

Environment Canada Imaging Cover Page

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A SURVEY OF THE URBAN EFFECT ON
THE CLIMATES OF CANADIAN CITIES

By

M.K. THOMAS

On April 12, 1965 the Toronto Centre of the Royal Meteorological Society, Canadian Branch, held a symposium on the subject of "The Urban Effect on Climate". Mr. C.C. Boughner chaired the symposium and the speakers included D.W. Boyd, J.P. Bruce, Dr. P.W. Summers, F.D. Thompson and M.K. Thomas. The talks and papers delivered that evening were never published. There has been, however, a continuing demand for copies of "A Survey of the Urban Effect on the Climates of Canadian Cities", and many copies of the text have been duplicated and given to students and others interested in urban meteorology and climatology.

With the present increased interest in this subject, it has been thought worth-while to publish the original text and diagrams in an informal way in the Climatic Data Sheets series, although today, more than six years since the date of the meeting, a survey could be made which would probably yield better and more informative data and information. Also, since the symposium was held, our Service has become part of the new Department of the Environment and we are all much more aware of the role meteorology can and will play in maintaining the quality of our environment. Perhaps the publication of this paper will spark more up-to-date and complete studies of the climates of Canadian cities.

Those interested in the subject of urban meteorology and climatology should refer to DS No. 2-69 "Selected References to Papers Concerning Canadian and Urban Climates" which was prepared early in 1969. A revised version of this Documentation Sheet with references to papers published over the past three years will be available early in 1972.

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A SURVEY OF THE URBAN EFFECT ON
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By

MORLEY K. THOMAS

Until fairly recently, meteorologists have turned their backs on cities. More and more of us have come to live in urban areas, but in the office we use "good" or representative data - data that are representative of the macroclimate - temperatures and humidity data observed in a shelter four feet above a level grassy surface, yards and yards away from any trees or buildings, wind measured 30 feet above a level plain, etc., but the "micro" or local "topo" conditions in an urban area seldom afford these ideal exposure sites, and in addition, we pollute the atmosphere - we produce heat, dirt and smell, so that great dark murky palls sometimes hang over our urban areas.

Of course, meteorologists have not turned their backs on city climates just because they are hard to measure. To forecast the weather over wide areas, weather information and data are required, and because of the economics of both time and money, each weather report must represent an area of more than 10,000 square miles, even in southern Canada. Since urban areas still cover only a small percentage of the landscape, you can see why an observation taken at Malton airport is more valuable to a forecaster in Canada and the United States than one taken at the corner of College and Bay Streets in downtown Toronto.

But more and more people are living in urban areas - more than 70% of us, compared to less than one-third of all Canadians at the turn of the century. By the next turn of the century it is forecasted that 80 to 90% of Canadians will be living in large urban areas. Even with all our wide open space - farm land, prairies, forests, mountains, arctic, right now 50% of us are living in urban areas of 100,000 people or more, and the proportion is increasing every day. So it seems to me that we are going to be forced to pay considerable attention to urban meteorology - weather reports, short-range forecasts, advice and information for urban planning, zoning and building design, pollution control, floods and droughts, etc.

City climates consist of thousands of microclimates. By changing the surface of the land - replacing fields, forests and stream by slabs of stone, brick, concrete and asphalt piled to varying heights, by changing the composition of the atmosphere through the release of gases, chemicals and solid matter, and by producing vast quantities of heat in factory, home and automobile - by all these, we are producing what is generally called the urban effect. But we are not yet ready to delve into the microclimatology of urban climates. We do not yet know enough about the changes in the relatively large scale meso or topo climates due to the urban effect and, so, our first task is to isolate the facts of city climates, and to compare them with rural climates in order that we may see just what we have done to the climates in which most of us live.

The earliest specific study of an urban climate was carried out by Howard when he published a paper in 1833 regarding the London climate. By using the very early instrumental records, he showed how that climate

differed from that of the surrounding countryside. In the first third of this century urban climates received more attention in Europe than at either England or America. In 1937, Kratzer of Germany published a book on the subject and compiled a list of references. Also in the early 1930's Schmidt of Austria began automobile trips across Vienna with a recording thermometer developing a technique that has been used in many cities since that time.

It was, in fact, this type of research that led to a paper from which a figure is used as our first slide.

Figure 1 - Temperature Profiles in Toronto

Middleton and Millar attached a resistance thermometer to an automobile and investigated the distribution of temperature across the city of Toronto under various meteorological conditions. Figure 1 represents a cold winter night with a very clear sky and a slight northerly breeze, when an almost unbelievable difference in temperature, some 27 degrees, was observed between the bottom of the valley and its crest. This slide is shown because it illustrates the effect of lake water temperatures along the immediate shore, and the result of air drainage into hollows and ravines. This illustration is a classic, it has been reproduced in many papers and text books giving Toronto a perhaps undeserved reputation of being a city where large temperature contrasts may be expected.

Figure 2 - Climatic Changes Produced by Cities -
A Summary Table Prepared by Landsberg

One of the most useful contributors to the field of urban climates over the past two decades has been Dr. H.E. Landsberg, Director of the Office of Climatology, United States Weather Bureau. In one of the keynote addresses at a Symposium on the Climates of Cities, a few years ago, he

showed a table which is shown as Figure 2. In this table he tabulates the general climatic conditions produced by cities in comparison with rural environments. Mimeographed copies of this table are available, and for the remainder of my portion of this symposium I propose to consider the urban effect on radiation, precipitation, temperature, etc., giving examples from Canadian cities. It will subsequently be noted that the changes noted in large metropolitan urban areas such as Montreal, Toronto, Vancouver, etc., will sometimes agree with the change of values as summarized by Landsberg, and sometimes are at variance.

Several of the figures to be shown have been made for this symposium, others you will recognize as ones that I have borrowed from published pages and circulars. I want to thank the authors of these papers, and also my many colleagues at a dozen or so meteorological offices across the country who have taken the time and trouble to correspond with me and to provide unpublished studies, and reviews of local urban climates.

Figure 3 - Toronto Observing Stations

This figure is shown primarily to illustrate the relative locations of the principal observing stations in the Metropolitan Toronto region, namely Malton, Downsview and the Island Airports, 315 Bloor Street, and the Scarborough Field Research Station. The boundaries of Metropolitan Toronto are shown along with a line approximating the edge of the urban development in the general areas. A circular line has been drawn at a radius of 25 miles from downtown Toronto, and a station plot illustrates the density of stations presently in operation in one of the best covered urban areas of the country.

In particular, attention is drawn to the location of Toronto City and Scarborough stations from which radiation data will be shown on subsequent slides, and the relative locations of Brampton and Toronto City from which locations bright sunshine data will subsequently be illustrated.

Figure 4 - Solar Radiation at Toronto 1960 - 1964

The upper part of this figure illustrates the annual variation of solar radiation at Toronto. In the low-sun season generally cloudy months of November, December and January, the mean monthly totals average in the neighbourhood of 100 langleys increasing to a maximum of slightly in excess of 500 langleys during the months of June and July.

The solar radiation recorder at Scarborough field station regularly records more radiation than the one in the city. The excess averages between 5 and 10%, which is only about half as much as the 15 to 20% less suggested by Landsberg. There is an annual variation with the winter time atmosphere over Toronto depleting relatively more radiation than the summertime atmosphere. Quantitatively, however, it should be remembered that a depletion of 10% in January amounts to only 10 langleys, but a depletion of 5% in June, amounts to 25 langleys over the month.

The diurnal variation of solar radiation is relatively uniform when averaged over five years. The figure also illustrates that there is on the average more depletion of summer solar radiation in the afternoon hours than there is in the period before noon.

Figure 5 - Bright Sunshine at Toronto 1951 - 1964

This slide presents bright sunshine data at Toronto over the period 1951 through 1964 compared to similar data observed at Brampton, some 20 miles to the northwest of the city centre. An attempt has been made to present the data in a manner similar to that shown on the previous radiation slide, and it is noted while there are many similarities, there are some

interesting differences. The upper portion of the figure shows the mean monthly totals at Toronto over this recent 14-year period. The number of hours of bright sunshine averages in the neighbourhood of 100 hours a month for the months of November through February, while a definite maximum is reached in July when the average is about 275 hours.

In looking at the portion of the figure illustrating the mean excess at Brampton over Toronto, it is noted that on the average there is slightly more bright sunshine at Brampton than in the centre of the urban area at the Toronto observing station. This is particularly the case in the summertime when Brampton records on the average of 12 hours more bright sunshine during the months of June and July. On a percentage basis the mean excess at Brampton over Toronto amounts to from 4 to 6%, except during the months of August and September.

In general, even without the Toronto urban development, you might expect to observe more bright sunshine at Brampton than in the city. This conclusion is based on the fact that Brampton is situated closer to, and is more under the protection of the Niagara Escarpment, and is located 350 feet higher above the Lake Ontario than is the Toronto station. Toronto is also much closer to the lake and subsequently might be expected to have more low cloud and fog. When in addition to these factors the presence of atmospheric pollution over Toronto is included, it is not surprising that there is more bright sunshine recorded at Brampton. The anomaly in August and September is believed to be due to the general stability of the atmosphere during this time of the year, and the resulting stratification of the low atmosphere and the formation of radiation fog in rural areas at and shortly after daybreak. Most of the differences between Toronto and Brampton in August and September occurs during these early morning hours.

The curve illustrating the diurnal variation in July of bright sunshine at Brampton and Toronto illustrates that there is in general a broad, flat plateau at both stations as there is at most stations across southern Canada during the summer months. In other words, the days with clear mornings and convective activity in the afternoon are balanced off with days with foggy low cloud conditions in the morning and clear afternoons.

Figure 6 - Greater Edmonton Airports

Before considering temperatures at the Edmonton airports, it is perhaps well to consider the relative locations of Namao and the new International Airport in comparison to the location of the Industrial Airport which has been for the past several years well within the limits of the Edmonton urban area. The immediate north Saskatchewan River valley is well marked, and although none of the airports lie in the valley, the city and the Industrial Airport are between 100 and 300 feet lower than Namao and International Airports. With the move to the new airport and the new observing site at Edmonton, there has been considerable local speculation over the effect on Edmonton temperatures. The official Edmonton temperatures are those observed at the Industrial Airport, where the actual site, if not the surroundings, has been unchanged for the past 25 or so years.

Figure 7 - Hourly Temperatures at Edmonton - July and December 1964

Considering long time Edmonton records, December 1964 was the third coldest December ever recorded since observations began in 1881. The upper portion of this figure illustrates the diurnal variation of temperature at both the International and Industrial Airports, and reveals that on the average temperatures were lower at the International Airport than they were at the Industrial Airport, for every hour of the day. The difference averaged 3 to 4 degrees during nighttime hours, and about 2 degrees during the daytime.

From December 20 to 31 the average difference in minimum was nearly 9 degrees, while the maximum difference during the winter just past was 20 degrees on February 2. The July portion of the figure illustrates that the combined urban topographical effect is in existence in summer but not to such a great magnitude as in the winter.

Figure 8 - Winnipeg Urban Temperatures

The area surrounding Winnipeg has been called one of the flattest stretches of land in the world. Several years ago two Winnipeg meteorologists investigated the heat-island effect by undertaking traverses of the horizontal temperature field in Winnipeg with an automobile mounted resistance thermometer on nights favouring radiational cooling. The centre of the city was found to act as a heat-island with temperature differences as great as $22\frac{1}{2}$ degrees being observed between the city centre and open country. Figure 8 shows that the average difference was approximately 6 degrees. While there would be minor effects due to wind, cloud cover, vegetations, soil type and terrain, the actual urban effect would be the most important one in this example.

Figure 9 - Difference in Mean Hourly Temperature - Toronto

This diagram shows the difference in mean hourly temperature between Toronto City and Malton Airport averaged for each month over a 10-year period, from 1941 to 1950. The diagram illustrates both the diurnal and annual variation of this temperature difference. On the average Toronto City shows an excess of 3 degrees over Malton Airport during the nighttime hours in all but a few of the summer months, and the greatest excess on the average is 4 degrees just before dawn in winter. On the other hand, at midday in mid-summer there is a deficit which averages about one degree. These figures agree well with the general values suggested by Landsberg of two to three degrees for winter minima, and one to one and a half degrees for an annual mean.

The slight deficit of temperature at midday corresponds well with the deficit of both bright sunshine and radiation in downtown Toronto. It must be remembered that these are average data based on ten years of record during cloudy and clear spells, wet and dry, etc. Surprisingly, a larger excess does not appear in the summer evening hours when the city's heat is retained much more effectively than that in the rural areas. In general, during cloudy, windy conditions the difference between the city and rural areas is at a minimum, whereas on clear winter nights with little wind when radiational cooling proceeds in rural areas but is inhibited due to layers of atmospheric pollution in the city, there are often differences of as great as 20 degrees. Differences of this magnitude happen on the average of one or two mornings each winter.

Figure 10 - Temperature Extremes at Montreal

About ten years ago Montreal experienced some extremely high temperatures during the summer of 1955, followed by extremely low temperatures during the winter of 1956-57. The extremes recorded in July 1955 and January 1957 are outstanding in the last decade or so, and have been used as examples of extremes at stations in the Greater Montreal area in order to illustrate the urban effect. Maximum temperatures recorded were from 94 to 97 degrees, and there is little evidence of either an urban or geographical effect. There is, however, a marked difference in minimum temperatures where stations to the north of Montreal Island reported values as low as -43° to -47° and stations south of the Island reported temperatures as low as -42° and -44° . The low land and suburban stations reported temperatures in the -30's, but the temperature at the McGill Observatory in the city did not go below -22° , revealing a temperature excess of about 20 degrees due to the urban effect.

Figure 11 - Halifax Thermal Pattern - 7 May 1953

This figure is shown to illustrate a geographical effect on city temperatures, namely - the effect of the sea breeze on May 7, 1953 at 1300 AST. The temperature of the sea surface was 40°F, and city temperatures as recorded at a few fixed stations and from an automobile were as low as 56° in the southeastern portion of Halifax, and as high as 70° on the northern lee side of the city. This thermal pattern is believed to be entirely due to geography and the presence of the sea breeze, and it is felt that very little, if any, urban effect is evident.

Figure 12 - Mean Annual Precipitation at Vancouver

Landsberg has suggested that urban areas produce an increment of 5 to 10% in precipitation. As was illustrated in an earlier figure, we presently have about 35 precipitation observing stations in Greater Toronto, and many of these have been in operation for 10 to 15 years, but we have as yet been unable to determine any urban effect on precipitation. There are occasions when there is more rainfall on the east side of the city as one might expect with prevailing westerly winds, but there have been occasions when thunderstorms produced two to three inches in areas on the west side with practically no precipitation in Scarborough. Figure 12 is shown, however, as an illustration of what geography can do to the distribution of annual precipitation over an urban area. While the annual precipitation at Sea Island Airport averages but 41 inches a year, short-period averages from some stations located above North Vancouver average more than 100 inches a year.

Figure 13 - Normal Winter Snowfall in the Toronto Region

This figure showing the average annual snowfall over Greater Toronto is shown to illustrate the effect of topography on snowfall across the Metropolitan area. Orographic influences appear to be the major factor in the distribution of snowfall in the Toronto region. The ridge of heavy snowfall which extends northeastward from the centre of the city lies on the southeastward facing slopes, where the land rises from an elevation of approximately 400 to 600 feet. The relatively light snowfall over the broad Humber valley may be due to subsidence with winds from ^{the} easterly quadrant during snowstorms. In addition, the lake effect and the city effect are both strong enough to perhaps change snowfall to rainfall over the central urban area when surface temperatures are near freezing.

Figure 14 - Relative Humidity at Toronto

One of the most difficult meteorological elements to deal with is humidity. The three slides that follow are based on relative humidity data observed at Toronto City and Toronto Malton Airport. Figure 14 shows that over the 20 years from 1941 to 1960 relative humidity values at Toronto averaged less each month than did values at the airport. This is in line with Landsberg's estimate of the urban effect decreasing the winter relative humidity, however, there seems to be a greater difference in winter than in summer in contrast to Landsberg's estimate. At Toronto the biggest difference seems to be in the months of March and April, and the smallest difference in August. The subject of the urban effect on humidity is a complex one, and one which might be discussed for hours. From these investigations it is becoming apparent that the immediate surroundings of an observing site are very important in humidity observations. In fact, before the move of the observing site at Malton in January 1964 from near the old Terminal Building to a new and better location, the Malton humidity data were becoming more urban than data

observed at 315 Bloor Street West. Using average values for the decade from 1941 to 1950 the differences between Toronto and Malton were much greater than for the decade between 1951 and 1960, but I believe the old differential pattern has been re-established at the new Malton observing site.

Since humidity can be exceedingly objectionable in mid-summer let us look at the July diurnal variation at Toronto and Malton. Surprisingly while nighttime relative humidity is greater at the airport than in the city, it is less during midday. It should be noted that the two curves are not based on data from an identical period of time. I believe that there must be enough lake effect as far north as 315 Bloor Street to counteract the urban effect in the middle of the day, giving Toronto slightly lower temperatures and higher humidity in the mid-summer daytime. On the other hand, at night the true urban-rural difference is in evidence when radiational cooling takes place resulting in condensation and an increase in wet-bulb temperature.

The lower part of Figure 14 illustrates the average difference in relative humidity at synoptic hours over the past four years, and shows there to be very little difference at midday between Downsview, Malton and city. The Island does, of course, have higher relative humidity. During the nighttime hours Malton has a higher relative humidity than any other site. It should be noted that relative humidities at synoptic hours are generally higher at all other southern Ontario locations than they are at these Toronto stations.

In summary, we should be cautious in comparing Toronto and Malton humidity since during the decade of the 1950's the Malton observing site was perhaps in many ways more urban than the site at 315 Bloor Street West.

Figure 15 - Difference in Mean Hourly Relative Humidity
Toronto City Minus Malton Airport

Figure 15 which shows a difference in mean hourly relative humidity values between Toronto City and Malton Airport is revealing in that it shows the city to be somewhat more humid in midday during the summertime, whereas in the winter season the airport humidities are significantly higher at all times of the day. Although identical periods of record were not available for use, the features appear to be real.

Figure 16 - Climatic Data Resources for Urban Studies

Finally, the tabular data in Fig. 16 gives an indication of the sources of meteorological data within 25 miles of each of the large urban centres of Canada.

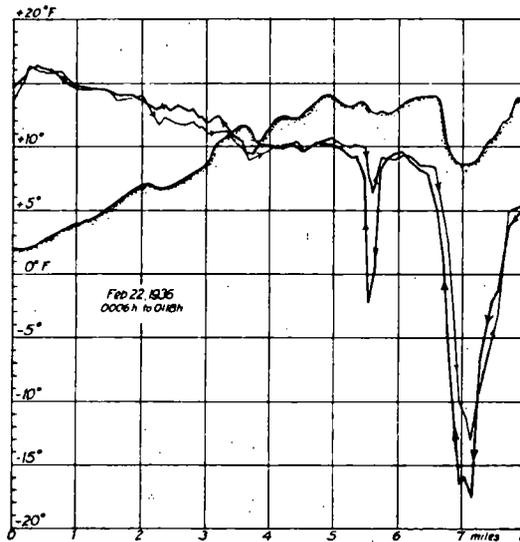


Figure 1. Temperatures in Toronto on a clear winter night with profile of Yonge Street.

Figure 2. Climatic changes produced by cities.

<u>Element</u>	<u>Comparison with Rural Environs</u>
Contaminants:	dust particles..... 10 times more
	sulfur dioxide..... 5 times more
	carbon dioxide..... 10 times more
	carbon monoxide..... 25 times more
Radiation:	total on horizontal surface 15 to 20% less
	ultraviolet, winter..... 30% less
	ultraviolet, summer..... 5% less
Cloudiness:	clouds..... 5 to 10% more
	fog, winter..... 100% more
	fog, summer..... 30% more
Precipitation:	amounts..... 5 to 10% more
	days with 0.2 in. 10% more
Temperature:	annual mean..... 1 to 1.5°F more
	winter minima..... 2 to 3°F more
Relative Humidity:	annual mean..... 6% less
	winter..... 2% less
	summer..... 8% less
Wind Speed:	annual mean..... 20 to 30% less
	extreme gusts..... 10 to 20% less
	calms..... 5 to 20% more

From H.E. Landsberg "City Air - Better or Worse" Symposium: Air Over Cities, U. S. Public Health Service, 1961. pp. 1 - 22.

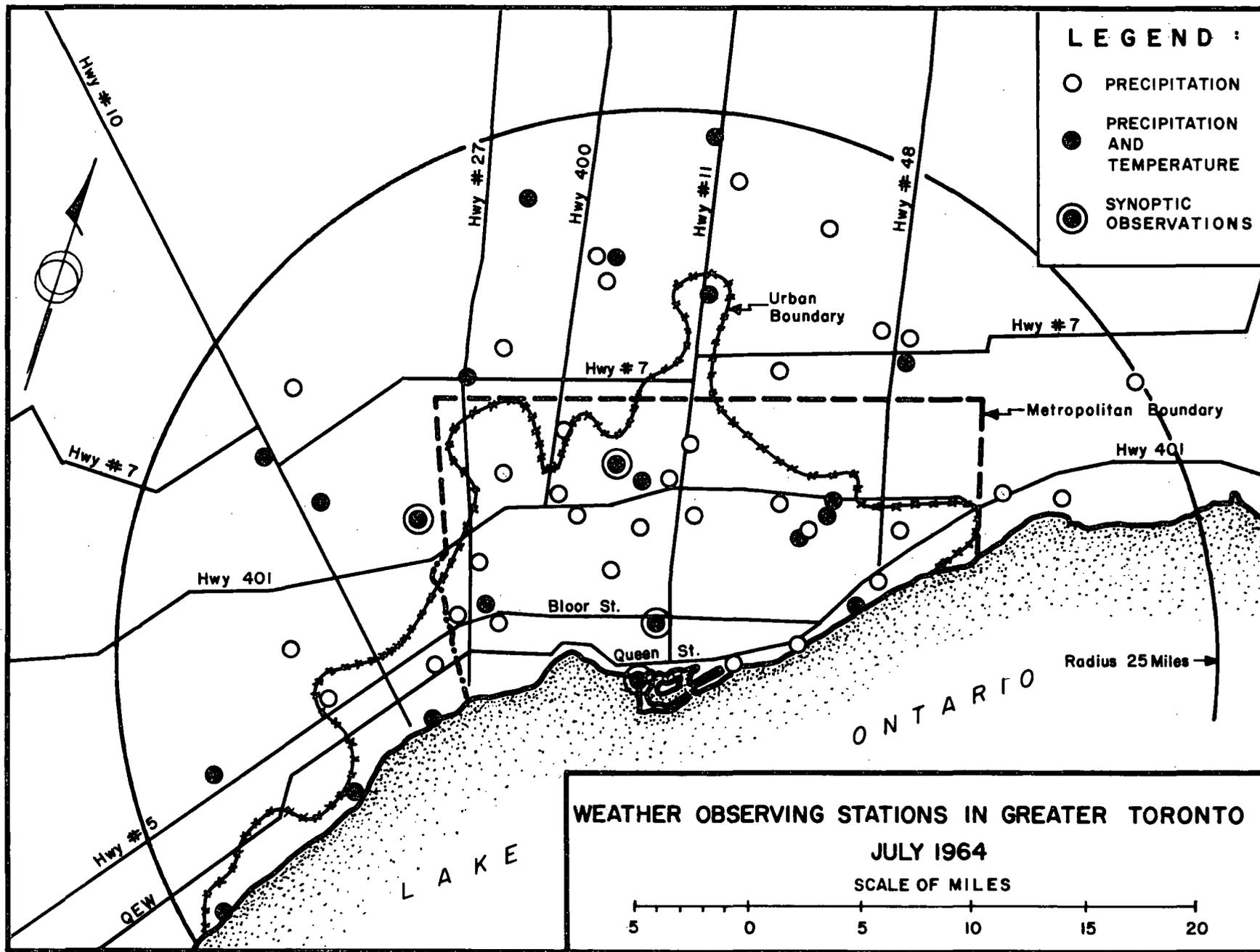
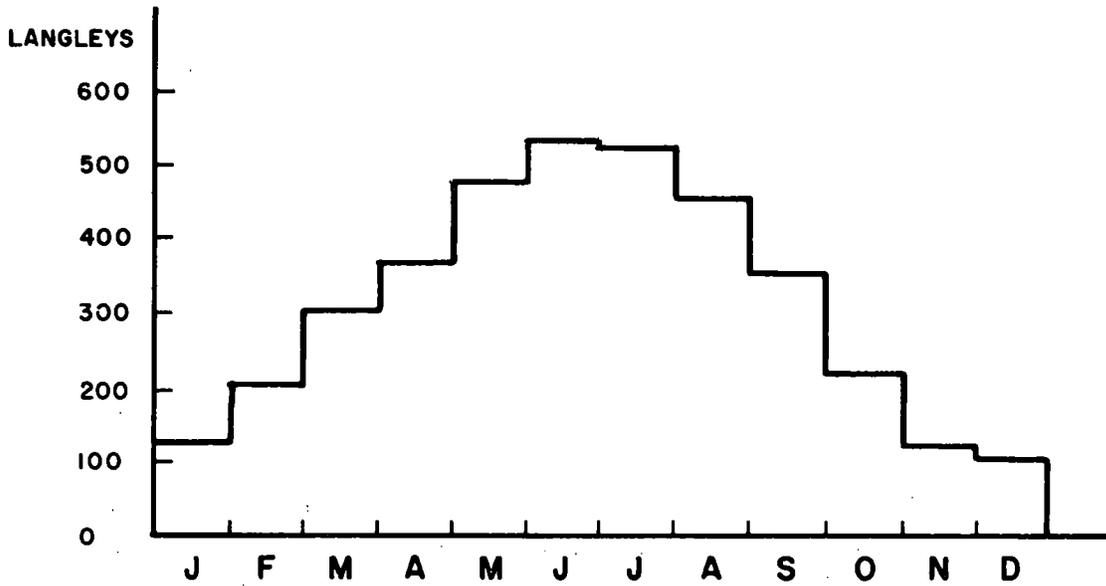
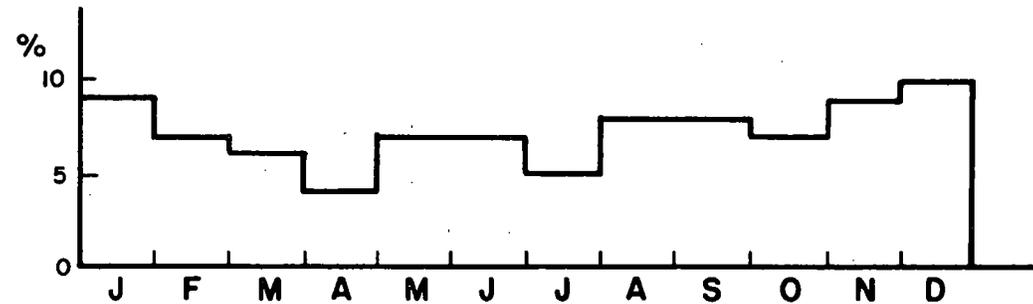


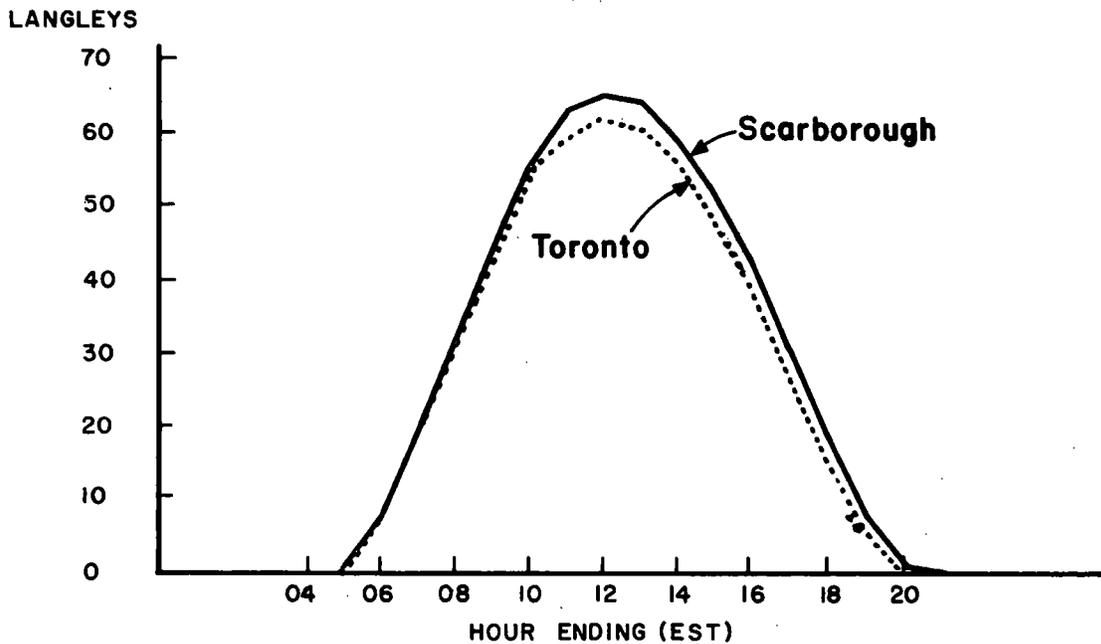
Figure 3. Weather observing stations in Greater Toronto.



MEAN MONTHLY TOTAL IN TORONTO



MEAN PERCENTAGE AT SCARBOROUGH OVER TORONTO



DIURNAL VARIATION IN JULY

Figure 4. Solar radiation in Toronto 1960-64.

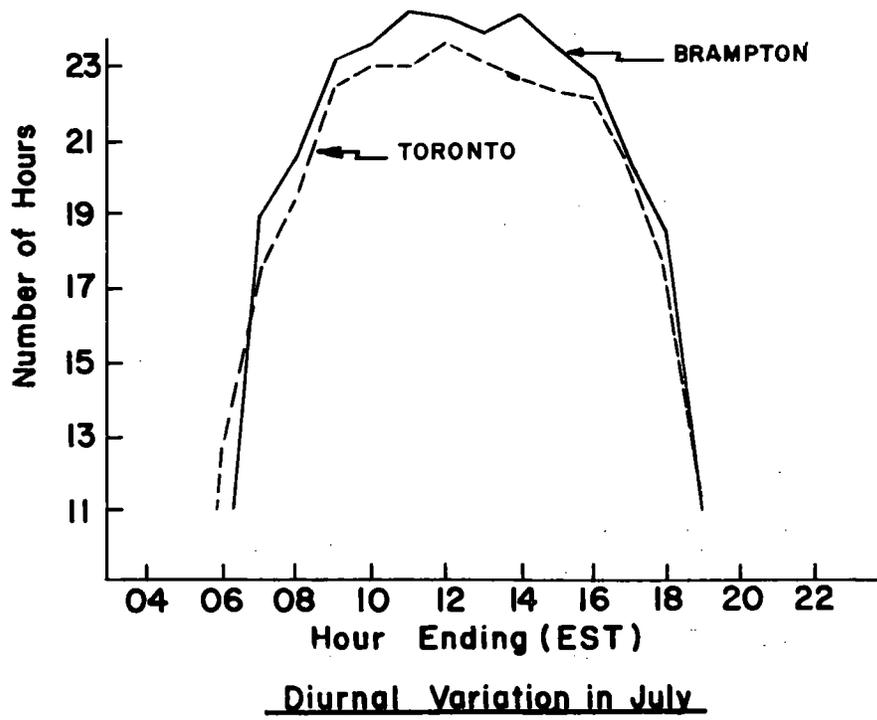
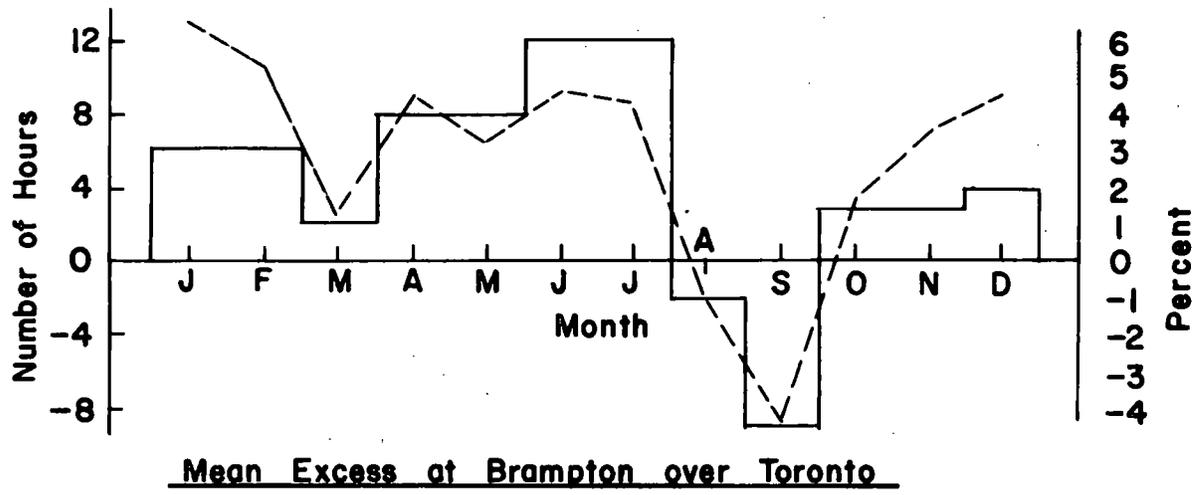
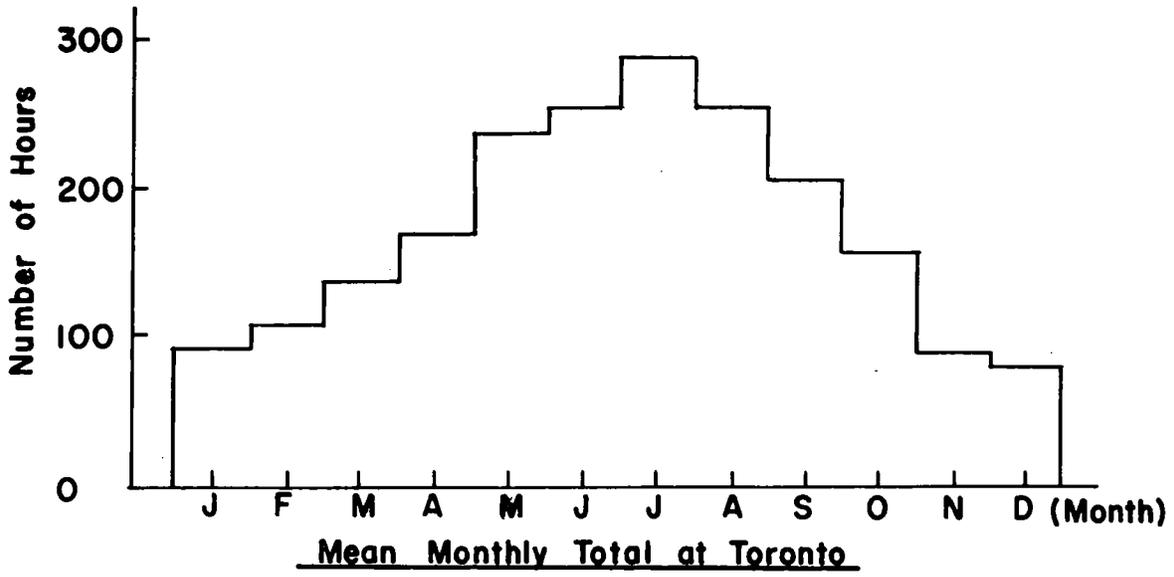


Figure 5. Bright sunshine at Toronto 1951 - 1964.

GREATER EDMONTON AIRPORTS

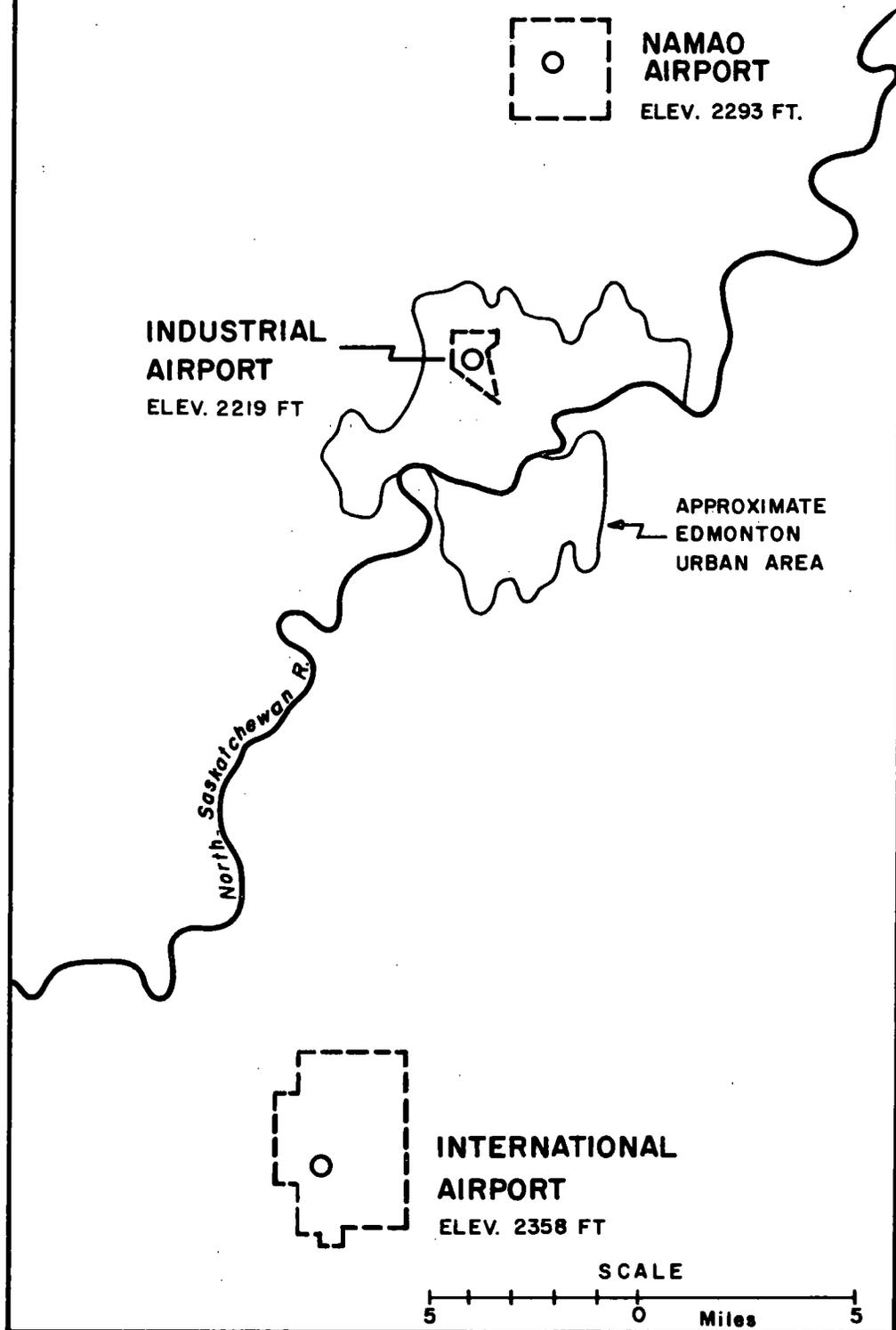


Figure 6. Greater Edmonton airports.

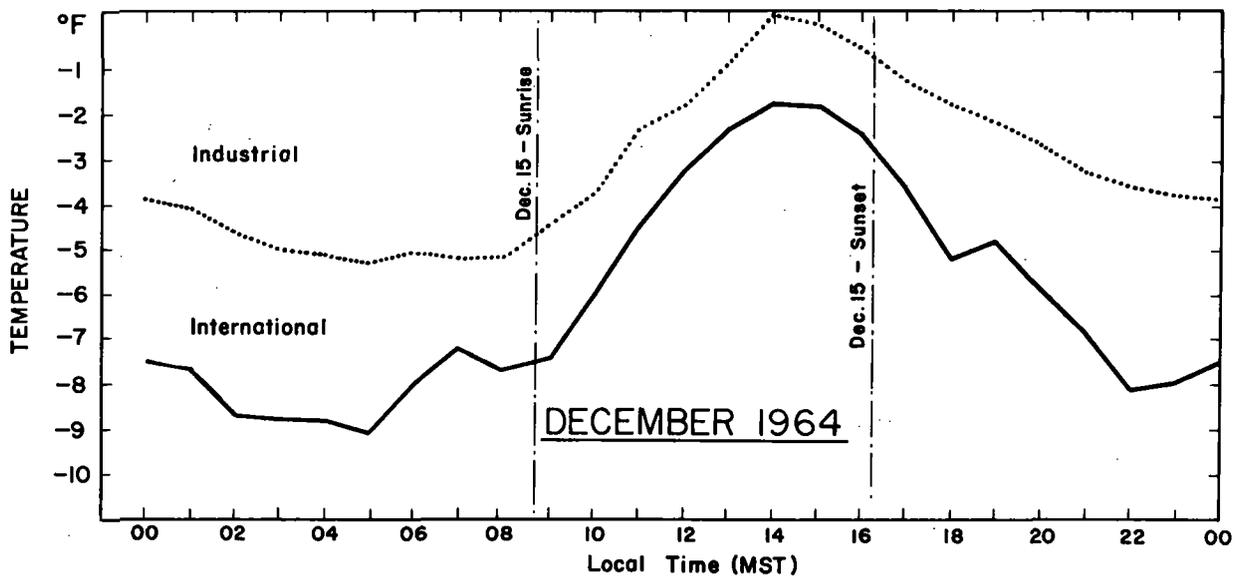
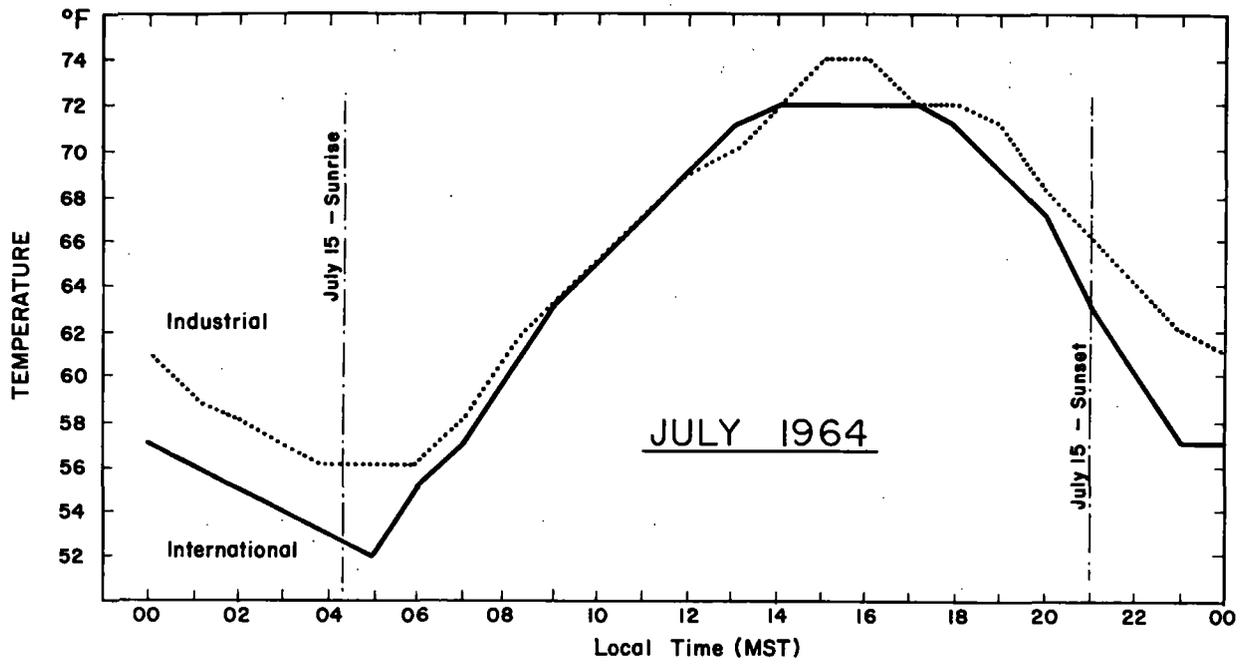


Figure 7. Hourly temperatures at Edmonton, July and December 1964.

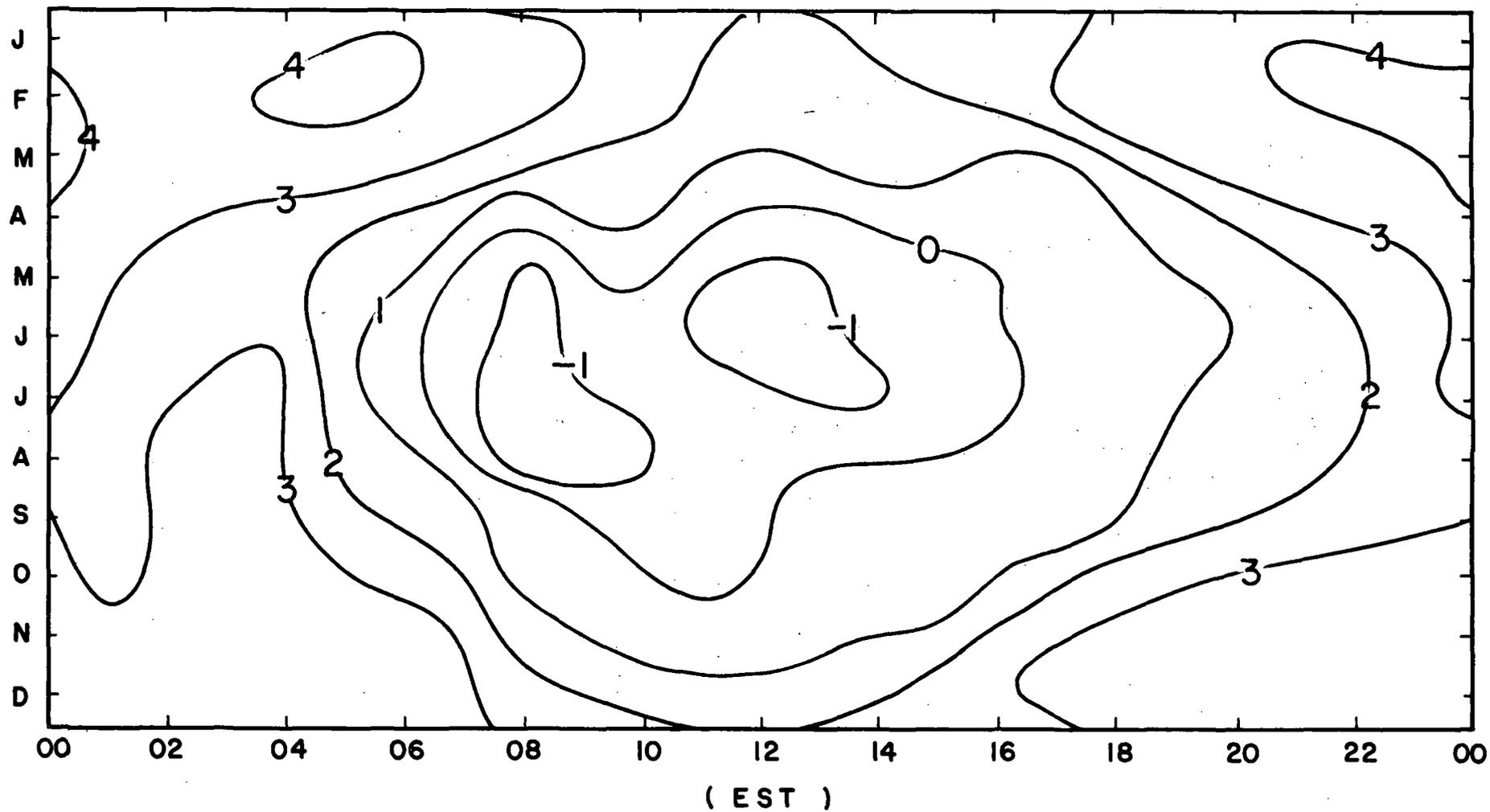


Figure 9. Difference in mean hourly temperature ($^{\circ}\text{F}$) Toronto City minus Malton Airport, 1941 - 1950.

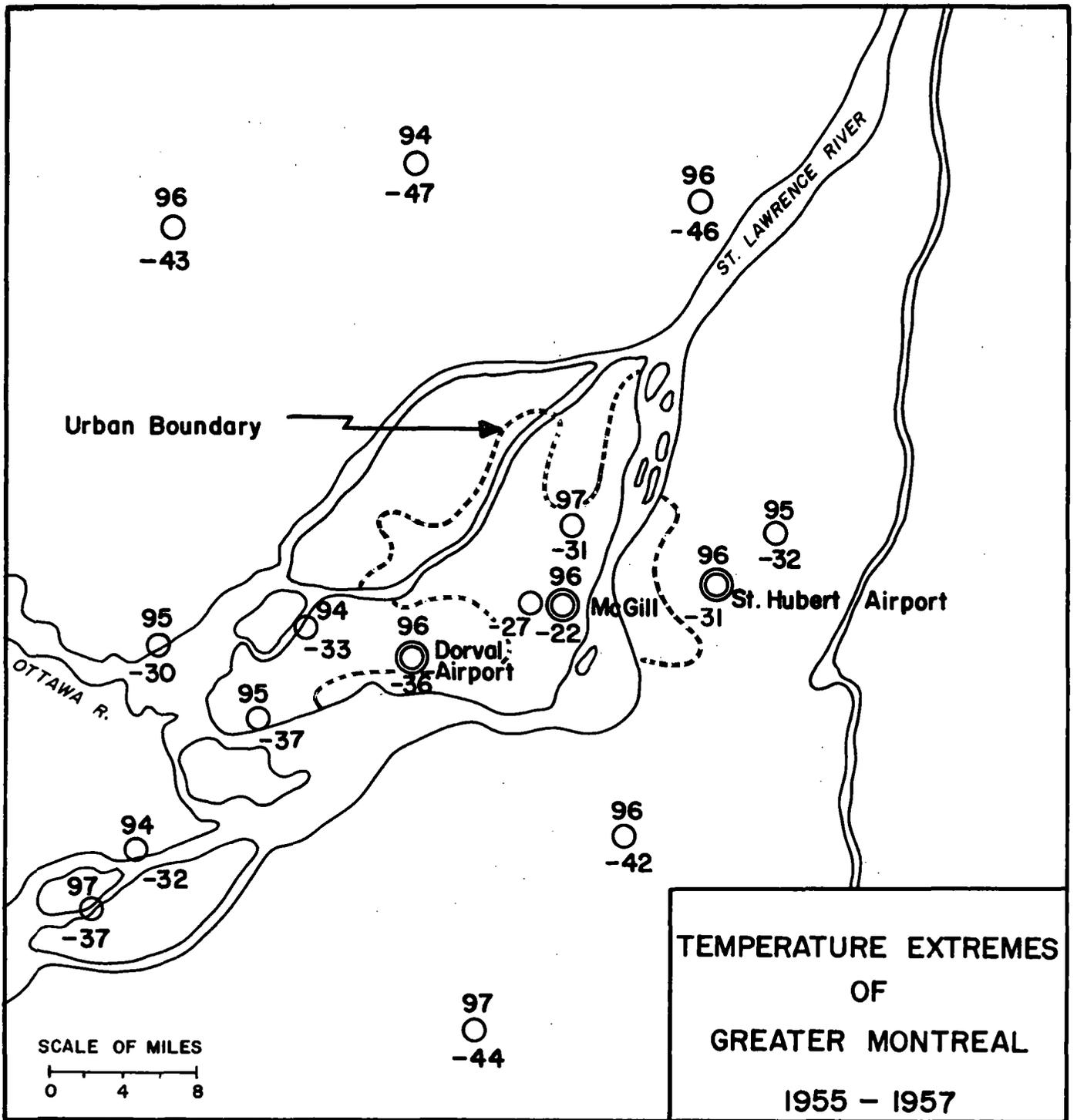


Figure 10. Temperature extremes of Montreal 1955 - 1957

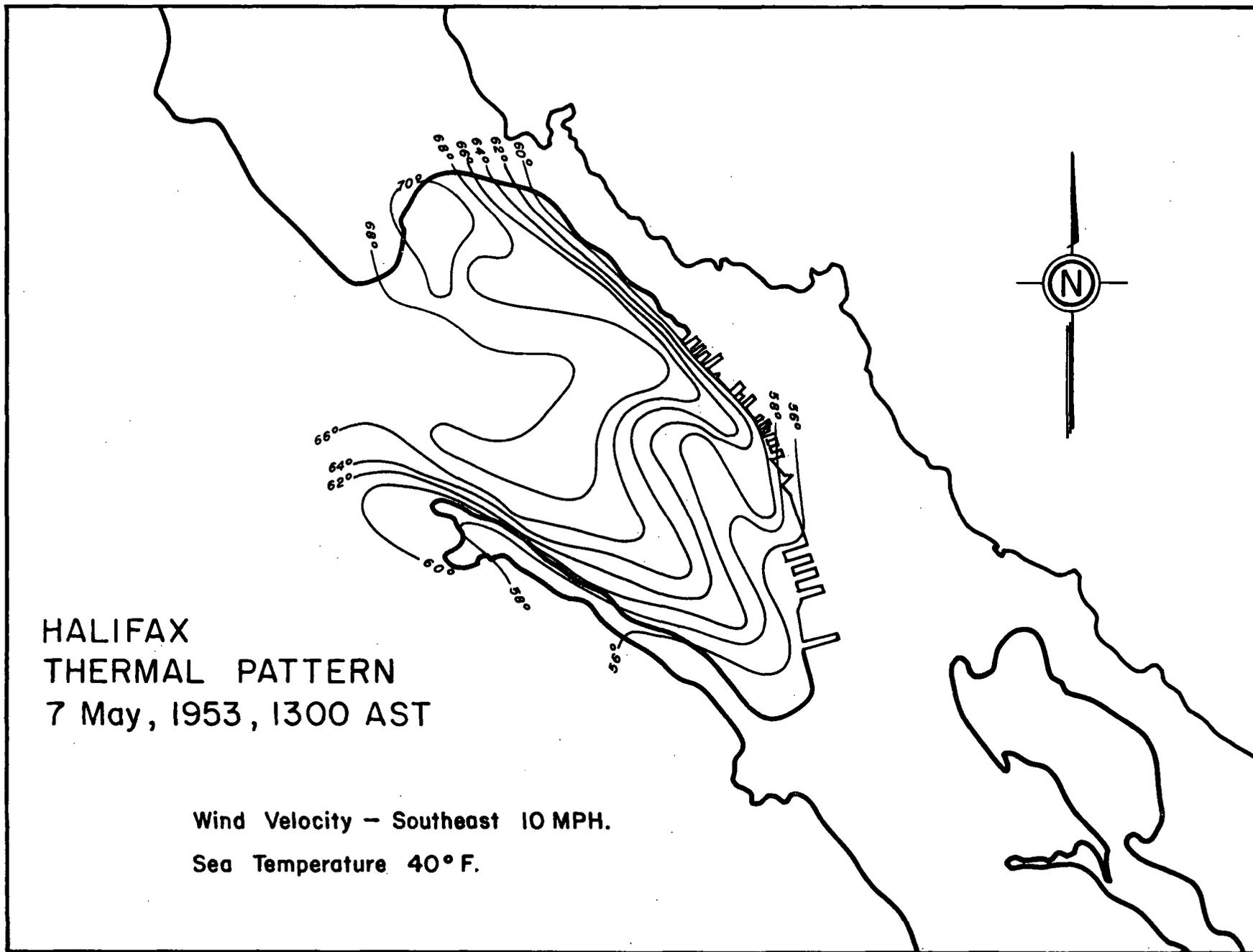


Figure 11. Halifax Normal Pattern. (From R.V. Dexter, 1954)

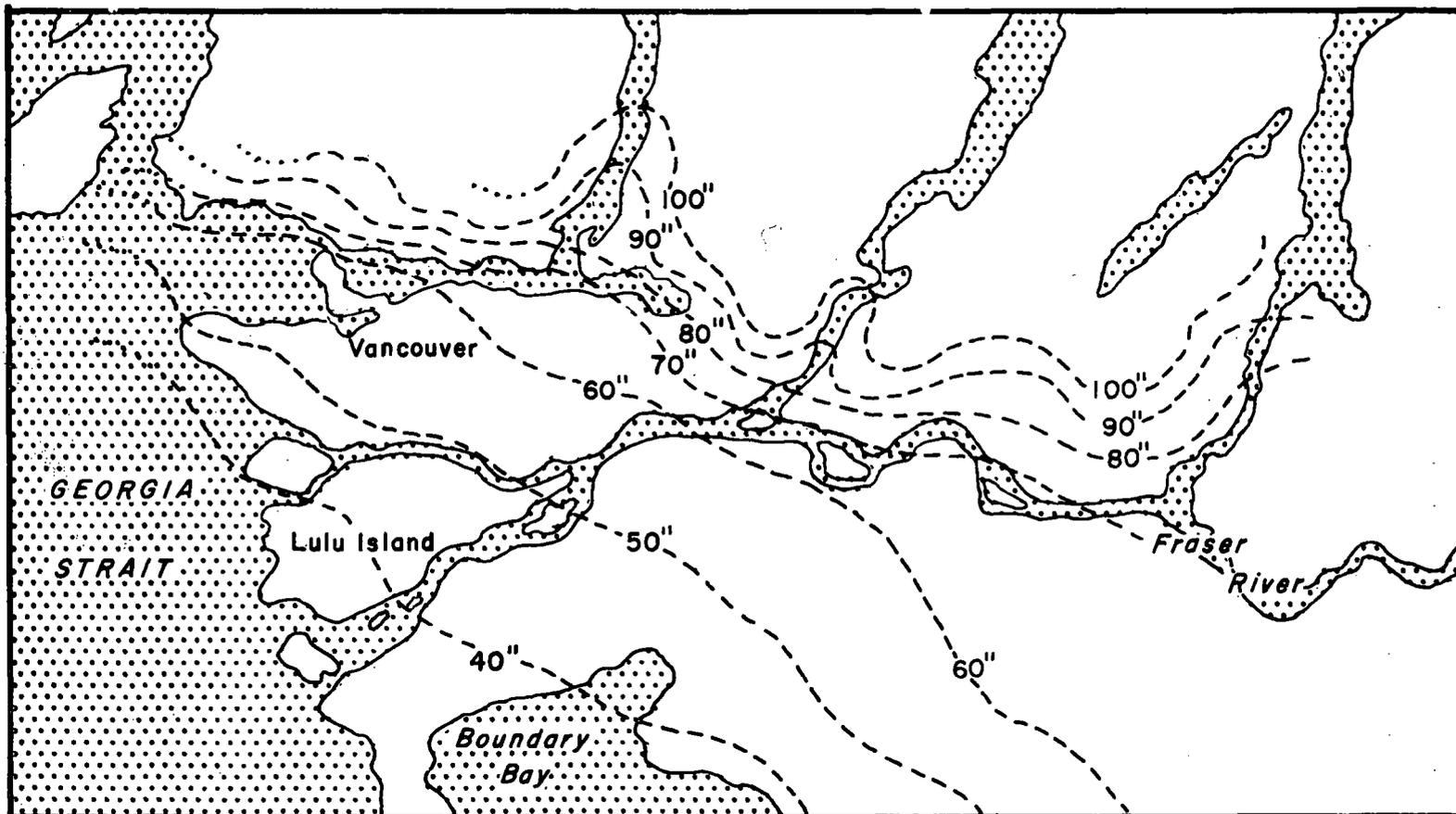


Figure 12. Greater Vancouver: Average Annual Precipitation (inches). (From K.F. Harry and J.B. Wright, 1957).

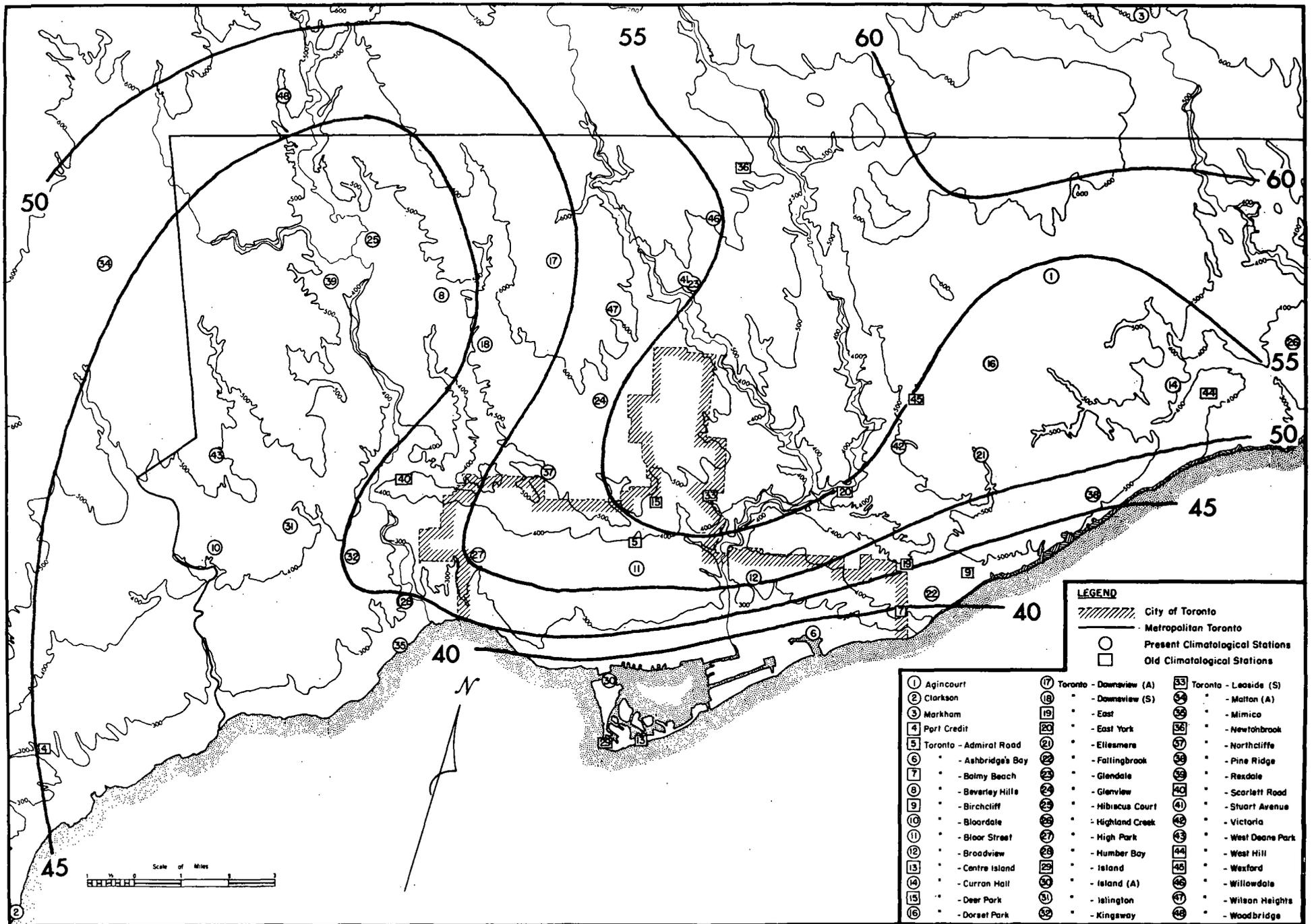
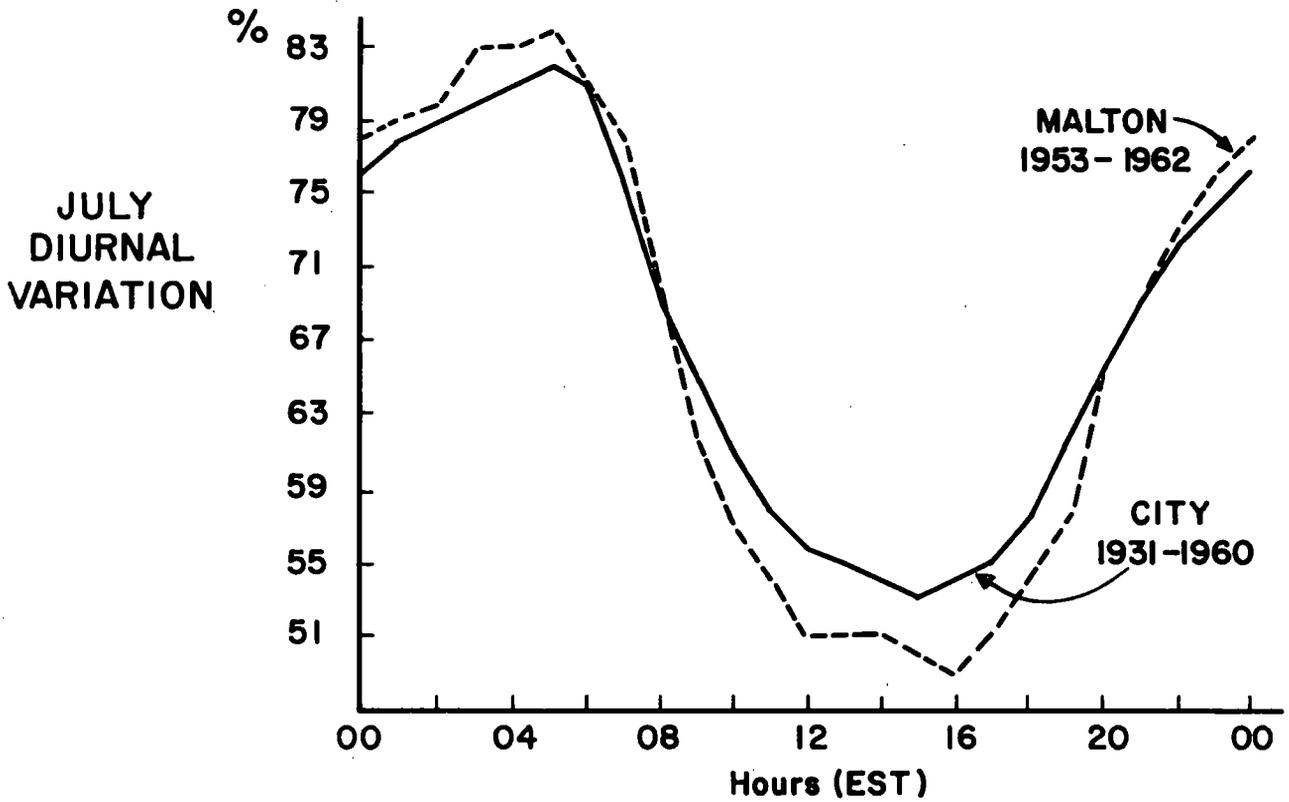
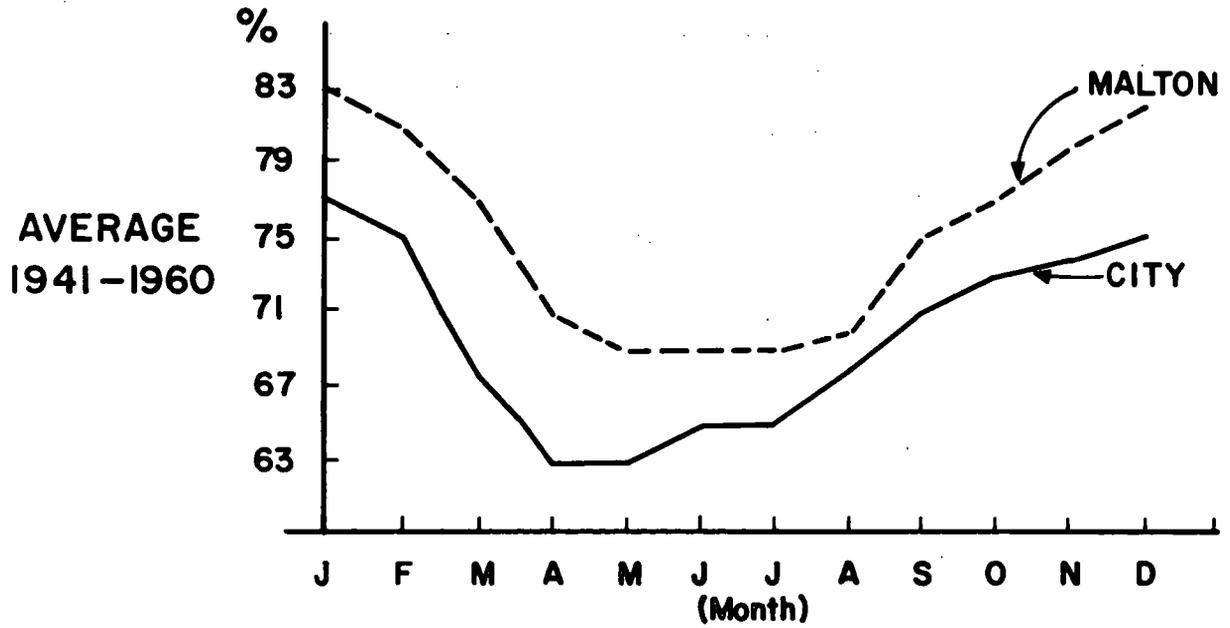


Figure 13. Normal winter snowfall. (From J.G. Potter, 1961)



AVERAGE AT SYNOPSIS HOURS 1961-1964	00	06	12	18	Location
	76	77	53	60	Island Downsview
	80	80	53	59	Malton
	74	74	55	58	City

Figure 14. Relative humidity at Toronto

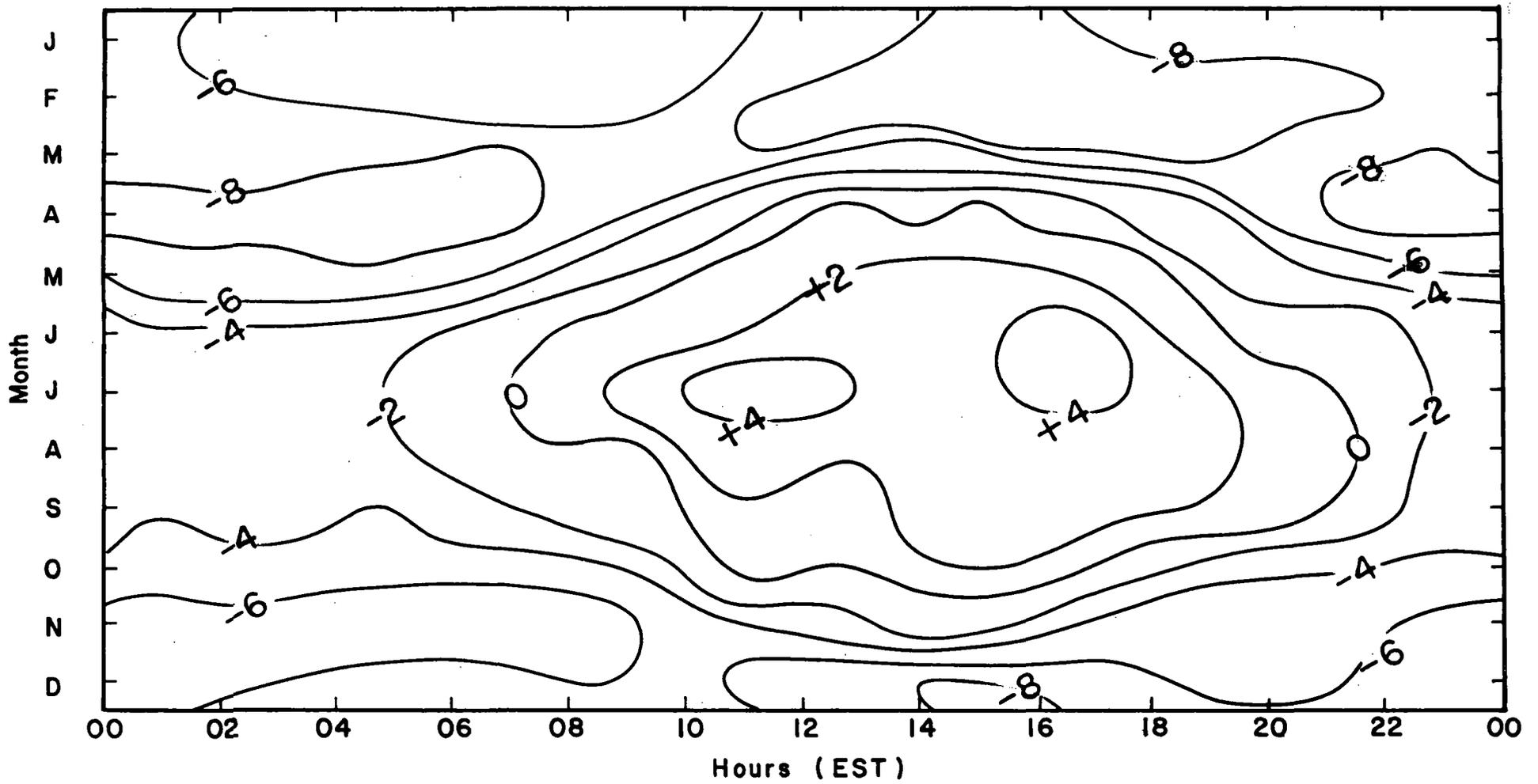


Figure 15. Difference in mean hourly relative humidity (%) Toronto City (1931-1960) minus Malton Airport (1953-1962)

Figure 16. Climatic data resources for urban studies.

Census Metropolitan Areas	Population 1961	Number of Weather Observing Stations Within 25 Miles of Urban Centre									
		<u>T</u>	<u>P</u>	<u>SY</u>	<u>W</u>	<u>SU</u>	<u>ST</u>	<u>R</u>	<u>RI</u>	<u>E</u>	
Montreal	2,109,509	22	24	3	2	9	0	0	5	0	
Toronto	1,824,481	22	56	4	4	3	1	2	8	0	
Vancouver	790,165	25	73	2	3	3	1	1	10	1	
Winnipeg	475,989	6	11	1	1	1	0	1	3	1	
Ottawa	429,750	8	14	1	3	1	1	1	1	2	
Hamilton	395,189	19	28	1	4	2	0	0	4	0	
Quebec	357,568	7	7	1	1	3	0	0	1	0	
Edmonton	337,568	7	9	3	3	2	0	1	2	0	
Calgary	279,062	2	5	1	1	1	0	0	1	1	
Windsor	193,365	4	6	1	1	1	1	0	1	1	
Halifax	183,946	8	11	2	3	2	0	0	2	0	
London	181,283	9	14	1	1	1	0	0	3	0	
Kitchener	154,864	9	17	0	2	1	1	1	11	1	
Victoria	154,152	13	25	2	2	2	0	0	3	0	

T: Daily temperature extremes	ST: Daily soil temperature
P: Daily precipitation totals	R: Hourly solar radiation
SY: Synoptic observations	RI: Recording rain gauge data
W: Hourly winds	E: Daily evaporation totals
SU: Hourly bright sunshine	

Official stations active in July 1964.