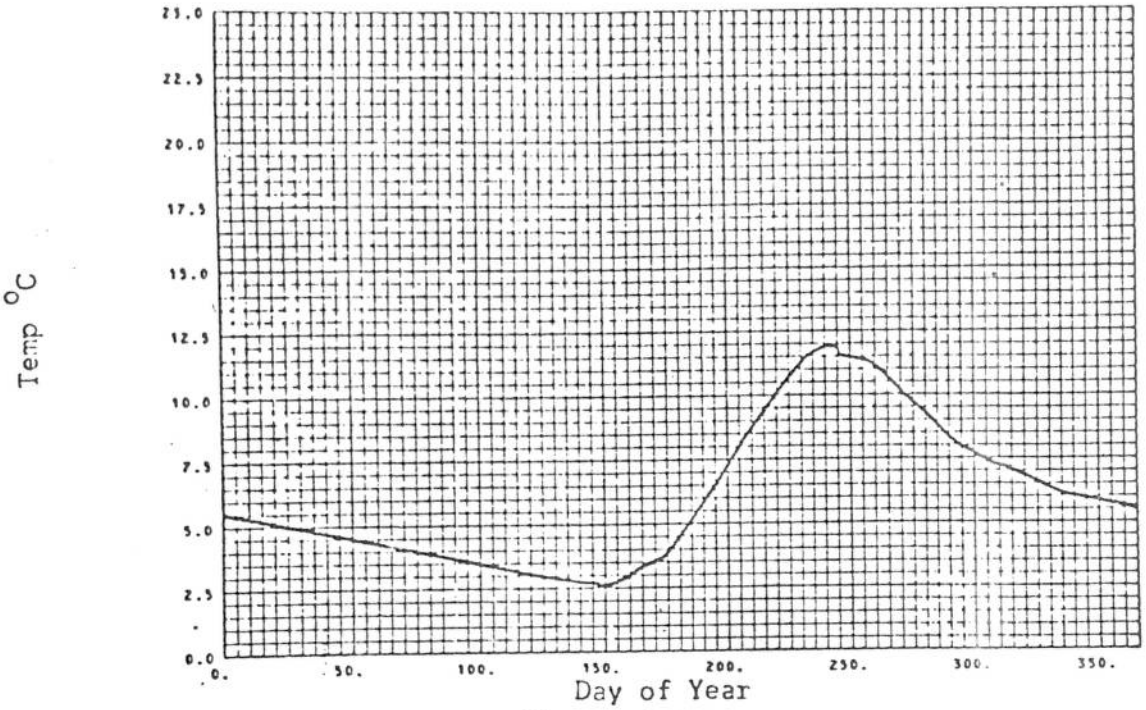
Observed Averages



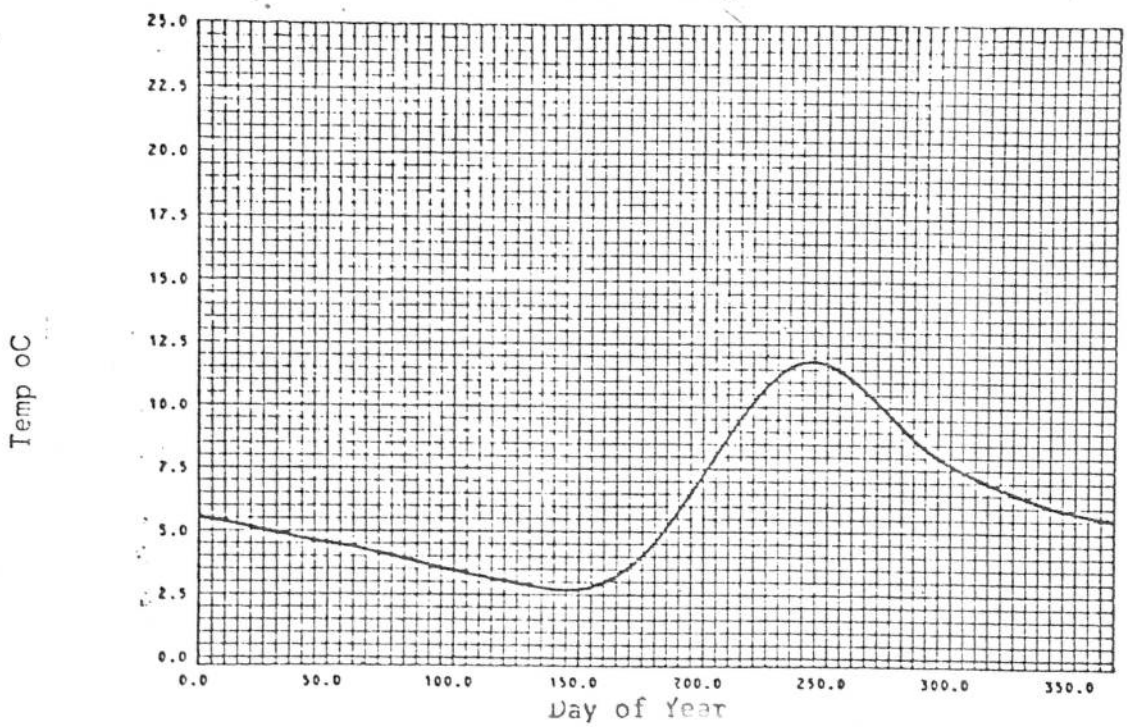
Fourier Curve

Avg. Obs. Max. Temp.	17.6°C	Avg. Obs. Max. Temp.	1.5°C
Std. Dev. of Max.	1.4°C	Std. Dev. of Min.	.5°C
Avg. Day of Year of Obs. Max. Temp.	232	Avg. Day of Year of Obs. Min. Temp.	104
Std. Dev. of Date	18	Std. Dev. of Date	29

Figure 7. Huron North, climatic graph and Fourier curve based on 8 years of data, 69 observations.



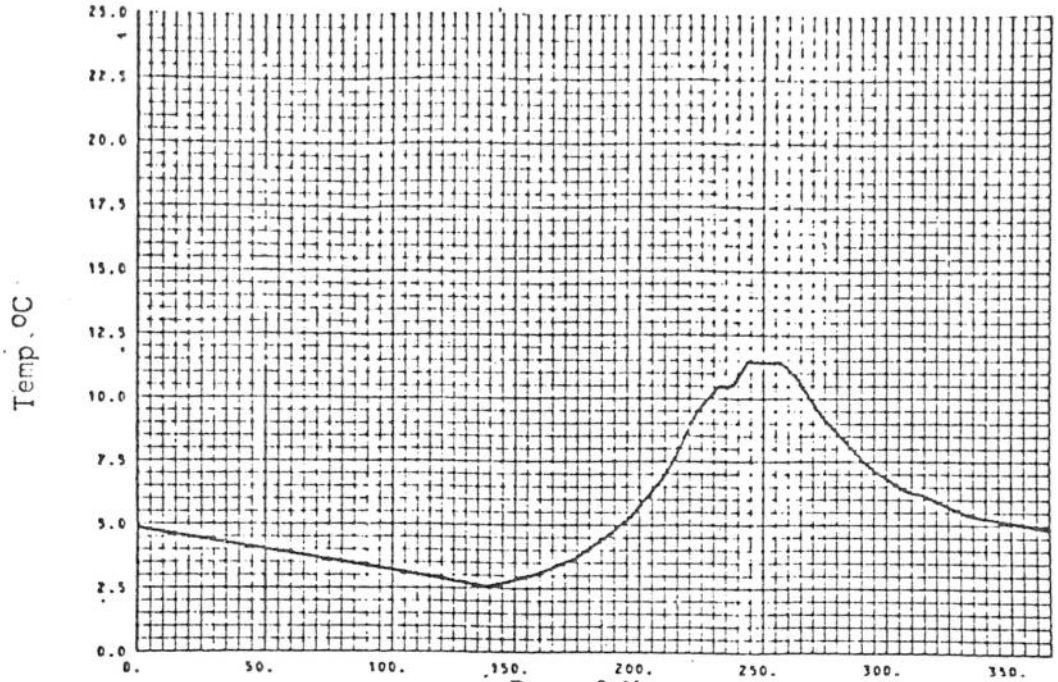
Observed Averages



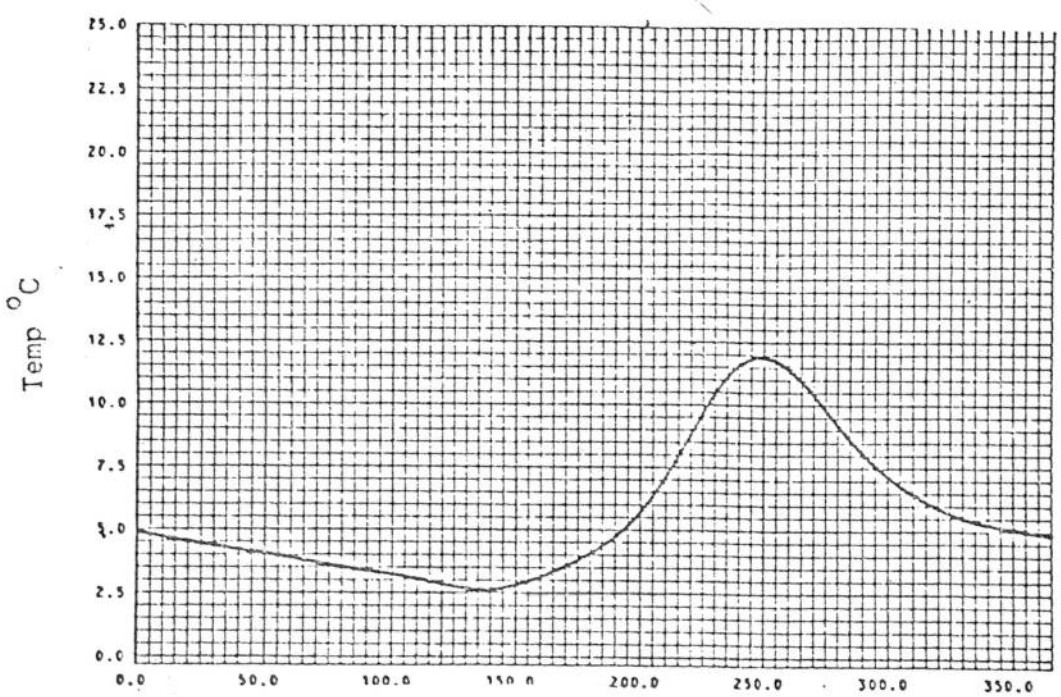
Fourier Curve

Avg. Obs. Max. Temp.	12.6°C	Avg. Obs. Min. Temp.	2.1°C
Std. Dev. of Max.	1.3°C	Std. Dev. of Min.	.3°C
Avg. Day of Year of Obs. Max. Temp.	244	Avg. Day of Year of Obs. Min. Temp.	112
Std. Dev. of Date	14	Std. Dev. of Date	69

Figure 8. Superior East, climatic graph and Fourier curve based on 8 years of data, 40 observations.



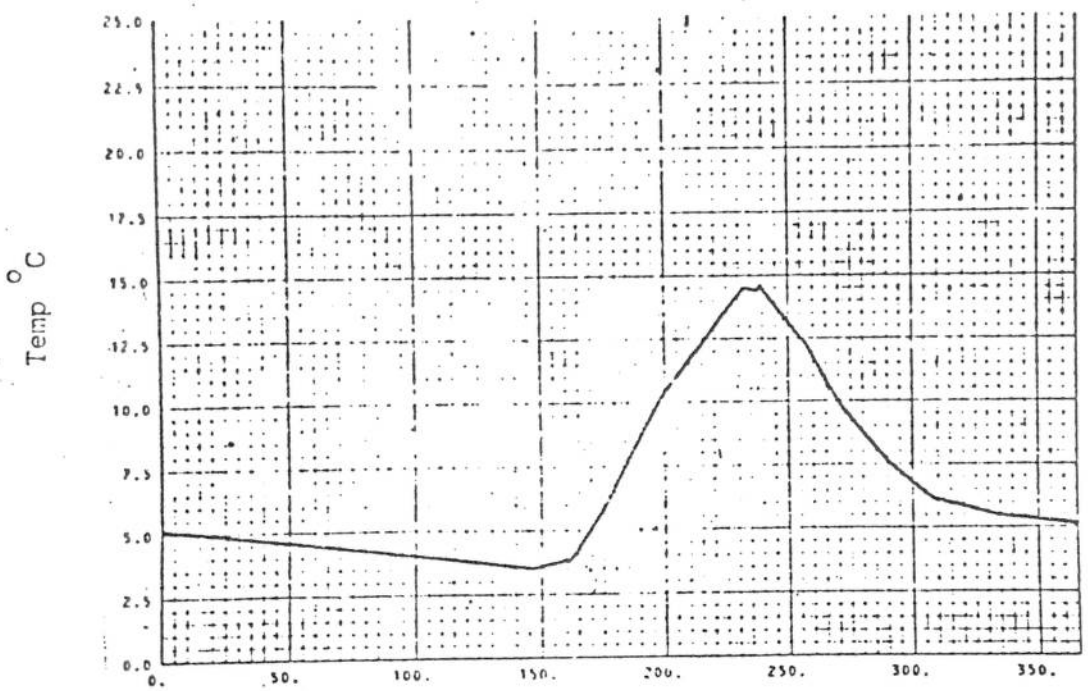
Observed Averages



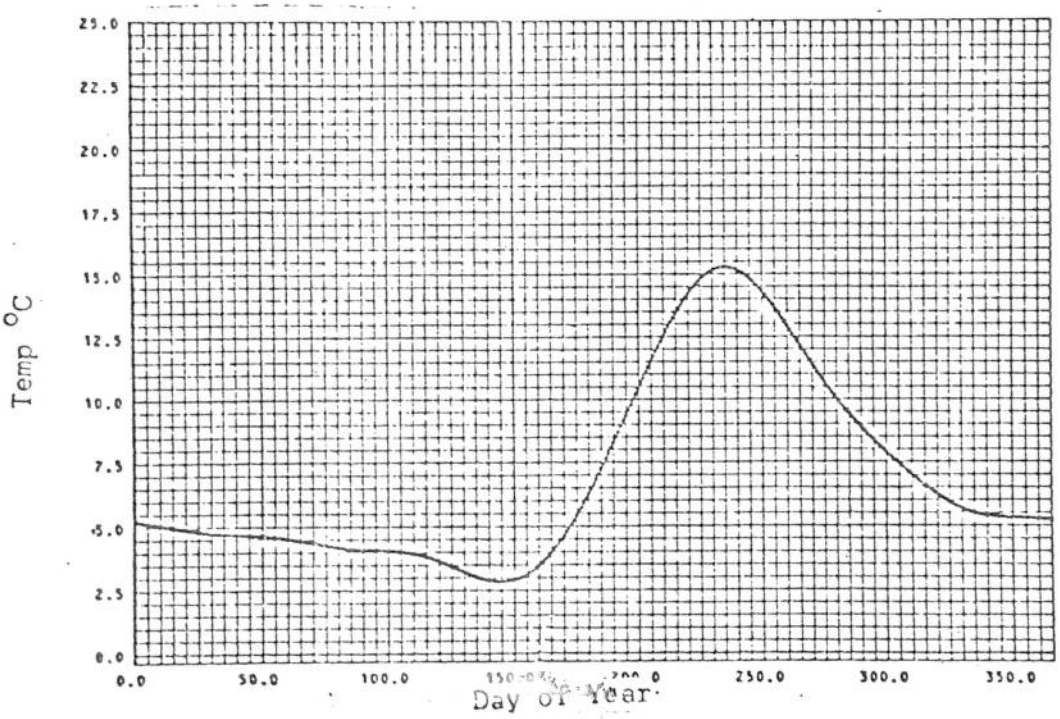
Fourier Curve

Avg. Obs. Max. Temp.	13.4°C	Avg. Obs. Min. Temp.	2.5°C
Std. Dev. of Max.	1.4°C	Std. Dev. of Min.	.2°C
Avg. Day of Year of Obs. Max. Temp.	244	Avg. Day of Year of Obs. Min. Temp.	138
Std. Dev. of Date	16	Std. Dev. of Date	6

Figure 9. Superior Central, climatic graph and Fourier curve based on 8 years of data, 40 observations.



Day of Year
Observed Averages



Fourier Curve

Avg. Obs. Max. Temp.	15.6°C	Avg. Obs. Min. Temp.	3.8°C
Std. Dev. of Max.	1.9°C	Std. Dev. of Min.	.6°C
Avg. Day of Year of Obs. Max. Temp.	240	Avg. Day of Year of Obs. Min. Temp.	161
Std. Dev. of Date	12	Std. Dev. of Date	10

Figure 10. Superior West, climatic graph and Fourier curve based on 5 years of data, 27 observations.

Table 1. Fourier constants and coefficients for all forecast locations.

	Ontario East	Ontario West	Erie East	Erie West	Huron South	Huron North	Superior East	Superior Central	Superior West
A_o	8.7372	8.5964	10.0202	10.7955	8.6193	6.9809	6.1891	5.7083	7.0385
A_1	-4.5114	-5.6227	-6.4995	-7.2855	-4.0556	-2.4299	-0.2367	-0.3022	-1.6229
A_2	0.0123	0.7845	1.0446	0.8212	0.0253	-0.4902	-0.8186	-1.1447	-0.8573
A_3	0.2759	-0.1711	-0.8588	-0.7742	0.0179	0.5385	0.6182	0.7534	0.8321
A_4	0.0763	0.5705	0.1808	0.0269	0.0573	-0.3024	-0.1725	-0.0547	-0.2540
A_5	-0.0336	-0.2949	-0.1332	-0.1285	-0.0049	0.1829	-0.0240	-0.1107	0.0350
A_6	0.0274	0.1573	-0.0423	-0.0085	0.1178	0.0723	0.0442	0.0744	0.1119
B_1	-7.8328	-6.9153	-7.9168	-7.6750	-7.4368	-5.8359	-3.4018	-3.3077	-4.1090
B_2	2.7287	2.7558	1.7588	1.3733	2.4054	2.4154	1.5525	1.3823	2.5535
B_3	-0.7480	-0.3847	0.0680	0.2752	-0.4694	-0.5636	-0.2576	0.1484	-0.6826
B_4	0.3067	0.1109	-0.3166	-0.1997	0.0329	0.0925	-0.0770	-0.3285	0.1355
B_5	-0.2774	-0.1117	0.0860	0.0276	0.0613	0.0626	0.0462	0.1347	0.0481
B_6	0.1406	0.0155	0.0053	0.0857	-0.0402	-0.0780	0.0289	-0.0308	-0.0560