THE ROLE OF "LAKE EFFECT STORMS" IN THE DISTRIBUTION OF SNOWFALL IN SOUTHERN ONTARIO*

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INTRODUCTION

During recent years the term "lake-effect storms" has been used to describe the heavy snowfalls resulting from cold outbreaks of polar continental air sweeping across the Great Lakes into the so called "snow belt" areas to the lee of the individual lakes. Although the small scale characteristics of the individual storms are just beginning to be explored there is no doubt that the net effect is one of greatly increased snowfall in favored locations caused by:

1. The lakes acting as a heat source during the winter months. This thermal effect creates instability in the lower layers of the atmosphere. It also produces a pressure trough (thermal trough) over the lakes which creates convergence and a further lifting of the atmosphere.

2. The introduction of additional moisture and hence a further development of instability, through evaporation from the lakes.

3. The orographic lift produced by the higher land to the lee of each lake.

As a result, the snow belt areas receive not only the snowfall attributable to the regular traveling extratropical storms but also the additional contributions from "lake effect storms". The contribution of these "lake effect storms" to the annual snowfall total may be gauged by comparing the totals of 137 inches at Durham and 120 at Owen Sound in the snow belt, with 42 inches at Windsor and 72 inches at Sudbury and North Bay, where there is little or no lake effect.

Purpose

This study was initiated with a two-fold purpose; (i) as an effort to more fully understand the climatology of the southern Ontario snow belt areas and (ii) as a first step in an investigation of "lake effect storms". Subsequent steps will include the study of individual storms (where possible on a meso scale) followed by an investigation of the dynamic processes involved. An additional analysis using machine methods and punched card data is currently underway. It is expected to throw more statistical light on the cause and effect of these storms.

* Approved for publication by the Director of the Meteorological Branch

The basis of the current study is as thorough as possible an analysis of the mean annual snowfall distribution in the southern Ontario snow belt and the mean monthly snowfall patterns for the months of October to March inclusive. Results are then interpreted to estimate the snowfall contribution due to the lakes and to topographic features.

Data

The data used in this study were those already abstracted on an annual basis up to the end of 1960 and tabulated by the Climatology Division of the Meteorological Branch, Canada Department of Transport. Basic snowfall figures were taken from stations for which 30 year normals for the period of 1931-60 were available. To fill gaps and to produce as full a coverage as possible all additional snowfall records were also plotted. This amounted to a total of 232 stations with periods of record ranging up to 89 years.

The data were analyzed paying strict attention to the 30 year normals with the analyst using the remainder of the data more subjectively in light of the length and dates of record, i.e. greater weight was given to longer periods spanning more recent decades.

DISCUSSION

Annual Snowfall

The annual snowfall map (figure 1)clearly delineates the acknowledged snow belt areas in southern Ontario with the 100-inch iso-line outlining an area from just northwest of London to Owen Sound and thence to the south and east of Georgian Bay to Parry Sound. Annual falls exceed 120 inches in the Owen Sound - Durham area (Durham with 137 inches reports the highest mean annual snowfall), in the Blue Mountain region south of Georgian Bay, and in the Muskoka Highlands just east of Georgian Bay. Further south another area of maximum falls (in excess of 100 inches) is evident between Goderich and London.

This pattern of maximum falls is in complete agreement with the snow-producing mechanisms outlined in the first paragraph. A comparison with the topographic map (figure 2) shows the snowbelt areas consistently on the lee side of the lakes and on the windward side of the higher terrain. Conversely, precipitation shadows are apparent on the lee side of the higher ground. These are particularly noticeable in the valleys of the Grand, the Beaver, the Maitland and the Thames Rivers.

To strengthen the lake effect theory it should be noted that the area of heaviest falls centered at Durham represents a "double exposure" to the lake effect, i.e. this area is exposed to Lake Huron in west to northwest winds and to Georgian Bay in north to northeast winds.

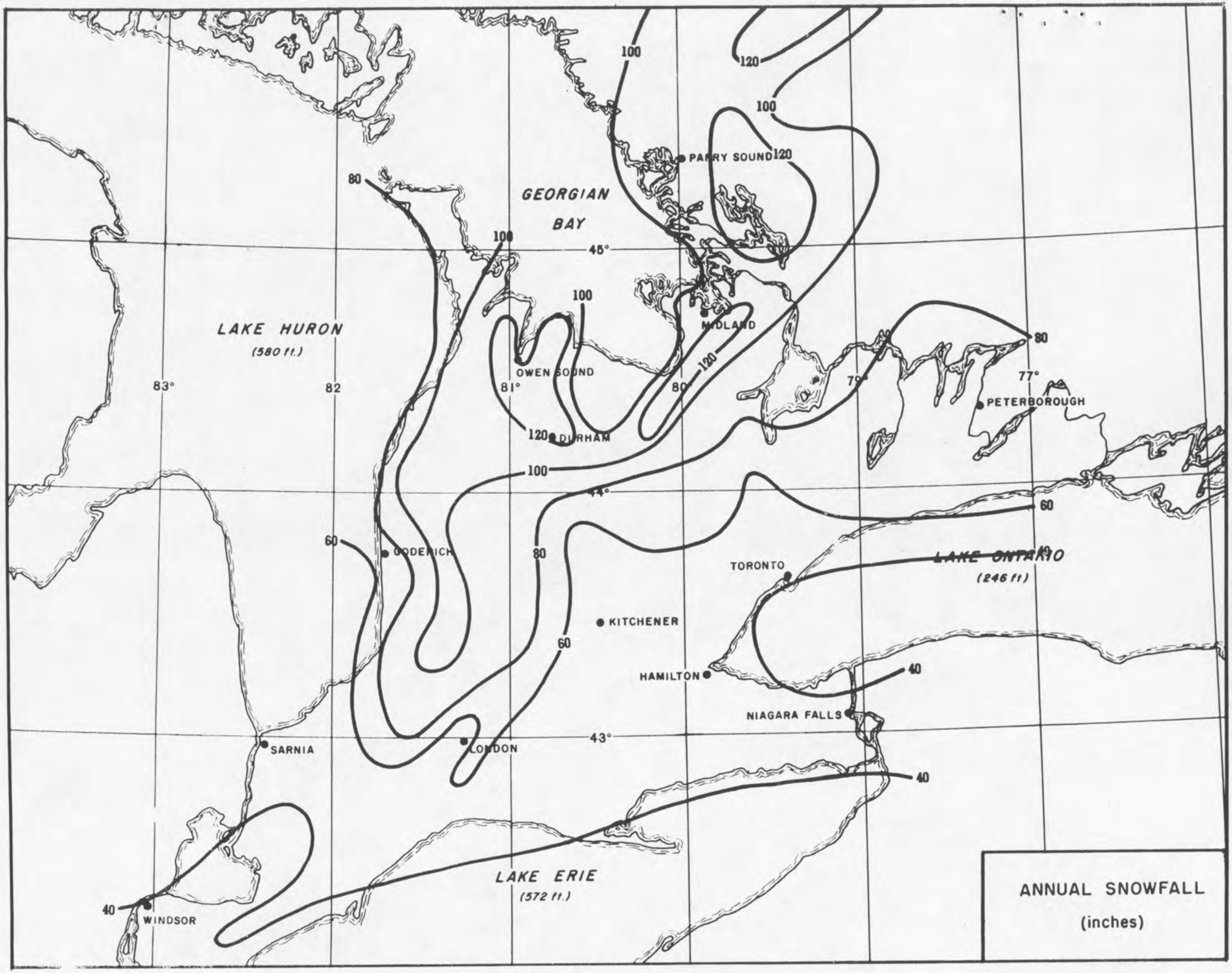
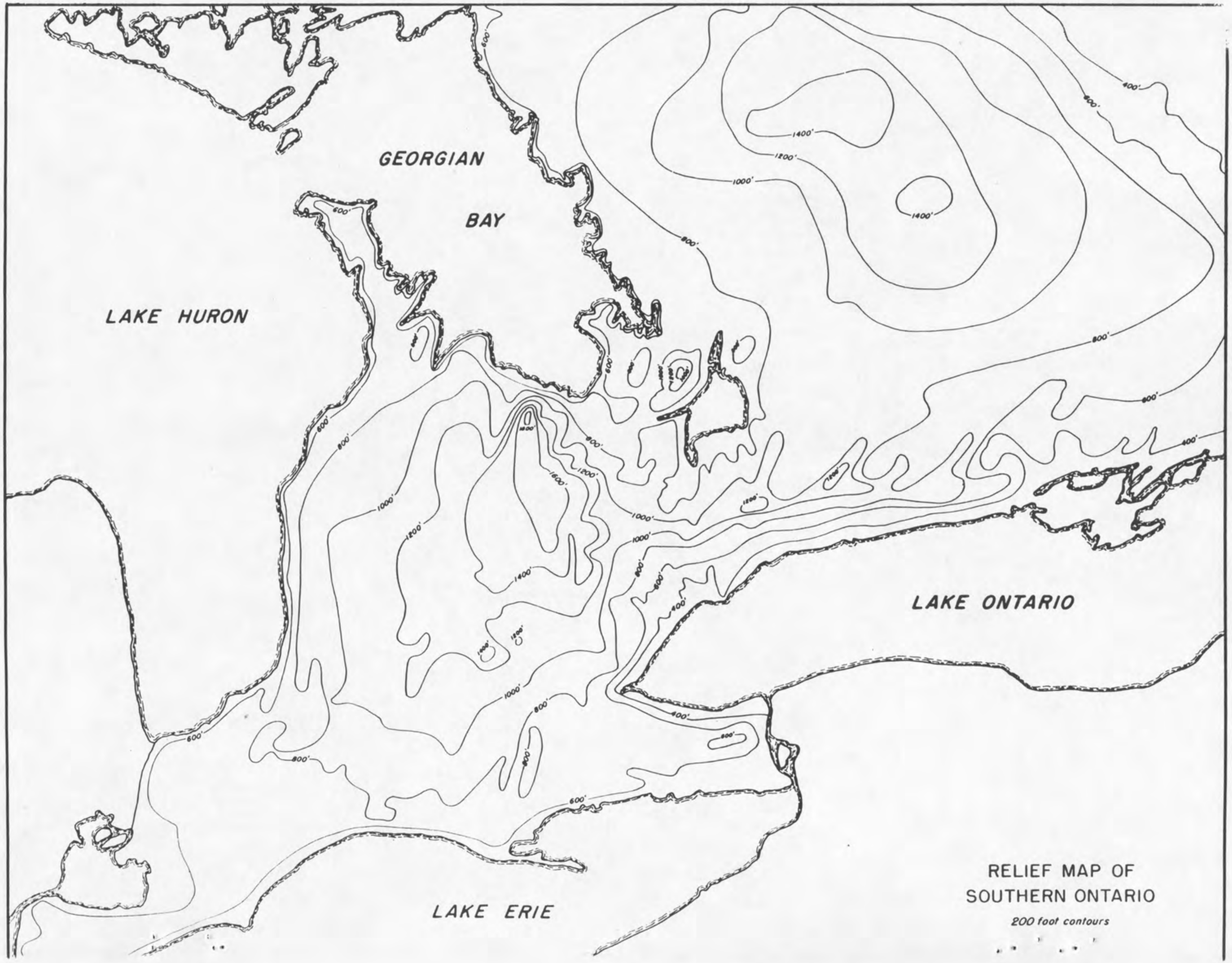


Figure 1 - Annual Snowfall in Southwestern Ontario


GEORGIAN
BAY
LAKE HURON
LAKE ONTARIO
LAKE ERIE
RELIEF MAP OF
SOUTHERN ONTARIO
200 foot contours
400'
600'
800'
1000'
1200'
1400'
1600'

Monthly Snowfall

The monthly snowfall maps generally follow the pattern of the annual snowfall map except for several noteworthy and meteorologically consistent exceptions.

October shows greater snowfalls from Parry Sound northward. This of course represents the latitudinal effect where the precipitation during the month is mainly snow in northern areas and mainly rain in the south.

November returns to the annual pattern.

December and January are the months of heaviest falls. This is compatible with the maximum difference between air temperature and lake water temperature during these months resulting in the additive snow-producing effects of instability, "thermal troughing" and evaporation.

February shows a noticeable change in distribution with a marked decrease in snowfall to the east of Georgian Bay and with a lesser decrease in the Owen Sound - Durham area. There is little doubt that this is a direct result of ice formation on Georgian Bay. Meteorological Branch aerial ice-reconnaissance during the years 1960-61-62 reports 8-10/10 ice cover in Georgian Bay from late January to early March. Such a cover would almost entirely eliminate the snow-making mechanisms introduced by open water. A quantitative interpretation of this phenomenon is discussed later in connection with figure 10.

March snowfall returns to the more general snowfall pattern as the ice leaves Georgian Bay.

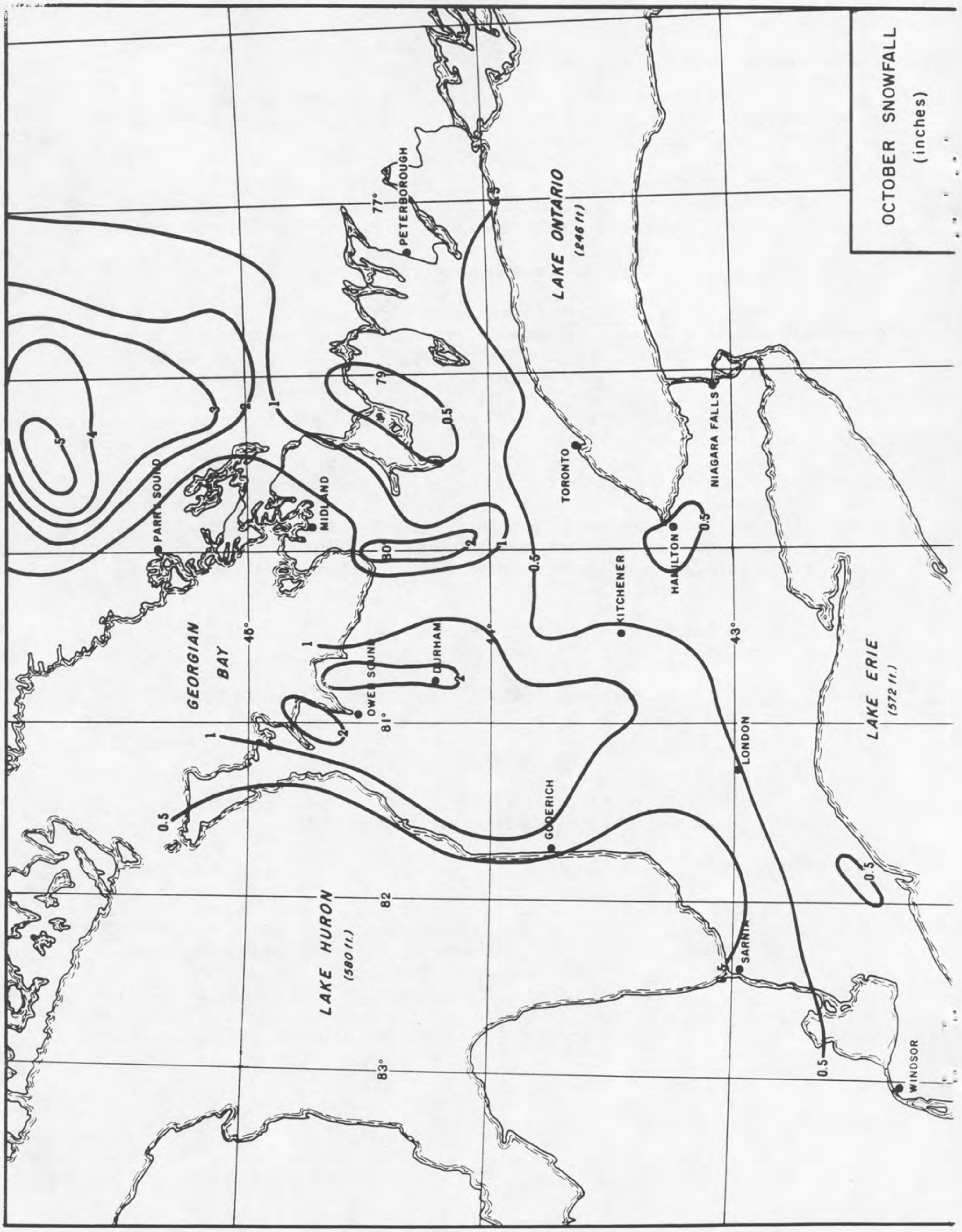
April shows the same latitudinal effect noticeable in October, i.e. more snow in the north.

INTERPRETATION

The snowfall patterns outlined in the annual and monthly maps lead to a number of quantitative and qualitative interpretations.

1. Contribution of "Lake Effect Storms"

As might well be expected maximum snowfalls occur to the lee of the open lakes (in west to northerly flows of cold air) and on the windward side of the elevated terrain. As indicated earlier the annual map shows snowfalls in excess of 120 inches in the major snow belts as compared to measurements in less exposed areas running from 42 inches at Windsor, to 72 inches at North Bay. From this it is subjectively evident that "lake effect storms" are responsible for roughly 50% of the snow in the snow belt areas.


OCTOBER SNOWFALL
(inches)
LAKE ONTARIO
(246 ft.)
LAKE ERIE
(572 ft.)
LAKE HURON
(580 ft.)
GEORGIAN
BAY
PETERBOROUGH
TORONTO
NIAGARA FALLS
HAMILTON
KITCHENER
LONDON
SARNIA
WINDSOR
GODERICH
OWEN SOUND
DURHAM
MIDLAND
PARRY SOUND

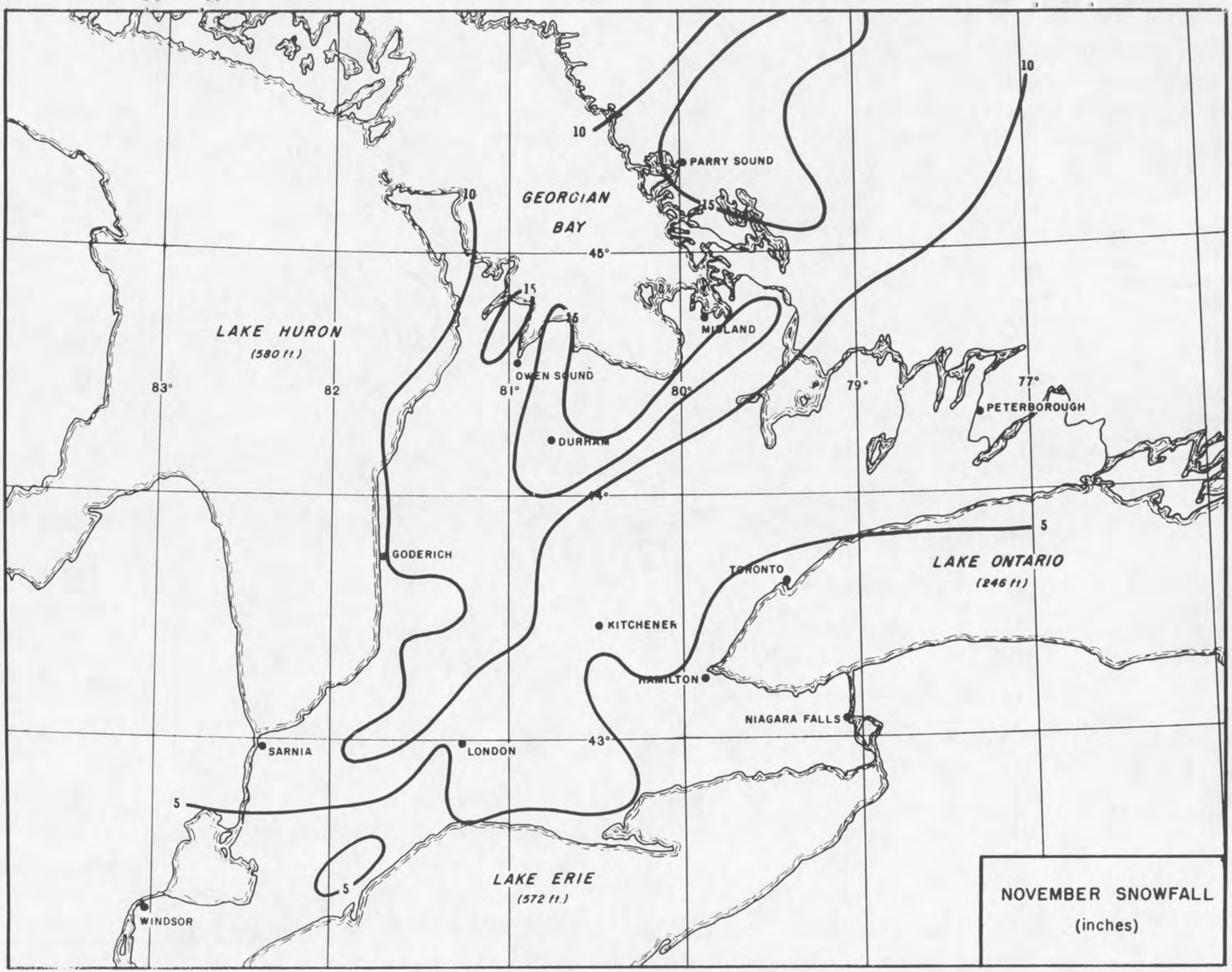
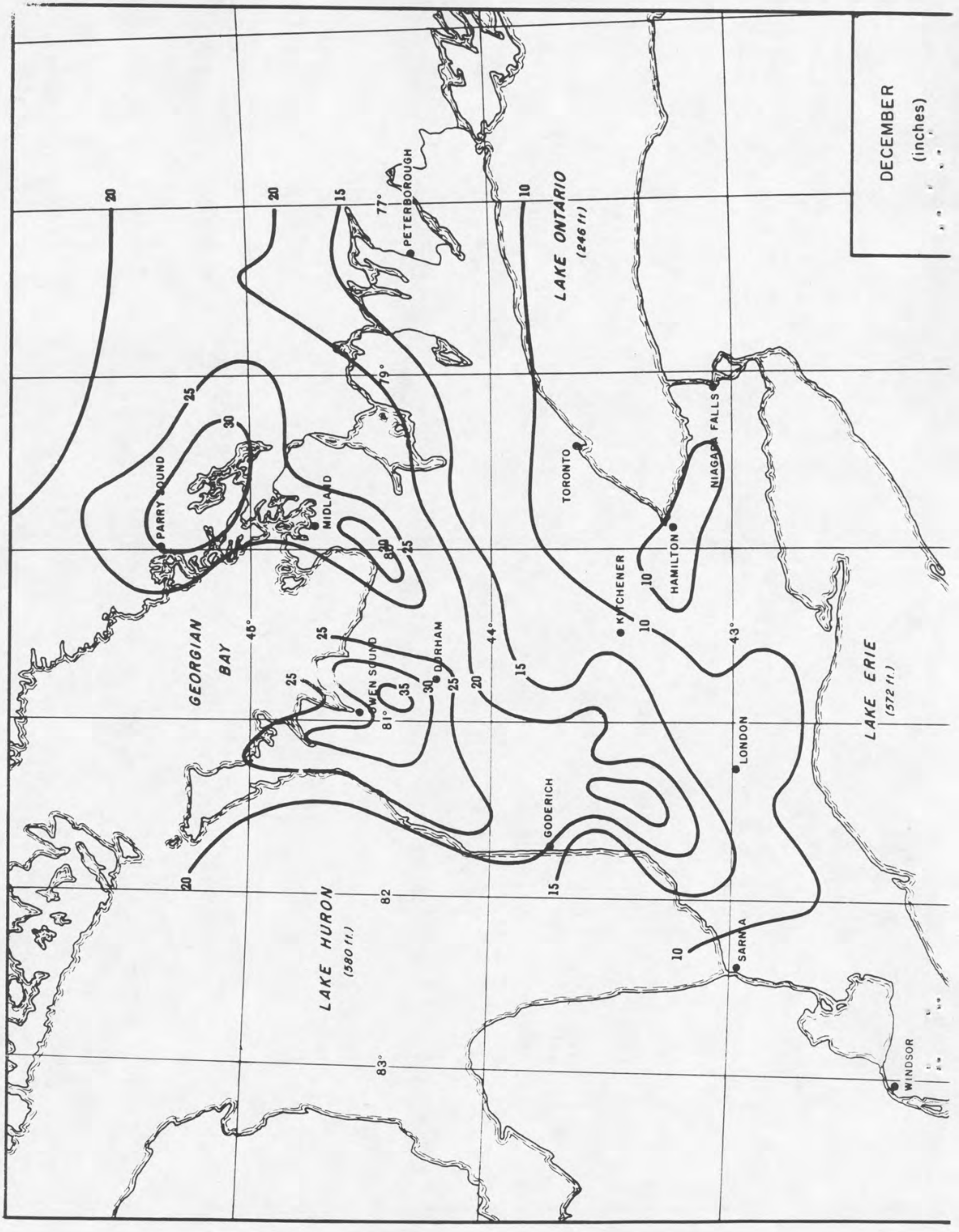


Figure 4 - November Snowfall in Southwestern Ontario


DECEMBER
(inches)
LAKE ONTARIO
(246 ft.)
LAKE ERIE
(572 ft.)
LAKE HURON
(580 ft.)
GEORGIAN
BAY
PETERBOROUGH
TORONTO
NIAGARA FALLS
HAMILTON
KITCHENER
LONDON
GODERICH
SARNIA
WINDSOR
MIDLAND
PARRY SOUND
OWEN SOUND
DURHAM

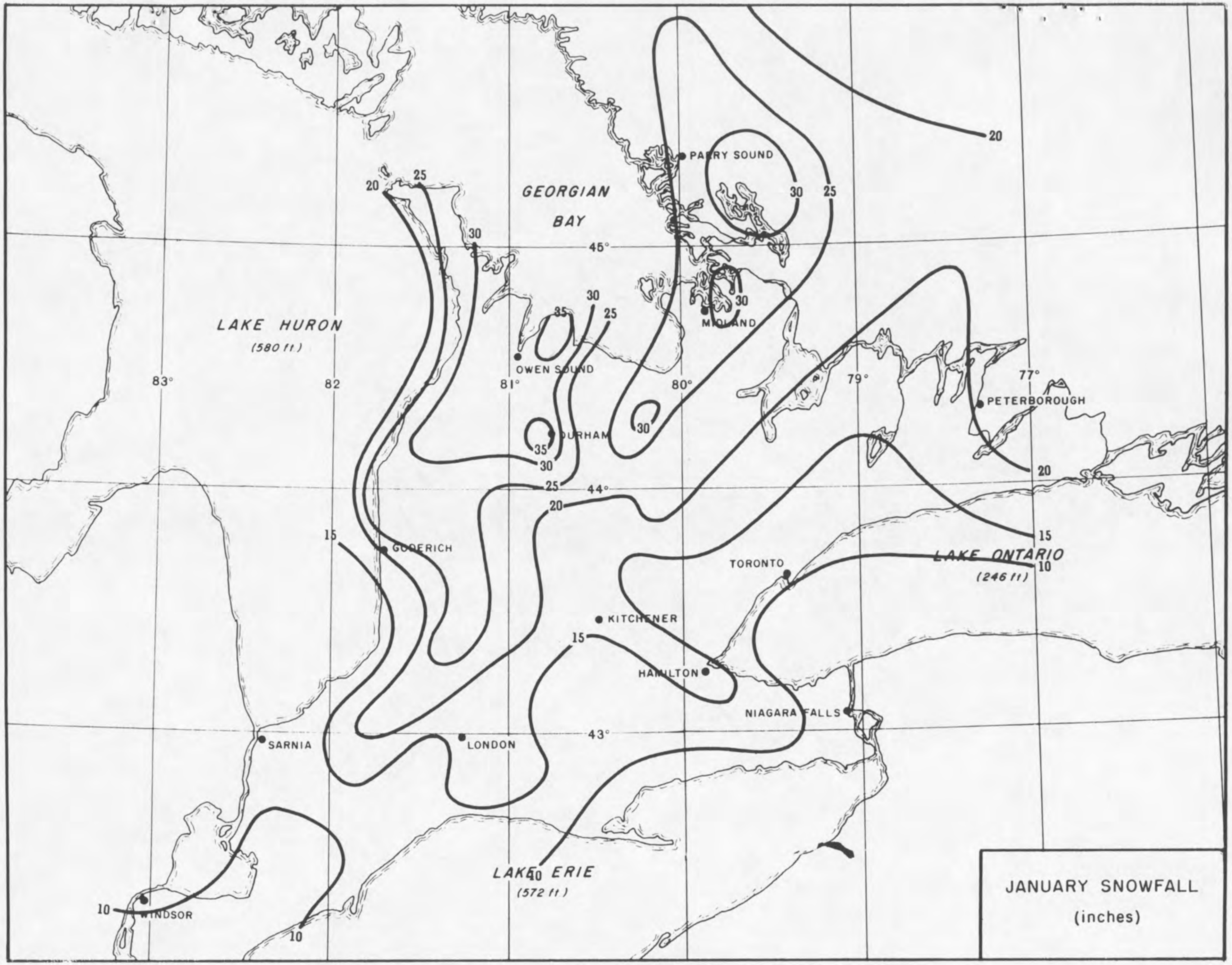
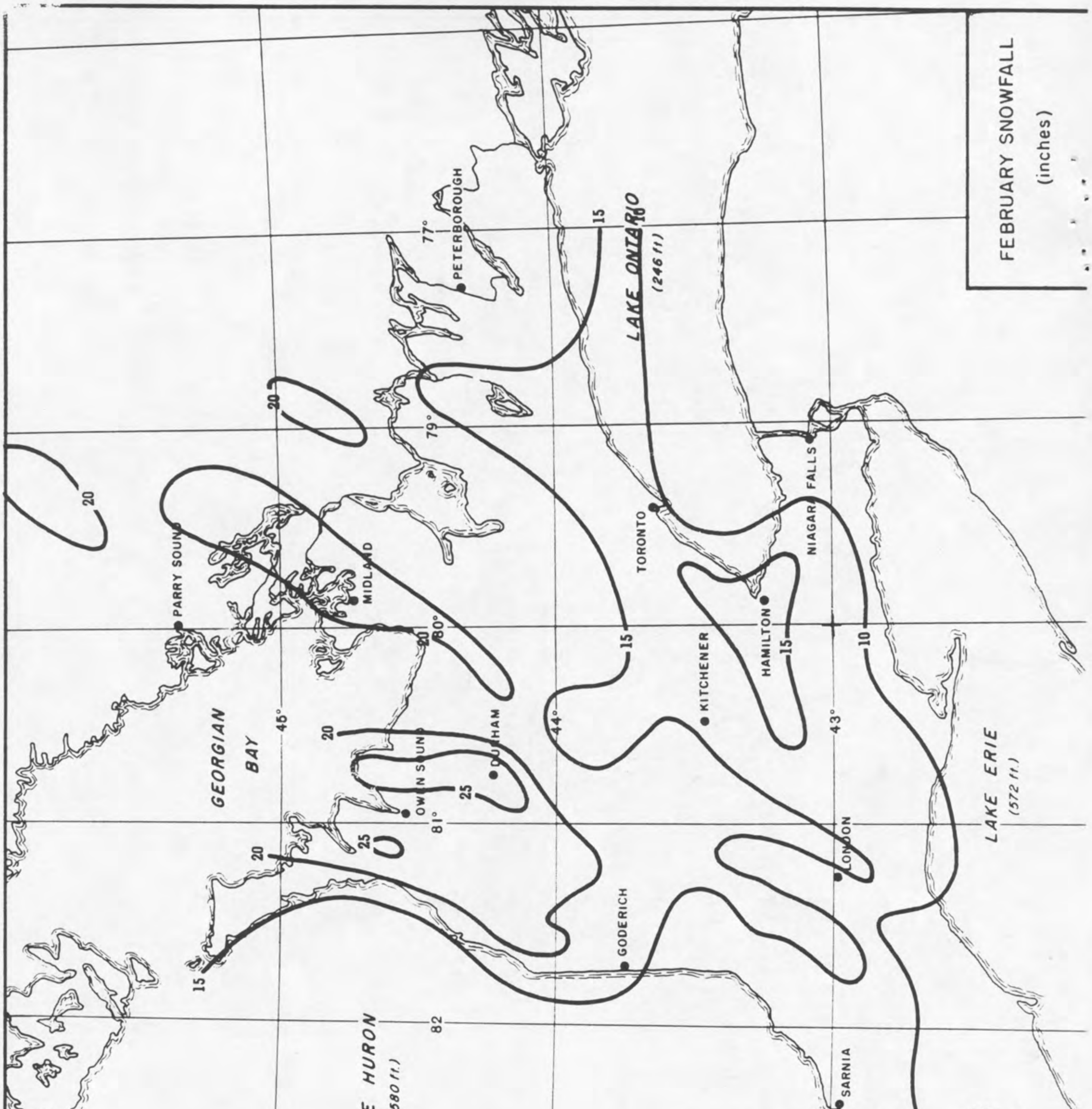


Figure 6 - January Snowfall in Southwestern Ontario


FEBRUARY SNOWFALL
(inches)
LAKE HURON
(580 ft.)
GEORGIAN
BAY
LAKE ONTARIO
(246 ft.)
LAKE ERIE
(572 ft.)
PARRY SOUND
MIDLAND
OWEN SOUND
DURHAM
GODERICH
KITCHENER
HAMILTON
TORONTO
NIAGARA FALLS
LONDON
SARNIA
WINDSOR
PETERBOROUGH
77°
79°
80°
81°
82
83°
44°
45°
43°
10
15
20
25

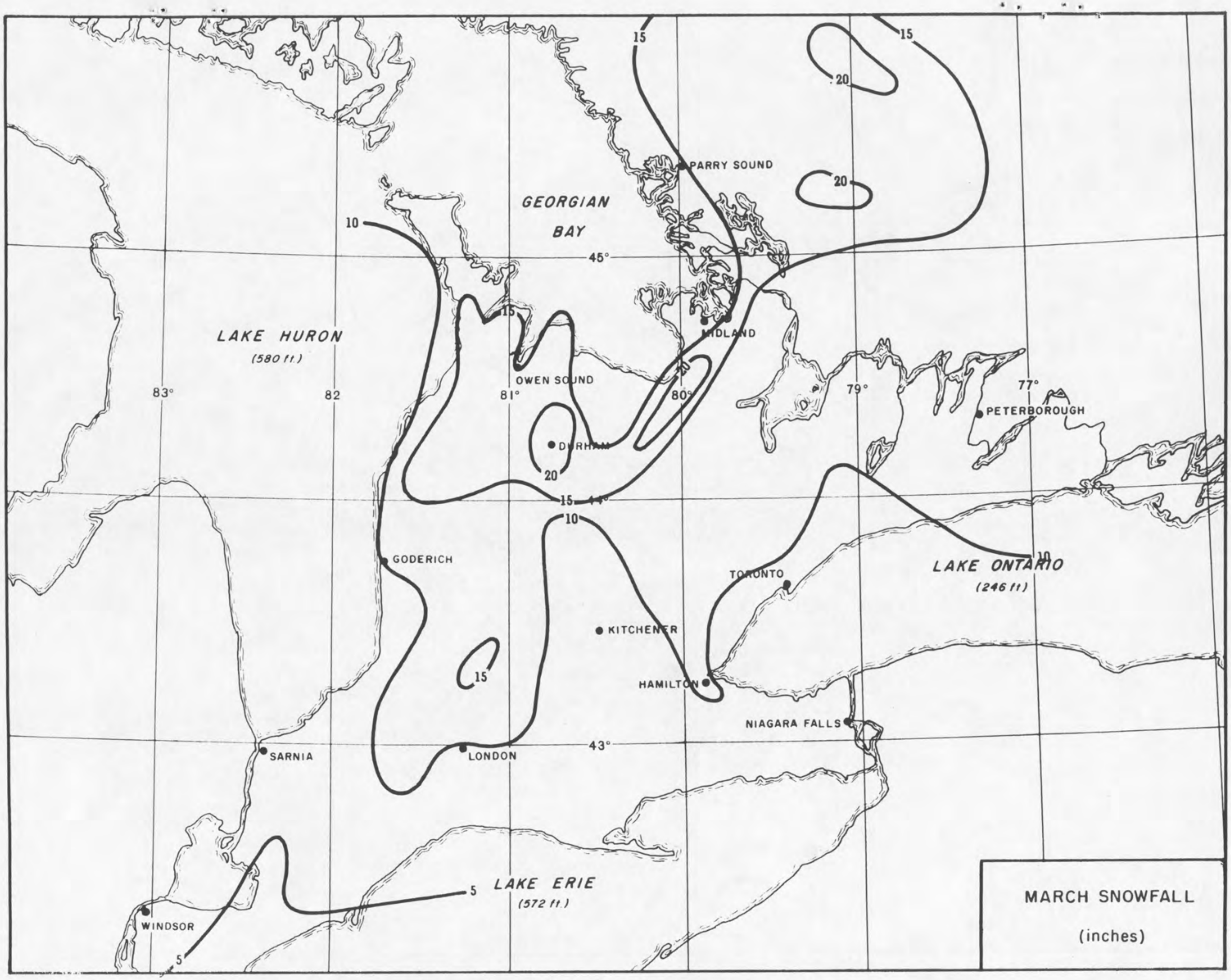
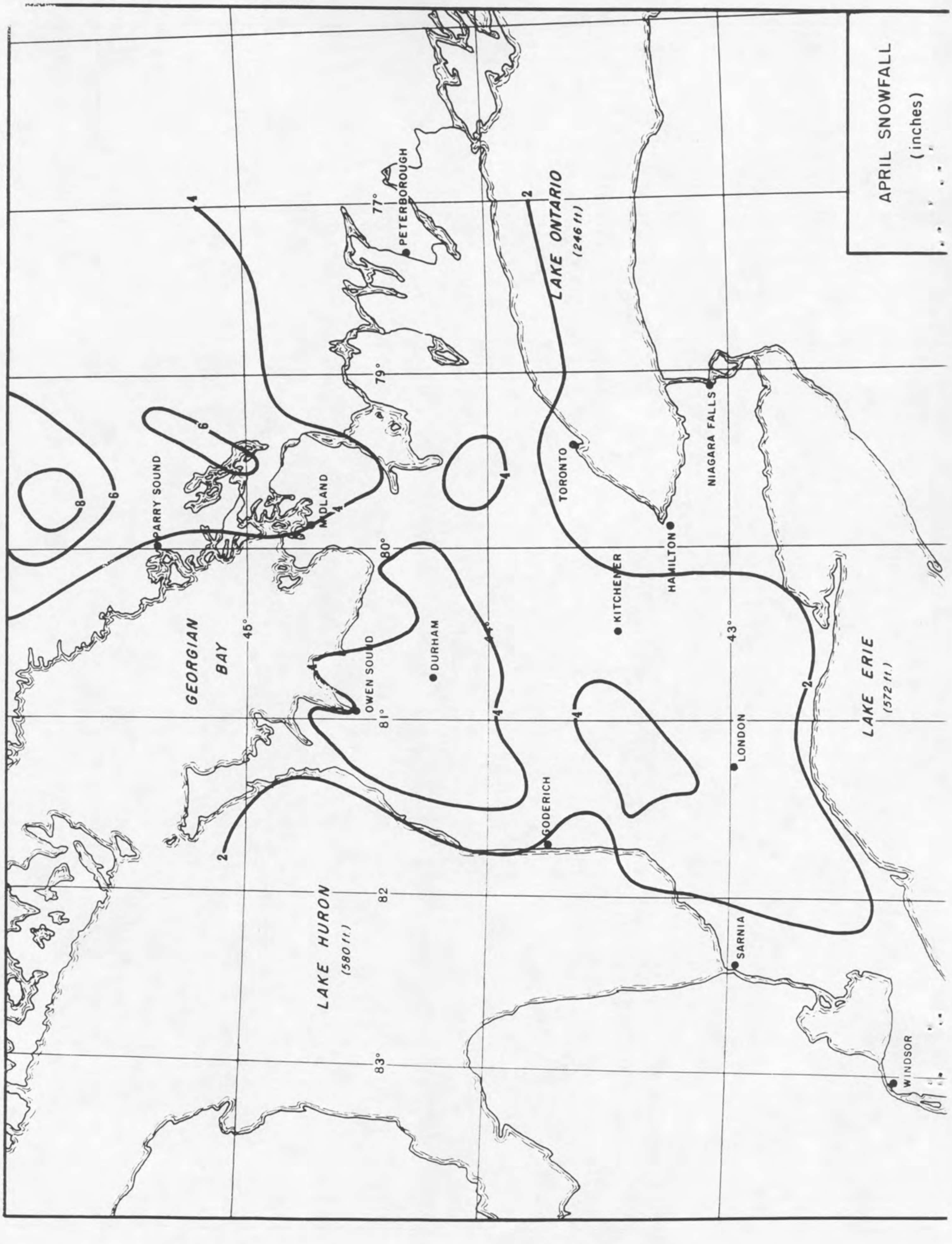


Figure 8 - March Snowfall in Southwestern Ontario


APRIL SNOWFALL
(inches)
GEORGIAN BAY
LAKE HURON
(580 ft.)
LAKE ONTARIO
(246 ft.)
LAKE ERIE
(572 ft.)
PARRY SOUND
MIDLAND
OWEN SOUND
DURHAM
GODERICH
KITCHENER
LONDON
SARNIA
WINDSOR
TORONTO
HAMILTON
NIAGARA FALLS
PETERBOROUGH
77°
79°
80°
81°
82
83°
45°
44°
43°
2
4
6
8

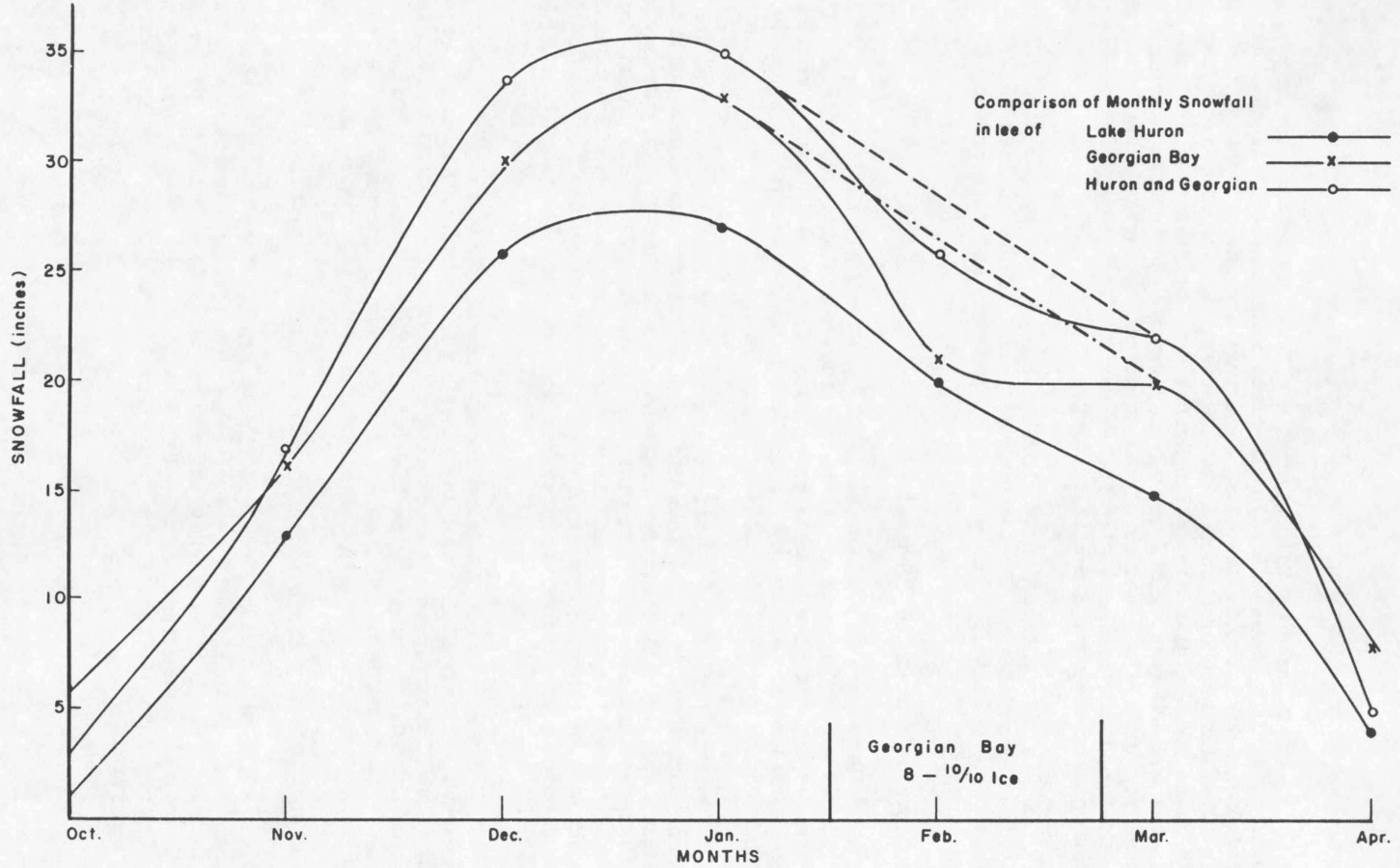


Figure 10 - Comparison of Monthly Snowfall in the Lee of Lake Huron, Georgian Bay and Huron and Georgian (combined).

2. Contribution of Orography

As estimate of the orographic effect may be made by comparing annual snowfall vs. elevation in the three main snow belt areas. A traverse from Lake Huron to the area of maximum snowfall northwest of London reveals an increase of 8 inches per 100 feet. Similarily, traverses from Lake Huron and Georgian Bay to the Durham snow belt show an increase of 7 inches per 100 feet, and from Georgian Bay to the Muskoka Highlands 6 inches per 100 feet. Because of the complicating factor of the Georgian Bay freeze-up the estimate of 8 inches per 100 feet to the lee of Lake Huron appears the more acceptable figure.

In this connection it should be noted that Muller (1961) (1), in a study of snowfalls to the lee of Lake Ontario found an increase of 25 inches per 100 feet up to elevations of 700 feet and an increase of 5 inches per 100 feet higher in the Adirondacks.

3. Contribution of the "Thermal Effects" of the Lakes.

Peterssen and Calabrese (1959) (2) have already reported on the influences due to warming of the air by the Great Lakes in winter. They have shown that the heat source provided by the lakes in winter could produce a pressure drop of up to 6 millibars over open water and a snowfall of up to 2 inches per day over adjacent flat land.

This present study offers a unique opportunity to assess the thermal contribution of the lakes using a different approach. As indicated earlier, snowfall decreases noticeably to the lee of Georgian Bay in February. This is coincident with the freeze-up of the bay during this part of the winter. Figure 10 shows separate graphs of monthly snowfall throughout the winter for the three major snow belt areas i.e. to the lee of Lake Huron, to the lee of Georgian Bay and the "double exposure" snow belt of the Durham area.

The effect of the Georgian Bay freeze-up is brought to light by the marked February minimum in the Georgian Bay curve and by a lesser minimum in the Durham curve. On the assumption that these curves would parallel the Lake Huron curve if the bay did not freeze (dashed lines) it is apparent that the February snowfall to the east of Georgian Bay is reduced by 6 inches or about 22% and in the Durham area by 3 inches or 11%.

4. Contribution of Evaporation and Lake Induced Instability

The major consequence of the "thermal effect" of the lakes is the creation of instability in the lower layers of the atmosphere due to the winter heat source of the lakes and the contribution of additional moisture to the air through evaporation. While it is difficult at present to quantitatively assess these factors their relationship to the monthly snowfall is quite apparent.

Figure 11 illustrates this relationship between monthly snowfall to the lee of Lake Huron, instability created by the lake, and evaporation from the lake. The monthly instability term $T_W - T_A$ was obtained from monthly mean air temperatures (T_A) at Sudbury just north of the lakes and the monthly mean surface water temperature for Lake Huron (T_W) taken from Snyder (1960) (3). The monthly evaporation figures were computed by the Mass Transfer Method using long term climatological data from shore stations adjusted by the land/lake ratio technique described by Richards (1962) (4).

An instability maximum in January and an evaporation maximum in December are completely compatible with a snowfall maximum in December and January.

SUMMARY

It would appear that "lake effect storms", as they are becoming popularly known, are responsible for about 50% of the snowfall in southern Ontario's snow belt area. These storms are actually a combination of effects including orographic lift and the "thermal effect" of the heat source created by the lakes during the winter. In effect the lakes contribute additional moisture to the atmosphere through evaporation and create instability in the air mass and a "thermal troughing" resulting in convergence: - all snow producing mechanisms, - and all compounded by orographic left.

There is no doubt that other meteorological factors are involved. These include the phasing of cold temperatures and troughs aloft with favorable surface conditions. The advection of vorticity also influence the timing and severity of the storms. In addition there is much to be learned of the characteristics of the individual storms - their shape and the dynamic forces involved. As indicated at the outset, this particular study is looked upon as a first step only, - the researcher of "lake effect storms" has much to look forward to.

REFERENCES:

1. Muller, Robt. A. (1962)

Snowfall patterns in the eastern Lake Erie and eastern Lake Ontario snow belts and their relation to snowfall in New York. Proceedings of the Conference on Lake Effect Storms, Fredonia, N.Y. 18-25.

2. Petterssen, S. and P. A. Calabrese (1959)

On some weather influences due to warming of the air by the Great Lakes in winter.
Journal of Meteorology, Vol. 16, 646-652

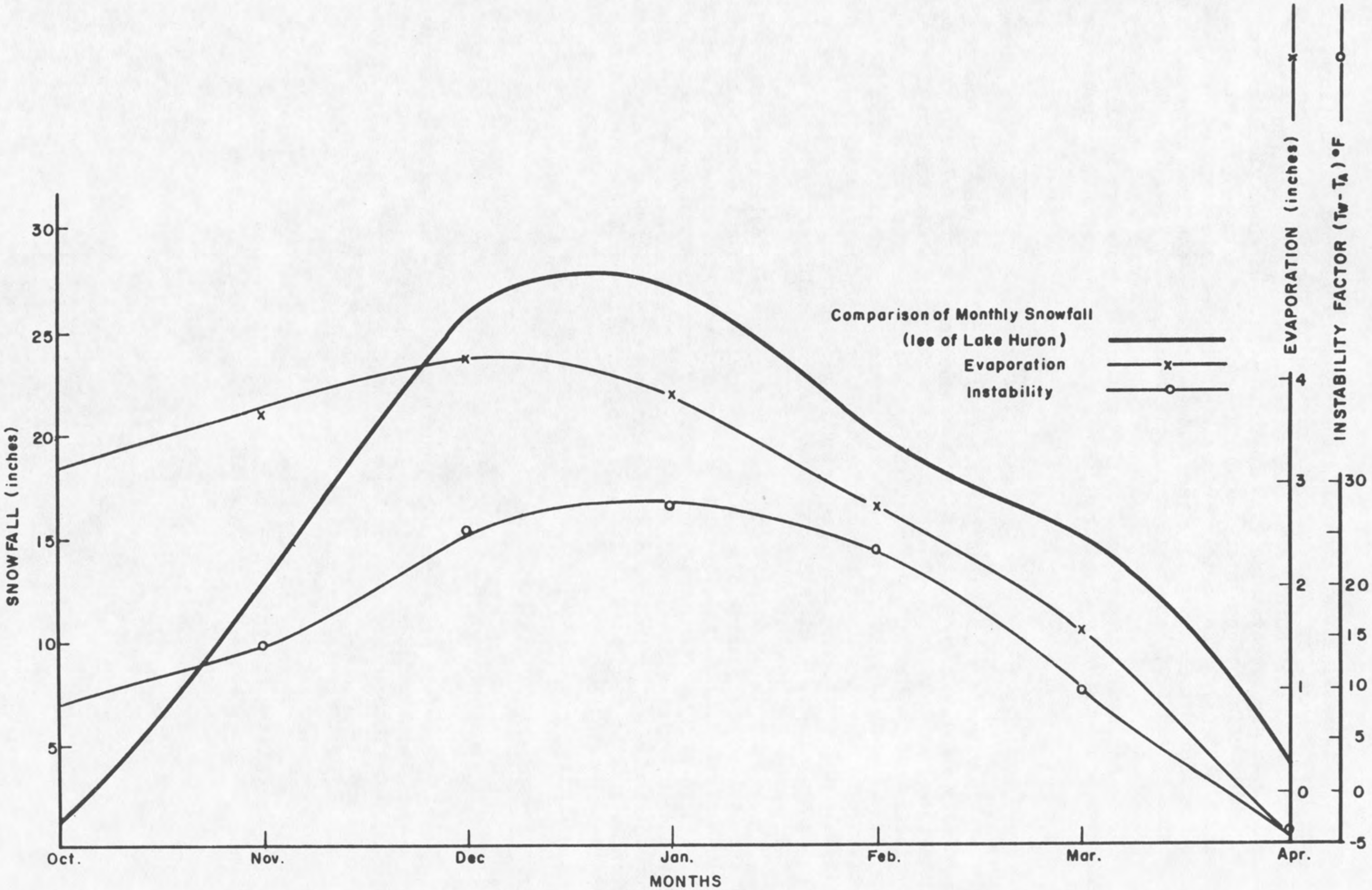


Figure 11 - Relationship between Monthly Snowfall (lee of Lake Huron), Monthly Evaporation and Instability (T_W - T_A) created by the lake.

3. Snyder, Franklin F. (1960)

Evaporation on the Great Lakes
Proceedings of the IASH, I.U.G.G., Helsinki, Finland.

4. Richards, T.L. (1962)

Recent developments in the field of Great Lakes evaporation
Proceedings of the XV International Congress on Limnology,
Madison, Wis.

THE ROLE OF LAKE EFFECT STORMS IN THE DISTRIBUTION

OF SNOWFALL IN SOUTHERN ONTARIO

Discussion by D. N. McMullen, Conservation Authorities Br., Ont. Dept. of Lands and Forests.

I found Mr. Richards' paper most interesting as it covers a subject which is of major concern to us who live along the shores of the Great Lakes. I am sure we are quite agreed, as Mr. Richards has well indicated, that lake effect storms play a major role in the distribution of snowfall in Southern Ontario. However, I am concerned that the method of analysis that has been used might, because of the completely integrating effect of monthly and annual values, possibly lead one to making assumptions that may not be completely valid.

In this regard, I would refer you to Mr. Richards' remarks concerning the February monthly snowfall map when it was stated, and I quote "February shows a noticeable change in distribution with a marked decrease in snowfall to the east of Georgian Bay and with a lesser decrease in the Owen Sound-Durham area. There is little doubt that this is the direct result of ice formation on Georgian Bay." Further comment was made on this with reference to the chart showing comparison of snowfall in the Lake Huron and Georgian Bay area.

I do not feel that the ice formation on Georgian Bay is the basic cause for the change of snowfall distribution in February though of course it does have some effect. I believe that the ice itself is simply one other manifestation of a large-scale airmass movement, the intrusion into central Ontario of the cold dry Arctic airmass. During the earlier part of the winter, the polar front lies in an east-west line across the Great Lakes and extensive wave activity along these lines create conditions that assist the development of lake effect storms. As the winter progresses however the polar front moves south of the Great Lakes and the polar airmass is displaced by an even colder Arctic airmass in which the moisture is considerably reduced. The region of major frontal activity is then moved well south of the area. To confirm this opinion, I would point out that the pattern of seasonal snowfall at stations in northern and central Ontario shows a pronounced dip in the monthly snowfall charts during the month of February.

The increase in the snowfall from March over that of February in the northern regions is therefore a result of the movement northward again of the polar front. This effect can be readily seen on the graph of monthly snowfall for Cochrane, a station which is located well to the north and east of the Great Lakes. In Southern Ontario, where the Arctic airmass is not a permanent fixture, the monthly distribution of snowfall at all stations away from anamolous lake effects is quite even with a regular progression of snowfall throughout the winter, increasing gradually to a peak in January and falling off gradually after. This airmass movement would also account for the change of snowfall pattern in the Georgian Bay area and the ice condition is only a further manifestation of this change.

Mr. Richards' statement and its implication "March snowfall returns to the more general snowfall pattern as the ice leaves Georgian Bay", is not entirely valid as much above freezing temperatures are required to melt the lake ice and such conditions are not conducive to producing snow.

In considering Mr. Richards' chart in which he compared the distribution of monthly snowfall in the Georgian Bay area and the Lake Huron shore, I was unable to ascertain whether these were composite charts or charts for individual stations. I therefore plotted the average monthly snowfall for a number of stations with the thought in mind of comparing the patterns for stations along the lake in order to remove, as much as possible, the orographic effect which might obscure the general features of the lake effect storms. A few of these charts are shown on this slide.

As I mentioned, those stations which are not unduly effected by the lakes, such as Kitchener in the central section of south-western Ontario and Lindsay, which is about 70 miles northeast of Toronto, show an evenly distributed curve with the months before January having much the same values as those after January. On the other hand, Southampton, on the shore of Lake Huron just south of the Bruce Peninsula, and Parry Sound, on the Georgian Bay shore, show a distorted distribution caused by the lake effect storms in the earlier part of the winter.

Mr. Richards commented on the orographic effect on the distribution of snowfall and quoted values of "increases of 7 to 8 inches per hundred feet elevation." This I find, as can be expected, depends very much on the direction of traverse across the slope.

Southampton, on the eastern shore of Lake Huron just south of the Bruce Peninsula, has a north-west exposure and an annual snowfall of 111 inches while Durham, 40 miles south-east and some 600 feet higher on top of the plateau, has 137 inches. This then with a preferred exposure to lake effect storms is only an increase of 4 inches per hundred feet.

I mention this point primarily to bring out another interesting feature on the snowfall distribution and that is, the snowfall variation with the exposure to a varying length of wind trajectory over the Great Lakes. In comparison to 111 inches at Southampton and 137 inches at Durham, Goderich which is also on the shore of Lake Huron and 50 miles south of Southampton, receives only 76 inches of snow annually or 35 inches less than Southampton.

The exposure to the lake at Goderich is across the narrow part of Lake Huron while at Southampton it is across the widest sector and beyond that across all of Lake Superior.

This would suggest that exposure to the prevailing winds accompanying the lake effect storms is an even more significant feature of snowfall distribution than the orographic effect.

The more charts I plotted the more appreciative I became of the problem of analysis which this subject presented. I was gratified to know that Mr. Richards will carry on his study of "the role of lake effect storms in the distribution of snowfall in Southern Ontario."

THE ROLE OF "LAKE EFFECT STORMS" IN THE DISTRIBUTION

OF SNOWFALL IN SOUTHERN ONTARIO

Discussion by: Livingston Lansing, Research Affiliate, ASRC - State University of New York

This paper by Mr. Richards and Mr. Derco, which is one of the first published by Canadian authors on the role of lake effect storms on the distribution of snowfall pretty well lines up with the findings of researchers in the United States who have made similar studies.

The Richards-Derco paper finds an increase of approximately 8" of snow per each 100 ft. of increase in altitude in southwestern Ontario. The greatest yearly snow precipitation apparently occurs at Durham, 137" at an elevation of 1250 ft. One would normally expect the greatest snow precipitation to occur in the Shelburne-Dundalk area about halfway between Toronto and Owen Sound. This area is at an elevation of 1700 to 1800 ft. and at the highest point of the southwestern Ontario plateau. This compares roughly with the 1700 ft. elevation on Tug Hill, New York, where the highest snow precipitation east of Lake Ontario occurs. However, Richards and Derco find there is not as much snow reported in the higher Shelbourne area than there is at Durham. Perhaps, this situation is a function of distance from the lake because Durham is 40 miles from the lake and Shelburne is 30 miles more distant from the lake than Durham.

Richards and Derco feel that 50% of the snowfall on the elevated upland east of Lake Huron probably occurs because of lake effect storms. They compare the record at Durham with that of Sudbury and Windsor where there is no lake effect, and which averages half the snowfall of the Durham area. This "discusser" feels that this is probably a fair average, but in addition, the Durham area is on a relatively high and exposed plateau when compared with Sudbury or Windsor. Thus winds from south and southeast with snow of a non-lake effect nature would be normally given an orographic lift, which would produce heavier snows at Durham than at Windsor or Sunbury. Here I would like to cite the Boonville - Albany snow comparison of New York State. Boonville has approximately four times the snow that Albany has, and is in the Lake Ontario snow belt. However, I do not feel that it would be fair to say that 75% of Boonville's snow is lake effect because Boonville, with non-lake effect south or southeasterly winds on most occasions, will have several times the snow that occurs at Albany, because of the lifting effect given south and southeast winds by the Tug Hill plateau.

Richards and Derco talk about the monthly instability term, which is given as the difference between the monthly mean air temperature at Sudbury and the monthly mean surface temperature of Lake Huron. This is an interesting way of showing the potential for lake effect storms, but the writer feels that a check of the lapse rate of radio sounds observations, after passage of the cold front, would be somewhat more significant as the instability of the various air masses would then be graphically shown.

The authors mention that we know little of the size and shape of these snow cells that produce these snows over the lee shores of the lake. However, the WSR 57 Radar now located at the Buffalo, New York Airport is beginning to give us a graphic picture of these snow cells in the Lake Erie area southwest of Buffalo. Many of these cells in the December 1962 storm were seen to be 15 to 20 miles wide north and south and 20 to 60 miles long east and west with sections of non-precipitating cloud cover between these cells.

Richards and Derco quote a paper by Petterssen and Calabrese who have reported on how in winter the Great Lakes warm the lower layers of the air masses that pass over them. They have shown that the heat source, provided by the lakes in winter, could produce a pressure drop up to six millibars over open water and a snowfall up to 2" per day over adjacent flat land. This writer would agree with the pressure drop of six millibars due to the thermal heating of the air mass by the Great Lakes, but he has actually observed a snowfall of 36" per day from this lake effect condition rather than the 2" mentioned.

Again the Richards-Derco paper mentions the drop in snowfall from January to February in the Georgian Bay area is more extreme than the drop in snowfall of the southern Lake Huron area. This, they explain, is because Georgian Bay is often frozen over in winter whereas Lake Huron is not. That their hypothesis is correct, is indicated by several records east of Lake Erie and Ontario. Lake Erie often gets a greater percentage of its surface covered with ice in winter than Lake Ontario. The records show that there is a drop in snowfall on all the Lake Erie stations from January to February, whereas the records for Adams Center, New York, a station that gets a maximum lake effect condition east of Lake Ontario, actually shows that the February snow precipitation at Adams Center is slightly more than the January precipitation, in spite of the fact that February is several days shorter than January. Also to be noted, is that Adams Center has a good long 20-year record. To further back this up, in 1963 on January 22nd-28th, lake effect storms hit both the areas from Buffalo and south along Lake Erie and Watertown and south along Lake Ontario. At this time, Lake Erie was reported to be almost entirely frozen over whereas Lake Ontario had only a small percentage of ice cover in drifting ice fields. The storm of the 22nd-28th mentioned was considerably more severe with much greater quantities of snow over the east end of Lake Ontario than it was over the east end of Lake Erie.

Another interesting question for future researchers posed by the Richards-Derco paper is: where do the condensation neuclui, that produce these large lake effect snows, come from? Also, what per cent of the snow precipitation, that falls with the northwest wind on the southwestern Ontario plateau, originates from the waters of Lake Superior or northern Lake Michigan, both of which are northwest of this plateau. In addition, the writer has found that without any considerable orographic uplift, normally, the heaviest snow falls east of Lake Ontario occur 15 to 25 miles inland from the lake. Correspondence, with highway officials on the east shore of Lake Michigan, in the State of Michigan, indicates this is true of that relatively flat area also. Further, the immediate shore of Lake Ontario in New York State is a minimum snow area. This has been found true by eye observation and by many snow surveys in the Sandy Pond area on the east shore of Lake Ontario, just west of Sandy Creek. The Richards-Derco paper show Owen Sound to be in an area of maximum snowfall though it is actually on the shore of Georgian Bay. This perhaps could be explained by the fact that the majority of the lake effect snows that hit Owen Sound come from Lake Huron itself and not Georgian Bay, and that the Bruce Peninsula immediately to the west of Owen Sound probably gives the necessary lifting effect to produce this type of snowfall.

There was considerable discussion of the difference of snowfall at Goodrich and Southhampton, both on the east shore of Lake Huron. This "discusser" believes that the considerably heavier snow noted for Southhampton is due to the fact that immediately west of Southhampton there is a longer fetch over Lake Huron than there is for Goderich for westerly winds, because of Saginaw Bay on the west side of Lake Huron.

All in all, it might be said that the Richards-Derco paper was most interesting, that several new points were brought out and that many of the facts substantiated findings of researchers on lake effect snows in New York State.

THE ROLE OF 'LAKE EFFECTS STORMS' IN THE DISTRIBUTION OF SNOWFALL

IN SOUTHERN, ONTARIO

Closure by T.L. Richards and V.S. Derco

In dealing with Mr. Lansing's discussion first, the authors must admit that they, too, were surprised that the greatest snowfall in southern Ontario was not found on the height of land in the Shelbourne-Dundalk area. It may be as Mr. Lansing suggests that this situation is a function of distance from the lake or it may also be at least partially due to the precipitation shadow associated with the Beaver River.

The source of the very large number of condensation nuclei required for these storms has long puzzled meteorologists. An intriguing investigation would be the use of nuclei counters up-wind and down-wind from the lake,- and if possible over the lake itself. The usefulness of radiosonde data and radar in the study of these storms is acknowledged. As indicated in the paper a proposed "next step" will be the study of individual lake effect storms. Upper air data will certainly be used at this time. The use of radar on the Canadian side of the border will have to await the installation of more powerful and more sophisticated equipment in the not too distant future.

Mr. McMullen questions the "completely integrating effect" of the study. It appears to the authors that an integrating or climatological approach is required. Anyone using snowfall data must be aware that accurate and consistent snow measurements are difficult to achieve. Two observers, taking simultaneous observations at the same site, may differ by significant amounts. Different observers only a few miles apart may differ by large amounts: witness the extreme case of 106 inches average annual snowfall observed at Southampton as compared to 71 inches at North Bruce. These stations hav almost the same elevation and exposure and are only seven miles apart. Because of such discrepancies in data an integrating or smoothing approach seems an necessity.

Mr. McMullen uses Southampton's high snowfall figure to question the authors' estimate of the effect of orography. The North Bruce figure would have shown approximately the same magnitude of difference but with the opposite sign. Other nearby stations would indicate an average between these extremes. The figure in the paper was based on the annual snowfall map and represents a smoothed or average value. As can be seen the use of data from a single station may be misleading.

The point made by both discussors that a longer over-water fetch will lead to a greater snowfall is an extension of the authors' discussion of thermal effect and evaporation and is a point well made. However it is the authors' belief that the effect is not nearly as large as indicated by Mr. McMullen's use of the Southampton data.

Finally Mr. McMullen feels that ice formation on Georgian Bay is not the basic cause of the change in snowfall distribution in February. He would rather believe that this is due to the change in paths of extra-tropical storms. Perhaps only analysis of individual snowfalls will settle this question. However, it should be pointed out that although storm tracks do move northward in March, there is no significant change in tracks from January to February. Yet it is in February that there is a greater reduction in snowfall in those areas where the lakes become frozen over. i.e. south and east of Georgian Bay and Lake Erie. It should also be stressed that climatologically speaking the southern Ontario snowbelt is a relatively small area. The Georgian Bay maximum snowfall area and the Lake Huron maximum are separated by little more than one degree of latitude, - surely a distance too small to be responsible for a 22% drop in snowfall due to a seasonal change in storm track. Mr. McMullen finds an increase in March snowfall at Cochrane and proposes that this is due to "storm track effect". Cochrane however is another 4 degrees north of Georgian Bay. Ottawa and Montreal, on the same latitude as Georgian Bay, but well away from the lake effect, show no such characteristics.

Mr. Lansing, as opposed to Mr. McMullen, agrees that there is a marked and inverse relationship between ice cover on the lakes and snowfall to the lee of the lakes. He quotes from long experience to support his views. Perhaps the best known example of this effect is the observed drop in frequency and severity of snowsqualls and flurries associated with off-lake circulation at Buffalo and Cleveland airports after Lake Erie freezes over. That this relationship exists is one of the "facts of life" soon learned by meteorologists forecasting for the Great Lakes area.