# GENETIC CLIMATOLOGY OF THE GREAT LAKES REGION

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# GENETIC CLIMATOLOGY OF THE GREAT LAKES REGION

By

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AN ABSTRACT

Submitted to the College of Science and Arts
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ABSTRACT

The anomolous nature of the climate of the Great Lakes Region due to the presence of the lakes themselves and to the convergence of cyclonic tracks in that part of North America is generally recognized. Yet, in spite of the great importance of the region, its peculiar climate has received surprisingly little attention on a comprehensive and regional scale. Furthermore, relevant studies, whether statistical or genetic in approach, have tended to explain that climate only in general and qualitative terms. The need, therefore, has arisen for a genetic climatology of the region which will draw the require quantitative relationships between the dynamics of the atmospheric circulation and actual regional element occurrences.

Various methods of analyzing regional atmospheric behavior are examined to determine the type of classification to which elements may best be related. Of particular note are "weather type" classifications based on either air masses or recurrent synoptic patterns. A modification of the latter method is selected over the air mass approach because it is more easily adapted to accommodate frontal precipitation and more easily applied to simultaneous regional analysis in a region of frequent air mass conflict.

Three criteria form the bases of differentiation of the major weather types of the Great Lakes Region: (1) surface synoptic circulation pattern, that is, whether they are represented by cyclonic or anticyclonic systems; (2) approximate direction of origin of these

systems; and (3) local trajectory of the systems relative to the Great Lakes. As such, the various weather types are recognized largely by their surface reflections which, for the present, are most easily and directly associated with the elements. They are, none the less, based on upper-level flow patterns. Because the types are represented by synoptic systems following definite tracks which are related to the upper-level westerlies and the general circulation they are truly dynamic and can be referred to as "dynamic-synoptic system weather types".

In the Great Lakes Region, eleven dynamic-synoptic systems are sufficiently distinctive for isolation as weather types. For each type, day frequencies and normal element characteristics are established. Element characteristics associated with each type are found to be distinct and remarkably constant. On the other hand, type frequency variation from season to season is quite marked. Type frequencies and element characteristics, therefore, are clearly reflected in, and in fact explain, not only the day to day character of the climate, but also the distributional differences of average temperature and total precipitation from season to season and year to year.

Each of the four mid-season months is analyzed with respect to: (1) frequencies of dynamic-synoptic system weather types, (2) effect of the individual types on daily element values; (3) interpretation of the distribution of "normal" temperature and precipitation in terms of type frequencies; (4) deviations from "normal" as explained by type frequency variation. January is found to be characterized by a high frequency of the two coldest anticyclonic types and by a diversity of the cyclonic types which bring warmer temperatures to the southeast and fairly reliable and evenly distributed precipitation to the region as a whole. Modification of temperatures by the lakes is at a maximum in this season, particularly during the coldest type, and precipitation is significantly heavier to the lee of the lakes with several of the types, both cyclonic and anticyclonic. In April, two cyclonic types bringing high warm sector temperatures to the southeast and heavy but variable precipitation to the entire region reach a maximum frequency. Anticyclonic types appear in greater variety than in winter and are less severe. In July the coldest anticyclones are at a minimum. Milder anticyclonic types, however, are at a maximum and along with a fair number of cyclonic types with warm sectors reaching quite far north maintain high average temperatures with low latitudinal gradient. Precipitation is primarily associated with two of the cyclonic types and one anticyclonic type; in all cases it is variable in area of concentration. October is largely dominated by one dry, mild anticyclonic type. The remainder of the month is divided among a wide variety of types with their associated variety of element characteristics.

By showing these relationships between type frequencies and element occurrences, dynamic-synoptic system weather types give the required quantitative understanding of the climate of the Great Lakes Region, and at the same time provide the necessary missing link for a new, fully integrated framework for climatic synthesis based on the genetic character of the climate.

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## PREFACE

Climate has traditionally been defined as "average weather" through the preoccupation of Classical Climatology with mean values of the main weather elements. This definition has long lost scientific acceptance but there must be, none the less, a close relationship between "climate" and daily weather as we experience it.

Early climatologists sought to describe climates merely by analyzing norms and means. There was little quantitative attempt to discover co-variances of the elements through synoptic processes, nor even to explore the variations of single elements to greater detail than monthly averages and extremes. In contrast to the impression given by the traditional definition, the close relation between climate and weather was often almost completely lost. Their entire quantitative approach was static and in the abstract. In most cases there was no empirical equivalent, in either the arithmetic or "normal" sense, to the averages used to describe climate for variation itself is more frequently the norm. To circumvent these criticisms and to generally make their systems more understandable, writers as a rule attempted to add qualitative explanations and descriptions to their statistical material. This method was practical considering the data available, but far from satisfactory. Furthermore, it virtually necessitated that climatic classifications use other phenomena, such as vegetation, to decide arbitrary, quantitative boundaries rather than be based on the character of climate itself.

The immediate needs arising from the early studies were obviously twofold: (1) quantitative explanations and descriptions, empirically verified, of the dynamics of atmospheric circulation; (2) quantitative interpretation of the elements as directly related to actual daily local occurrence. Much of more recent work has been toward these ends. Investigations with relevance to the first include the many studies dealing with energy balances, winds, fronts and air masses; those with relevance to the second include statistical analyses of frequencies, co-variances, variations, and deviations of the elements. Long term means are still widely used for gross comparisons, but because of the local and short term variations and deviations their direct application to detailed scientific work is limited. Their widest use, therefore, is as a relatively constant datum to which deviations can be referred.

With the rapid development of exploration into the dynamics of the atmosphere and into the statistical frequencies and probabilities of elements, climatology has vastly improved. One important aspect, however, remains to the present with limited attention but which must be approached in detail before the climatological image is complete. The works have, for the most part, tended to develop independently along one or the other of the two problems, leaving the seemingly obvious gap, that of the quantitative connection between them. Although many of the studies of atmospheric circulation even develop classification systems, detailed descriptions of the accompanying elements are rare and then almost invariably qualitative. Conversely, studies of the elements often deal entirely with statistical frequencies or probabilities and rarely correlate quantitatively and comprehensively with air masses, fronts, or the general circulation.

Needed then is, first, a classification of regional atmospheric behavior to which local element occurrences can be directly and comprehensively related, and at the same time, a classification founded in the broader horizon of the general world circulation; second, a detailed and modern analysis of the elements related to each characteristic behavior; and finally, a quantitative synthesis of element occurrences and atmospheric behaviors in the interpretation of climates of the world. The approach is entirely genetic. The present study, apart from its local importance, is only a small exploration into the difficulties and possibilities of such investigation, the completion of which shall eventually give the true and logical relation between climate and the weather.

At this time I wish to express my thanks to those who have assisted me in the writing of this thesis. I would particularly like to thank Dr. D.H. Brunnschweiler of the Department of Geography, Michigan State University for his careful reading of the original manuscript, for his many constructive criticisms and suggestions, and especially for his unrestrained encouragement, consideration, and willingness to give of his own personal time to accommodate its completion. I am also indebted to my wife, Nancy for her patience, encouragement, and occasional prodding during the preparation, and for the typing of the manuscript and final copy. I would like to thank Dr. A. K. Philbrick of Michigan State University for cartographic advice; Dr. F.K. Hare of McGill University for article reprints, recent climatological ideas, and inspiration; Mr. M.K. Thomas and the Toronto climatological office of the Meteorological Branch, Canadian Department of Transport for bibliographic and statistical material; Mr. A.H. Eichmeier, Michigan State climatologist and the East Lansing Weather Bureau for use of daily weather maps and office space; and the Toronto Meteorological Office Library for prolonged loan of maps and statistical material.

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## INTRODUCTION

The anomalous nature of the climate of the Great Lakes Region as a result of the influence of the Lakes themselves and of the convergence of the cyclonic tracks of North America in that region is generally recognized. Yet, in spite of the great economic, political and social importance of the region, there have been surprisingly few comprehensive examinations of its peculiar climate. In fact, descriptions of the climate of the Great Lakes Region as a whole have rarely been attempted. At best, local and continent-wide analyses can be pieced together with these few rare studies for a general and overall understanding.

### Standard Climatic Descriptions of the Great Lakes Region

According to the Koeppen[1] classification, the entire Great Lakes Region is within the belt of D climates, termed humid microthermal by Trewartha, having January mean temperatures below 26.6° F. and July means above 50° F. Mean annual temperatures range from just over 32° F. north of Lake Superior to near 50° F. south of Lakes Michigan and Erie. Three subtypes of the humid microthermal climates appear, but the differences are mainly in degree of temperature. Illinois, Indiana and Ohio (Dfa) experience long warm summers with their warmest month above 71.6° F.; Minnesota, Wisconsin, Michigan and Southern Ontario (Dfb) have short summers with their warmest month below 71.6° F.; most of Northern

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[1]Koeppen W., Die Klimate der Erde (Berlin, 1931).

Ontario is subarctic (Dfc) with less than four months above 50° F. Annual precipitation ranges from just over 20 inches in the northwest to over 40 inches in the southeast. There is no predominant wet season. Most humid microthermal climates of the world show a summer maximum; but significant areas of the Great Lakes Region, particularly in the east, have surprisingly uniform seasonal distribution or even a slight winter maximum.

Trewartha[1] characterizes the climate of humid microthermal regions as a whole by cold winters, durable snow cover, long frost seasons, and large annual ranges of temperatures. He emphasises that they are largely land controlled and are therefore distinctly continental. Though largely true of the West, this perhaps tends to minimize, first, the great importance of moisture and heat transfer from the Gulf to year round reliability of rainfall and to summer temperatures; and second, the more local importance of the Lakes themselves. Temperature extremes for the year, however, are accentuated by the dominance in winter of northern continental air and by the monsoonal tendencies of maritime tropical air in summer. Winter is dominated by the non-periodic changes of cyclones and anticyclones; diurnal changes are subordinate. Monthly averages are of limited value for the description of winter temperatures because of their great variation from day to day. Particularly noteworthy are strong importations of arctic air known as "cold waves" during which temperatures drop rapidly in many cases to below 0° F. In summer diurnal changes become relatively more significant, but air mass control is still important. Of note is the summer

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[1]Vernor C. Finch and Glenn T. Trewartha, Elements of Geography (New York: McGraw-Hill Book Co., 1949), pp. 185-204.

counterpart of the cold wave, that is, the heat wave in which steady transportation of tropical air northward keeps maximum temperatures above 90° F. for some time. The general humid microthermal summer maximum of precipitation, Trewartha attributes to 1) the greater reservoir of moisture in the warmer air, 2) the greater prevalence in winter of anticyclonic circulation particularly in subarctic regions, 3) summer convection, 4) the tendency to strong inflow of moist maritime tropical air in summer and to the outflow of continental polar air in winter. The increase of winter precipitation in eastern North America, he attributes to frontal activity and the absence of a barrier to maritime tropical air. Spring and autumn are characterized by a struggle between winter and summer controls. Mild days are followed by frosts. Spring is famous for its fickleness. Autumn brings some of the nicest days, those known as Indian Summer, with clear skies, warm mid-days and crisp nights associated with anticyclonic circulation; but it also brings, with cyclonic circulation, some of the rawest and gloomiest days.

Strahler,[1] in strong contrast, uses a more genetic classification to describe the climate of north central and northeastern United States and southeastern Canada as "humid mid-latitude continental in the battleground of polar and tropical air masses". The bases of the analysis are air masses, fronts, cyclones and anticyclones. Mean element values are secondary and exemplary rather than primary and requiring explanation. The interpretation is noticeably different. The region referred to is intermediate between the source region of polar continental air masses on the north and northwest and the maritime tropical air masses

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[1]Arthur N. Strahler, Physical Geography (New York: John Wiley & Sons Inc., 1951), pp. 374-77.

on the south and southeast. Maximum interaction of the air masses occurs in this region along warm and cold fronts associated with eastward moving cyclones. In winter, northern continental air dominates and cold prevails; in summer maritime tropical air dominates and high temperatures prevail; seasonal contrasts, therefore, are great. Strong air mass contrasts result in much violent frontal activity, highly changeable weather, and ample precipitation throughout the year. In the west, a summer maximum of precipitation and strong continental temperature contrasts and ranges particularly reflect the predominance of tropical air masses in summer and northern air masses in winter. In the east, maritime air masses have ready access to the region throughout the year; precipitation is more evenly distributed; and temperatures, though still noticeably continental in daily range, have smaller annual ranges.

Kendrew[1] using a regional organization is primarily elemental in approach but stresses the significance of the almost unbroken procession of cyclones and anticyclones in the extremely variable weather and temperature of North America. In referring specifically to the Great Lakes and St. Lawrence region, he points out that this region has perhaps the most variable conditions owing to the convergence there of the most frequenct cyclone tracks of the continent. Similarly he accounts for the "increase in precipitation to more than 30 inches annually in the neighbourhood of the Lakes" by the abundant winter precipitation. In that season not only are the cyclones especially vigorous, but also

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[1]W.G. Kendrew, Climates of the Continents (New York: Oxford Clarendon Press, 1953).

the warmth of the Lakes tends to attract the lows and thus accentuate the convergence of the tracks.

Of more specific nature, numerous discussions of the importance of the lakes[1] themselves to temperature, precipitation, and pressure are available. For the Great Lakes Region as a whole, analyses of the effects on temperature are the most common.

According to Lautzenhiser,[2] the air masses most modified are the very cold, continental arctic masses of winter as they pass over the warmer lake water. In contrast, cP air is little affected in summer, for it is warmed in its travel across land and temperature differences between air and water are small. Conversely, tropical maritime air from the Gulf is little changed in winter as it has already cooled in its northward travel and the lakes are relatively warm. In summer and especially spring, when the lakes are cool, the air may be many degrees warmer than the water and cooling by the water prevents heat waves from reaching the northern and eastern shores. The same cooling will often cause heavy fog and low stratus to develop if the moisture content of the Gulf air is sufficiently high.

Kendrew,[3] on the other hand, merely demonstrates the influence of the Lakes on temperature by the resulting gross pattern of mean isoterms. It should, however, be noted that this is a mean analysis and

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[1]The lakes warm slowly in summer and cool slowly in winter. Even in the coldest winter they do not freeze over. In summer the surface of Lake Superior warms only to the fifties, but Lake Erie and southern Lake Michigan reach water temperatures in the low seventies.

[2]R.E. Lautzenhiser, "Great Lakes Weather", Weatherwise, Vol. VI, No. 1 (Feb., 1953), pp. 3-5.

[3]Kendrew, p. 316.

frequently west shores are similarly modified by easterly winds.

Putnam[1] in a more local description of Southern Ontario climate, further illustrates the effects of the lakes in the diminished difference between day and night temperatures and the resulting longer frost free season. At Leamington, the frost free season is 170 days but inland at Algonquin Park, it is less than 100 days.

Perhaps the most detailed quantitative study of the effects of the lakes on temperature has been done by Leighly.[2] The modifying influences of the lakes on the annual march of temperatures are examined by a series of isopleth maps showing rate of temperature rise in spring, temperature and date of maximum, rate of fall in autumn, temperature and date of minimum and finally annual range. In spring he finds the most rapid warming in the northeast, whereas in fall the most rapid cooling is in the northwest. Leighly accounts for this difference by the change in principal source of moist maritime air, in winter the Pacific and in summer the Atlantic, which leads to a great shift of continentality. The explanation is dubious in view of the fact that the Gulf is the primary source of moisture in all seasons.

In a second series of maps corresponding to the first, Leighly draws hypothetical isopleths to represent the pattern supposing the absence of the Lakes. Anomaly lines are then drawn by graphic subtraction. The effects of any one lake are found to vary "directly with its area and inversely with the temperature of the air over the land

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[1]Putnam, Donald F. (ed.), Canadian Regions (New York: Thomas Y. Crowell Co., 1952), pp. 221-25.

[2]Leighly, J., "Effect of the Great Lakes on the Annual March of Air Temperature in the Vicinity", Papers of the Michigan Academy of Science, Arts and Letters, Vol. XXVII (1941), pp. 377-414.

surface about it", except for the effect of Lake Superior in summer which is greatly out of proportion.

Regarding pressure, Lautzenhiser expands on the influence previously suggested.[1] In winter a low tends to form over the warm water and in summer a high develops over the cold water. Thus, the tracks of lows and highs tend to be steered to or away from the Lakes area according to the season. Highs are strengthened in summer and weakened in winter, and for lows the reverse is true.

Detailed studies of the importance of the Lakes to the precipitation of the region as a whole are virtually nonexistent, though there are many studies of the various winter "snow belts". Lautzenhiser describes as the "most spectacular effect of the Lakes" the movement of cold continental air across the lakes in late fall or early winter. The great temperature difference created by the heating, along with the humidifying, of the surface layer of cold air lead to turbulent convection currents and excessive snow to the lee of the lakes. He further suggests that only in winter with the appreciable "lake snows" is the surface water an important source of moisture for precipitation. Slight variations occur in the theory of development of the "lake snows" but most[2] agree roughly with that of Lautzenhiser. The most frequent addition to the theory is that of the orographic lift of the potentially unstable air by the highlands which are somewhat inland but experience the heaviest fall. Such is the case in the zone east of Lake Erie to the Adirondacks and in

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[1]Kendrew, above, p. 5.

[2]See, for example, C.L. Mitchell, "Snow Flurries along the Eastern Shore of Lake Michigan", Monthly Weather Review, Vol. XLIX (1921), p. 502, or B.L. Wiggin, "Great Snows of the Great Lakes", Weatherwise, Vol. III, No. 6 (1950).

the uplands of Southern Ontario facing Lake Huron and Georgian Bay. Remick[1] is unique in his analysis of frictional influences on wind velocity and direction leading to a field of convergence on the right hand portion of the lee side of Lake Erie. Fast moving air from the lake is forced up over the slower land air, is cooled adiabatically, and with sufficient condensation produces precipitation.

Much more rare than studies of the importance of the lakes themselves are studies of the effects of relief bordering the shores. Differences of relief are not great in any part of the region but several areas are of significance. The importance to precipitation of the few relative highlands has already been pointed out. Putnam further illustrates their importance in the "cold loops" of the northern Southwestern Ontario highland which reaches in elevation of 1800 feet and of Algonquin Park which is at about 1600 feet.

## The Need for a Quantitative and Comprehensive Genetic Climatology of the Great Lakes Region

From the foregoing rough synthesis and discussion of various descriptions and explanations of the general climate of the Great Lakes Region, it can be seen that there have been two different and rather distinct approaches, the elemental and the genetic. The first approach, exemplified by Koeppen, Trewartha, Kendrew, and many local studies both old and new, is fundamentally an organized analysis and presentation of the elements with qualitative explanations. The second approach, that of Strahler or Lautzenhiser, is in essence the converse of the first.

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[1] J.T. Remick, "The Effect of Lake Erie on the Local Distribution of Precipitation in Winter", Bulletin of the American Meteorological Society, Vol. XXIII, No. 1 and 3 (1942), pp.1-4 and 111-17, respectively.

Genetical dynamics of the atmosphere are the basis of the description and resultant element characteristics are secondary. Generalizations are again presented qualitatively and details are given in the form of examples.

The present study, on the other hand, is an attempt to draw quantitatively the genetic relationships between the dynamics of the atmosphere and actual regional element occurrences. At the same time, it is hoped that it helps to fill the more general need for a more comprehensive study specifically of the climate of the Great Lakes Region. Various methods of analyzing regional atmospheric behavior are examined to discover the type of classification to which the great variety of element occurrences of the Great Lakes Region may best be related. The suitability of the "fundamental" basis of the selected type of classification is discussed. The behavior of the atmosphere in the Great Lakes Region is classified, and the classification applied to the observation and analysis of actual daily element occurrences. Finally, the climate of the Great Lakes Region, its seasonal and yearly variations, and its variations from place to place, are discussed in terms of a synthesis of element occurrences and atmospheric behavior.

## METHODS FOR THE ANALYSIS OF REGIONAL ATMOSPHERIC BEHAVIOR AND ELEMENT OCCURRENCE: THEIR ADVANTAGES AND DISADVANTAGES

The methods available for the analysis of regional atmospheric behavior and element occurrences are many and most have been expanded in detail elsewhere.[1] It is useful, nevertheless, to briefly summarize the various procedures in order to show why the particular method of this study has been chosen, and to emphasize its capabilities and relative advantages.

Three general groups may be distinguished: (1) mean patterns, (2) point or areal frequency distributions, and (3) recurrent "types".

### Mean Patterns

Until recently most attempts to interpret world and regional circulation and climate have been on the basis of mean pressure or prevailing wind patterns. The quantitative disabilities and inclination to error of such interpretations need not be reiterated. Fundamentally both patterns are of limited validity. Mean pressure patterns are generally employed to suggest or compute mean wind directions; however, even over short periods of time considerable directional difference

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[1]See especially Wesley Calef and Others, Winter Weather Type Frequencies Northern Great Plains, Technical Report of the Quartermaster Research and Engineering Command, United States Army, through a contract study with the University of Chicago, Regional Environments Research Branch, Natick, Mass., August 1957; F.K. Hare, "Dynamic and Synoptic Climatology", Annals Assoc. American Geographers Vol. XLV, No. 2 (June 1955), pp. 152-162; and Arnold Court, "Climatology: Complex, Dynamic, and Synoptic," Annals Assoc. American Geographers, Vol. XLVII, No. 2 (1957), p. 125.

may occur in the real wind and for relatively longer periods the pressure pattern itself is highly variable. For prevailing winds, if streamlines are drawn parallel to the most frequent direction there is usually no possible corresponding pressure distribution; if they are drawn through resultant winds they are perhaps more useful, but it is conceivable that wind in such direction could be either minor or almost nonexistent. To generalize, either mean pressure or prevailing wind patterns represent abstractions that may never exist in actual synoptic cases, and accurate relating of the patterns to element occurrences is virtually impossible.

Point or Areal Frequency Distributions

Frequency distributions are used primarily to reach a more direct interpretation of daily synoptic charts over large areas, and to illustrate the reality behind the abstraction of the mean surface circulation or pressure maps. For a grid of sampling points or areas, frequencies of sign of vorticity, frontal passages, specific air masses, cyclone and anticyclone centres, etc., are recorded and isopleth maps drawn. The character of the circulation over the area is thus demonstrated quantitatively and a link is made between the large scale movements and specific isolated patterns to which element characteristics may be related.

The major weakness of the method for the present purposes arises from the fact that element characteristics may be compared with the occurrences of any one circulation parameter for only one station or areal block at a time. Correlation of elements occurring simultaneously over large areas with the genetical phenomena as considered is impossible for the occurrences represented on the frequency maps are based on point recognition and have no direct relationship to any specific areal distribution of elements as recorded on a daily weather map. Comparisons might be made between the frequency maps and mean element distributions, but the relations would be necessarily gross and bear the inherent fallacies and inadequacies of mean analysis. Conceivably, element frequency maps could be drawn which would show a strong distributional coincidence with the frequency of certain circulation phenomena, such as high temperature with mT air or rain with frontal passages. Though extremely useful for illustrative purposes, the genetic relationship, that is, whether they actually occurred together, is verifiable only for one station at a time. Furthermore, specific quantitative element values cannot be logically assigned to the parameters independent of location because the associated values vary from place to place. Only if large areal blocks are considered one at a time is simultaneous correlation over even a limited area possible and then the study is primarily that of taxonomy and of "type" frequencies over a given region.

Secondly, each of the major parameters, frontal passages, air masses, cyclones and anticyclones, is itself composed of a great variety of types, particularly if considered on a scale of refinement detailed enough for intelligible relation of the accompanying elements. Not only are there the usual taxonomic problems but also, coupled with the variety in nature of the parameters themselves, there is a considerable loss of unity and coherence in the analysis.

The method, nevertheless, is an important aid to the isolation of the location of circulation phenomena occurrences, as well as to general synthesis of world climates. For regional climatology it is primarily a tool for relating isolated circulation patterns over small areas to the broader atmospheric circulation.

Recurrent "Types"

The number of theoretically possible combinations of weather elements is infinite. For many practical purposes, however, certain weather states, or at least ranges of states, are sufficiently repetitive for classification. The bases of such "weather type" classifications may vary in scale from zonal circulation, involving three spatial dimensions and time, to instantaneous element characteristics at a single point; but each classification attempts to consider the totality of weather, rather than single elements, during a short time interval. Four broad categories of "weather types" have been recognized as follows: types based on the conjunction of elements, either genetic or non-genetic; types based on standard time periods; types based on air masses; and types based on total synoptic patterns.

Conjunction of Elements and Standard Time Periods, "Complex" Approaches

Court, in combining these two approaches, has defined "complex" climatology as follows:

> Each weather type is defined by the simultaneous occurrence within specified narrow limits of each of several weather elements. In any given system of complex climatology the elements for each type are fixed, as well as the time period to which the typing applies. Different systems use different element limits and even different elements, and may even use different periods.[1]

Element conjunction classifications focus on the percentage frequency over all observations, of the various element complexes; whereas, standard time period classifications give the frequency of

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[1] Court, Annals Assoc. Amer. Geog., Vol. XLVII, No. 2, p. 127.

hours, days, months, or seasons with given element complexes.

"Complex" types can again only be applied to single station analysis or to limited areas over which a single value of an element parameter is valid. Regional synthesis is made especially difficult by a second major drawback, that of a great multiplicity of types. Classifications with hundreds of types are not uncommon. Calef[1] in his study of the Great Plains chooses the "weather day" method. Using only temperature, humidity, wind velocity and sky cover, each arbitrarily divided into a number of ranges, and eliminating such key factors as precipitation and wind directions, the system ends up with 600 element-complex types of days. "Weather Day" frequencies are then recorded for a ten year period. Such statistical probability is perhaps useful for forecasting and for recording detailed information but is cumbersome for climatic description. Indeed, a large percentage of the Calef study is devoted to "more useful generalization" by analysis of the individual elements. Lesser difficulties lie in the handling of "duration" and in the possibility of great changes within the given time units. The great advantage of the method is its entirely statistical, emperical and objective nature.

The overriding objection for the present purposes, however, is the complete absence of genetic relations to the general circulation and therefore, to regional and world climate. The interest of the method is primarily probability, not explanation. Conjunction of element types if based first on wind direction or curvature of the isobars are to some extent genetic but still are subject to (1) the same limitations

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[1] Calef, p. 7.

to a small area which, in this case, must be represented by a single wind vector; (2) the multiplicity of types, and (3) only partial relationship to causative factors.

Air Masses and Synoptic Patterns, Genetic Approaches

The Great Lakes Region is characterized by strongly contrasting and rapidly alternating weather regimes. Under such demonstrative conditions there are few people unaware of certain elementary relationships such as the coming of cold waves from the north. Statistical analyses support such conceptions by emphasizing the much higher frequency of certain element complexes. One is immediately led to suspect that there are frequently recurring genetic situations which bring with them distinctive element complexes. Air mass and synoptic pattern weather type classifications are attempts to isolate such phenomena.

> Synoptic pattern weather types and air mass weather types are genetic classifications. Both are based on the hypothesis that similar genetic situations occurring at approximately the same time in the calendar year will produce essentially the same conjunction of weather elements, essentially the same duration of weather type, and approximately the same sequence of weather changes.[1]

> The conservatism and distinctiveness of the properties of types of air masses give them tangible identity. . . .Thus the climate is describable in terms of sequence and frequencies of air masses of given type each having known and specifiable values of the elements important in climate.[2]

> If a satisfactory set of synoptic weather types could be designed it would be a nearly ideal system. Not only would it describe the conjunction of weather elements and their duration and sequence; it would also describe this situation for large

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[1] Calef, p. 3.

[2] R.G. Stone, "On Some Possibilities and Limitations of Air Mass Climatology," Annals Assoc. Amer. Geog., Vol. XXV (1935), p. 56.

areas, indicate simultaneous occurrences of different weather types at different places, and, provide explication of the atmospheric processes that produce the weather "types".[1]

Air mass climatology averages each element for each air mass type for every month, season or year. Normal characteristics are thus "determined for each air mass and along with the normal frequencies of each air mass they describe the climate in terms at once quantitative and directly relatable to the weather map".[2] Not only are the elements grouped into a limited number of frequently recurring types but also their local origins are described and may be easily related to the general circulation.

Unfortunately, numerous problems arise in air mass analysis, particularly in conflict zones some distance from source regions. The Great Lakes Region clearly illustrates these difficulties. Here, the convergence of cyclone tracks on the region means rapid and frequent alternation of air masses. Two or more masses are present over the region a high percentage of the time and the masses in combination are not always the same. It is, therefore, almost impossible to classify the entire region by a single air mass. The problem can be handled in either of two ways: either the classification is expanded to include combinations of air masses, or the air mass frequencies are calculated for individual stations and isopleths drawn. In the first case, the types thus isolated are in reality closer to synoptic patterns except for the omission of explicit reference to fronts and isobar curvature and, therefore, of many important relationships. In the second case the difficulties of relating elements to frequency maps have already

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[1] Calef, p. 3.

[2] Stone, Annals Assoc. Amer. Geog., Vol. XXV, p.57.

been discussed.[1] In addition, this latter approach has led, for example, to the description of the Great Lakes as a region characterized in winter by northern continental air masses. The Great Lakes Region, however, is certainly characterized as much, or more so, by the frequent passage of cyclones and fronts, and their accompanying element complexes. In both approaches the necessary omission of fronts and cyclones is crucial.

Finally, the identification of air masses themselves and the validity of their "normal" properties are at best approximate and subjective. Considerable modification in a given air mass takes place enroute due to external forces on the mass itself as well as by mixing with air from other sources.

At attempt to reduce some of these difficulties has been made by Brunnschweiler[2] in his "aerosomatic" (i.e. air mass) study of the northern hemisphere in which he endeavours to correlate element values with air masses. In so-called "somograms" (air mass diagrams) and in tables he tries to establish that air masses behave specifically over any area at a given time. From the type station somogram of Chicago can be derived that the individual air masses bring distinct surface weather characteristics to the Great Lakes region, particularly in the winter half-year. Types and frequencies of fronts are also recorded but not related to actual weather behavior.

The air mass concept is indeed valuable and numerous references are made to specific masses in the following analysis, but air mass

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[1]Above, p. 11.

[2]D.H. Brunnschweiler, "Die Luftmassen der Nordhemisphaere", (in German, with English abstract), Geographica Helvetica, Heft III (1957), pp. 164-195.

frequencies and average property values cannot be relied upon too uncritically.

Synoptic pattern weather type classifications, on the other hand, attempt to overcome the major weakness of air mass weather types by incorporating into the classification entire synoptic patterns including isobar curvature, circulation, multiple air masses, and fronts. Again, "normal" characteristics can be determined for each type and, along with the frequencies of each type, used to describe the climate.

The advantages of the synoptic pattern method have already been suggested.[1] The method, however, is not without difficulties. Primary among these is the formulation of an objective classification of the patterns and the subsequent "typing" of individual synoptic charts. No two weather maps, and especially no two sequences, are exactly the same. The problem is the usual scientific taxanomic one of classifying a continuum. Every climatic classification is faced with the same difficulty; but, because of the reliability of the general world circulation,[2] the majority of synoptic situations are sufficiently distinctive and repetitive to be recognized as "types". With careful refinement and revision, and with particular reference to the controlling influences of the upper atmosphere, it is believed a satisfactory classification can be attained. The synoptic pattern weather type method, therefore, has been selected for this study of the Great Lakes Region. For the present the method cannot be as quantitative as might be desired because

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[1]Above, p. 15, see second quotation from Calef.

[2]See, for example, F.K. Hare, "The Westerlies", Geographical Review, (to be published July, 1960).

of the limited knowledge of these controlling factors;[1] however, the required details are, indeed, close at hand. Secondary difficulties arise in the type of data available and in the recording of pattern frequencies, but these will be handled in subsequent discussion.

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[1]Upper-level flow patterns, and moisture, heat, and momentum transfer.

## SYNOPTIC PATTERN WEATHER TYPE CLASSIFICATION

The potential advantages of synoptic pattern weather types have been generally recognized for some time, particularly by meteorologists interested in "analogue" forecasting. Consequently, a considerable amount of effort has gone into this kind of classification. Numerous schemes from various countries have been proposed, all with fundamentally the same purpose but varying somewhat in basis, scale, number of types, and presentation. It is surprising that in almost all cases the classifications are preoccupied with the establishing of "types", whereas the accompanying climatic elements are described only incidentally and qualitatively. Older classifications are based entirely on surface pressure anomalies, that is, on the movement of cyclones and the position, orientation, and expansion of the semi-stationary polar and subtropical highs. Newer classifications bear more relationship to upper air flow patterns and are, therefore, more fundamental and more closely associated with the broader world circulation. A few examples will suffice.

By the early thirties the importance of the upper air flow was beginning to be realized though it was still far from being understood. In 1933, Blair[1] devised a system of weather types based solely on pressure anomalies, but he did recognize that there was some correlation between the relatively longer trends of weather sequence and the "general

[1]Thomas A. Blair, "Weather Types and Pressure Anomalies", Monthly Weather Review, Vol. LXI, No. 7 (1933), pp. 196-198.

circulation".

In 1935 Dejordjo,[1] a Russian, developed a classification of weather types for Central Asia. Weather types are each taken as one brief phase of the continuing general synoptic process and are characterized by a natural combination in the sequences of weather phenomena and the prevalence of some definite kind of weather, such as dull rainy weather during cyclonic intrusion.

By World War II, the importance of the general circulation to local climate had been fully realized. Under the impetus of military demands, analysis of the upper air flow developed rapidly and many new and greatly improved weather type classifications appeared based on the mean upper air flow patterns rather than the traditional surface features. The Germans developed a detailed classification of "Grosswetterlagen" in northern Europe, and the Americans "extended" the classification to the Mediterranean.[2] In both cases, the classifications were based on "zonal circulation index".

Of particular interest, is a classification of weather types of North America developed and tested during the war years by the California Institute of Technology. Elliot has described the nature of the classification and its types.

> One characteristic of the majority of the older schemes is the use of a single typical synoptic chart to represent a given weather type. In contrast to this the guiding principle of the California

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[1] V.A. Dejordjo, "Weather Types of Central Asia", (In Russian with English Summary), Geophysics, Vol. V, No. 2 (1935), pp. 163-200. Summary in R.G. Stone, "A Modern Classification of Weather Types for Synoptic Purposes", Bulletin of the American Meteorological Society, Vol. XVI (1935), pp. 324-26.

[2] University of Chicago, Institute of Meteorology, A Report on Synoptic Conditions in the Mediterranean Area, (Chicago, August 1943).

> Institute of Technology weather types is that a typical series of daily synoptic charts represents each type.[1]

For example, one of the types in Eastern North America is represented on the surface synoptic charts by the progression and development of a cyclonic disturbance from just north of the Gulf, across the Great Lakes, and into northern Quebec. These successions of surface patterns are, however, only reflections of the all important upper air flow.

> Various arrangements of the large upper-level waves, meridional flow patterns, and different degrees of expansion of the ring of strongest westerlies, zonal flow patterns, form the basic framework upon which the weather types are based.[2]

Twelve meridional flow types are differentiated by the longitudinal position of wave crests and troughs, four of which are peculiar to eastern North America; and four zonal flow types are distinguished by the latitudinal position of the strongest upper-level westerlies.

This important and extensive work on the broader continental scale for all of North America having already been done, it is profitable in more local analyses to be able to make at least a rough correlation to the types then established. Furthermore, the significance of the upper air flow patterns, upon which the continental types are based, cannot be overemphasized. Not only do these patterns represent the fundamental genetic structure of world circulation and climate; but also, the extreme conservatism of the upper air westerlies and their waves make them an ideal basis for recurrent weather types.

The weather types of the present study, therefore, have been devised as adaptions of the broader continental types to the needs of

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[1] R.D. Elliot, "The Weather Types of North America", Weatherwise, Vol. II, (1949).

[2] Ibid.

the more local application to the Great Lakes Region. Because the primary purpose of weather types in this study is a means of relating element occurrences to atmospheric behavior rather than an aid to analogue forecasting, they are largely differentiated by surface features which, for the present, are more easily and directly associated with the elements. They are, none the less, based in the upper-level flow patterns and, therefore, may also be easily and directly related to the fundamental world circulation.

In devising the weather types of the Great Lakes Reg ion, the surface reflections of the continental types were first examined in order to determine the typical synoptic pattern sequences which are significant to the region. It was found that several of the types could be ignored or combined with others because their major differences occur in parts of the continent other than over the Great Lakes. Weather systems represented in the remaining sequences were then differentiated first on the basis of their gross circulation patterns, that is, whether they were cyclonic or anticyclonic, and secondly by the approximate directionsto their points of origin. For each system the gross circulation pattern is used as the major surface reflection of the upper air flow pattern and also to give a general suggestion of the nature of its total synoptic form. The approximate direction to its origin gives an indication of the initial character of the air masses involved upon entering the region, and also an idea of the trajectory of the system due to the steering effects of the upper air flow. The types thus distinguished are small in number and reasonably distinct because of the conservatism of the upper air flow patterns.

In regional application, however, where a clear relation to actual element occurrences is sought, and particularly in a non-uniform region such as that of the Great Lakes, the exact local tracks of the systems are extremely important and must be a criterion in the final differentiation. The different tracks determine the positions of the synoptic systems with respect to actual ground locations and, therefore, also determine how specific areas within the region will be affected by a given type. Fortunately, because of the local modification of the cyclone and anticyclone tracks due to the seasonal influences of the Great Lakes,[1] the most frequent tracks either pass distinctly over the Lakes or well to the north, south, or east of the Lakes. Therefore, the problem of subjectivity[2] is again limited, and only a very small number of types is added to the classification.

These three criteria, origin, circulation, and local trajectory, form the basis for differentiation of the major weather types of the Great Lakes Region. Because the types are represented by synoptic systems following definite tracks which are related to the general circulation, they are truly dynamic and can be best referred to as "dynamic-synoptic system weather types".

Such a classification produces a limited number of types with remarkably recurrent element-range complexes. The extraction of an infinite number of types and statistics is avoided because the element-range complexes are natural groupings by origin rather than by arbitrary

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[1]See above, p. 7, Lautzenhiser.

[2]In a more uniform area cyclone and anticyclone tracks might not be quite so distinctly divided, but then the need for local trajectory differentiation is not so great.

divisions. Variations within a given type can be readily described and explained, rather than necessitating entirely new types. Furthermore, both cyclonic frontal precipitation and non-frontal anticyclonic precipitation are covered logically; temperature contrasts across fronts may be demonstrated; and isotherms can be drawn that will show not only the temperature distribution within the different air masses, but also the extent to which the air masses reach across the region. Finally, the limited number of types provides a directly usable and natural framework within which specific problems may be attacked.

## THE DYNAMIC-SYNOPTIC SYSTEM WEATHER TYPES OF THE GREAT LAKES REGION

Eleven major dynamic-synoptic system weather types of the Great Lakes Region have been differentiated on the threefold basis discussed above. Each of the criteria for a given type is represented by a letter in the type symbol as follows: (1) approximate direction of system origins - by points of the compass or first letter of a geographic location; (2) cyclonic or anticyclonic circulation - by L or H respectively; (3) relation of system tracks to the Great Lakes - by points of the compass. Once explained, types will be referred to in subsequent discussion by their appropriate three-letter symbol.

### Cyclonic Types[1]

#### aLn (Alberta Low North)

At the surface the well known Alberta cyclone moves from northern Alberta (a) almost directly eastward, with the centre of the Low passing across Hudson Bay or James Bay (n). The associated fronts are usually occluded as far south as the northern Great Lakes; over the southern Great Lakes they may be either occluded or separate. The warm front is often poorly developed, depending on the importation of Gulf air which is in turn primarily dependent on the preceeding type. The cold front is usually followed by an anticyclone from the west with moderate temperatures or by another cyclone.

The mean upper-level flow pattern is usually characterized by

[1] See Fig. 1. For each cyclonic type three successive phases of the system are combined on a single map.

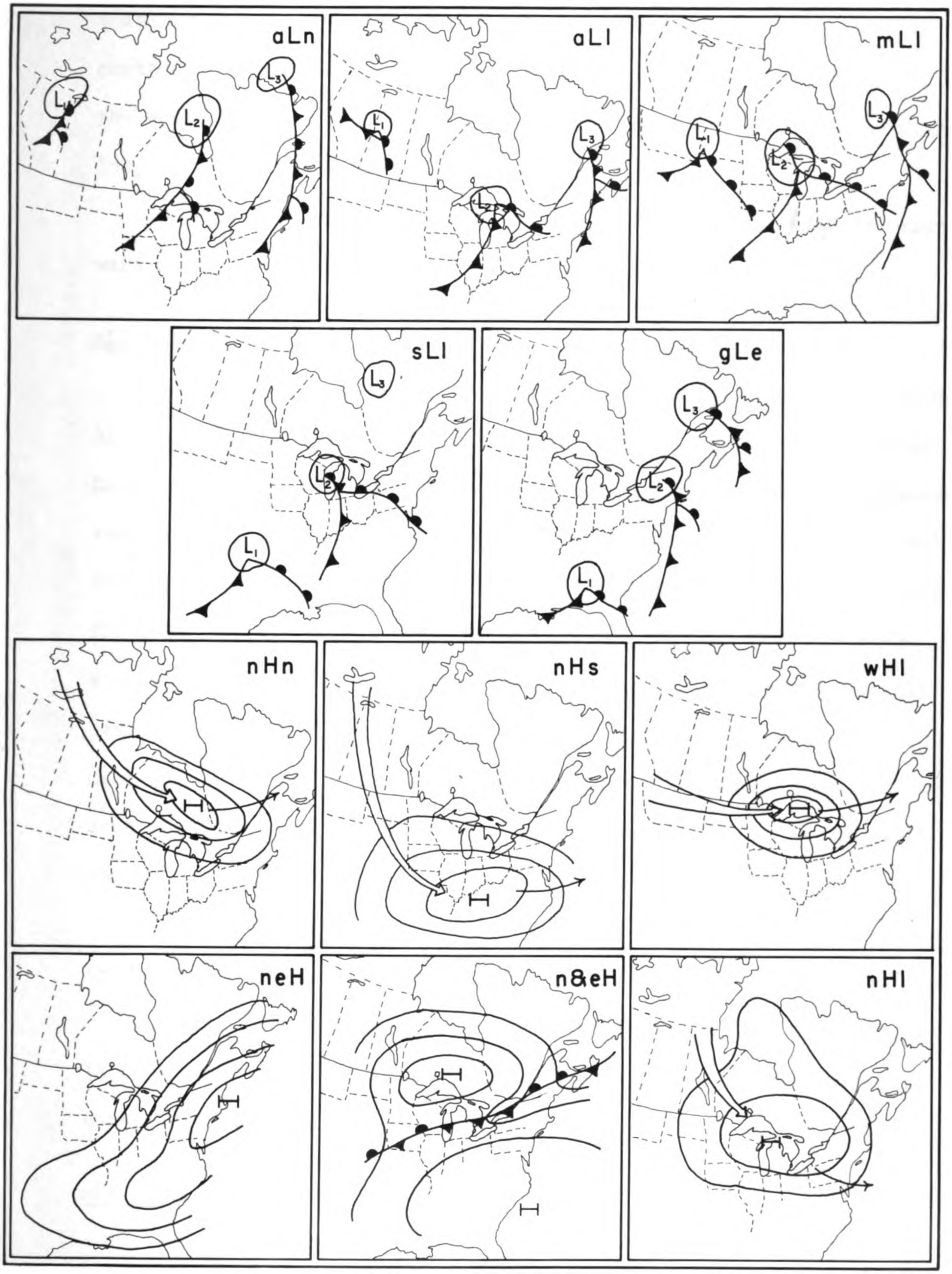


Fig. 1.--Schematic diagrams of the [illegible]ic-Synoptic [illegible] [illegible] Types of the Great Lakes Region

a fairly smooth west to east zonal flow concentrated somewhat farther north than for other types. Occasionally there is a slight trough in the east, in which case the surface fronts, though not the centre of the low, may sweep quite far south.

This type is most common in summer and early fall with the northward shift of the general circulation, but may occur in any season.

aLl (Alberta Low through the Lakes)

At the surface this type is again represented by a cyclone from Alberta (a), but in this case, it moves southeastward across the Great Lakes (l). Associated fronts occlude gradually as the system progresses eastward and may reach the Great Lakes at any one of three stages: well developed, with open warm sector; partially occluded; or entirely occluded. The cold front is usually well developed, but the warm front is occasionally unidentifiable. The centre of the low usually moves directly over the Lakes at a latitude approximately that of Upper Michigan. Occasionally in the occluded and partially occluded cases, it passes just slightly to the north of Lake Superior but the main frontal development is still over the Lakes Region.

The mean upper-level flow pattern is characterized by a marked trough in about the same longitude as that of the Great Lakes.

This type is roughly the winter equivalent of the aLn type. It does occur rarely in other seasons, but it shows a marked winter concentration.

mLl (Montana Low through the Lakes)

In this type, a cyclone from Montana (m) moves directly eastward across the Great Lakes (l), and out the St. Lawrence. Two frontal forms are characteristic: either a single cold front; or a cold and a warm front, usually partially occluded, but with a broad open warm sector beyond the occlusion.

The mean upper air flow is again remarkably west-east in trend across most of the continent but farther south than in the case of aLn. East of the Great Lakes it swings north to a crest over the Atlantic.

Over the year, mLl is by far the most common type. It occurs often in all seasons, but has a maximum in spring and minimum in fall.

sLl (Southern Low through the Lakes)

A low just to the northeast of the Gulf (s), which either has reformed after passing over the American Rockies or is a new centre along the frontal zone of another low, draws in warm moist air from the Gulf, intensifies, and moves north through the Great Lakes Region (l) to northern Quebec. Fronts and warm sectors are strongly developed and bring heavy precipitation to the entire region and high temperatures to the southeast. Generally the fronts begin to occlude over the Lakes and disappear by the time the centre of the low reaches northern Quebec.

The mean upper-level flow pattern is characterized either by a very deep trough over the western states, reaching almost to Mexico, and a slight crest over the eastern seaboard; or occasionally, by a west to east zonal flow, south of normal, over the central states.

Although highly concentrated in spring, sLl is also responsible for the major severe thaws of winter.

gLe (Gulf Low East)

Intense cyclones originating in the Gulf region (g), move northeastward, along the Appalachians, following a track somewhat farther east than that of sLl systems, and pass to the east of the Lakes (e). Fronts and warm sectors are well developed, but usually do not extend far enough west to reach the Great Lakes. Because the centre of the Low is usually quite far east, this type is often accompanied over the Great Lakes Region by the beginning of another type in the west.

A very pronounced upper-level trough in the east reaches as far south as the Gulf and then rises sharply to a crest just east of the continent.

This is almost excusively a winter and fall type. The occasional fall hurricanes which reach the Lakes region are of this type.

## Anticyclonic Types[1]

nHn (Northern High North)

At the surface the centre of an anticyclonic outbreak from northwestern Canada (n) moves south and then east, passing to the north (n) of the Great Lakes.

The mean upper-level flow pattern is characterized by a displacement of the band of strongest westerlies and their associated disturbances far to the south and out of reach of the Great Lakes.

This type has a strong maximum in winter with the southward shift of the general circulation, but does occur occasionally in all seasons.

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[1]See Fig. 1. Open arrows indicate trajectories of the systems preceding the phases shown; single line arrows, those following.

nHs (Northern High South)

This type is much the same as the nHn type except that the outbreak (n) is much more severe, and the centre of the high passes to the west and south (s) of the Great Lakes.

There is an extreme displacement of the band of strongest upper-level westerlies to the south.

Again concentrated in winter, nHs is also fairly common in spring and occurs occasionally in summer and fall.

wHl (Western High through the Lakes)

Anticyclones moving eastward from about the international border (w) generally pass directly across the Great Lakes (l). The high is usually so intense that its track is little affected by the lakes.

Occasionally, however, the centre of a Western High passes to the south of the Great Lakes; in such cases, the type has been subclassified as wHs.

The mean upper-level flow pattern for this type is unusual in that the band of strongest winds is split into two over the western part of the continent; one part forms a crest and the other a trough in about the same longitude. Cyclonic disturbances often accompany each of these bands, and pass to the north and south of the eastward moving high.

This type reaches a strong maximum development in fall. In other seasons it occurs only infrequently. In winter it is rare and then invariably of the wHs type.

neH (New England High)

Anticyclones of the neH type are unusual in that they do not follow either of the usual trends from west to east or from south to northeast. As other anticyclonic types, particularly wHl, move to the east of the Lakes they are able to draw in much warm mT air, and temperatures rise rapidly by ten to fifteen degrees. Over New England (e) or New Jersey the highs become semi-stationary and extend in a curved oblong form, first toward the south, and then west. This unusual pattern often becomes quite persistent and comes to dominate much of the eastern United States until it is destroyed or converted to a n&eH by an aLn or mLl. It is actually the end product or remnant of other anticyclonic types; but it is greatly modified by the influx of mT air and has a remarkably distinctive pattern development.

The mean upper-level flow pattern is, likewise, quite distinctive. A crest forms in the east, and a closed anticyclonic centre appears at the upper-level over the central states, generally from about Iowa to eastern Tennessee. Over the Plains a slight trough forms and allows cyclones to attack the neH from the northwest.

This type occurs primarily in the fall with the highest frequency of wHl and when the land mass between the Lakes and the Atlantic is relatively cool. It occurs rarely in other seasons, but then is somewhat modified in form and position, and is not as persistent.

n&eH (Northern and Eastern Highs)

Also unique, n&eH is composed of two anticyclonic cells: a relatively cool dry anticyclone centred anywhere from northern Quebec and Hudson Bay to the Prairies (n); and the large, warm and humid, Bermuda High centred off the southeast coast of the United States (e). Separating the two strongly contrasting systems is a linear frontal zone running from southwest to the northeast roughly over the Great Lakes Region. This pattern is almost invariably introduced by the cold front of an Alberta or Montana Low, and most frequently by the aLn type. As the cold front moves eastward it is blocked in the south by the large Bermuda High and is forced to swing to its southwest to northeast alignment. The front then generally migrates slowly toward the southeast as a quasi-stationary front. Very small waves sometimes form along the front and move toward the east.

The details of the pressure pattern vary, but there are always two anticyclonic centres and a tendency to lower pressure in the frontal area. The southern high is usually not as intense, but it covers a large area and is very distinct. The exact position of the front itself, which is very important for local conditions, is also variable: when introduced by an aLn, the front generally passes completely across the Lakes but when introduced by an aLl or mLl it may reach its initial alignment even slightly to the south of the Lakes.

The most distinctive feature of the mean upper-level flow pattern is a closed anticyclone to the southeast of the continent which may persist for very long periods. Over the Lakes the flow is from west to east.

Although remarkably concentrated and common in summer, n&eH does occur in other seasons, especially spring.

nHl[1] (Northern High over the Lakes)

In this type, a weak high from the northwest (n) moves south-

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[1]The very approximate correlation of the weather types of the Great Lakes Region to the continental weather types of the California Institute of Technology as outlined by Elliot are as follows: aLn - B,

eastward into the Lakes area (1); there it persists and intensifies over the cold water of spring and summer. Occasionally, it joins along a ridge with another centre over Hudson Bay. The best developments of this type show a definite closed anticyclone over the Lakes; but others, particularly in spring may be represented merely by a pronounced dip of the isobars southward.

The mean upper-level flow pattern is usually characterized by a fairly smooth, moderate, west to east flow just south of the Lakes, but surface lows are deflected around the high lying over the Lakes.

This type occurs only in spring and summer.

Type Durations and Frequencies

The analysis of type durations and frequencies is essential to an understanding of the relative contributions of the various types to seasonal and yearly climate. The following observations are the results of a detailed examination of daily weather maps[1] of North America for the months of January, April, July and October of the years 1953 to 1957 inclusive. The significance of these observations when combined with the element characteristics of the various types to the seasonal and yearly climate of the region will be discussed in a subsequent section.

The duration of any one weather type over the Great Lakes is highly variable. Especially is this true if a series of occurrences

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Pn-a; aLl - Pn-b, Pn-c, Pe; mPl - D; sLl - A, Bl; gLe - Ca; nHn - Bn, Gb; nHs - Eb; wHl - C; neH - no equivalent; nbeH - Fb; nHl - Ha.

[1] U.S., Dept. of Comm., Weather Bureau, Daily Weather Map, for the years 1953-1957.

of the same type is considered as a unit. If only single occurrences are considered, the approximate durations for individual types are as follows:[1] aLn and aLl, 1-2 days; mLl, sLl, and gLe, 2-3 days; the northern Highs and wHl, 2-4 days; n&eH and neH, both very variable, from 1-5 days.

The problem of quantitatively analyzing type frequencies is both more important and more difficult. Occurrence frequencies could be recorded, but because of the variability of durations they would have limited significance. Approximations of the comparative total times that the Great Lakes are dominated by each of the given types, however, are of great value; such approximations can be obtained by typing the dynamic-synoptic systems in the region[2] for each day or shorter standard time period. This has been done for each day of the twenty months covered by this study by comparison of the 1:30 a.m. and 1:30 p.m. charts of a given day and 1:30 a.m. chart of the following day. The accompanying chart shows day frequencies in the Great Lakes Region of the various weather types (Fig. 2). A fairly accurate estimate of the actual number of occurrences of any one type may be obtained by dividing the day frequencies by the appropriate average duration.

In typing both for an entire region and for a standard time period as great as a day, certain difficulties immediately arise. Obviously type durations do not coincide exactly with days. Furthermore, type separation itself is difficult. However, individual types are remarkably distinctive even if their exact boundaries are not; and this flexibility of their boundaries can be utilized to obtain

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[1]See for examples Figs. 21 to 29.

[2]Compare frequency map and element-complex methods where individual stations must be typed; see above, pp. 11 and 14.

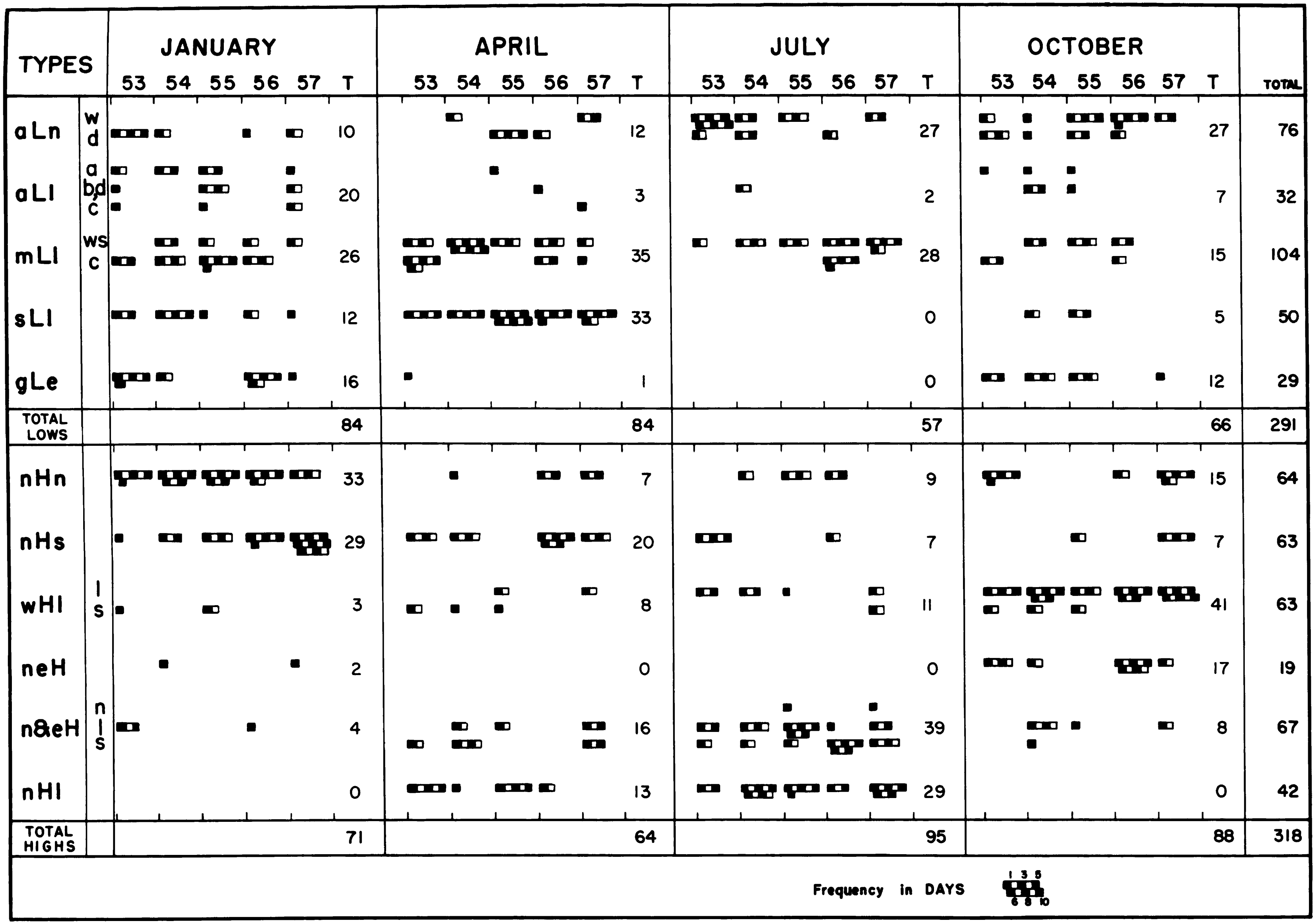


Fig. 2.--Day Frequencies of Great Lakes [illegible] Types, 1953-57

closer coincidence of type durations and days. In most cases, days can be awarded to a certain type with enough validity that the final frequency generalization is of an order of accuracy at least in line with that justified by the short five year observational period. Transition days must either be awarded to the type dominant for the longest period of the day, or be divided by half day periods between the two types. Greater accuracy can only be obtained by using shorter standard time periods, more frequent synoptic charts, and a longer total observational period. As in the case of a forecaster's prediction, in the classification of patterns which fit a given type only moderately well, or in any natural classification, a certain amount of subjectivity cannot be avoided.

In the accompanying frequency chart it will be noted that subtypes, some of which have already been suggested, have been included. Most of these were discovered, during frequency or element analysis of the major types, on the basis of different element-complexes, slight shifts in position of the patterns, or different frontal arrangements.

Finally, it should be noted again that the observations cover only a five year period. The frequencies obtained should not be taken as absolute figures of probability. However, the seasonal frequency distributions appear sufficiently repetitive that their major features can be accepted as valid as long as they are considered in relative rather than absolute terms. For individual types, the variation in their frequencies from year to year gives some indication of their reliability.

## ANALYSIS OF WEATHER TYPE ELEMENT CHARACTERISTICS

### Boundaries and Stations Employed

Although numerous studies have been made of the Great Lakes Region, none have suggested significant boundaries. For detailed analysis of the element complexes and distributions for the various weather types, however, some workable boundary is required in order to limit the number of stations considered and to keep the discussion relevant to the Great Lakes. The most logical boundary would be the one that delimits the area whose weather elements are perceptibly influenced by the lakes themselves.

In determining this boundary it is justifiable to use only work already available. A detailed study of the extent of influence of the lakes is not the present purpose, and boundaries are required merely for convenience and to concentrate interest on the core area. Leighly's article on the effects of the Great Lakes on air temperature[1] forms an excellent basis for temperature limits; but unfortunately, no equivalent study of precipitation has yet been made. An investigation of the actual extent of influence of the lakes on precipitation would be enormous and very difficult in itself. The effects of the lakes cannot be distinguished by a simple hypothetical isopleth method because of the complications of bordering relief and also because of the variable distribution of frontal precipitation independent of the Lakes. Temperature alone,

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[1]See above, p. 6.

therefore, has been used for the determination. Although Leighly's study is one of mean values, it is nevertheless adequate. For the present practical purpose, those areas which show an influence great enough to be represented in mean values are most likely to be the most significantly affected. A more detailed analysis such as by weather types, would tend to extend the limits rather than restrict them.

Leighly's analysis of the various seasonal effects of the lakes on temperature has already been outlined in some detail. In a final map he summarizes the cumulative summer and winter effects by combining the individual phenomena anomalies. Five arbitrarily chosen units are used to draw isopleths indicating the total relative modification due to the lakes in each of the two seasons. Toward the outer limits and the zero line the effects of the lakes are limited, especially in summer, to one or two of the phenomena considered.

The boundary for the present study is drawn to correspond roughly with Leighly's "1" unit line for winter but is somewhat smoothed out to include all areas immediately adjacent to the Lakes even if they are not apparently influenced to the same degree (see Fig. 3). The winter isopleth is chosen because the effects of the lakes are greatest in that season. The "1" unit line is selected so that all areas are at least influenced at some time.

Beyond this boundary the lakes may still be significant in some cases, but the additional analysis for these extensions would merely add detail to the periphery and would not alter the basic conclusions for the core area with which we are primarily concerned. In addition, detailed mean monthly precipitation maps suggest not only that this

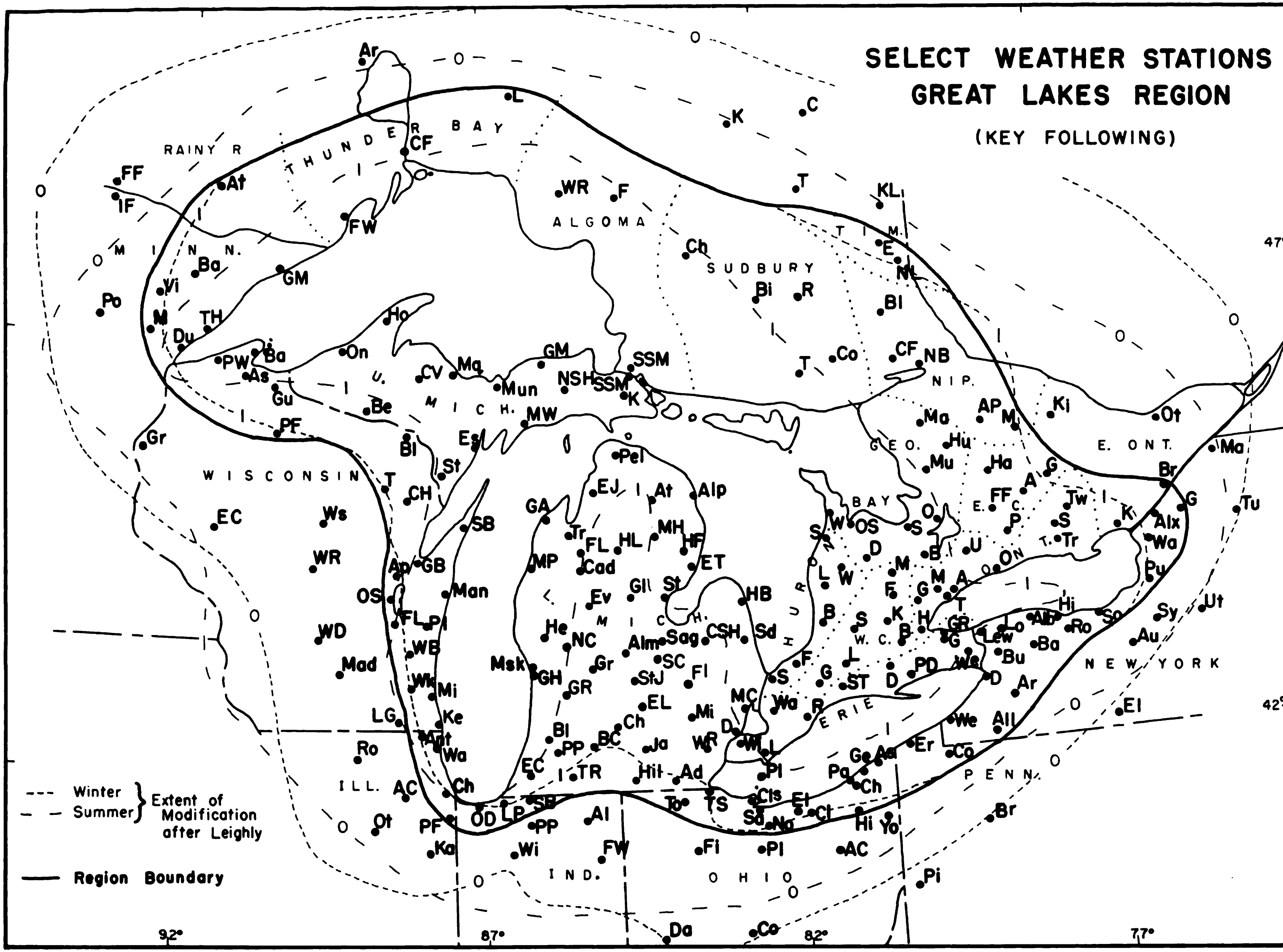


Fig. [illegible].--Weather Station Index

Fig. 3.--Continued, Station Key

U.S. STATIONS[1]

NEW YORK

Alb Albion W 6
Alx Alexandria E 6
All Allegany St.Pk.W 6
Ar Arcade W 6
Au Auburn E 12
Ba Batavia W 6
Bu Buffalo WBAP W 12
D Derby W 8
El Elmira E 12
G Gouverneur E 6
Hi Hilton W 6
Lew Lewiston W 6
Lo Lockport W 8
Ma Massena AP E 12
Pu Pulaski E 7
Ro Rochester WBAP W 12
So Sodus W 7
Sy Syracuse WBAP E 12
Tu Tupper L. E 8
Ut Utica AP E 12
Wa Watertown AP E 12
We Westfield W 8

OHIO

AC Akron Canton E 12
As Ashtabula E 6
CIs Catawba Is. W 6
Ch Chardon E 6
Cl Cleveland WBAP E 12
Co Columbus WBAP W 12
Da Dayton WBAP W 12
El Elyria E 7
Fi Findlay AP W 12
Ge Geneva E 6
Hi Hiram E 6
No Norwalk W 6
Pa Painesville E 12
Pl Plymouth W 7
Sa Sandusky W 12
TS Toledo Sewage W 12
To Toledo WBAP W 12
Yo Youngstown WBAP E 12

PENNSYLVANIA

Br Brookville AP 12
Co Corry 6
Er Erie WBAP 12
Pi Pittsburg WBAP 12

LOWER MICHIGAN

Ad Adrian SE 12
Alm Alma C 7
Alp Alpena WB N 12
At Atlanta N 6
BC Battle Creek AP S 8
Bl Bloomingdale SW 6
CSH Caro St.Hosp. CE 5
Ca Cadillac N 12
Ch Charlotte S 6
D Detroit WBAP SE 12
EJ East Jordan N 6
EL East Lansing WB S 12
ET East Tawas CE 6
EC Eau Claire SW 6
Ev Evart C 5
FL Fife Lake N 6
Fl Flint WBAP SE 12
Gl Gladwin AP C 12
GA Glen Arbor N 5
GH Grand Haven C 6
GR Grand Rapids WBAP CW12
Gr Greenville C 5
HF Hale Five Channels Dam N 12
HB Harbor Beach CE 7
He Hesperia CW 6
HL Higgins Lake N 6
Hil Hillsdale S 7
Ja Jackson AP S 12
MP Manistee Power N 12
Mi Milford GM. SE 12
MH Mio Hydro N 12
MC Mount Clements SE 12
Msk Muskegon WBAP CW 12
NC Newaygo Croton CW 12
PP Paw Paw SW 7
Pel Pellston AP N 12
Sag Saginaw AP C 12
SC Saint Charles C 6
StJ Saint Johns C 6
Sd Sandusky CE 5
St Standish CE 6
TR Three Rivers SW 5
Tr Traverse City AP N 12
WR Willow Run SE 12

UPPER MICHIGAN

Be Beechwood W 5
CV Champion Van Riper Pk. W 5
Es Escanaba W 12
GM Grand Marais AP E 12
Ho Houghton AP W 12
K Kinros A.F.Base E 12
MM Manistique Mtrwks. E 6
Mq Marquette WB W 12
Mun Munising E 7
NSH Newberry St.Hosp. E 12
On Ontanagon W 5
SSM Sault Ste. Marie WBAP E 12
St Stephenson W 7

INDIANA

Al Albion 6
FW Ft.Wayne WBAP 12
LP La Porte 6
OD Ogden Dunes 7
PP Plymouth Power 6
SB South Bend WBAP 12
Wi Winamac

ILLINOIS

Ant Antioch 7
AC Aurora College 7
Ch Chicago WBAP 12
Ka Kankakee 6
Ot Ottawa 7
PF Park Forest 12
Ro Rockford AP 12
Wa Waukegan 7

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[1]Particulars are given in the following order: map symbol, station name, area of state, final hour (all p.m.) of observational day. AP denotes Airport; WB, Weather Bureau stations.

Fig. 3.-- Continued, Station Key

U.S. (Continued)

### WISCONSIN

| | |
|---|---|
| An | Appleton E 12 |
| As | Ashland N 6 |
| Ba | Bayfield N 6 |
| BI | Brule Is. NE 12 |
| CH | Crivitz High Falls EN 6 |
| EC | Eau Claire AP W 12 |
| FL | Fond du Lac E 6 |
| Gr | Grantsburg AP W 12 |
| GB | Green Bay WBAP E 12 |
| Gu | Gurney N 6 |
| Ke | Kenosha SE 12 |
| LG | Lake Geneva SE 7 |
| Mad | Madison WBAP W 12 |
| Man | Manitowac E 6 |
| Mi | Milwaukee WBAP SE 12 |
| Os | Oshkosh E 8 |
| PF | Park Falls W 12 |
| Pl | Plymouth E 6 |
| PW | Port Wing N 6 |
| SB | Sturgeon Bay EN 6 |
| To | Townsend NE 6 |
| Wk | Waukesha SE 12 |
| Ws | Wausau AP W 12 |
| WB | West Bend SE 6 |
| WD | Wisconsin Dells W 12 |
| WR | Wis. Rapids W 12 |

### MINNESOTA

| | |
|---|---|
| Ba | Babbitt 5 |
| Du | Duluth WBAP 12 |
| GM | Grand Marais 9 |
| IF | International Falls WBAP 12 |
| M | Meadowlands 6 |
| Po | Pokegama Dam 5 |
| TH | Two Harbours 6 |
| Vi | Virginia 5 |

## CANADIAN STATIONS

### RAINY RIVER

| | |
|---|---|
| At | Atikokan |
| FF | Fort Frances |

### THUNDER BAY

| | |
|---|---|
| Ar | Armstrong AP |
| CF | Cameron Falls |
| FW | Ft. William AP |
| L | Longlac |

### ALGOMA

| | |
|---|---|
| F | Franz |
| SSM | Sault Ste. Marie |
| WR | White River |

### SUDBURY

| | |
|---|---|
| Bi | Biscotasing |
| Ch | Chapleau |
| Co | Coniston |
| GB | Gore Bay AP |
| R | Ruel |
| T | Turbine |

### TIMISKAMING

| | |
|---|---|
| C | Cochrane |
| E | Earlton AP |
| K | Kapuskasing AP |
| KL | Kirkland Lake |
| NL | New Liskeard |
| T | Timmins |

### NIPISSING

| | |
|---|---|
| AP | Algonquin Park |
| BI | Bear Island |
| CF | Crystall Falls |
| M | Madawaska |
| NB | North Bay AP |

### EASTERN ONTARIO

| | |
|---|---|
| Br | Brockville |
| Ki | Killaloe AP |
| K | Kingston |
| Ot | Ottawa AP |

### GEORGIAN BAY

| | |
|---|---|
| Be | Beeton |
| D | Durham |
| Hu | Huntsville |
| Ma | Magnetawan |
| Mu | Muskoka AP |
| O | Orillia |
| OS | Owen Sound |
| S | Stayner |
| Wi | Wiarton AP |

### LAKE HURON

| | |
|---|---|
| B | Brucefield |
| F | Forest |
| L | Lucknow |
| S | Sarnia |
| So | Southampton |
| W | Walkerton |

### LAKE ERIE

| | |
|---|---|
| D | Delhi |
| G | Grimsby |
| GR | Grimsby Rock Chapel |
| L | Leamington |
| PI | Pelee Island |
| PD | Port Dover |
| R | Ridgetown |
| ST | St. Thomas |
| Wa | Wallaceburg |
| We | Welland |
| Wi | Windsor AP |

### WEST CENTRAL

| | |
|---|---|
| B | Brantford |
| F | Fergus Shand Dam |
| G | Glencoe |
| L | London AP |
| M | Monticello |
| S | Stratford |
| K | Kitchener |

### LAKE ONTARIO

| | |
|---|---|
| A | Agincourt |
| G | Georgetown |
| H | Hamilton |
| M | Malton |
| O | Orono |
| S | Stirling R. |
| T | Toronto |
| Tr | Trenton |
| Tw | Tweed |
| U | Uxbridge |

### EAST CENTRAL

| | |
|---|---|
| A | Apsley |
| FF | Fenelon Falls |
| G | Gilmour |
| H | Haliburton |
| P | Peterborough |

boundary includes at least those areas most obviously influenced in all seasons; but also that a detailed map of the outer extent of influence, if it could be prepared, would again merely provide for an extension.

Within this boundary stations used in the elemental analysis of the types have been selected primarily on the basis of the final hour of their observational day. Major stations generally end their day at midnight, but it was found necessary to use the majority of stations with final hours as early as 6 p.m. to obtain a fairly tight network and a reasonably uniform distribution. The dangers of using stations with earlier final hours in determining daily regional distributions is obvious. A few major stations have been selected beyond the boundary to the "0" line to give a more generalized coverage of this peripheral zone.

## Data Used

In the present study, only temperature, precipitation, and occasionally wind direction[1] are considered. Other elements, however, such as cloud cover and insolation, could easily be included because the method is comprehensive in contrast to classifications which allow for only a limited number of elements, usually temperature and precipitation alone. The inclusion of these other elements would not complicate the classification or require an increased number of types; it would only add detail to the analysis because the classification

[1]Note: Wind direction is not taken as given in detail by the synoptic pressure pattern. Where required, exact directions are observational for the individual cases and not computed.

is based on genetic aspects, not on the resultant element values. Temperature and precipitation are selected here because they are the most frequently recorded and generally the most demonstrative of the elements. Wind direction is sometimes considered because of its importance with regard to modification by the lakes. Furthermore, the proper information for other elements is simply not available for many stations and if it were, it would be two voluminous for hand methods.

Only four months of each year, and only five years, 1953-1957, are considered in order to limit the volume of statistics and analysis. January, April, July and October are selected as representative of the four seasons. General conclusions should again be regarded in the light of the short observational period.

The statistical observations themselves are based on three primary sources: (1) Climatological Data,[1] published each month for each state in the United States; (2) Monthly Record,[2] the monthly publication of element statistics for all Canadian stations; and (3) the Daily Weather Map of North America.[3]

The use of statistical data for detailed regional analysis of this kind has many limitations and dangers. Some of these arise from the great importance of local environment, but most are the result of varying observational conditions and reliability. Statistics for any

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[1] U.S., Dept. of Comm., Weather Bureau, Climatological Data (Vol. varies for different states), 1953-1957.

[2] Canada, Dept. of Transport, Meteorological Branch, Monthly Record: Meteorological Observations in Canada, 1953-1956.

[3] U.S., Dept. of Comm., Weather Bureau, Daily Weather Map, 1953-1957.

one station particularly for any one type, may be quite different than for surrounding locations and in such cases certainly cannot be used for generalizations. The trends, therefore, of numerous stations, (usually 3 or more) must be examined in order to make valid conclusions. Even then the validity is questionable if a conclusion is drawn from only one occasion. However, when comparisons are made for several occurrences of the weather type and similar element range patterns are found to occur, generalizations may be made with a degree of accuracy roughly proportioned to the number of cases compared. Indeed, if several occurrences are considered and a similar pattern emerges, local conditions may be considered as part of the "norm" itself.

Method of Analysis and Presentation

For the following elemental analysis, daily statistical data and synoptic charts were used to discover the character and spatial distribution of the elements as associated with specific cases of type occurrences; and thus, by comparisons, to determine normals and variations for each of the eleven dynamic-synoptic system types.

For each type, an initial survey of statistics and synoptic charts was first made to discover significant differences in either its synoptic patterns or its associated element occurrences; subtypes have been established where necessary. Representative days from the season of the type's peak frequency, were then selected, and various isopleth maps have been drawn for these days.

Mean temperature maps demonstrate the cumulative regional distribution for periods of a day; that is, they are examples of the general character of the type which may be directly related by frequency to monthly averages.[1] The influence of the lakes, especially for anticyclonic types, is usually shown by temperature range isopleths. For cyclonic types, the primary interest lies in the warm sectors because temperatures outside the fronts are generally related to preceding and following types and, also, because the warm sectors are responsible for many above normal temperatures. Temperatures within a warm sector, contrasts across fronts, and the extent of a warm sector are shown either by synoptic examples or by special isotherm maps. For the latter, means are calculated from maxima and minima which may occur on different days depending on the regional position of the warm sector. The appropriate figures, those that represent warm sector temperatures, are selected either on the basis of which are highest, or by correlation with the 12 hour synoptic charts. Unfortunately, the map times do not coincide exactly with observations; however, with subjective allowance the 1:30 a.m. chart is taken to roughly correspond to the time of minimum temperature and the 1:30 p.m. chart to the time of maximum temperature. Corresponding temperatures beyond the reach of the warm sector are valid regardless of when they are taken.

Maps of total precipitation encompass logically all types of precipitation, frontal or non-frontal. They again give the general distribution and illustrate the values which are significant in monthly totals. For many purposes a more detailed quantitative breakdown

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[1] In subsequent maps and quantitative discussions "mean" refers to a figure intermediate between two extremes, usually maximum and minimum temperature for a single day; "average" refers to the result obtained by dividing a sum by the number of quantities added, for example, the average temperature for a given month; "normal" refers to standard values for long periods of time, for example, long term temperature averages for January.

of origin would be useful, but this is impossible using only daily statistics. Such an analysis would require knowledge of the exact local conditions at the moment of fall for individual stations. Detail of this order is far beyond the scope of this study; but nevertheless, the dynamic-synoptic weather systems provide the preferred framework. For the present, the distribution of precipitation can be considered only as related to the movement of an entire synoptic system for a given day. For this reason, the influence of the lakes in cyclonic types is difficult to detect. For anticyclonic types, the influence of the lakes may be inferred either from the total precipitation map, or from a sequence of synoptic charts showing observed wind directions and areas receiving precipitation.

Distributional and quantitative normals and variations for both temperature and precipitation were then established for each type by comparison of all their occurrences over the five years in their maximum frequency month. These are presented either in terms of a comparison with the selected isopleth maps or with long term monthly normals (temperature only), or in terms of range values.

Finally, a comparison is made of occurrences of the respective types in the months other than that of their peak frequency.

Types are presented, primarily, in order of their major analysis month, and secondarily, in order of highest frequency. It should be noted that the types analyzed for any one month are not necessarily the most common types of that month.

Analysis by Types

nHn (Northern High North)

This type has a strong maximum frequency in January and it is also the dominant type of that month (see Fig. 2). It brings the usual cold weather of winter but is not as extreme as the "cold waves" of the nHs type. Winds are northerly only in the initial stages and then become easterly and southerly.

January 22, 1954 (see Fig. 4B), with winds north to northeast, represents close to the extreme of cold attained by the nHn type in the initial stages; January 23, 1954 (see Fig. 4D), on the other hand, is typical with winds more east and southeast. Maximum and minimum temperature for either day may be approximated by comparison of the mean and range isopleths.

For all January occurrences, temperatures in all areas are well below long term normals[1] during the initial stages. Even maxima are often below the mean normals. In Northern Ontario minima may be in the minus forties. As the centre of the anticyclone moves east temperatures rise throughout the region but especially in Wisconsin, Minnesota, and Thunder Bay which experience the greatest shift in wind direction from north to south. In final stages, as the centre continues to move still farther east, temperatures slightly above normal occur first in Wisconsin and then move east (e.g. compare January 22 and 23, Figs. 4B and 4D). Usually a new type develops before the whole region is above normal.

Temperatures to the lee of each lake are always relatively

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[1]For all subsequent references to normal temperatures see Figs. 15-18, Normal Temperature: January, April, July, and October, respectively.

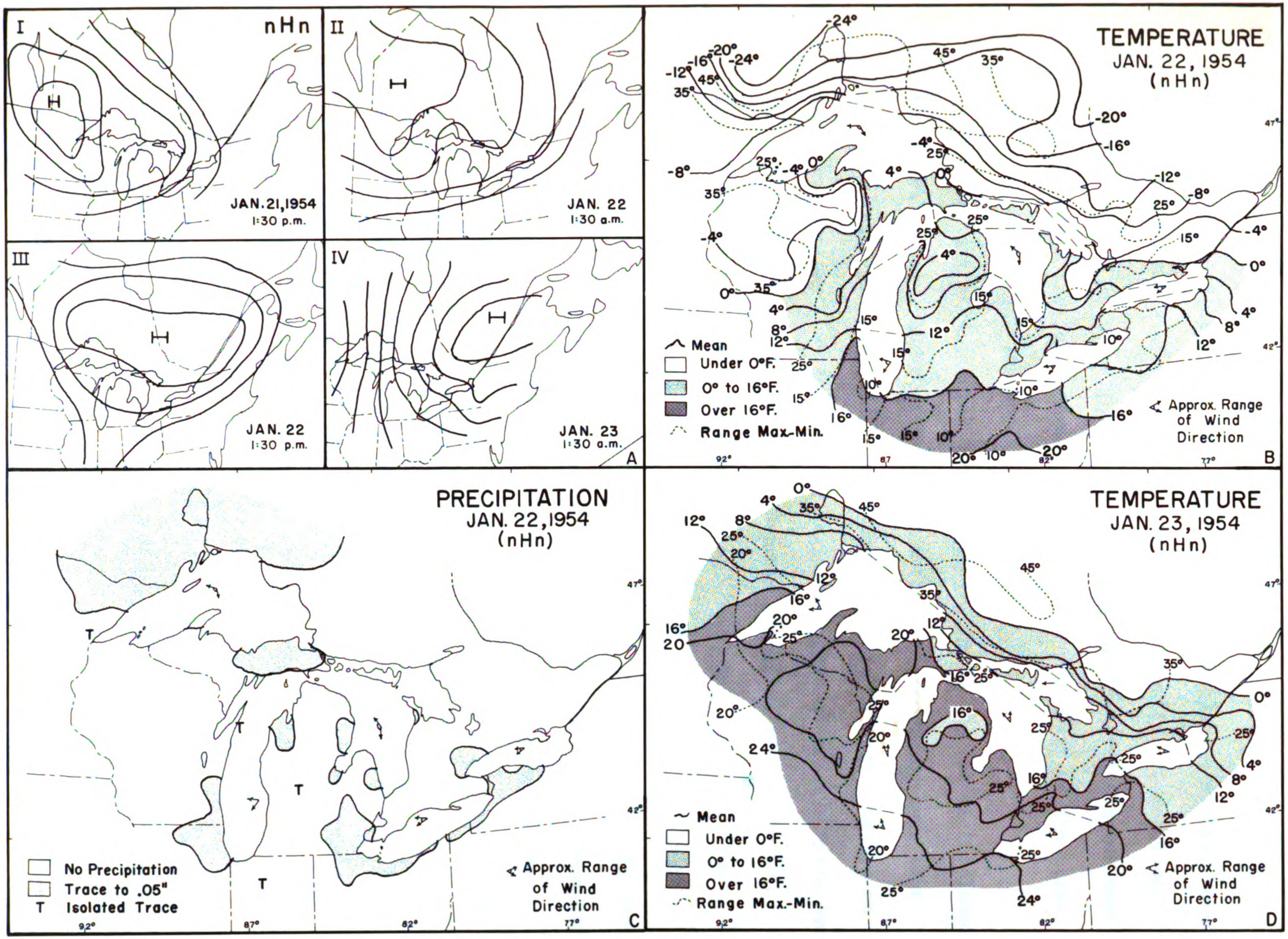


Fig. 4.--nHn (Northern High North)

high. Both maximum and minimum temperatures are increased since they both are below freezing and the temperature of the lakes; minima, however, are most noticeably affected (e.g. compare distribution of means and ranges, January 22 and 23, Figs. 4B and 4D). As the system moves east smaller ranges are found first in areas to the southwest of the lakes and then to the west and north of the lakes.

Precipitation, which occurs principally to the lee of the lakes, is generally light and scattered with most areas receiving less than .03 inch (e.g. see Fig. 4C). Large areas receive no precipitation on any one given day, but much of the region may have at least a trace over the full duration. The most exposed areas sometimes get .03 to .20 inch. Rarely single stations receive up to .60 and .80 inch. The specific areas of concentration are not always the same. In early stages the following areas may be significant: Upper Michigan, Illinois, southeastern Michigan, Ohio, western New York, and Lake Huron, Georgian Bay and Lake Ontario districts of Ontario. In later stages northwestern Ontario usually has the heaviest fall, but here the total precipitation may be increased by the succeeding low.

In April, temperatures follow a similar sequence but are not quite so low in relation to normals. Means are only slightly below or even, rarely, slightly above normal, but temperature increases in the later stages are also not as pronounced. The systems are generally weaker than in January and more attacked on the fringes by cyclonic disturbances. The lakes, being relatively cool, tend to lower temperatures. Maxima are particularly affected, minima remaining about the same. There is usually no precipitation since the lakes have a stablizing effect on traversing air masses.

In July, temperatures are again near normal; to the lee of the lakes they are below normal but otherwise are very close to, or above normal. There is no distinct warming as winds swing south since even northerly winds of the summer continental anticyclones are relatively warm and usually a front to the south blocks warm air in latter stages.

October occurrences are variable in frequency and usually occur in groups. Temperatures are below normal for October except in areas to the lee of the lakes where they may be a few degrees above normal due to modification by the warm water. There is a slight warming in final stages to just above normal, especially if there is no front to the south. Precipitation is very rare and then in the form of scattered showers to the lee of the lakes.

The overall effect of the nHn type in January is a lowering of average temperatures, particularly because of the low initial temperatures. In April and July it is of little importance because the type is fairly rare and temperatures are about normal. In October, although the frequency of the type is not great, it usually occurs in groups. In these years it tends to increase average temperatures in the west, especially in areas modified by northerly and easterly flow, and to lower them in the east, especially in areas not modified by north and east winds. Precipitation is of very limited importance to monthly totals.

nHs (Northern High South)

The nHs type represents the familiar "cold wave" of mid-latitude continental regions. It is best known for its mid-winter occurrences because of their frequency and, especially, their extremely low temperatures; it may, however, also occur in other seasons, particularly in spring (see Fig. 2). In winter, air temperatures are much lower than those of the lakes and the effects of the lakes on temperature and precipitation are the most demonstrative of any type in any season.

In January, temperatures in all areas are well below normal. In the north they are the same as for nHn, although they do not rise as high in latter stages; in the south they are much colder. Daily means are close to, or even below $0^{\circ}$ F. in unmodified areas of the west as far south as Chicago (e.g. see Fig. 5B). All maxima are below $32^{\circ}$ F.; in the north when unmodified they are often below $0^{\circ}$ F. Northern Ontario minima again reach to the minus forties. Over the duration of any one occurrence of this particular type, it is important to note that the modification of temperature to the lee of the lakes is generally more significant than changes due to directional variation of the wind itself.

The accompanying map for January 12 and 13, 1954 (Fig. 5D) indicating the day of highest maximum and/or minimum temperature illustrates minutely the effects of the lakes with changing wind direction during the passage of a system. The example type sequence (Fig. 5A) depicted for the same days, gives the approximate wind directions at times roughly corresponding to the minima and maxima of temperatures. At 1:30 a.m. on January 12, Ohio, Indiana, northwestern Wisconsin, and most of both Upper and Lower Michigan were exposed to air masses having passed over at least one of the lakes; higher minima were recorded on that day than on the following day for these areas. Northwestern Ontario, Illinois, southern Wisconsin and north central Lower Michigan were reached only by unmodified air from the north or northwest, and the lower minima for the two days were recorded. Northeastern Ontario

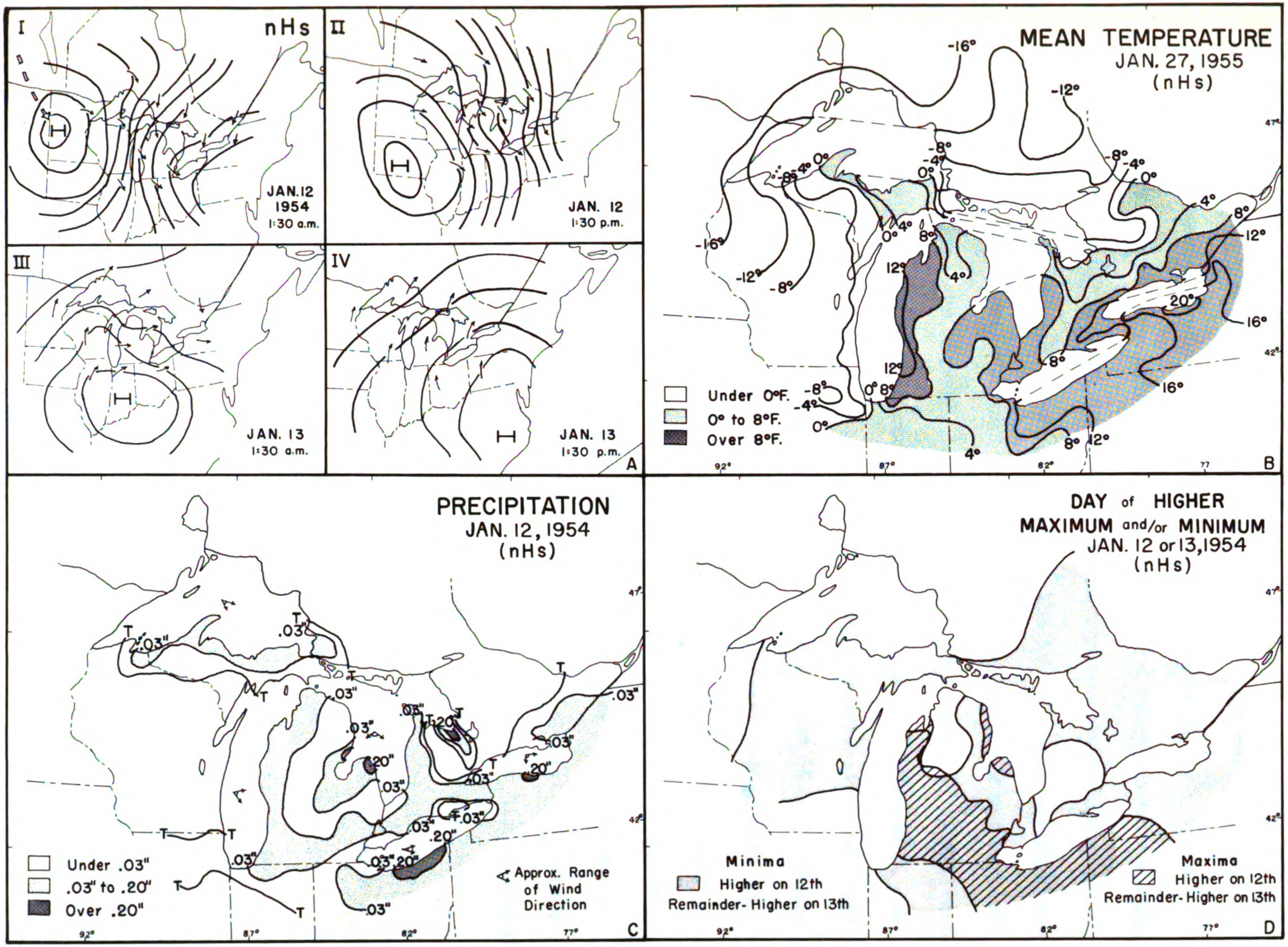


Fig. 5.--nHs (Northern High South)

and New York had higher minima on the twelfth, but these were due to the more easterly winds associated with the preceding Low. By mid-afternoon winds were generally more westerly and temperatures were unmodified throughout Ontario and from Minnesota to eastern Indiana. Higher maxima, however, were recorded to the lee of Lakes Michigan and Erie in Lower Michigan, Ohio, and Pennsylvania. New York was exposed to winds from Lake Ontario, but modification here was less significant than the more southerly direction of the winds on the thirteenth. On January 13, northwestern Ontario and Minnesota experienced both their highest maxima and highest minima with southerly winds plus the modification by Lake Superior. In Wisconsin maxima were higher with the more southerly winds, but minima were lower because of the greater modification of minima on the twelfth. Illinois, unmodified on the twelfth, recorded higher temperatures throughout the day. Minima in Indiana and Ohio were lower on the thirteenth with unmodified morning westerly winds, but by afternoon winds were southerly and higher maxima were recorded in Indiana. Ohio maxima, like Wisconsin minima, were still lower in spite of southerly winds because of lake modification on the twelfth. In eastern Ontario and New York minima were lower with unmodified westerly winds, but temperatures in southwestern Ontario were modified by Lake Huron; by noon winds were southerly in these areas and higher maxima were recorded.

Precipitation associated with the nHs type is even more clearly dependent on the lakes. January 12 (Fig. 5C) illustrates the distribution. To the lee of the lakes the most exposed areas generally receive .20 to .40 inch and occasionally up to .50 inch; less exposed areas receive .03 to .20 inch. No precipitation occurs to the windward.

In April temperatures are similarly well below normal. Maxima and minima in Chicago vary from 42° to 50° F., and 25° to 35° F., respectively. In Armstrong, Northern Ontario, minima are in the low twenties and occasionally down to 10° F. United States means are generally 35° to 40° F., though they may get as low as 25° in Chicago or 15° in International Falls. As the winds become more southerly, temperatures in the west and north may rise 5° to 10° F.; minima, nevertheless, are still generally below 32° F. Precipitation is slightly less than in January.

Though rare in July and October the type has similar relative characteristics. Temperatures are well below normal, particularly in October, and precipitation is associated entirely with the lakes. In July the lakes are cool and their importance is at a minimum: temperatures are little modified and precipitation is much lighter and more scattered than in January. In October the lakes are again relatively warm and modification to temperatures and precipitation to the lee is significant. Minima are below, and averages close to or slightly above freezing.

The occurrence of nHs in any season is extremely important because of its very low temperatures. Numerous occurrences in any one month will strongly reduce average temperatures. In winter nHs is significant in the formation of snow belts to the lee of the lakes.

### aLl (Alberta Low through the Lakes)

This cyclonic type is primarily a winter type but is not as common as mLl (see Fig. 2). The variety of the frontal patterns associated with all has already been suggested.[1] Two major subtypes are distinct: (a) well developed fronts and warm sector; and (c) entirely occluded fronts. Two other subtypes may also be noted: (b) partially occluded fronts with warm sector reaching only to southeastern areas; and (d) only the cold front distinguishable. Subtypes (a) and (b), or (b) and (c) may occur in the same sequence if the process of occlusion takes place over the Lakes (see Fig. 6A).

For subtype (a), temperatures of the warm sector, which usually covers most of the region except Northern Ontario, are most important. Temperatures beyond the warm front and behind the cold front depend on preceding and following types. Mean temperatures of the warm sector are about freezing, varying from 25° to 35° F., or 5° to 10° above normal (e.g. Fig. 6B). Maxima, all above freezing, may reach into the low forties. Temperatures for subtype (c), which has no warm sector, are entirely dependent on the preceding and following types, but the cold front is usually followed by a nHn or nHs and the appropriate below normal temperatures.

The partly occluded subtype (b) brings warm sector temperatures as in (a) but the sector is much narrower and influences only the southeastern areas. The cold front subtype (d) has poorly developed warm sectors and lower temperatures than subtype (a).

Precipitation for all subtypes is fairly heavy in certain areas and widespread in lesser amounts. With the open warm sector subtype (e.g. Fig. 6C), most areas receive over .03 inch. Greater amounts occur

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[1]Above, p. 28.

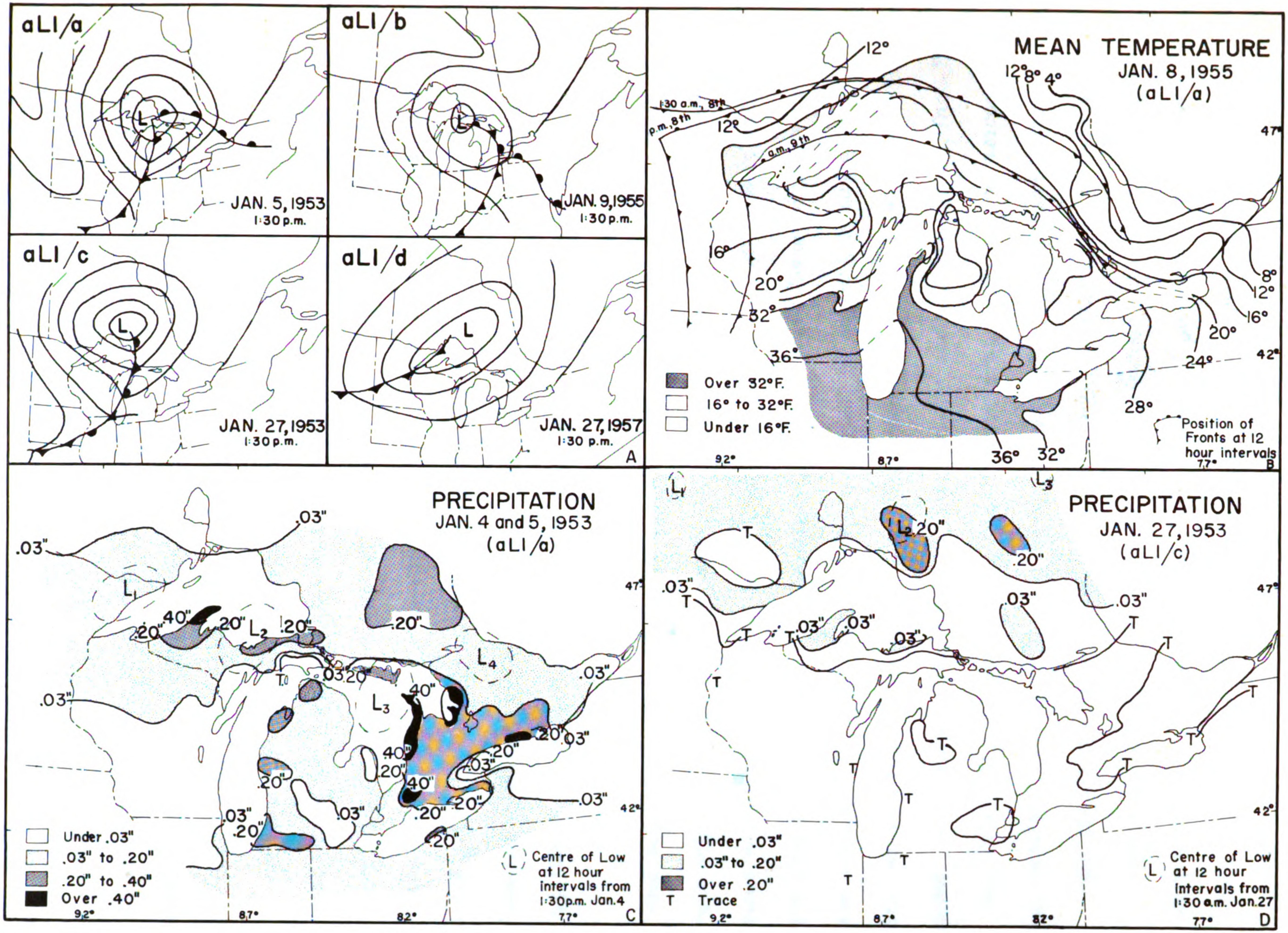


Fig. 6.--aLl (Alberta Low through the Lakes)

(1) associated with the apex of the fronts and the centre of the low, and (2) to the lee of the lakes, in particular the south shore of Lake Superior, the east shores of Lakes Michigan and Huron, and the north shores of Lakes Erie and Ontario. These areas of concentration generally receive .20 to .50 inch and occasionally up to one inch with the centre of the low. Precipitation with the occluded subtype (e.g. Fig. 6D), is generally under .10 inch except across Northern Ontario. Amounts from .30 to .60 inch and occasionally up to one inch are associated with the centre of the low as in the distinct frontal subtype, but there are no areas of heavy precipitation farther south. The partly occluded subtype is similar in its concentration across the north, but in the south amounts are intermediate between the warm sector and the occlusion subtypes. Precipitation with the cold front subtype varies with the contrasts across the front.

Occurrences of aLl in other months are rare and, therefore, it is difficult to establish normals. The distribution patterns, however, are roughly the same. Temperatures of warm sectors are $5^{\circ}$ to $15^{\circ}$ above normal for the given month and other temperatures about normal. Precipitation concentrations and amounts are about the same in July and October as in January. In April amounts are much less, but there is still a slight tendency to identical concentration characteristics.

The aLl type is of little importance except in January when the main features are the concentration of precipitation in amounts occasionally up to one inch across Northern Ontario and up to one-half inch in Upper Michigan and the Lake Huron counties of Ontario, and the above normal temperatures for much of the region with subtype (a) and for the southeastern areas with subtype (b).

gLe (Gulf Low East)

Although gLe occurs most frequently in winter, it is most important and best known in fall because of its occasional hurricane form in that season.

In January no part of the region is reached by the warm sector; nevertheless, temperatures are very close to, or slightly above normal (e.g. Fig. 7C). Precipitation is concentrated in the southeast, that is, in Southern Ontario, New York and Ohio (e.g. Fig. 7D). It varies from quite light, with the centre of the low far east off the coast, to very heavy, with the low well developed immediately east of the Lakes.

Since the cyclone centre is east of the region, other systems, usually a Northern High, are able to approach from the west. Temperatures are lowered accordingly in the west and lee areas may receive some precipitation. The attacking Northern High is usually blocked temporarily and spreads both longitudinally from north to south, sometimes uniting with another High spreading from the southwest, and toward the east to the north of the Lakes (e.g. Fig. 7A). Thus, both isobars and isotherms form a distinct right angle as they trend north-south to the west of the Lakes and west-east to the north of the Lakes with highest temperatures and lowest pressure in the southeast. Temperatures in the west vary with wind direction but are generally 10° to 20° F. colder than in the east and occasionally are almost as low as normal nHs temperatures.

In April and July, gLe is virtually nonexistent.

In October, as in January, temperatures are close to, or slightly above normal in the southeast and usually just below normal in the north and west due to attacking highs. Some occurrences bring the usual

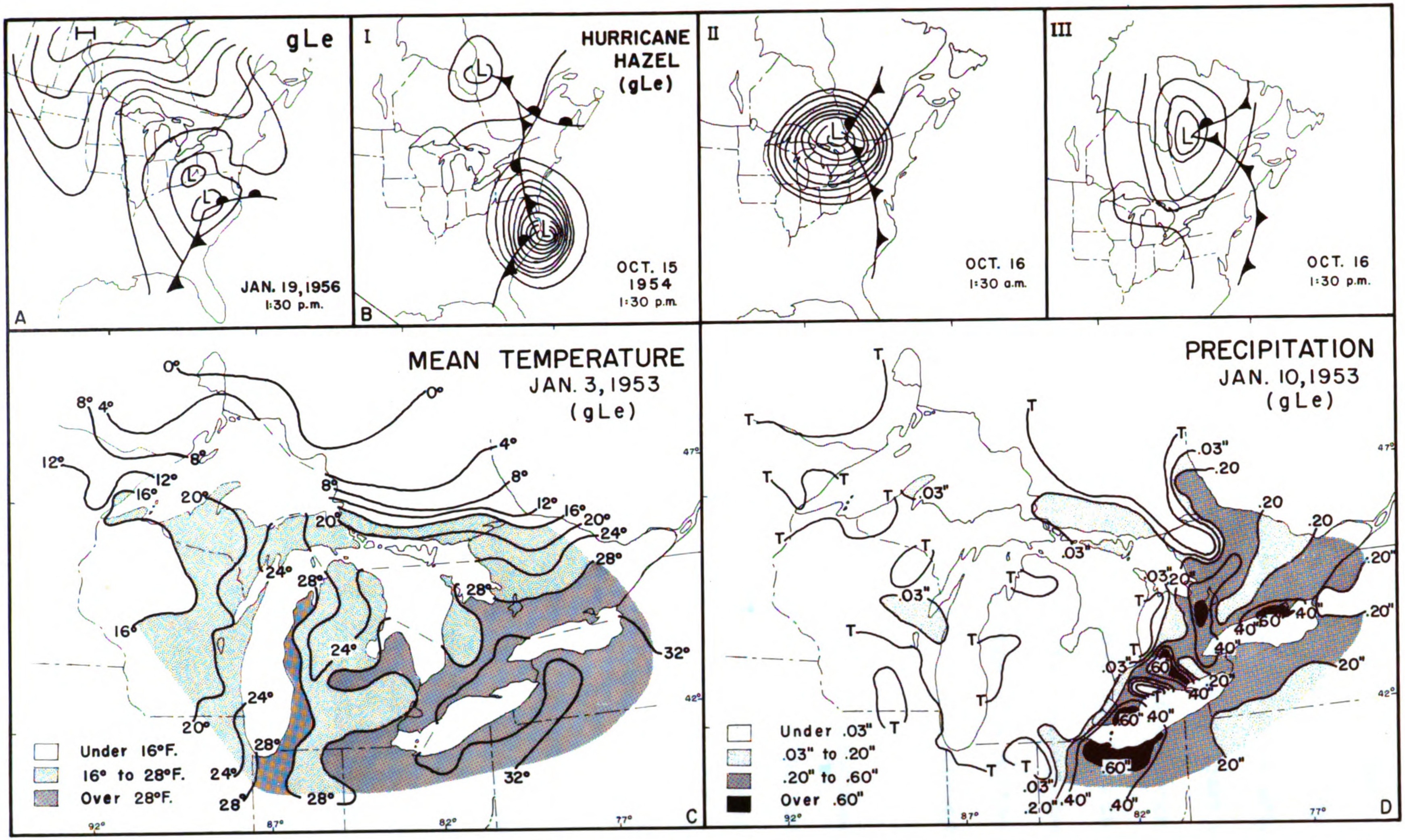


Fig. 7.—gLe (Gulf Low East)

southeastern concentration of precipitation, but the hurricane subtype is of particular interest. Hurricane precipitation is similarly concentrated in the southeast but amounts are much greater. On October 15, 1954, Hurricane Hazel (see Fig. 7B) brought most areas at least one inch of rain and in many cases in the east up to almost 6 inches. A similar system on the same date in 1955 yielded over .50 inch in most areas; many areas received almost 2 inches, and a few areas, over 3 inches. Such intense storms usually occur only once in a month; yet their precipitation is great enough to very significantly increase southeastern totals.

The gLe type is primarily important for its high southeastern precipitation, particularly when in its fall hurricane form. Average monthly temperatures tend to be raised slightly in the southeast and lowered in the northwest by frequent occurrences.

mLl (Montana Low through the Lakes)

The most common and most familiar cyclonic type in the Great Lakes Region is mLl. It reaches a maximum frequency in April and in that month it is also usually the most frequently occurring type (see Fig. 2). Two major subtypes have been indicated:[1] (ws) with both cold and warm fronts distinct, sometimes partially occluded, yet always embracing a broad open warm sector that usually reaches into Lower Michigan and southwestern Ontario; and (c) with only a cold front distinguishable (see Fig. 8A). By the latter days of long durations of mLl occurrences beginning in the (ws) form, the fronts often pass to the east of the

[1]Above, p. 29.

region even though the circulation over the Lakes is still cyclonic; element characteristics on these days more closely resemble those of subtype (c) and the days, therefore, have been recorded as such. The warm sector subtype is much more common than the cold front subtype in all seasons except winter.

In April, warm sector temperatures are 10° to 15° above normal; daily means vary from 50° to 65° F. and maxima from 65° to 80° F. The accompanying map (Fig. 8B) of mean isotherms for the highest maxima and highest minima occurring from April 24 to 26, 1953, is representative for warm sector temperatures and contrast across the fronts; note the crowding together of the 52° and 56° isotherms. Temperatures for the cold front subtype (c), and for areas outside the warm sector in subtype (ws) vary from normal to 10° above normal (e.g. see Fig. 8D). Southern means are in the forties and maxima in the fifties; northern means are in the thirties and low forties and maxima in the forties. Areas with southerly winds, especially, are well above normal, whereas areas with northerly winds are close to, or sometimes even below normal. There is a tendency, therefore, for temperatures to drop slightly over the duration of the type, and the final day is sometimes 5° to 10° colder than initial days.

Precipitation is generally high throughout the type's duration. Almost all areas receive at least .03 inch each day and much of the region, particularly southern and central parts, receive over .20 inch, (e.g. see Fig. 8C). Areas of concentration, which are primarily associated with the fronts and the centre of the low and, therefore, usually in northeastern Wisconsin, southern Upper Michigan, northern

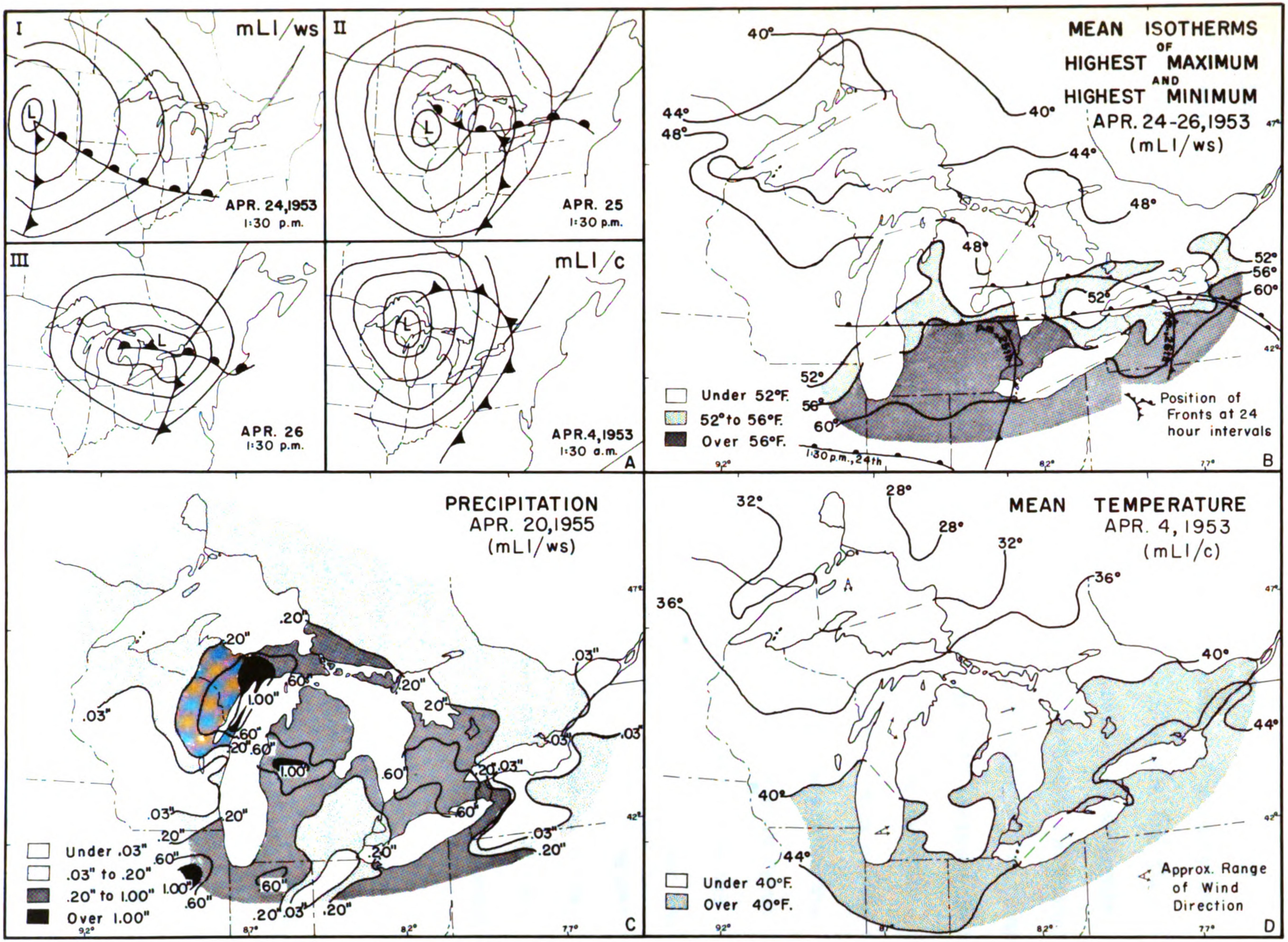


Fig. 8.--mLl (Montana Low through the Lakes)

Lower Michigan and Southern Ontario, receive at least .40 inch, generally over .60 inch, and occasionally up to 1.40 inches. Amounts as high as 2.5 inches have been recorded. Precipitation tapers off slightly after the passage of the fronts, but amounts are still considerable over large portions of the region and some areas get at least .40 inch. Precipitation with the cold front subtype is similarly high, but maximum amounts are generally from .60 to .70 inch a day. In both subtypes much of the region receives from 1 to 1.5 inches over a three day duration.

In July, mL1 is still the dominant cyclonic type. Warm sector temperatures are 5° to 10° above normal and southern maxima are in the eighties. Temperatures outside the warm sector and for the cold front subtype are about normal or even slightly below in the west where the winds are northerly. Means run in the low sixties in the north and the low seventies in the south. Southern maxima are in the high seventies. Precipitation is again considerable for all areas associated with the fronts and the warm sector and is concentrated near the centre of the low. Amounts are about the same as in April with 1 inch per day common and a fair number of cases over 2 inches a day.

In October the type reaches a minimum frequency but relative to other types is still very important. Warm sector temperatures are 10° to 15° above normal with southern daily maxima from 75° to 85° F. Other temperatures vary from about normal to 10° above normal. Precipitation for subtype (ws) in October is quite variable. Although many days are very wet, amounts are often not quite as high. Many stations receive over .30 inch and up to .90 inch, yet large areas may have very little. Falls reaching 1.5 inches are not too common, but as much as 4 inches has been recorded. In contrast, there may be days of very little rain when warm sector air is drawn in from continental areas to the southwest. Precipitation for the cold front subtype is generally over .20 inch with maxima rarely above .45 inch.

In January, mLl is again the dominant cyclonic type, but the cold front subtype is far more common than the warm front subtype. Also, in this month, durations are usually not more than two days; hence actual occurrence frequencies are relatively even greater. Warm sector temperatures are from 10° to 20° above normal with means from 35° to 45° F. and maxima from 40° to 55° F. Temperatures for the cold front subtype are again generally from normal to 10° above normal and southern maxima are above freezing. Areas with north winds are sometimes slightly below normal. Precipitation for subtype (ws) is from .10 to .40 inch for much of the region, occasionally up to .70 inch in concentrated areas, and rarely to 1.20 inches. Subtype (c) usually brings less precipitation; widespread areas receive .03 to .30 inch and concentrated areas up to .50 inch. Scattered areas may receive none at all. Rarely precipitation for either of the subtypes varies to approximately the limits of the other.

Warm sector temperatures in all seasons are well above normal and, therefore, high frequencies of subtype (ws) tend to raise monthly averages for southern areas of the Lakes Region. For the cold front subtype (c), temperatures are closer to normal but still tend to keep averages up. The type is particularly important for fairly heavy widespread precipitation, and very heavy concentrations in some areas. It is a leading contributor to monthly totals in all seasons, though amounts in fall are quite variable.

sLl (Southern Low through the Lakes)

The sLl type is generally responsible for the highest temperatures of spring and winter in the southeast. In spring it occurs almost as frequently as mLl and along with mLl dominates that season (see Fig. 2). In winter it does not occur as frequently but is well known for its January thaws.

April warm sector temperatures (e.g. Fig. 9B) are 10° to 20° above normal. Daily means in Indiana and Ohio, vary from 55° to 70° F. with maxima into the seventies and occasionally the low eighties. In eastern Ontario and New York means are in the fifties and maxima generally in the sixties though high seventies do occur. Outside the warm sector and after passage of the fronts (e.g. Fig. 9D), temperatures are close to normal in the south and slightly above in the north. Northern means run from 30° to 40° F. with maxima in the forties, and southern means from 40° to 50° F. with maxima in the low fifties. Temperature contrasts between areas in the southeast in the warm sector and areas to the northwest of Lake Superior may be as much as thirty or forty degrees.

Like mLl, this type is conducive to very high precipitation. The heaviest fall usually occurs just northwest of the path of the centre of the low, that is, in the belt running from southwest to northeast across the region (e.g. Fig. 9C). Totals are even greater than for mLl. Almost all areas, particularly those east of the belt of heaviest fall, receive over .20 inch; many areas receive over .60 inch. The belt of heaviest fall usually gets over 1 inch and occasionally over 2 inches.

This type does not occur in July and is rare in October.

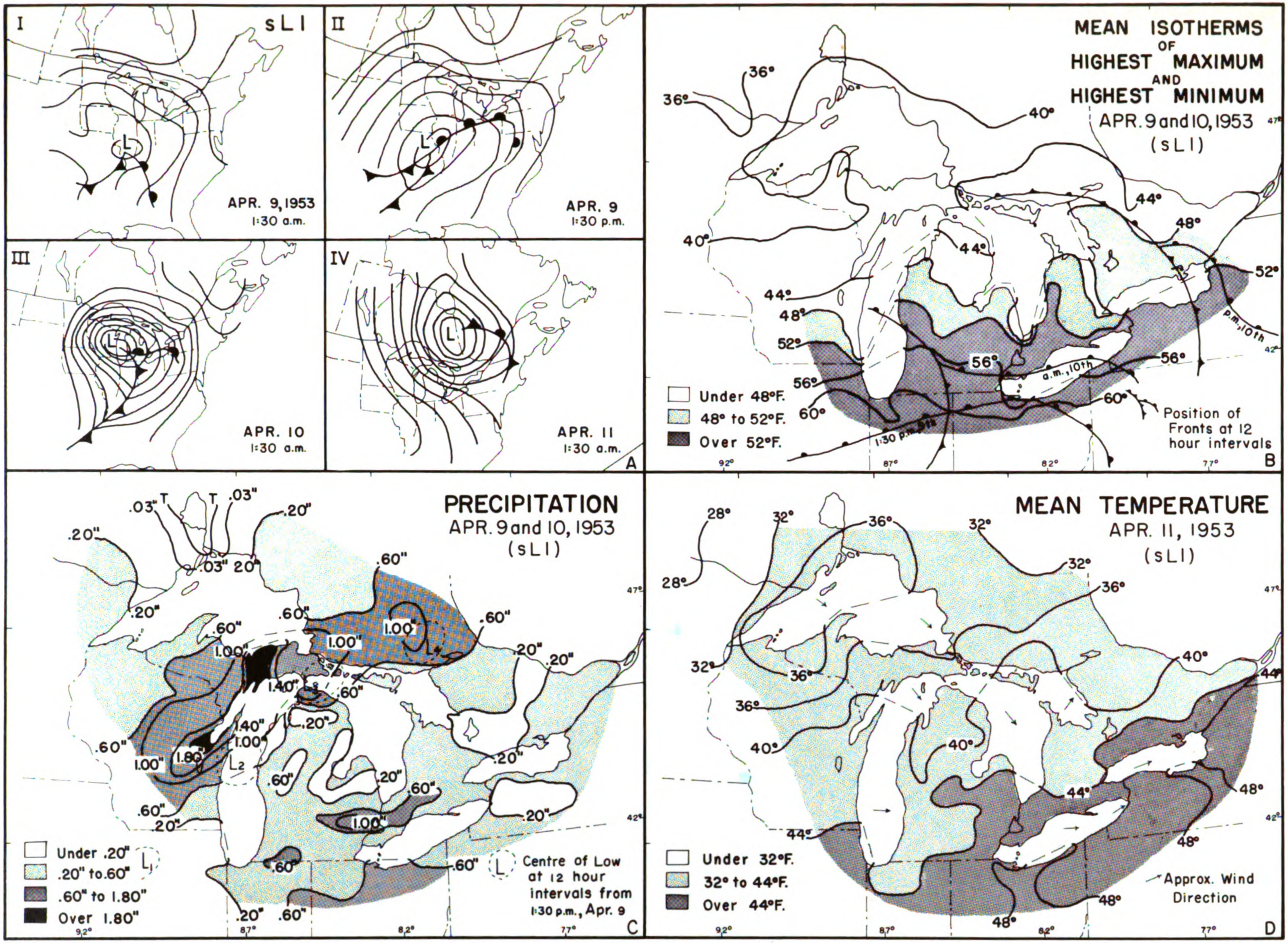


Fig. 9.--sL1 (Southern Low through the Lakes)

Temperatures in October appear to be about the same as in April or slightly less above normal. The precipitation pattern, also, is very much like that of April.

In January warm sector temperatures are 10° to 25° above normal. Southern means vary from 45° to 55° F. and maxima from 50° to 60° F. Eastern Ontario means run from 35° to 50° F. and maxima from 45° to 55° F. Outside the warm sector, temperatures are from about normal to 10° above normal. Northern means are from 0° to 10° F. with maxima about 30° F. Southern means are from 30° to 35° F. and maxima from 35° to 40° F. Temperature contrasts between southeast and northwest vary from forty to sixty degrees. Precipitation is almost as heavy as in April. In addition, slight lee-of-the-lakes concentrations may be distinguished. Occasionally in January, sLl systems develop with no distinguishable fronts; temperatures are colder and precipitation is less, though still widespread. Occurrences in 1956 and 1957 were of this type.

For monthly figures, sLl is important primarily in spring. In that season the frequent occurrences maintain high average temperatures in southeastern areas and increase total precipitation generally for the entire region and particularly for central areas. In some years, January average temperatures are raised and total precipitation is increased, but the type often does not occur frequently enough to significantly affect the monthly figures.

n&eH (Northern and Eastern Highs)

This type clearly dominates much of the summer season. In July it has a higher frequency than any other type in any month except wHl in October (see Fig. 2). In spring it occurs quite often but is only of secondary importance in that season compared to the Montana and southern cyclonic types. Three situations, each with noteably different element distribution characteristics, are distinguishable on the basis of the position of the quasi-stationary front separating the two highs: (n) with the front north of the Lakes; (l) with the front lying over the Lakes; and (s) with the front south of the Lakes (see Fig. 10A). In summer, when the front is north of the Lakes the entire region is hot and humid and there is little or no precipitation. When the front is south of the Lakes the region is cool and heavy precipitation occurs across the southern lakes. When the front is over the Lakes, on the other hand, strong contrasts between north and south are characteristic: north of the front it is cool as in (s) and south of the front it is hot and humid as in (n). Heavy precipitation occurs in a narrow belt along the frontal zone.

In July temperatures south of the front are usually 10° to 20° above normal, but north of the front they are about normal. In general the following values apply. When the front is over the Lakes, daily means in the south vary from 80° to 90° F., maxima from 90° to 100° F., and minima from 65° to 75° F.; in the north means run from 55° to 70° F., maxima from 65° to 80° F., and minima from 40° to 55° F. (e.g. Fig.10B). Toward the front temperatures are not quite so extreme. When the front is south of the Lakes, temperatures in the north are the same as for subtype (l); in the south means run from 65° to 75° F. or just slightly above normal, maxima from 70° to 85° F., and minima from 55° to 65° F. When the front is north of the Lakes, temperatures in the south are just slightly below those for (l), and in the north means are from 65° to

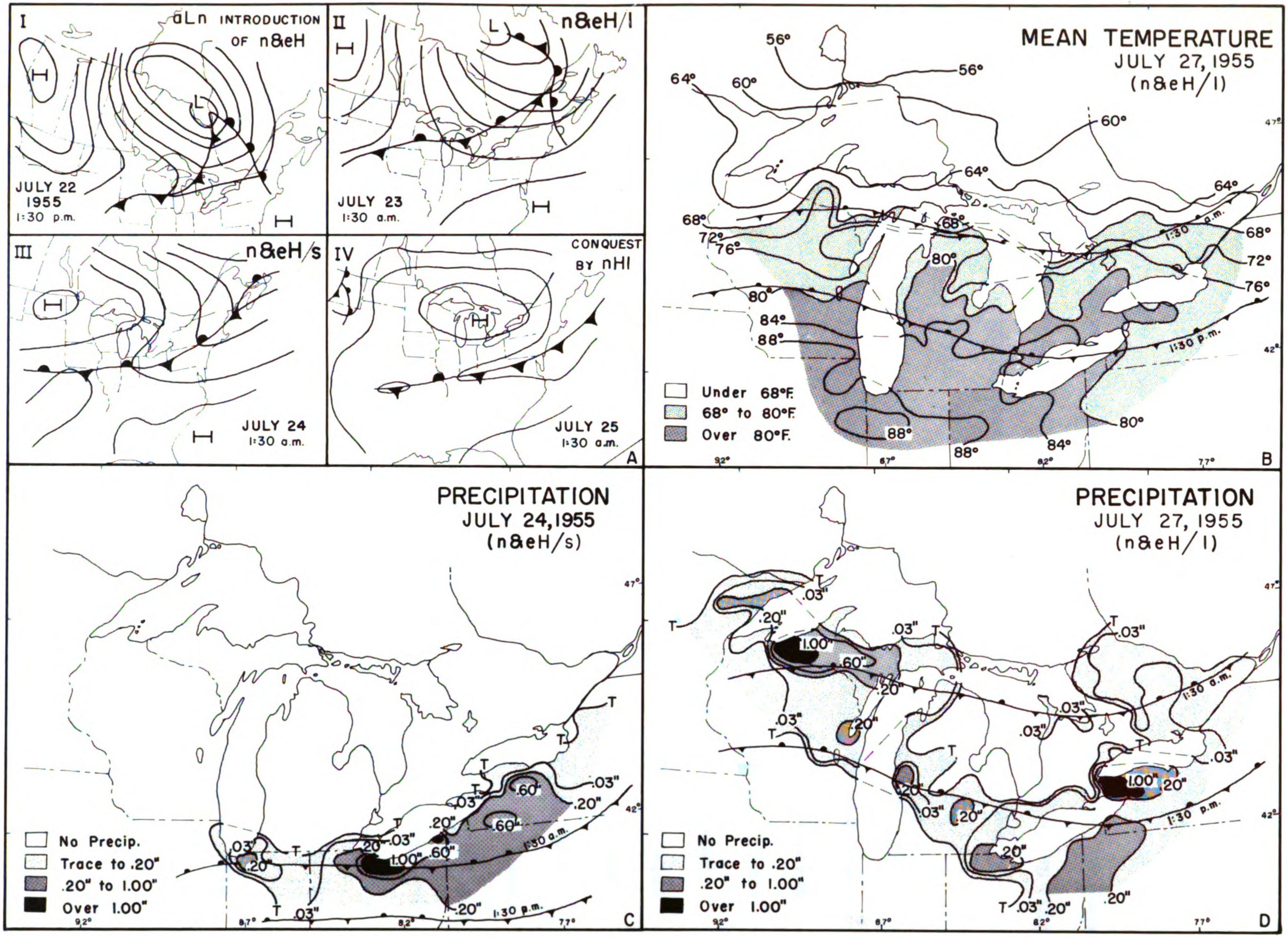


Fig. 10.--n&eH (Northern and Eastern Highs)

75° F., maxima from 80° to 85° F., and minima from 55° to 65° F.

Modification by the lakes, north of the front, is quite important. Temperatures, particularly maxima, are much lower to the lee of the lakes. With northeast winds, stations in the north may even have higher maxima than modified stations in the south. For example, on July 4, 1956, maxima and minima respectively at various stations were as follows: Sault Ste. Marie, 71° and 49° F.; Chicago, 69° and 65° F.; Cleveland, 71° and 67° F.; and International Falls, 75° and 52° F.

When the front is over the Lakes, most areas within the precipitation belt receive from a trace to .20 inch (e.g. Fig. 10D), but various areas may get up to 2 inches and rarely up to 3 inches. When the front is south of the Lakes the belt, lying across the southern lakes, receives slightly less precipitation, but often there are also showers to the lee of the lakes. A close resemblance of this latter case to nHn except for the additonal belt of precipitation may be noted; however, the overall pattern is definitely the n&eH type. When the front is north of the Lakes, there are, at the most, very scattered showers. These occur particularly in the northwest associated with the front. On the other hand, when the front is pushed far enough south by the northern High so that it brings no precipitation to the area and the centre of the high is able to move over the Lakes, the day has been classified as nH1. Such a situation is usually accompanied by a weakening and disappearance of the high to the southeast.

In October, n&eH is fairly rare, but element characteristics are much the same as in July. South of the front temperatures are 10° to 25° above normal with means from 65° to 80° F. in the south. North of the front temperatures are about normal or slightly above, with means from 40° to 50° F. in the north and 50° to 60° F. in the south. Precipitation occurs as in July. Variations in the form of the system, however, are significant. Often the southeastern high is not as well developed and tends to centre more over West Virginia and Cape Hatteras rather than off the southeast coast. The upper-level anticyclone is also more poorly developed and lies over the southeastern states. As a result, the positions of the surface highs vary considerably from east to west and, thus, alter the angle of the fronts across the Lakes. Sometimes the front runs almost north-south or even from northwest to southeast with the northern high over Quebec.

This type rarely occurs in January.

In April, temperatures north of the front are slightly above normal. South of the front means run from 50° to 65° F. or about 10° to 15° above normal; maxima vary from 65° to 80° F. and minima from 40° to 50° F. Precipitation is considerable but varies from not quite as heavy as in July to quite light depending on the flow of maritime tropical air from the south. The lighter precipitation occurs when the high extends farther to the southwest drawing in continental air, or when the flow from the Gulf is blocked by a front south of the high centering off Georgia and North Carolina.

In April there is a tendency for the southeastern high to be more dominant than it is in July and it may gradually push the front, once formed in its east-west trend, to the north rather than allowing it to move south. Furthermore, the type is more frequently introduced by mLl in this month and, therefore, the front is more often first established to the south of the Lakes and may cross the entire Lakes in the reverse direction. As the front is pushed north, fairly heavy precipitation occurs first in southern areas and then gradually farther north. Temperatures in the south behind the front in these cases may be 15° to 20° above normal, that is, means from 65° to 75° F., maxima from 75° to 85° F. and minima from 55° to 65° F.

Type n&eH is a leading source of summer precipitation, and this precipitation is widespread because of the fluctuation of the quasi-stationary front. In spring amounts are again considerable but only secondary to those of nLl and sLl types. In summer, average temperatures are also noticeably influenced: because of the high dominance of the type, the relative frequencies of the frontal positions may make the difference between a hot, humid season and a comparatively cool season.

nHl (Northern High through the Lakes)

This type occurs only in spring and summer when the lakes are relatively cool. In summer it is usually second in frequency only to the dominant n&eH type, which it often follows in sequence (see Fig. 2 and 10A). In spring it is much less important and often poorly developed. With nHl is associated cool, dry weather.

Temperatures in July for the entire region are usually below normal and noticeably colder than regions either to the west or east. Areas in the east with north winds tend to be quite cool, while areas in the west with south winds are markedly warmer. The resulting isotherm pattern is much the same as the normal July pattern, only several degrees cooler. Eastern means are approximately 10° to 12° below normal with temperatures in the sixties reaching only to New York or southeastern

Ontario. Western means are $4^\circ$ to $7^\circ$ below normal, with sixty degree temperatures into northwestern Ontario, and they have a remarkably small latitudinal gradient (e.g. Fig. 11C). Temperatures to the lee of the lakes, particularly maxima, are significantly lowered--usually $3^\circ$ to $6^\circ$. Modified western areas may be as cool as unmodified eastern areas; but conversely, areas in the east which are modified are much colder than areas in the west which are unmodified. Maximum temperatures are often as cold or colder in Cleveland than in International Falls and lower in New York than in Minnesota and Upper Michigan (e.g. Fig. 11A). As the high moves east temperatures rise slightly.

There is virtually no precipitation with this type except around the fringes of the region, where it is associated with other attacking systems, or rare showers below .10 inch in lee areas.

April temperature patterns are much the same though they are a few degrees warmer, compared to normals. The east is generally somewhat colder than the west and areas to the lee of the lakes are again relatively cooled. Examples are indicated on the accompanying map for April 28, 1954 (Fig. 11B). Unmodified western areas are up to $10^\circ$ above normal, having means from $40^\circ$ to $55^\circ$ F., maxima from $50^\circ$ to $65^\circ$ F., and minima from $30^\circ$ to $45^\circ$ F. Modified southwestern areas and eastern areas are about normal with means from $40^\circ$ to $50^\circ$ F., maxima from $45^\circ$ to $55^\circ$ F., and minima from $35^\circ$ to $45^\circ$ F. Precipitation is nil as in July.

The nHl type is significant primarily in July average temperatures. Eastern temperatures tend to be lowered and western temperatures at least maintained. The pattern, however, is very close the normal pattern; hence

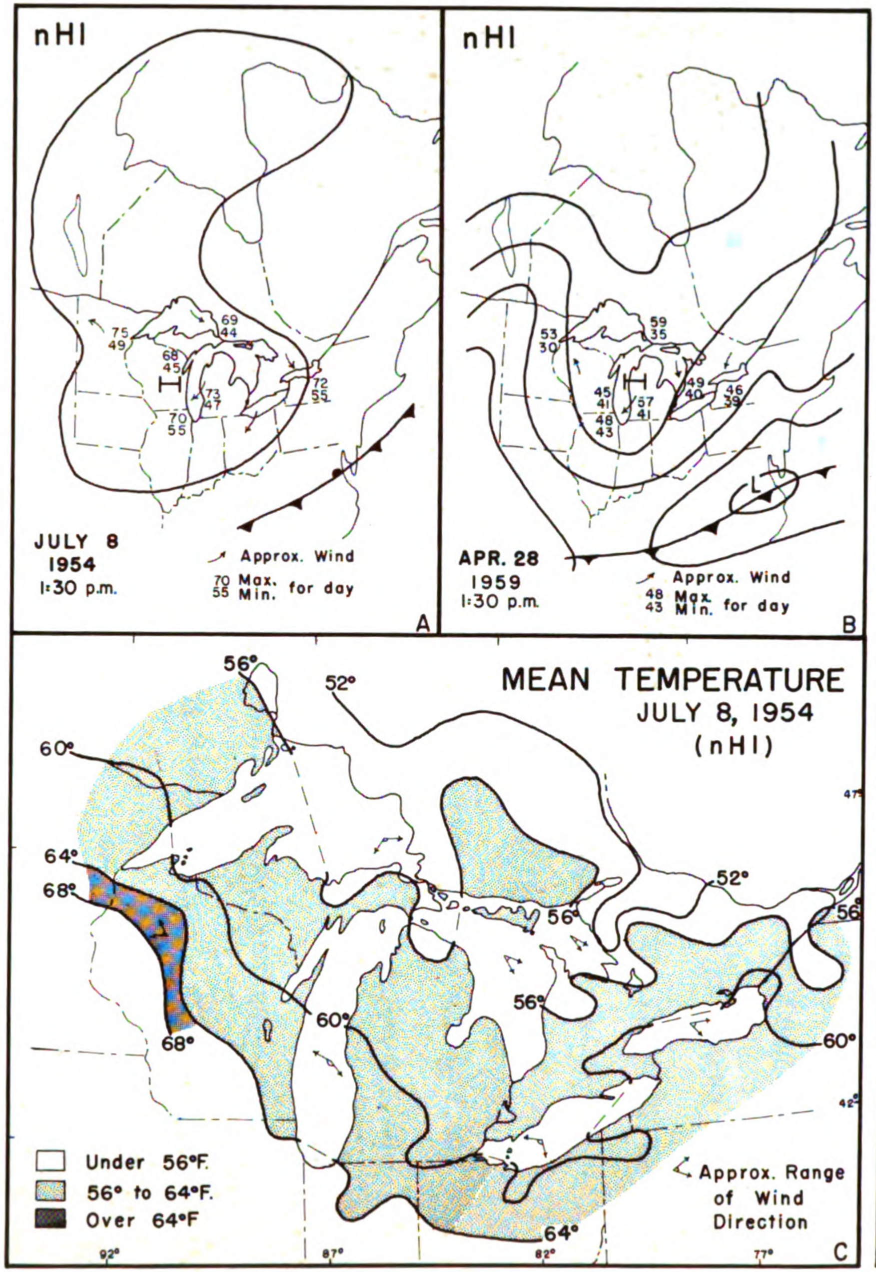


Fig. 11.--nHl (Northern High through the Lakes)

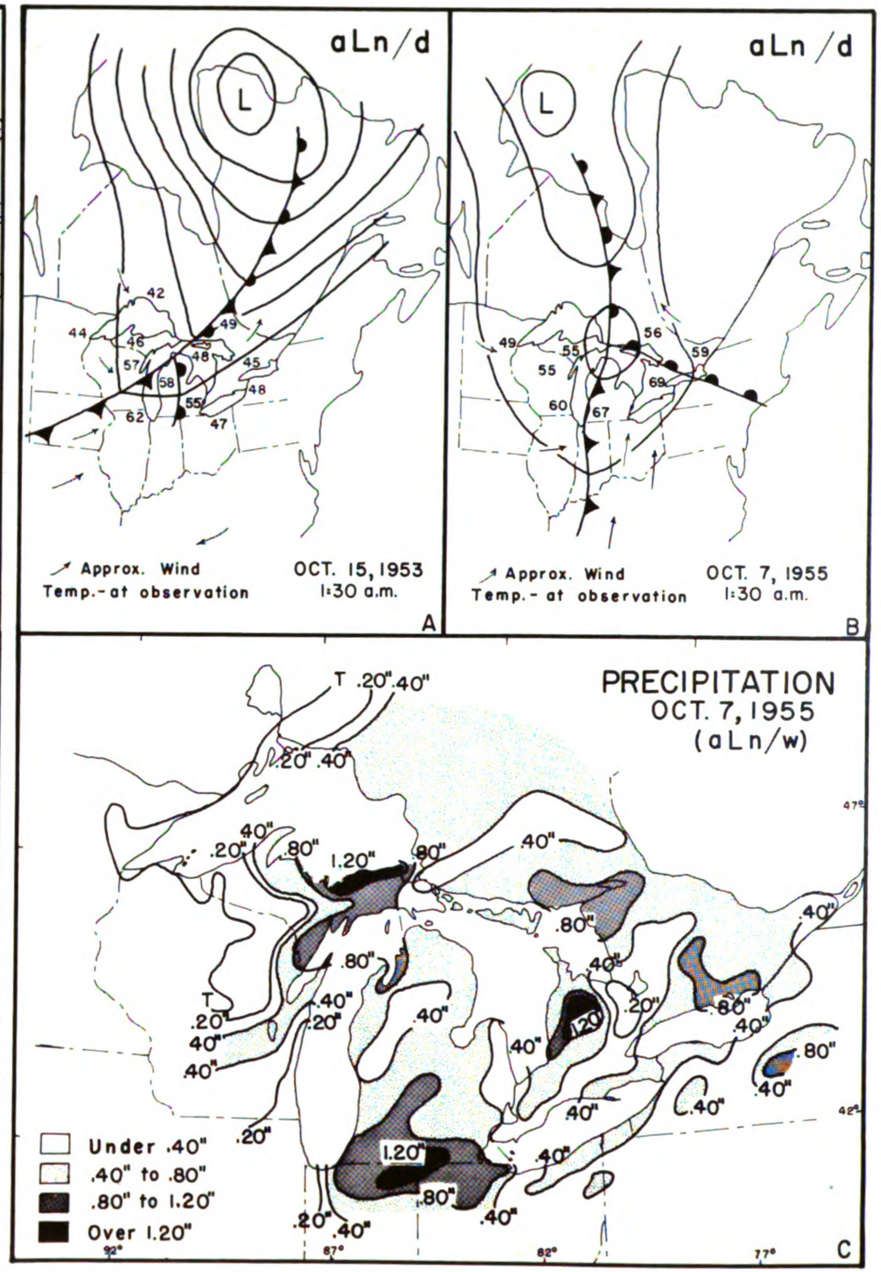


Fig. 12.--aLn (Alberta Low North

its importance to monthly averages is difficult to detect from year to year.

wHl (Western High through the Lakes)

The anticyclonic type wHl is by far the dominant system of fall; in October it shows the highest frequency in a single month of any of the eleven types. In other seasons it is of limited importance. The subtype wHs occurs only rarely in any of the seasons.

In October, temperatures are all close to normal. Daily means for the entire region are between 35° F. and 50° F., and there is very little latitudinal gradient. Areal variation is largely dependent on the degree of modification by the lakes: the accompanying map of mean temperature isotherms for October 20, 1954 (Fig. 13B) is representative. Minimum temperatures, in particular, may be raised by as much as 10° to the lee of the lakes. For example, on October 25, 1953, with winds north to northeast, Fort Wayne recorded a 1:30 a.m. temperature of 49° F. and Armstrong in northwestern Ontario only 25° F.; but on the following day winds were more southerly and Armstrong jumped to 44° F. while Fort Wayne dropped to 41° F. Thus, in early stages of the type, when winds are northerly, there is a considerable range between southern and northern minima; but later, when winds are southerly, minima are remarkably uniform or even lower in the south. Maxima, on the other hand, generally remain about the same, or are even lowered slightly by the lakes. The accompanying maps showing range isopleths for a representative occurrence in October of 1953 (Figs. 13C and 13D) clearly demonstrate these differences and changes in modification with changing wind directions. Northern maxima are generally in the high forties and southern maxima in the high fifties or low sixties. Northern unmodified

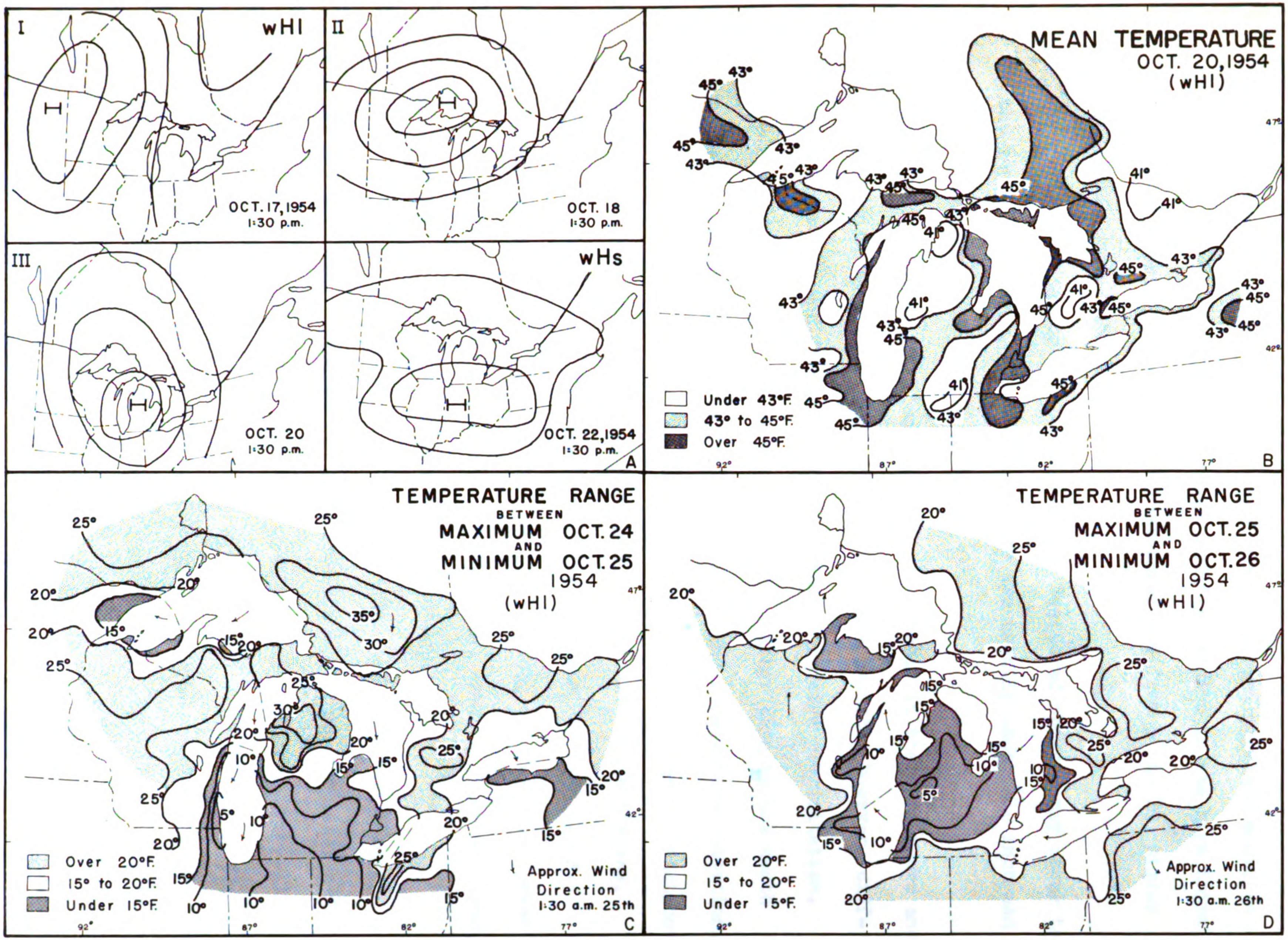


Fig. 13.--wHl (Western High through the Lakes)

minima are in the twenties, southern unmodified and northern modified minima in the thirties, and southern modified minima in the high thirties and low forties. Occasionally temperatures are from 5° to 10° higher than those quoted above.

Precipitation with wHl is rare. Scattered showers may occur to the lee of the lakes, but total amounts are usually under .10 inch and only occasionally up to .20 inch.

For subtype wHs, temperatures are roughly in the same range and precipitation occurs in approximately the same amounts; however, different areas are modified and different shores receive precipitation. Lee areas are more to the east of the lakes rather than to the north or south, and these areas alone are modified and receive precipitation. On October 9, 1955, maxima and minima respectively for various stations were as follows: Grand Rapids, Michigan, 61° and 49° F.; Milwaukee, Wisconsin, 65° and 44° F.; Traverse City, Michigan, 59° and 44° F.; Wausau, Wisconsin, 63° and 39° F. On the same day the following areas received precipitation: western Lower Michigan, eastern Upper Michigan, most of New York state, and southwestern Ontario.

In January, occurrences are very rare and then distinctly of the wHs subtype. Temperatures are above normal in the north and below normal in the south. Lee areas are distinctly warmer than unmodified areas. Precipitation is light and occurs to the east of the lakes.

In April and July the type is only slightly more common than in January, but a distinct difference to the October occurrences may be noted. Temperatures are again close to normal and have little latitudinal gradient; but, because the lakes are cool, it is the lowering of the maxima to the lee of the lakes which is important rather than the raising of the minima. On April 28, 1957, maxima and minima respectively were 66° and 30° F. at Sault Ste. Marie but 57° and 51° F. at Chicago. On April 13, 1954, for a wHs, Grand Rapids recorded 49° and 33° F., but Milwaukee had 58° and 36° F. In July, with southeast winds, Milwaukee, recorded 71° and 58° F., while Grand Rapids had 76° and 51° F. Also, since the lakes are cool, precipitation in these months is even less than in October.

Temperatures in all seasons are close to normal and, therefore, have little reflection in departures of monthly averages from normal. Even in October, in spite of the type's dominance in that month, its influences are only suggested in a lower latitudinal gradient in the years of its higher frequency. Precipitation is virtually nil and certainly of no significance to monthly totals.

aLn (Alberta Low North)

Two distinct subtypes of aLn with very different element characteristics may be distinguished. In one, the entire system is relatively cool and dry, and temperature contrasts across the fronts are not great. For the other, temperature contrasts across the fronts are relatively great and heavy precipitation is associated with frontal passages and the warm moist air of the warm sector. These differences, however, are not due to internal circulation and frontal pattern of the type, which indeed shows little variation except for a slightly greater development of the warm front with the wet type. Rather, the element characteristics are determined by the preceding type which may or may not establish a strong flow of warm moist air from the Gulf into the aLn system. The dry subtype (d) occurs when the type is preceded by neH, wHl or n&eH. The wet subtype (w) occurs when the type is preceded by nHn, wHs, mLl, or another aLn. (e.g. see Figs. 12A and 12B)

The aLn type occurs with about equal frequency in October and July. In October, when it is responsible for much of the poor weather, it is second only to wHl, whereas in July it is of much less relative importance. In both months the wet subtype (w) is far more common. In January and April the type occurs only infrequently and is usually of the dry subtype.

In October, there is virtually no precipitation associated with subtype (d), as only cool dry continental air from the southwest or occasionally cool eastern air immediately after nHn is drawn into the low. All temperatures are above normal, frontal contrasts are not great, and the warm front is often poorly developed. The warm sector, which usually influences only the southern lakes, has mean temperatures from 60° to 70° F. or 10° to 15° above normal; maxima are from 70° to 80° F., and minima from 45° to 55° F. Behind the cold front, mean temperatures in Wisconsin run from 50° to 60° F., and in northwestern Ontario into the forties.

In contrast, precipitation with the wet subtype is generally over .20 inch and much of the region gets over .40 inch; several areas usually receive over 1 inch and the odd station records over 2 inches (e.g. Fig. 12C). The fall is heaviest in the zone following the cold front, particularly in southern areas which are best reached by the maritime tropical air from the south and where contrasts across the front are greatest. Warm front precipitation is less because the air is somewhat modified as it moves north and contrasts across the front are not as great. Temperatures are again high. In the warm sector they are 10° to 20° above normal. Means vary from 65° to 75° F., and maxima from 75° to 82° F. Minima in particular, ranging from 55° to 65° F., are higher than for the dry subtype. Behind the cold front temperatures are about the same as for its counterpart.

In January only the dry subtype occurs. It is usually preceded by aLl, nHn, or sLl and only continental air is drawn into the system. Precipitation up to .10 inch and occasionally .20 inch may occur and this is primarily to the lee of the lakes. If the type is preceded by gLe, precipitation may be just slightly greater with amounts up to .30 inch due to the warm moist air brought in by the low. The warm front in this month is never developed and the cold front is often poor. Temperatures are only slightly above normal and contrasts across the front are not great.

In April either subtype may occur but both are rare. There is almost no precipitation with the dry subtype. With the wet subtype, amounts up to .50 inch are common, especially in the south, and up to 1 inch may occur. Mean temperatures before the cold front of the dry subtype are usually between 50° and 60° F. or 10° to 15° above normal, and behind the front are from 40° to 50° F. Warm sector temperatures of the wet subtype may be in the sixties or well above normal. In July, subtype (d) is again very dry, but temperatures are close to normal. Mean temperatures before the cold front are from 70° to 75° F., and behind the front from 60° to 70° F. Subtype (w) is as wet as in October, with .20 inch general and 1 inch common, particularly in the south. Temperatures in the warm sector are from 70° to 80° F., just slightly higher than for the dry subtype but behind the cold front they are identical.

The aLn type is important primarily for the above normal temperatures and heavy precipitation associated with the wet or (w) subtype of summer and early fall.

neH (New England High)

Over the year the type with the lowest frequency is neH (see Fig. 2). It is almost exclusively a fall type, but it occurs much less often than either wHl or aLn. It is, nevertheless, very important because of the strong flow of air from the south which it establishes over the eastern half of the continent and the Great Lakes.

In October the areas most noticeably affected by this flow from the Gulf or southern states are those, usually south of the lakes, whose temperatures were unmodified by the lakes during the latter stages of the preceding anticyclonic type. Minima, in particular, are much higher in the south and, therefore, form a very different pattern to those of wHl,[1] the type which it most frequently follows.[2] To the north, the slight cooling with latitude is counteracted by the modifying effects of the lakes. For these reasons, mean temperatures over the entire region are within a range of ten degrees, usually from $45^{\circ}$ to $55^{\circ}$ F., or slightly higher (e.g. Fig. 14C). Minima in the north are from $40^{\circ}$ to $50^{\circ}$ F., and in the south generally from $45^{\circ}$ to $50^{\circ}$ F. but with extremes of $40^{\circ}$ and $65^{\circ}$ F. Maxima are more variable. In the north they vary from $50^{\circ}$ to $70^{\circ}$ F., and in the south from $55^{\circ}$ to $75^{\circ}$ F. Actual temp-

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[1]See above, p. 77. In latter stages of wHl, minima in the south are about the same as, or even lower than in the north.

[2]See above, p. 32, regarding formation of neH following other anticyclonic types.

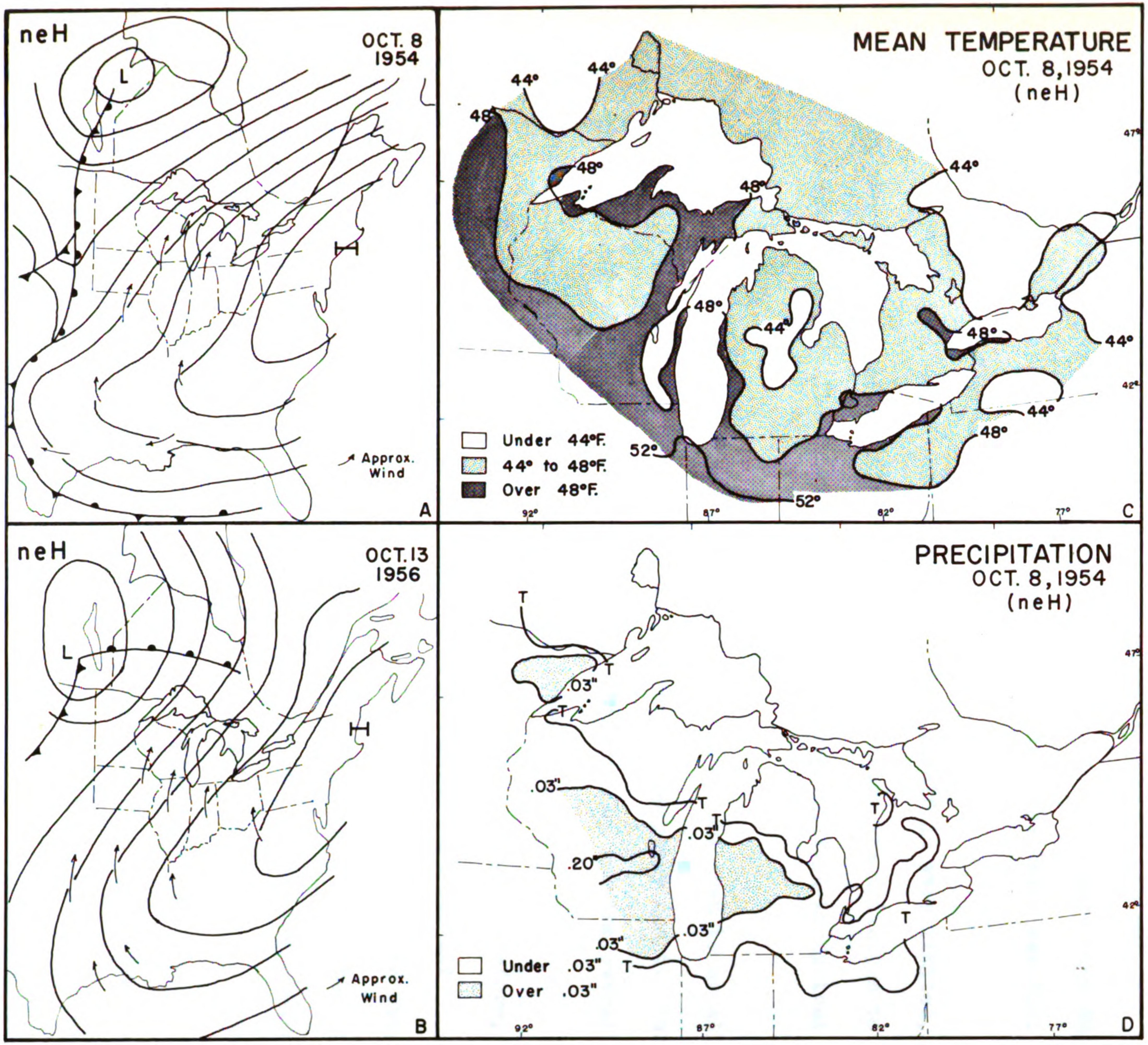



Fig. 14.—neH (New England High)

erature occurrences within these rather broad ranges are largely dependent on whether or not a front develops over the northern part of the Gulf. Cooler temperatures occur when this front blocks much of the warm mT air; highest temperatures occur when there is a free northward flow and the high extends in its oblong form well south over the Gulf (see Fig. 14A and 14B, respectively).

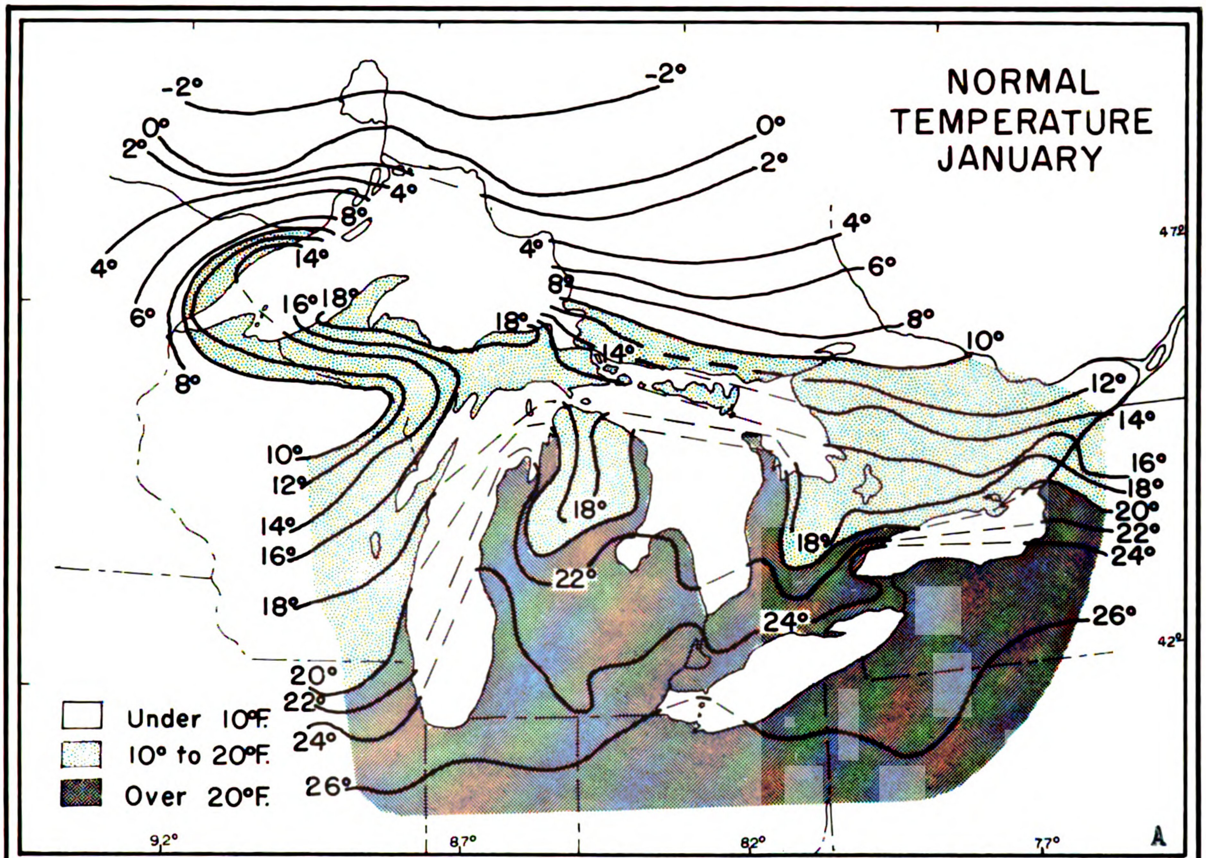
Precipitation associated with the type itself is very limited, but the frequently attacking cyclonic types may bring precipitation to the west or north. The isohyet pattern for October 8, 19.4 is typical (Fig. 14D).

In other seasons neH occurs only very rarely and then is usually of too short a duration to be recorded in the day frequency chart. Furthermore, the position ofthe centre varies considerably and the overall form is often somewhat distorted from the ideal of October.

In January there are almost no wHl occurrences and, therefore, neH is dependent on other anticyclonic types, chiefly nHs, for its initiation. When following a nHs system, the high tends to centre over Georgia and South Carolina rather than over New England. The system is, therefore, much more open to cyclonic attacks in the Great Lakes Region. One occurrence was observed following a nHn system and in this case the high centred over the Maritimes. In both the latter occurrence and in all those which were introduced by nHs, the pattern was quickly destroyed either by mLl or aLl. In each case, however, maximum temperatures rose at least temporarily to above freezing in the south and close to 32° in the north, and the northward flow of air established during this time helped to feed the warm sector of the following cyclonic system.

In April and July, wHl is only slightly more frequent; hence neH is again largely dependent on other types less conducive to its formation for its occurrence. In April the neH pattern sometimes forms after nHl or nHs, but the centre tends to lie, respectively, farther east off the coast than in October, or to the south as in January, but off the coast. In the first case, a front is usually present over the Gulf; consequently the development is weak. In the second case, cyclones are able to easily enter the Great Lakes Region. In July, any high to the southeast tends to develop off the coast and then either to unite with a high from the north over the Lakes, or to form a typical nceH giving a similar northward flow but within a very different synoptic pattern.

For monthly figures, neH is significant only in October. Temperatures are above normal, particularly in the north and occasionally throughout the entire region; hence in years of high frequency it may noticeably influence average temperatures.



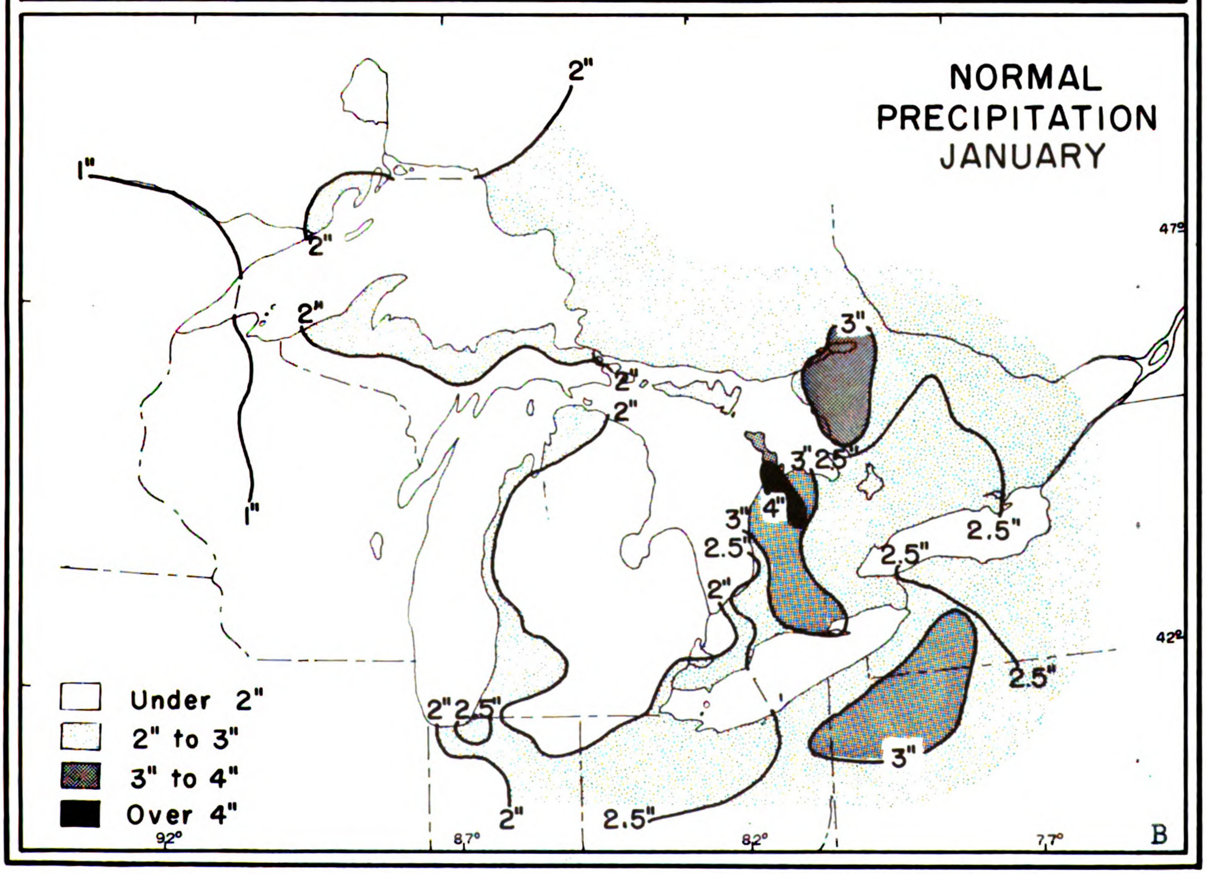




Fig. 15.—January, Normal Temperature and Precipitation

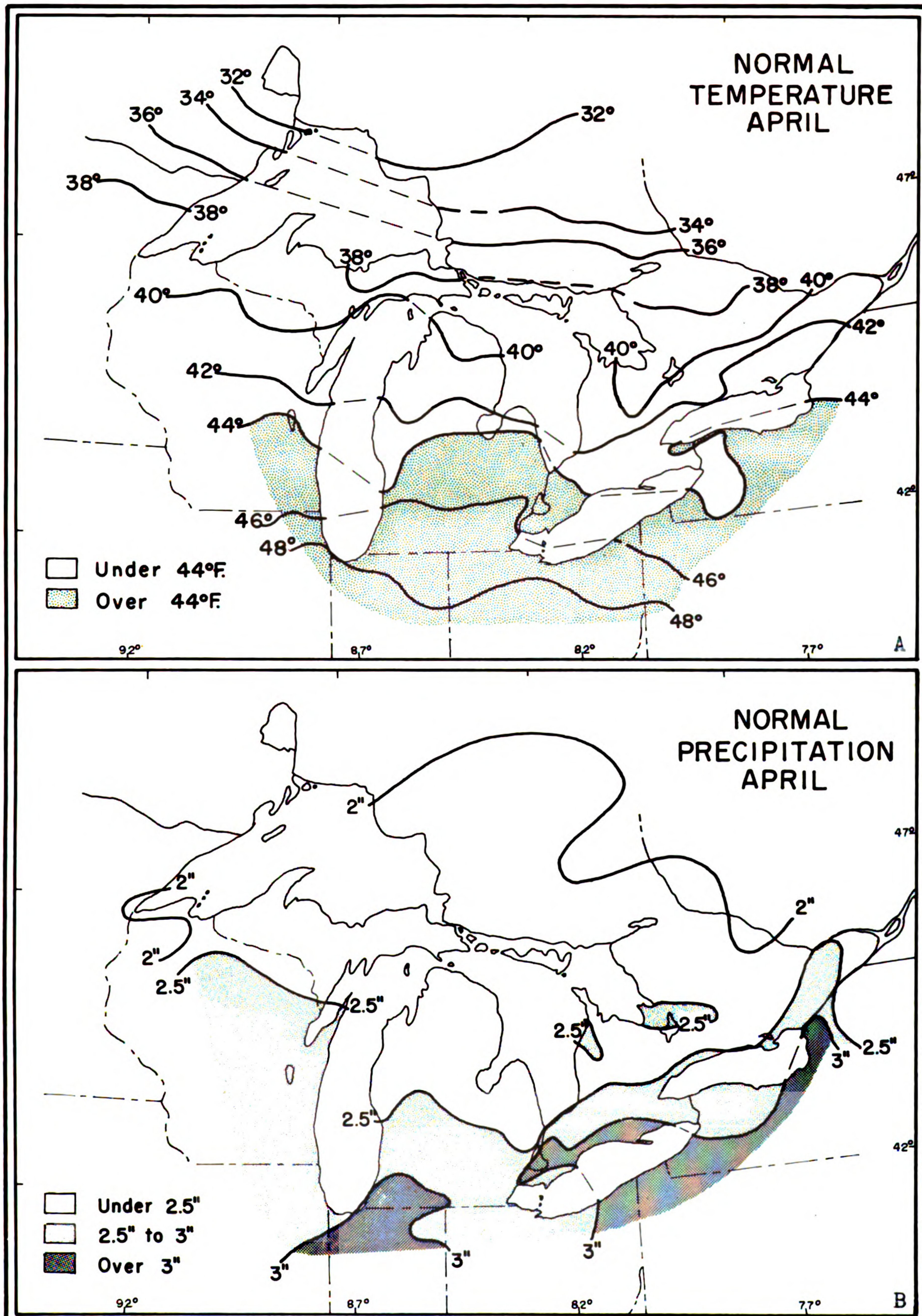



Fig. 16.--April, Normal Temperature and Precipitation

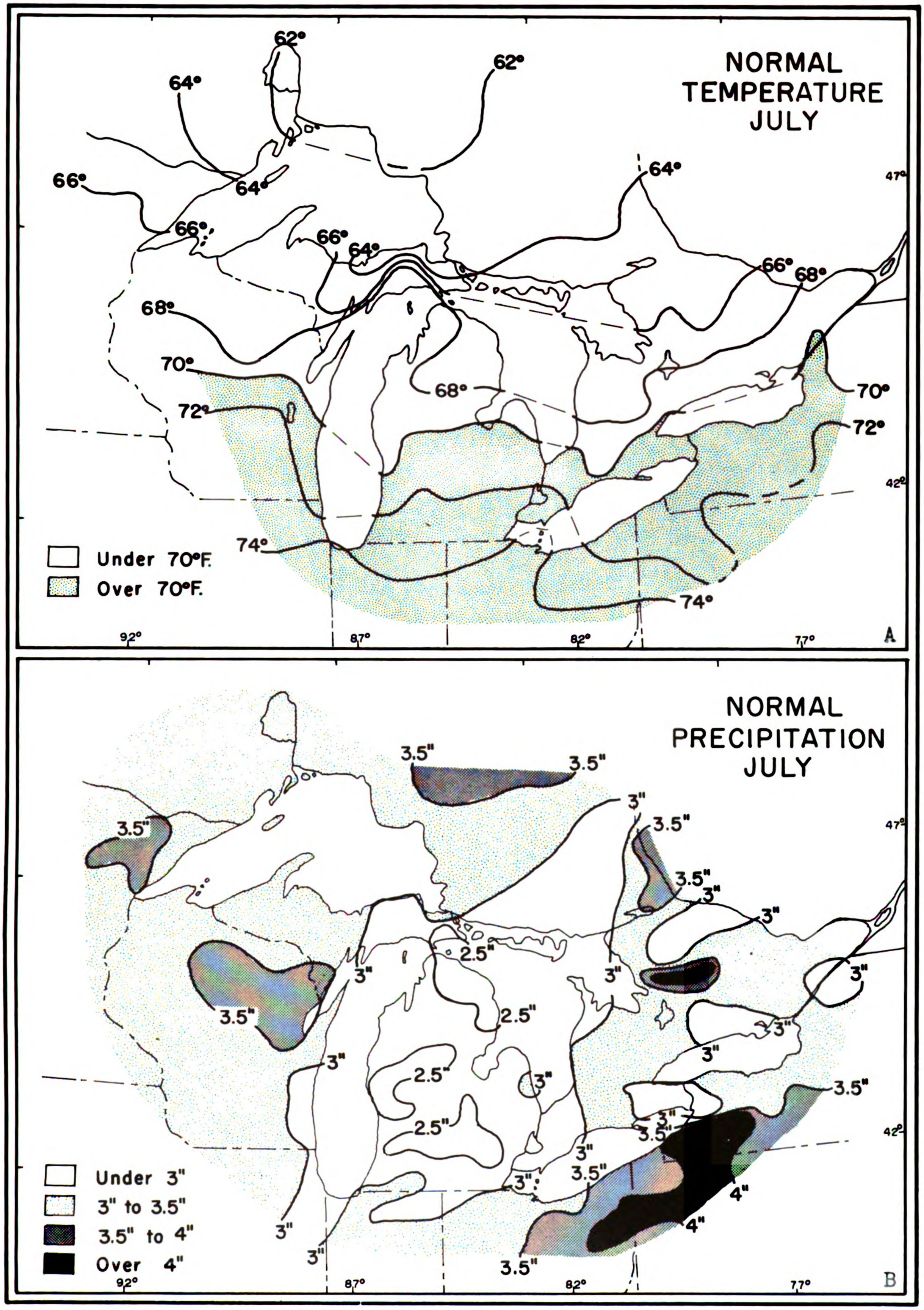



Fig. 17.--July, Normal Temperature and Precipitation

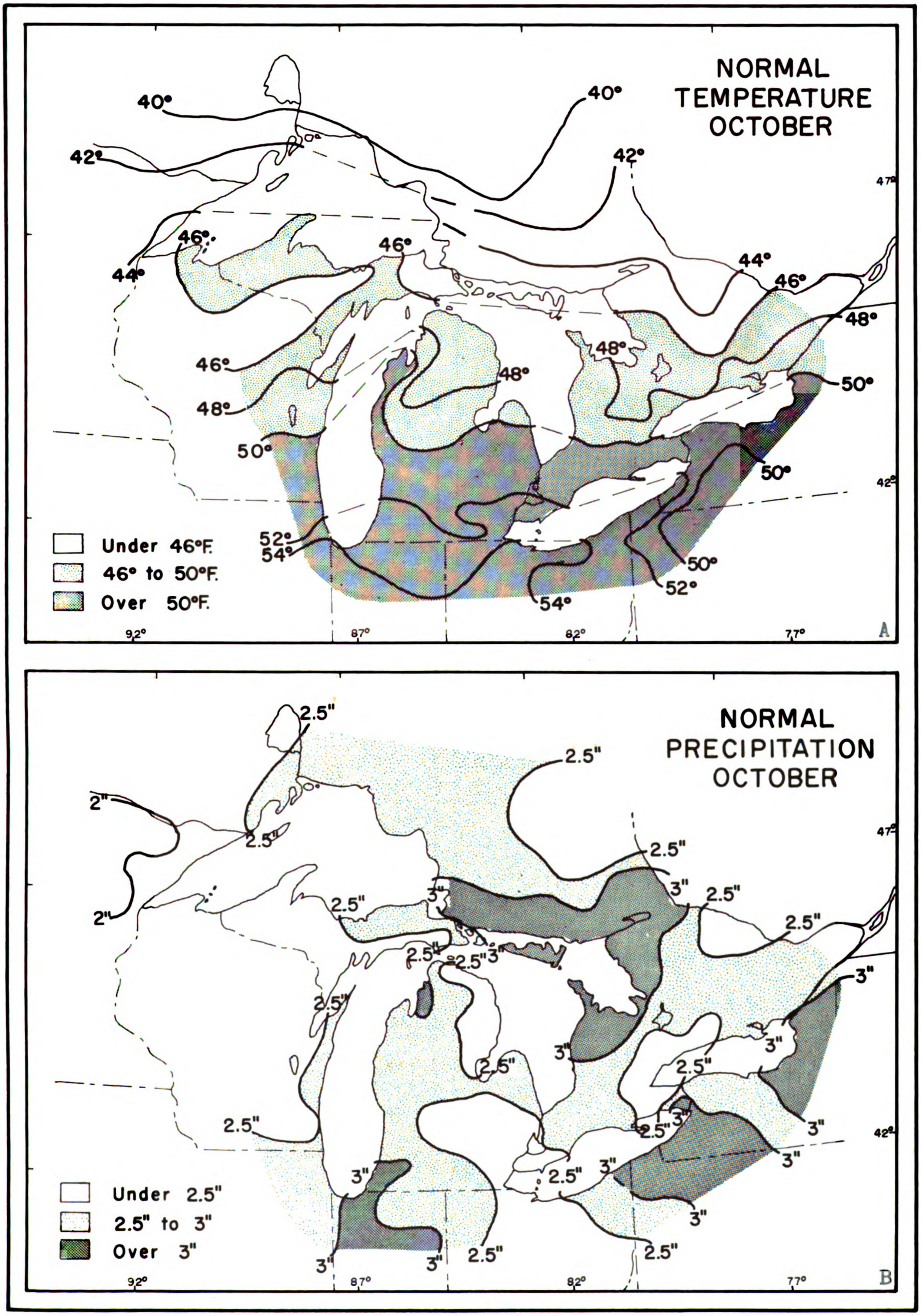



Fig. 18.--October, Normal Temperature and Precipitation

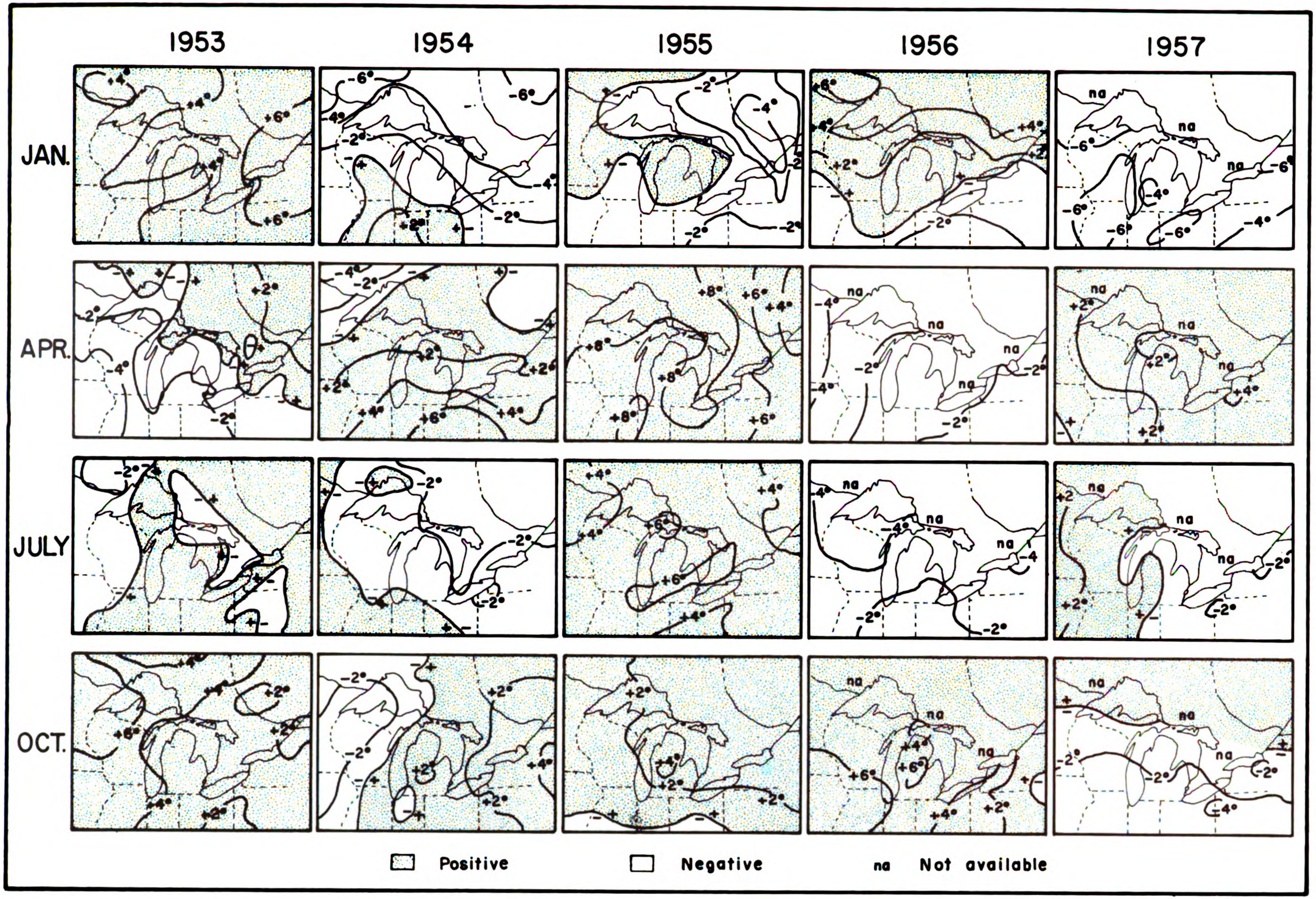



Fig. 19.—Departures of Monthly Average Temperatures from Normal, 1953-57

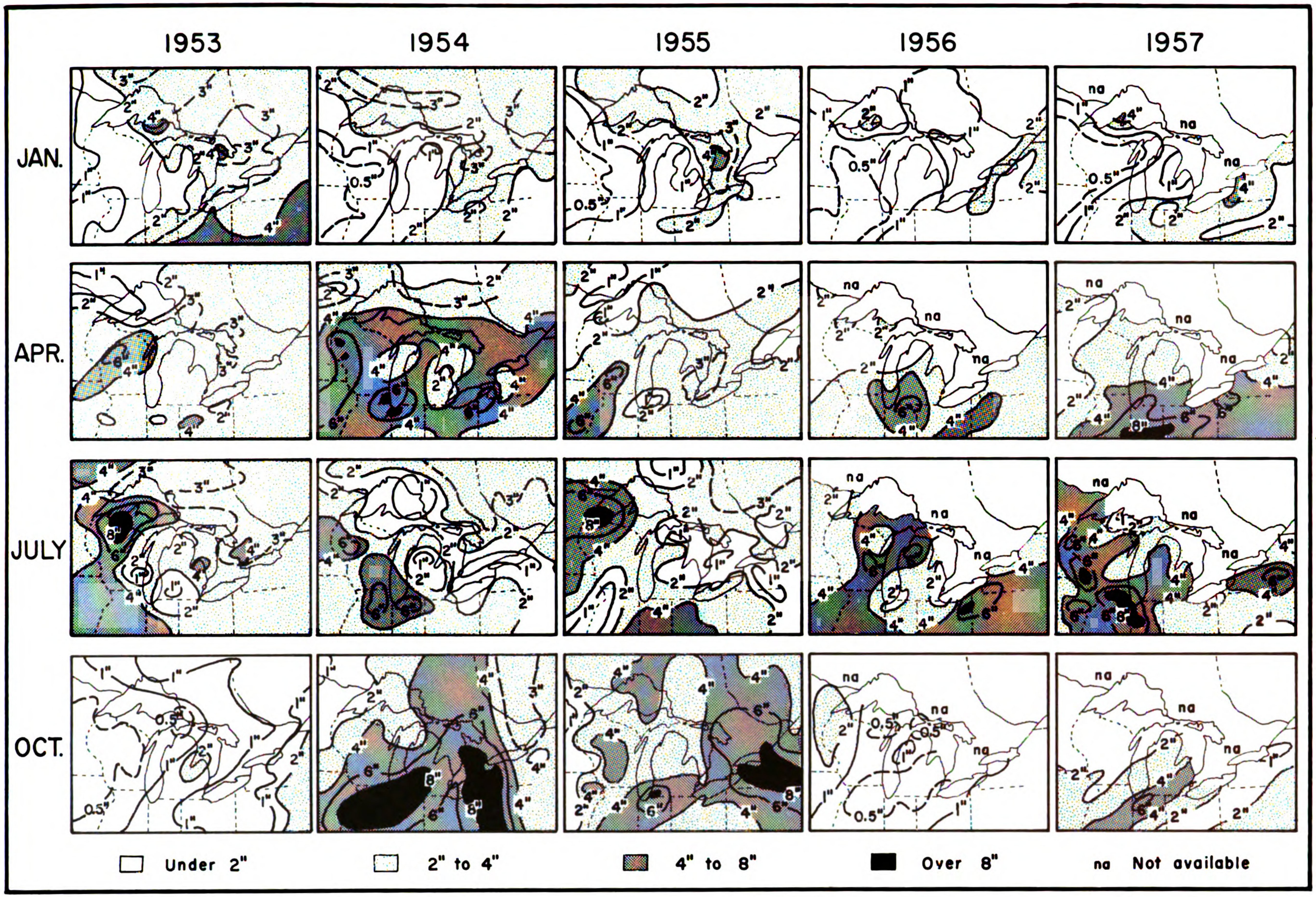



Fig. 20.--Monthly Total Precipitation, 1953-57

## SEASONAL CLIMATE OF THE GREAT LAKES REGION: A SYNTHESIS OF TYPE FREQUENCIES AND ELEMENTS

The ultimate purpose of establishing Great Lakes' weather types is, of course, a more complete understanding and description of the climate of the region through a synthesis of type frequencies and elements. In the following, each of the four months previously selected as representative of the seasons is analyzed with respect to: (1) frequencies of dynamic-synoptic system weather types; (2) effect of the individual types on daily element values and their regional variations in a sample month; (3) interpretation of the distribution of "normal" temperature and precipitation in terms of type frequencies; (4) deviations from "normal" as explained by type frequency v riations. Although the gross features of the relationships of type frequencies and elements to the overall climate are sufficiently distinctive to give them considerable justification for generalization, conclusions must be restricted to comparative statements at the level of dominant trends rather than be presented in detailed absolute terms. More exact quantitative analysis is not adviseable at this time in view of the probable inaccuracies due to the short observational period. Subsequent modification, no doubt, will be required.

### January

Mid-winter is clearly characterized first by a marked concentration of nHn and nHs (see Fig. [illegible]). Both of these types are very cold and together they are responsible for most below normal temperatures.

By far the colder of the two, nHs, is quite variable in its frequency from year to year; hence it is of great importance to average temperature fluctuations. Other anticyclonic types are very rare. Winter is, however, equally characterized by a diversity of the cyclonic types, all of which occur with fair frequency. Almost invariably, mLl is most numerous, but totaled over several years, there is a remarkably even distribution of the others. In most years, cyclonic days outnumber anticyclonic days because of this diversity, and the above normal temperatures associated with the warm sectors in the south tend to balance the cold of the anticyclones. Precipitation associated with the two dominant anticyclonic systems is very limited, except for snow flurries to the lee of the lakes with nHs. This lack is balanced by the variety of wet cyclonic types.

The accompanying table of daily temperatures for January 1954 (see Table 1) represents a typical winter month illustrating sequence, duration, and frequency of the various types and the related daily maximum and minimum temperatures. A few of the more significant relations follow. Except in Northern Ontario and in the extreme east, by far the lowest temperatures occurred on January 12 and 17 with nHs; in the north and east nHn is often as cold as nHs, for example, Buffalo on the 22nd or Chapleau on the 10th. In the southeast the highest temperatures occurred on January 2, with sLl. Other occurrences of sLl as well as mLl/ws were only slightly cooler. In contrast, in the northwest these days were frequently quite cold. Maxima in Cleveland were above 50° F. for every sLl; in Chapleau and Fort William they were below 10° F. On several occasions (January 3 and 29) the warm sector of a mLl reached farther north and the highest temperatures in the north were recorded either on these days or during one of the occurrences of aLl/a or aLn.

TABLE 1.--DAILY TEMPERATURE, JANUARY 1954

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTHEAST S.Ontario | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Kingston | mx | 36 | 21 | 20 | 22 | 24 | 26 | 20 | 2 | 2 | -1 | 0 | 4 | 6 | 10 | 37 | 38 | 36 | 12 | 27 | 37 | 6 | 3 | 26 | 36 | 33 | 42 | 30 | 32 | 30 | 25 | 21.8 |
| | mn | 3 | 3 | 10 | 9 | 17 | 16 | 6 | -5 | -10 | -11 | -15 | -21 | -13 | 0 | 24 | 18 | 14 | -13 | 22 | 35 | 2 | -15 | -10 | 6 | 33 | 33 | 12 | 0 | -10 | -2 | 4.2 |
| Malton | mx | 36 | 41 | 36 | 28 | 26 | 24 | 22 | 21 | 14 | 2 | 4 | 10 | 18 | 32 | 33 | 33 | 13 | 23 | 27 | 43 | 11 | 10 | 20 | 36 | 37 | 44 | 24 | 14 | 33 | 29 | 25.4 |
| | mn | 16 | 19 | 19 | 10 | 23 | 17 | 14 | 1 | 9 | -4 | -7 | -4 | -6 | 1 | 28 | 17 | -10 | 2 | 22 | 32 | 5 | -1 | 3 | 6 | 31 | 32 | 15 | 3 | -7 | 15 | 9.9 |
| South-ampton | mx | 35 | 41 | 24 | 25 | 28 | 26 | 22 | 19 | 21 | 10 | 14 | 13 | 20 | 33 | 34 | 33 | 16 | 28 | 36 | 39 | 17 | 15 | 27 | 36 | 38 | 38 | 22 | 13 | 35 | 33 | 26.1 |
| | mn | 11 | 20 | 13 | 2 | 22 | 22 | 14 | 9 | 12 | 3 | -4 | 4 | 3 | 8 | 29 | 15 | 1 | 6 | 20 | 31 | 2 | -2 | 2 | 20 | 33 | 30 | 15 | 6 | -3 | 17 | 11.8 |
| St.Thomas | mx | 40 | 46 | 32 | 29 | 29 | 28 | 30 | 24 | 40 | 16 | 22 | 15 | 24 | 32 | 37 | 32 | 14 | 29 | 41 | 49 | 17 | 16 | 31 | 36 | 44 | 43 | 32 | 20 | 35 | 26 | 30.3 |
| | mn | 17 | 15 | 21 | 14 | 23 | 21 | 18 | 10 | 15 | 6 | 4 | 3 | 4 | 9 | 14 | 21 | -9 | -16 | 25 | 30 | 12 | 3 | 7 | 19 | 32 | 33 | 19 | 7 | 2 | 14 | 13.2 |
| NY.Penn.Ohio | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Buffalo | mx | 38 | 49 | 47 | 33 | 33 | 25 | 25 | 18 | 40 | 13 | 17 | 12 | 20 | 34 | 36 | 33 | 15 | 32 | 43 | 53 | 40 | 12 | 31 | 46 | 37 | 52 | 24 | 16 | 34 | 34 | 31.2 |
| | mn | 19 | 21 | 23 | 23 | 25 | 21 | 12 | 10 | 13 | 5 | 6 | 6 | 5 | 12 | 28 | 15 | 1 | 6 | 29 | 40 | 10 | 5 | 5 | 38 | 34 | 34 | 15 | 7 | 4 | 15 | 15.7 |
| Rochester | mx | 33 | 47 | 43 | 28 | 27 | 23 | 25 | 18 | 28 | 16 | 14 | 15 | 21 | 23 | 42 | 33 | 15 | 27 | 36 | 51 | 42 | 15 | 26 | 47 | 38 | 50 | 47 | 16 | 30 | 34 | 30.6 |
| | mn | 16 | 22 | 25 | 24 | 24 | 23 | 14 | 9 | 8 | 6 | -1 | 5 | 2 | 6 | 25 | 15 | 1 | 1 | 29 | 30 | 12 | 3 | 4 | 21 | 34 | 34 | 21 | 2 | -1 | 17 | 14.5 |
| Erie | mx | 33 | 50 | 46 | 29 | 30 | 27 | 29 | 27 | 46 | 32 | 23 | 22 | 21 | 34 | 35 | 35 | 12 | 34 | 45 | 54 | 37 | 15 | 36 | 50 | 43 | 53 | 36 | 20 | 34 | 35 | 34.2 |
| | mn | 25 | 26 | 27 | 26 | 26 | 23 | 19 | 18 | 28 | 8 | 3 | 11 | 12 | 13 | 32 | 19 | 10 | 8 | 30 | 37 | 14 | 9 | 6 | 28 | 34 | 36 | 19 | 9 | 9 | 17 | 19.3 |
| Cleveland | mx | 42 | 54 | 50 | 30 | 31 | 30 | 32 | 33 | 50 | 28 | 27 | 21 | 13 | 34 | 36 | 35 | 20 | 35 | 42 | 57 | 35 | 23 | 38 | 41 | 46 | 54 | 51 | 23 | 37 | 38 | 36.4 |
| | mn | 29 | 29 | 26 | 26 | 25 | 26 | 26 | 22 | 28 | 16 | 2 | 10 | 3 | 13 | 31 | 25 | 3 | 3 | 32 | 35 | 25 | 15 | 11 | 31 | 33 | 37 | 20 | 17 | 16 | 16 | 20.5 |
| SOUTHWEST Ind.Ill.Wis. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Bend | mx | 42 | 50 | 36 | 37 | 32 | 34 | 37 | 37 | 43 | 28 | 22 | 15 | 22 | 31 | 33 | 31 | 14 | 30 | 42 | 52 | 23 | 23 | 36 | 34 | 43 | 52 | 35 | 30 | 27 | 36 | 34.0 |
| | mn | 29 | 35 | 29 | 29 | 19 | 15 | 22 | 20 | 25 | 13 | 12 | 3 | -1 | 21 | 20 | 13 | -2 | 8 | 30 | 22 | 12 | 9 | 14 | 28 | 32 | 34 | 24 | 17 | 23 | 16 | 19.1 |
| Chicago | mx | 42 | 43 | 36 | 34 | 40 | 33 | 36 | 43 | 45 | 27 | 22 | 14 | 24 | 33 | 34 | 30 | 15 | 30 | 43 | 53 | 25 | 23 | 37 | 35 | 43 | 51 | 34 | 32 | 33 | 37 | 35.2 |
| | mn | 33 | 33 | 31 | 30 | 30 | 29 | 24 | 28 | 19 | 14 | 5 | 0 | 3 | 23 | 21 | 5 | -7 | 10 | 30 | 22 | 13 | 18 | 17 | 29 | 28 | 31 | 21 | 17 | 32 | 17 | 20.1 |
| Milwaukee | mx | 41 | 43 | 35 | 39 | 36 | 36 | 36 | 36 | 36 | 24 | 24 | 9 | 22 | 35 | 30 | 28 | 9 | 25 | 37 | 38 | 18 | 22 | 31 | 34 | 29 | 22 | 29 | 29 | 37 | 28 | 30.7 |
| | mn | 34 | 31 | 28 | 29 | 27 | 29 | 22 | 30 | 13 | 9 | 1 | -4 | -4 | 19 | 13 | -8 | -13 | 8 | 19 | 11 | 6 | 12 | 15 | 26 | 23 | 25 | 15 | 5 | 28 | 7 | 15.2 |
| Green Bay | mx | 34 | 37 | 31 | 32 | 31 | 33 | 33 | 32 | 32 | 12 | 19 | 8 | 17 | 33 | 30 | 24 | -2 | 20 | 32 | 29 | 9 | 13 | 33 | 33 | 28 | 28 | 25 | 23 | 32 | 19 | 25.4 |
| | mn | 25 | 27 | 18 | 18 | 13 | 26 | 20 | 23 | 7 | 2 | 1 | -8 | -11 | 6 | 5 | -13 | -19 | -2 | 2 | -1 | -12 | -9 | 2 | 22 | 19 | 18 | 6 | -2 | 18 | 0 | 6.1 |
| WEATHER TYPES | | aLl/a | mLl/ws | mLl/ws | nHn | mLl, gLe | gLe | nHn | nHn | sLl | nHn | mLl/c | nHs | nHs aLl/a | aLl/a | aLn/d | aLn/d | nHs | neH mLl/c | mLl/c | sLl | nHn | nHn | nHn | neH mLl/c | sLl | sLl | sLl | nHn | mLl/ws | mLl/c | |

TABLE 1—Continued

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRAL | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alpena | mx | 33 | 36 | 38 | 38 | 33 | 31 | 25 | 20 | 23 | | 17 | 16 | 16 | 26 | 31 | 29 | | 18 | 30 | 36 | 29 | 17 | 24 | 34 | 31 | 32 | 27 | 24 | 29 | 34 | 27.7 |
| | mn | 15 | 15 | 24 | 0 | 24 | 24 | 14 | 11 | 14 | 4 | 0 | 5 | -5 | -2 | 13 | -1 | | -8 | 15 | 13 | 3 | -5 | 2 | | 27 | 26 | 13 | -13 | 9 | 13 | 9.2 |
| Detroit | mx | 42 | 50 | 44 | 30 | 29 | 31 | 32 | 31 | 43 | 26 | 22 | 21 | 19 | 32 | 35 | 31 | 14 | 30 | 41 | 51 | 26 | 17 | 32 | 40 | 32 | 51 | 33 | 25 | 34 | 35 | 32.6 |
| | mn | 33 | 32 | 24 | 26 | 26 | 27 | 21 | 22 | 26 | 12 | 10 | 13 | 10 | 17 | 23 | 12 | 6 | 11 | 29 | 26 | 13 | 9 | 12 | 23 | 35 | 32 | 16 | 8 | 21 | 11 | 17.5 |
| E.Lansing | mx | 33 | 46 | 36 | 28 | 22 | 31 | 30 | 27 | 37 | 24 | 20 | 14 | 21 | 30 | 32 | 23 | 11 | 28 | 40 | 48 | 35 | 13 | 32 | 33 | 32 | 44 | 25 | 26 | 33 | 29 | 32.3 |
| | mn | 31 | 25 | 22 | 24 | 25 | 25 | 10 | 19 | 24 | 6 | 10 | 6 | 3 | 21 | 21 | 12 | 2 | 9 | 23 | 19 | 8 | 7 | 9 | 31 | 32 | 25 | 10 | 1 | 17 | 4 | 15.9 |
| Muskegon | mx | 29 | 44 | 35 | 33 | 33 | 33 | 33 | 29 | 36 | 22 | 23 | 22 | 20 | 25 | 31 | 32 | 12 | 29 | 35 | 37 | 20 | 12 | 35 | 35 | 35 | 42 | 27 | 29 | 36 | 35 | 30.8 |
| | mn | 31 | 33 | 22 | 23 | 23 | 23 | 16 | 14 | 22 | 3 | 2 | 13 | 13 | 15 | 9 | 12 | 6 | 7 | 28 | 20 | 9 | 2 | 10 | 25 | 30 | 27 | 9 | -1 | 27 | 13 | 16.3 |
| Traverse City | mx | 35 | 42 | 27 | 31 | 33 | 32 | 29 | 26 | 27 | 13 | 19 | 18 | 17 | 32 | 33 | 30 | 10 | 23 | 34 | 34 | 18 | 18 | 30 | 35 | 35 | 34 | 23 | 25 | 35 | 29 | 27.7 |
| | mn | 20 | 22 | 9 | 8 | 23 | 25 | 15 | 8 | 18 | -9 | 3 | 9 | 5 | 15 | 11 | 7 | 0 | 5 | 21 | 18 | 7 | -10 | 8 | 23 | 26 | 21 | 4 | -8 | 20 | 11 | 11.6 |
| Upper Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Escanaba | mx | 31 | 35 | 31 | 32 | 21 | 22 | 29 | 28 | 28 | 18 | 20 | 10 | 16 | 29 | 27 | 21 | 3 | 14 | 26 | 24 | 10 | 17 | 30 | 34 | 26 | 27 | 24 | 23 | 32 | 29 | 24.2 |
| | mn | 14 | 22 | 20 | 26 | 23 | 26 | 15 | 18 | 11 | 4 | 3 | 0 | -13 | 16 | 10 | -7 | -16 | -3 | -6 | 7 | -2 | -6 | 17 | 25 | 22 | 15 | 11 | -2 | 20 | 6 | 9.2 |
| Sault Ste. Marie | mx | 26 | 19 | 24 | 26 | 30 | 29 | 15 | 8 | 10 | -1 | 12 | 2 | 16 | 25 | 28 | 25 | 7 | 17 | 30 | 31 | 7 | 6 | 25 | 24 | 23 | 23 | 15 | 13 | 30 | 21 | 19.4 |
| | mn | 12 | 10 | 6 | 9 | 25 | 9 | 3 | -3 | -6 | -16 | -4 | -7 | 1 | 15 | 20 | -3 | -16 | -3 | 0 | -2 | -10 | -8 | 2 | 21 | 17 | 9 | 3 | -7 | 11 | 10 | 2.9 |
| Marquette | mx | 31 | 29 | 32 | 30 | 33 | 33 | 29 | 26 | 23 | 15 | 19 | 8 | 13 | 27 | 23 | 16 | 7 | 14 | 27 | 25 | 7 | 14 | 32 | 36 | 24 | 26 | 22 | 26 | 33 | 17 | 23.3 |
| | mn | 16 | 19 | 22 | 24 | 29 | 27 | 24 | 16 | 11 | 8 | 6 | 2 | -5 | 10 | 15 | -7 | -11 | -2 | 7 | 7 | -1 | 14 | 22 | 20 | 17 | 17 | 11 | 17 | 5 | 12 | 11.3 |
| NORTH | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Minn., N.Ont. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Fort William | mx | 11 | 14 | 33 | 31 | 27 | 27 | 21 | 12 | -2 | 3 | -1 | -3 | 16 | 20 | 8 | -12 | -5 | 3 | 7 | 0 | -12 | 17 | 26 | 14 | 7 | 5 | 7 | 20 | 24 | 3 | 10.8 |
| | mn | -9 | -1 | -18 | 15 | -5 | 15 | 3 | 7 | -11 | -31 | -13 | -27 | -23 | 5 | -7 | -19 | -26 | -18 | -23 | -14 | -25 | -27 | -6 | 1 | -14 | -13 | -20 | -6 | 1 | -10 | -11.0 |
| Chapleau | mx | 7 | 11 | 18 | 25 | 22 | 2 | 0 | 8 | -4 | -4 | 8 | 1 | 25 | 20 | 25 | 10 | 5 | 13 | 23 | 7 | -4 | 10 | 6 | 21 | 8 | 3 | 0 | 16 | 5 | 6 | 10.4 |
| | mn | -24 | 1 | 4 | -4 | 12 | 2 | -16 | -22 | -7 | -39 | -36 | -22 | -30 | 5 | 10 | -12 | -10 | -41 | -19 | -7 | -29 | -34 | -21 | -14 | -4 | -6 | -11 | -24 | -19 | -2 | -15.3 |
| North Bay | mx | 22 | 9 | 19 | 17 | 22 | 16 | 12 | 0 | 2 | -1 | - | -1 | 16 | 27 | 28 | 25 | 0 | | | | | | | 33 | 33 | 22 | 10 | 10 | 22 | 29 | |
| | mn | -4 | -4 | -4 | -12 | 2 | 9 | -1 | -13 | -2 | -18 | -19 | -12 | -26 | 10 | 9 | -8 | -22 | | | | | | | | 15 | 10 | 0 | -7 | -11 | -6 | |
| Muskoka | mx | 31 | 26 | 22 | 18 | 24 | 20 | 12 | 13 | 5 | 3 | 6 | 2 | 15 | 29 | 30 | 28 | 10 | 26 | 33 | 29 | 4 | 4 | 22 | 35 | 34 | 33 | 16 | 14 | 31 | 20 | 20.1 |
| | mn | -3 | 3 | 11 | -14 | 4 | 14 | 0 | -12 | 0 | -16 | -16 | -8 | -25 | 2 | 10 | 2 | -22 | -15 | 15 | 27 | -6 | -19 | -11 | 10 | 30 | 28 | 10 | -5 | 13 | 11 | -0.6 |
| WEATHER TYPES | | aLl/a | mLl/ws | mLl/ws | nHn | mLl,gLe | gLe | nHn | nHn | sLl | nHn | mLl/c | nHs | nHs aLl/a | aLl/a | aLn/d | aLn/d | nHs | neH mLl/c | mLl/c | sLl | nHn | nHn | nHn | neH mLl/c | sLl | sLl | sLl | nHn | mLl/ws | mLl/c | |

Fort William recorded a maximum of 33° F. on January 3 during a mHl/ws and Chapleau 25° F. on January 15 during an aLn. Note the alternation of nHn and nHs with the variety of cyclonic types. Examples of Lake modification are abundant. Maxima and minima, respectively, with nHs on the seventeenth were 12° and 6° F. at Muskegon but 9° and -13° F. at Milwaukee. Similarly on January 12 they were 22° and 13° F. at Muskegon but 9° and -4° F. at Milwaukee.

The distribution of normal or long term temperature averages (Fig. 15A) reflects the dominant frequency generalizations and the importance of modification by the lakes. Temperatures over the entire region are quite cold, but have a fairly steep latitudinal gradient: in the south they are in the mid-twenties, in the north close to zero. Both the generally cold temperatures and the steep gradient demonstrate the balance between the northern cold of the anticyclonic types, nHn and nHs, and the cyclonic types which are more moderate, particularly in the south. In the southeast the isotherms even have a rough southwest-northeast trend which is coincident with the path of warm sector influence of all the lows. In more detail, several cold loops are remarkably apparent: north-central Wisconsin, the northern interior of Lower Michigan, and a fairly large but very well defined area south of Georgian Bay. North of the Lower Michigan loop and, especially, the Wisconsin loop there is even a marked reversal of gradient. These areas are, in most cases, the least influenced by the lakes. Identical isotherm patterns in these areas are characteristic of both nHs and nHn, and even of many of the cyclonic types. In contrast, almost all shores have relatively high temperatures for their latitude.

The accompanying maps of temperature departure from normal

(Fig. 19) demonstrate actual conditions from year to year as a result of variations in the frequencies of the different types (Fig. 2). The maps are very generalized, but the gross features are still easily recognized. Of particular note, as might be expected, is the contrasting influence of nHs to cyclonic types in the extremes of 1953 and 1957. In January, 1953, the entire areas was 4° to 6° above normal. In that year only one day of nHs was recorded whereas there were many cyclonic type days. The east was, relative to normal, slightly warmer than the west as a result of a higher frequency than usual of gLe and a number of very mild sLl days. In 1957, on the other hand, the entire region was 4° to 7° below normal. In that year there was a high incidence of nHs and a corresponding small number of lows. In the other three years no type or types were especially unusual in their frequency. The zero line of temperature departures passed through the region and type influences are much more difficult to detect. In 1954 the frequency distribution of types was fairly close to the long term distribution and temperatures in southern and eastern areas were close to normal; nHn, however, was more frequent than nHs with the result that the east was slightly colder than the west. Temperatures in the south were slightly higher relative to normal than in the north because of the large number of mLl and sLl. The year 1955 was again close to normal except for lower eastern temperatures due to the small number of sLl and gLe. In 1956 nHs was slightly more frequent and cyclonic types, particularly warm sector subtypes, were not overly common. Southern temperatures were therefore below normal while northern temperatures, less dependent on warm sector subtypes, were maintained by mLl and the one aLn.

January daily precipitation by type is illustrated by Table 2[1]. Of particular note are the heavy concentrations of precipitation on days of sLl (January 9, 20, and 25-7) and slightly less amounts with mLl and aLl, as opposed to the small amounts on days of nHn (January 4, and 21-23) and nHs (January 12 and 17). For sLl the fall is greatest northwest of the path followed by the centre of the low (e.g. Upper Michigan to Chapleau, Northern Ontario on the 9th; Detroit to the area east of North Bay on the 20th; Toledo to Muskoka on the 26th and 27th). East of this belt almost all areas receive heavy precipitation particularly those to the lee of the lakes. It should be recognized, however, that sLl does not usually occur as frequently as in 1954. Normally either mLl or aLl may be more important in monthly totals. Precipitation with mLl is widespread and areas of concentration vary. For aLl (e.g. January 1), the greatest amounts fall across Northern Ontario, south of Lake Superior, and east of Lakes Michigan, Huron, and Erie. Precipitation with nHs, although generally light, is sometimes considerable to the lee of the lakes (e.g. Cleveland and Southampton on the 12th).

The map of normal January precipitation (Fig. 15B) shows the importance of sLl and gLe. In the east, amounts are all over 2 inches

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[1]In this table and subsequent precipitation tables numerous significant departures from expected amounts according to type are apparent. Such discrepancies serve only to illustrate two dangers: (1) that of accepting statistics of isolated stations without placing them in their spatial context on a map giving a fairly dense network of stations; (2) that of using a full day interval for relating precipitation to types. (The "day interval" problem for temperature is not as great because of the effect of either averaging or of splitting the record into two instantaneous observations - as opposed to the cumulative record of precipitation). In the preceding daily precipitation maps for types the former has been eliminated in the drawing of isohyets and the latter minimized by careful selection of representative days. These maps, therefore, are more reliable for detail than the statistical charts.

TABLE 2.—DAILY PRECIPITATION,* JANUARY 1954

| Station | SOUTHEAST | | | | | | | | | SOUTHWEST | | | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S. Ontario Kingston | Malton | Durham | Southampton | NY.Penn.Ohio Buffalo | Rochester | Erie | Cleveland | Toledo | Ind.Ill.Wis. South Bend | Chicago | Milwaukee | |
| Day | | | | | | | | | | | | | |
| 1 | | T | | | 07 | 08 | | | | | | | aLl/a |
| 2 | | 02 | | | T | | T | | T | | | T | mLl/ws |
| 3 | | | | | 10 | 03 | 06 | 03 | T | T | T | T | mLl/ws |
| 4 | | T | | | T | T | T | | T | | T | 01 | nHn |
| 5 | T | 04 | | | 07 | T | T | 04 | 11 | 31 | 06 | T | mLl, gLe |
| 6 | 30 | 02 | 05 | | 14 | 10 | 04 | 06 | 05 | T | T | T | gLe |
| 7 | | | 05 | | T | T | T | 02 | 01 | | | T | nHn |
| 8 | | T | | | T | 02 | T | T | | | | | nHn |
| 9 | 10 | 11 | 05 | 02 | 10 | 07 | 01 | 04 | T | 01 | | T | sLl |
| 10 | | 01 | | | 04 | 02 | 01 | 14 | T | T | T | 03 | nHn |
| 11 | 15 | 12 | | | T | T | 06 | 02 | T | 06 | T | 03 | mLl/c |
| 12 | | T | | 25 | 07 | 07 | 11 | 35 | 04 | 06 | | | nHs |
| 13 | | T | T | 03 | 05 | T | T | T | | T | T | T | nHs aLl/a |
| 14 | 05 | T | | | 01 | T | T | 12 | 02 | 02 | 02 | T | aLl/a |
| 15 | | | | | T | T | T | 02 | T | 01 | T | T | aLn/d |
| 16 | 10 | 01 | 05 | 05 | 06 | 02 | 05 | 08 | T | 04 | T | T | aLn/d |
| 17 | | T | | T | 03 | 02 | T | 03 | T | T | | | nHs |
| 18 | 05 | T | | 10 | T | T | T | T | T | T | T | T | neH mLl/e |
| 19 | | 10 | | 03 | T | T | T | 02 | T | T | T | T | mLl/c |
| 20 | 53 | 50 | 53 | 20 | 47 | 23 | 26 | 69 | 95 | 15 | 21 | 31 | sLl |
| 21 | | | | | 33 | 06 | 12 | 05 | 01 | T | 07 | 02 | nHn |
| 22 | | T | | | T | 03 | T | T | T | | T | 01 | nHn |
| 23 | | 01 | | | | T | | | T | | | | nHn |
| 24 | | T | | | T | | T | 02 | 01 | 01 | T | T | neH mLl/c |
| 25 | 03 | 03 | T | 24 | T | T | T | T | 01 | 06 | 07 | 06 | sLl |
| 26 | 41 | 45 | 46 | 14 | 46 | 20 | 36 | 91 | 87 | 71 | 66 | 25 | sLl |
| 27 | 10 | 51 | 60 | 35 | 62 | 34 | 53 | 35 | 07 | 08 | T | 18 | sLl |
| 28 | | T | | | 05 | 06 | T | 01 | | 09 | T | 02 | nHn |
| 29 | 09 | T | T | 15 | T | 02 | T | 06 | 06 | 01 | T | T | mLl/ws |
| 30 | 04 | 09 | 20 | 20 | 27 | 15 | 14 | 05 | T | 01 | | | mLl/c |
| Total | 194 | 206 | 199 | 176 | 294 | 153 | 175 | 312 | 221 | 163 | 110 | 93 | |

*Unit of precipitation is 0.01 inch.

TABLE 2—Continued

| Station | CENTRAL Lower Mich. Alpena | Detroit | E. Lansing | Muskegon | Traverse City | Upper Mich. Escanaba | Sault Ste. Marie | Marquette | NORTH Minn.,N.Ont. Duluth | Chapleau | North Bay | Muskoka | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | | | | | | | | | | | | | |
| 1 | 09 | | | | 05 | 08 | 08 | 04 | 20 | 14 | 06 | 08 | aLl/a |
| 2 | | | T | | 02 | T | 15 | 18 | 16 | 25 | 60 | 12 | mLl/ws |
| 3 | 01 | T | T | | | | | T | T | | | 01 | mLl/ws |
| 4 | | T | | | | | T | T | | | | | nHn |
| 5 | T | 01 | T | 22 | 01 | T | T | | 05 | | 02 | T | mLl, gLe |
| 6 | 08 | 01 | | 01 | T | 02 | | 04 | T | 06 | 01 | 01 | gLe |
| 7 | | T | | 04 | 03 | 03 | T | 01 | T | | T | | nHn |
| 8 | 02 | T | | | T | 03 | T | 04 | 07 | | 18 | 03 | nHn |
| 9 | 05 | T | T | T | 15 | 16 | 10 | 31 | 07 | 72 | 24 | 02 | sLl |
| 10 | 08 | T | T | T | 09 | 01 | T | 13 | 11 | 03 | | | nHn |
| 11 | 06 | 04 | 03 | 35 | 15 | 41 | 04 | 21 | | 01 | 02 | | mLl/c |
| 12 | 17 | 04 | T | 05 | 11 | | 01 | 11 | T | 05 | T | | nHs |
| 13 | | | | T | T | 01 | 03 | T | 10 | | 03 | T | nHs aLl/a |
| 14 | T | 04 | T | T | 01 | 07 | 23 | 04 | 11 | | 09 | 17 | aLl/a |
| 15 | T | T | | | T | 04 | 03 | 05 | 04 | 10 | 22 | | aLn/d |
| 16 | 08 | 01 | T | 13 | 32 | T | 06 | 10 | 02 | | 10 | 04 | aLn/d |
| 17 | T | T | | 07 | 02 | | 03 | | T | | T | T | nHs |
| 18 | T | T | | 02 | 05 | 04 | 06 | 09 | 02 | 20 | 13 | 04 | neH mLl/c |
| 19 | T | 02 | 02 | 01 | T | | 02 | | 05 | | T | 03 | mLl/c |
| 20 | 42 | 64 | 18 | 31 | 28 | 06 | 11 | 09 | 04 | | 41 | 49 | sLl |
| 21 | | T | | T | 12 | | T | 01 | | 02 | | | nHn |
| 22 | | T | | | T | | T | | T | | | | nHn |
| 23 | | | | | | | T | | T | | | | nHn |
| 24 | | T | | T | T | T | T | T | T | 03 | 04 | T | neH mLl/c |
| 25 | T | 02 | | 05 | 01 | 06 | 02 | 09 | 36 | | 07 | 17 | sLl |
| 26 | T | 53 | 50 | 20 | 06 | 03 | 06 | 09 | 01 | 56 | 06 | 11 | sLl |
| 27 | 04 | 21 | 20 | 46 | 10 | | | 01 | 03 | | T | 54 | sLl |
| 28 | | | | 03 | T | 02 | T | T | T | | | | nHn |
| 29 | 07 | 11 | 03 | 05 | 22 | 13 | 05 | 02 | | 05 | 20 | 11 | mLl/ws |
| 30 | T | | T | 03 | 05 | | 26 | T | | | 04 | 06 | mLl/c |
| Total | 117 | 168 | 97 | 205 | 185 | 122 | 134 | 169 | 145 | 222 | 253 | 204 | |

whereas west of Lake Huron they are, for the most part, under 2 inches. The influence of the lakes in increasing precipitation to their lee during several of the types, noteably aLl, sLl and nHs, is even more demonstrative as all eastern and southeastern shores are areas of relatively heavy fall. In the west, Upper Michigan, western Lower Michigan, and Indiana average over 2 inches; in the east, the "snow belt" areas of Western Ohio, Pennsylvania, western New York, central southwestern Ontario, and eastern Georgian Bay average over 3 inches. Minnesota, farthest from both the eastern precipitation belts and the lake influence receives less than 1 inch.

Deviation from normal (see Fig. 20) is never very great because of the diversity and high combined reliability of the cyclonic types. In 1953 precipitation was fairly heavy in the east with a high frequency of gLe and sLl. In contrast, eastern areas generally received under 2 inches in 1955 when there were few gLe or sLl days. In 1956precipitation was light, especially across the north, with the smaller number mLl and no aLl. Finally, in 1957 amounts were again generally low, except east of Lake Erie, with the small number of cyclones and large number of nHs days.

Due to the variety of contributing types, in most years lee-of-the-lakes concentrations may be distinguished, especially on the south shore of Lake Superior and the Lake Huron peninsula of Ontario. The southwestern Ontario snow belt, for example, is particularly well developed in 1955 with the large number of aLl days but is nonexistent in 1956 when there were no aLl occurrences. The Lake Erie snow belt is developed best in 1957 with the high incidence of nHs and fair number of aLl days. Also clearly evident in all years is the Wisconsin minimum, while the Michigan Saginaw minimum appears in 1955-57.

April

The outstanding feature of April in the Great Lakes Region is the marked concentration of mLl and sLl, both of which are important warm sector and precipitation types. Together they occur on over 45% of the days. In contrast, aLn occurs only irregularly and gLe and aLl are almost completely absent. There are, however, still a fair number of nHs occurrences bringing periodic cold waves, n&eH becomes more frequent and, with the stabilizing effect of the cold lakes, relatively weak nHl systems appear in some years. The odd nHn is recorded, but the northern highs which usually form this type are generally weaker than those of nHs and tend more to be drawn across the Lakes. Occurrences of n&eH are introduced in this month primarily by mLl; hence they are mainly of the subtype (s) with fronts south of the Lakes. Thus, they as well as nHs and nHl are relatively cool and again tend to oppose the warmer lows, though not as effectively as the nHn and nHs anticyclones of winter, in the creation of a north-south gradient.

The temperature chart for April 1953 (Table 3) shows that by far the highest temperatures in the south occur with sLl or mLl/ws. Both these types had maxima occasionally in the seventies. Cleveland, generally the warmest station listed in the chart, recorded 77° and 75° F. with sLl systems on April 9 and 30 respectively and 73° F. with mLl/ws on April 25. Means on the same days were either 62° or 63°, approximately 14° above normal. Chicago and Milwaukee reached maxima of 80° and 79° F. respectively on April 22 with another mLl/ws. In the northwest, on the other hand, days of sLl and also the majority of days of mLl are normally

TABLE 3.--DAILY TEMPERATURE, APRIL 1953

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTHEAST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. Ontario | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Malton | mx | 50 | 50 | 54 | 53 | 44 | 47 | 51 | 56 | 54 | 60 | 51 | 43 | 48 | 43 | 53 | 42 | 41 | 42 | 43 | 45 | 51 | 64 | 60 | 58 | 43 | 50 | 45 | 47 | 46 | 54 | 50.5 |
| | mn | 33 | 32 | 23 | 38 | 35 | 30 | 32 | 32 | 42 | 43 | 38 | 33 | 36 | 26 | 28 | 36 | 30 | 23 | 23 | 31 | 30 | 33 | 44 | 30 | 42 | 43 | 39 | 39 | 30 | 32 | 34.0 |
| Durham | mx | 43 | 47 | 58 | 46 | 35 | 42 | 43 | 56 | 58 | 52 | 43 | 47 | 45 | 45 | 55 | 43 | 37 | 36 | 44 | 36 | 42 | 58 | 53 | 59 | 49 | 55 | 39 | 42 | 53 | 59 | 48.0 |
| | mn | 33 | 27 | 22 | 31 | 32 | 30 | 20 | 29 | 40 | 35 | 32 | 26 | 29 | 24 | 20 | 31 | 23 | 22 | 18 | 27 | 27 | 31 | 33 | 32 | 41 | 44 | 23 | 20 | 22 | 36 | 29.8 |
| St. Thomas | mx | 47 | 50 | 51 | 50 | 46 | 49 | 51 | 53 | 63 | 53 | 52 | 44 | 46 | 47 | 54 | 42 | 42 | 42 | 36 | 40 | 51 | 61 | 65 | 55 | 63 | 56 | 41 | 47 | 43 | 57 | 50.4 |
| | mn | 33 | 34 | 27 | 37 | 35 | 33 | 32 | 29 | 41 | 42 | 37 | 36 | 34 | 29 | 28 | 35 | 30 | 25 | 30 | 29 | 29 | 32 | 39 | 31 | 44 | 46 | 37 | 30 | 30 | 42 | 33.7 |
| NY.Penn.Ohio | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Buffalo | mx | 53 | 50 | 62 | 52 | 44 | 52 | 51 | 59 | 63 | 64 | 46 | 43 | 45 | 47 | 60 | 48 | 41 | 40 | 43 | 42 | 41 | 63 | 53 | 63 | 67 | 65 | 46 | 43 | 54 | 68 | 52.6 |
| | mn | 34 | 34 | 31 | 39 | 34 | 33 | 36 | 32 | 43 | 41 | 33 | 33 | 31 | 29 | 29 | 36 | 31 | 30 | 23 | 30 | 29 | 35 | 46 | 36 | 47 | 43 | 40 | 36 | 32 | 43 | 35.3 |
| Rochester | mx | 52 | 50 | 59 | 57 | 48 | 50 | 47 | 55 | 64 | 63 | 52 | 49 | 45 | 46 | 38 | 30 | 44 | 44 | 43 | 41 | 46 | 63 | 63 | 63 | 67 | 58 | 47 | 45 | 57 | 63 | 52.0 |
| | mn | 42 | 37 | 31 | 42 | 35 | 32 | 35 | 32 | 40 | 45 | 39 | 37 | 34 | 31 | 30 | 37 | 33 | 29 | 28 | 31 | 31 | 36 | 30 | 28 | 45 | 43 | 39 | 35 | 30 | 38 | 36.2 |
| Erie | mx | 46 | 46 | 50 | 54 | 46 | 43 | 47 | 53 | 65 | 61 | 49 | 45 | 44 | 44 | 60 | 44 | 40 | 37 | 40 | 39 | 46 | 62 | 66 | 52 | 73 | 61 | 42 | 46 | 51 | 63 | 50.3 |
| | mn | 36 | 32 | 26 | 37 | 33 | 31 | 31 | 26 | 44 | 43 | 38 | 37 | 35 | 29 | 28 | 36 | 32 | 32 | 27 | 27 | 32 | 43 | 43 | 31 | 52 | 42 | 33 | 33 | 23 | 44 | 35.2 |
| Cleveland | mx | 50 | 49 | 61 | 52 | 49 | 46 | 53 | 62 | 77 | 58 | 51 | 45 | 44 | 43 | 57 | 45 | 40 | 39 | 39 | 34 | 57 | 62 | 68 | 60 | 73 | 57 | 42 | 55 | 63 | 75 | 53.9 |
| | mn | 39 | 33 | 23 | 37 | 35 | 36 | 35 | 26 | 46 | 44 | 42 | 37 | 35 | 32 | 35 | 34 | 32 | 30 | 27 | 30 | 29 | 42 | 48 | 36 | 54 | 40 | 36 | 35 | 43 | 52 | 37.0 |
| Toledo | mx | 44 | 50 | 60 | 48 | 49 | 49 | 50 | 57 | 73 | 56 | 53 | 44 | 46 | 55 | 55 | 49 | 41 | 42 | 32 | 38 | 61 | 71 | 70 | 54 | 71 | 52 | 42 | 53 | 55 | 59 | 52.9 |
| | mn | 35 | 34 | 29 | 36 | 34 | 35 | 29 | 31 | 44 | 43 | 41 | 37 | 34 | 29 | 39 | 34 | 31 | 31 | 25 | 30 | 25 | 42 | 43 | 36 | 47 | 40 | 35 | 37 | 44 | 46 | 3[illegible].2 |
| SOUTHWEST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ind.Ill.Wis. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Bend | mx | 45 | 53 | 52 | 45 | 48 | 53 | 57 | 59 | 76 | 55 | 50 | 48 | 44 | 58 | 43 | 51 | 37 | 38 | 32 | 44 | 61 | 71 | 70 | 53 | 63 | 47 | 48 | 52 | 64 | 69 | 53.5 |
| | mn | 33 | 33 | 32 | 35 | 30 | 33 | 29 | 37 | 45 | 42 | 35 | 32 | 29 | 25 | 32 | 32 | 30 | 28 | 20 | 30 | 25 | 47 | 41 | 45 | 45 | 34 | 34 | 38 | 44 | 50 | 35.2 |
| Chicago | mx | 42 | 54 | 52 | 44 | 50 | 51 | 54 | 60 | 62 | 50 | 54 | 48 | 44 | 60 | 50 | 52 | 34 | 45 | 42 | 55 | 64 | 80 | 75 | 60 | 65 | 45 | 53 | 50 | 61 | 71 | 54.6 |
| | mn | 40 | 39 | 40 | 37 | 32 | 36 | 36 | 43 | 48 | 42 | 36 | 39 | 32 | 30 | 40 | 34 | 32 | 31 | 29 | 30 | 32 | 42 | 51 | 43 | 45 | 38 | 35 | 42 | 45 | 51 | 33.6 |
| Milwaukee | mx | 44 | 45 | 49 | 45 | 46 | 49 | 52 | 47 | 52 | 50 | 51 | 41 | 43 | 51 | 47 | 50 | 40 | 39 | 42 | 51 | 63 | 72 | 69 | 43 | 61 | 45 | 49 | 46 | 46 | 48 | 42.5 |
| | mn | 37 | 36 | 35 | 38 | 33 | 30 | 31 | 39 | 41 | 38 | 37 | 31 | 30 | 26 | 35 | 31 | 27 | 27 | 29 | 29 | 32 | 49 | 45 | 41 | 42 | 36 | 35 | 33 | 38 | 42 | 35.1 |
| Green Bay | mx | 43 | 52 | 47 | 45 | 45 | 52 | 56 | 51 | 44 | 48 | 51 | 47 | 49 | 55 | 43 | 44 | 40 | 36 | 41 | 52 | 63 | 75 | 66 | 55 | 50 | 43 | 47 | 51 | 42 | 46 | 49.7 |
| | mn | 35 | 32 | 35 | 34 | 31 | 32 | 29 | 35 | 39 | 36 | 36 | 31 | 25 | 27 | 35 | 28 | 25 | 23 | 27 | 25 | 28 | 45 | 25 | 35 | 42 | 33 | 32 | 23 | 33 | 40 | 32.7 |
| WEATHER TYPES | | sLl | nHl | mLl/c | mLl/c | mLl/c | nHl | nHl | nHl | sLl | sLl | sLl | gLe | wHs | wHs | mLl/c | mLl/c | mLl/c | nHs | nHs | nHs | nHs | mLl/ws | nHl | nLl/ws | mLl/ws | mLL/ws | mLl/c | nHeH/s | nHeH/s | sLl | |

TABLE 3--Continued

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRAL | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alpena | mx | 47 | 45 | 42 | 44 | 38 | 40 | 43 | 47 | 45 | 46 | 48 | 44 | 39 | 52 | 45 | 45 | 38 | 42 | 41 | 24 | 52 | 71 | 63 | 47 | 43 | 40 | 37 | 43 | 45 | 45 | 45.5 |
| | mn | 34 | 30 | 23 | 37 | 32 | 31 | 31 | 32 | 37 | 36 | 35 | 29 | 30 | 26 | 36 | 30 | 25 | 26 | 29 | 23 | 27 | 43 | 39 | 34 | 39 | 33 | 33 | 32 | 31 | 33 | 32.4 |
| Detroit | mx | 45 | 49 | 56 | 47 | 45 | 49 | 51 | 55 | 66 | 52 | 52 | 44 | 45 | 55 | 53 | 48 | 44 | 44 | 42 | 36 | 62 | 71 | 68 | 56 | 73 | 54 | 44 | 55 | 54 | 57 | 52.5 |
| | mn | 37 | 35 | 31 | 38 | 36 | 35 | 34 | 33 | 44 | 42 | 40 | 37 | 33 | 29 | 41 | 33 | 31 | 29 | 28 | 31 | 23 | 44 | 43 | 37 | 45 | 41 | 37 | 33 | 42 | 46 | 36.5 |
| E.Lansing | mx | 43 | 51 | 56 | 41 | 44 | 49 | 51 | 55 | 68 | 51 | 52 | 46 | 42 | 55 | 51 | 45 | 40 | 43 | 36 | 37 | 59 | 72 | 65 | 55 | 68 | 48 | 43 | 52 | 55 | 54 | 50.9 |
| | mn | 37 | 34 | 31 | 34 | 34 | 32 | 28 | 30 | 37 | 28 | 35 | 32 | 28 | 24 | 41 | 33 | 28 | 25 | 34 | 36 | 25 | 45 | 40 | 33 | 42 | 38 | 32 | 31 | 39 | 42 | 33.3 |
| Muskegon | mx | 51 | 50 | 48 | 42 | 44 | 52 | 54 | 58 | 66 | 55 | 48 | 48 | 41 | 52 | 48 | 47 | 38 | 37 | 40 | 41 | 57 | 62 | 62 | 57 | 63 | 45 | 44 | 52 | 55 | 52 | 50.3 |
| | mn | 38 | 33 | 28 | 36 | 34 | 34 | 28 | 38 | 44 | 33 | 34 | 30 | 28 | 20 | 40 | 33 | 29 | 30 | 30 | 28 | 24 | 45 | 39 | 36 | 45 | 35 | 34 | 28 | 38 | 44 | 33.9 |
| Traverse City | mx | 55 | 48 | 51 | 42 | 40 | 47 | 55 | 58 | 57 | 51 | 46 | 43 | 41 | 54 | 54 | 46 | 37 | 34 | 41 | 36 | 60 | 73 | 62 | 62 | 56 | 43 | 39 | 47 | 57 | 52 | 49.6 |
| | mn | 35 | 27 | 26 | 34 | 30 | 28 | 24 | 35 | 40 | 34 | 28 | 22 | 26 | 20 | 41 | 32 | 25 | 27 | 29 | 27 | 24 | 42 | 33 | 23 | 43 | 34 | 33 | 28 | 26 | 42 | 30.8 |
| Upper Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Escanaba | mx | 53 | 46 | 39 | 42 | 40 | 41 | 46 | 52 | 44 | 42 | 44 | 41 | 43 | 43 | 41 | 43 | 34 | 27 | 27 | 41 | 52 | 69 | 57 | 51 | 44 | 39 | 39 | 43 | 50 | 46 | 44.3 |
| | mn | 31 | 31 | 33 | 31 | 30 | 29 | 32 | 35 | 37 | 34 | 33 | 27 | 26 | 27 | 37 | 27 | 26 | 27 | 29 | 27 | 29 | 40 | 39 | 36 | 37 | 33 | 32 | 29 | 34 | 37 | 31.9 |
| Sault Ste Marie | mx | 50 | 43 | 42 | 40 | 33 | 38 | 51 | 54 | 49 | 46 | 41 | 41 | 37 | 53 | 46 | 39 | 29 | 23 | 27 | 32 | 54 | 53 | 50 | 57 | 45 | 38 | 36 | 44 | 54 | 53 | 44.1 |
| | mn | 31 | 27 | 26 | 32 | 30 | 29 | 29 | 31 | 30 | 33 | 31 | 28 | 29 | 23 | 30 | 25 | 19 | 20 | 29 | 24 | 27 | 32 | 32 | 23 | 37 | 31 | 32 | 30 | 29 | 37 | 29.9 |
| Marquette | mx | 40 | 41 | 42 | 36 | 34 | 39 | 41 | 45 | 42 | 41 | 44 | 36 | 37 | 54 | 40 | 39 | 29 | 37 | 32 | 40 | 55 | 64 | 52 | 51 | 33 | 34 | 37 | 45 | 42 | 40 | 41.6 |
| | mn | 31 | 31 | 32 | 29 | 28 | 27 | 26 | 32 | 36 | 33 | 32 | 23 | 26 | 27 | 36 | 24 | 23 | 27 | 28 | 29 | 32 | 43 | 30 | 37 | 33 | 31 | 30 | 29 | 28 | 36 | 30.7 |
| NORTH | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Minn., N.Ont. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Duluth | mx | 40 | 49 | 33 | 36 | 42 | 49 | 38 | 39 | 35 | 41 | 37 | 42 | 49 | 51 | 33 | 27 | 52 | 33 | 39 | 54 | 63 | 62 | 61 | 51 | 36 | 29 | 47 | 46 | 42 | 37 | 43.0 |
| | mn | 29 | 24 | 31 | 28 | 23 | 23 | 25 | 30 | 32 | 32 | 24 | 13 | 22 | 26 | 26 | 19 | 12 | 13 | 24 | 25 | 27 | 36 | 40 | 32 | 30 | 36 | 24 | 28 | 34 | 32 | 36.7 |
| Fort William | mx | 43 | 45 | 40 | 34 | 37 | 38 | 41 | 41 | 43 | 50 | 44 | 43 | 47 | 52 | 42 | 32 | 27 | 39 | 41 | 54 | 63 | 61 | 57 | 49 | 47 | 49 | 49 | 53 | 43 | 43 | 45.1 |
| | mn | 23 | 23 | 26 | 30 | 27 | 29 | 25 | 29 | 35 | 36 | 30 | 20 | 15 | 19 | 29 | 24 | 18 | 23 | 26 | 25 | 22 | 36 | 34 | 25 | 37 | 31 | 31 | 23 | 22 | 34 | 26.9 |
| Chapleau | mx | 37 | 41 | 41 | 30 | 31 | 34 | 41 | 47 | 47 | 34 | 36 | 32 | 35 | 46 | 38 | 37 | 30 | 37 | 30 | 32 | 40 | 43 | 50 | 40 | 43 | 40 | 43 | 46 | 40 | 40 | 38.6 |
| | mn | 28 | 15 | 16 | 31 | 24 | 26 | 28 | 17 | 30 | 33 | 29 | 23 | 20 | 12 | 16 | 28 | 17 | 10 | 26 | 20 | 19 | 29 | 26 | 32 | 26 | 30 | 21 | 21 | 23 | 23 | 25.5 |
| North Bay | mx | 46 | 45 | 53 | 43 | 37 | 37 | 44 | 52 | 52 | 43 | 40 | 45 | 39 | 46 | 54 | 39 | 35 | 37 | 42 | 43 | 51 | 50 | 47 | 55 | 45 | 37 | 33 | 37 | 48 | 50 | 44.2 |
| | mx | 31 | 27 | 26 | 32 | 32 | 27 | 32 | 28 | 34 | 37 | 31 | 26 | 24 | 20 | 26 | 33 | 25 | 22 | 25 | 20 | 27 | 32 | 35 | 29 | 39 | 32 | 31 | 27 | 25 | 29 | 29.1 |
| WEATHER TYPES | | sLl | nHl | mLl/c | mLl/c | mLl/c | nHl | nHl | nHl | sLl | sLl | sLl | gLe | wHs | wHs | mLl/c | mLl/c | mLl/c | nHs | nHs | nHs | nHs | mLl/ws | nHl | mLl/ws | mLl/ws | mLl/ws | mLl/c | nReH/s | nReH/s | sLl | |

quite cool. Duluth, except on two days, recorded maxima between 35° and 41° F. and means in the thirties, that is, very close to normal. The noteable exception was April 22 when the maximum reached 62° F. On this day the warm sector reached farther north and most northeastern stations recorded their highest temperature of the month. It is interesting to note that Chapleau with only 43° F. was much colder than any other station and obviously outside the warm sector. By far the coldest temperatures in the south were recorded during the occurrence of nHs from April 18th to April 21st. Cleveland, South Bend, and Chicago all had daily means in the thirties which is ten or more degrees below normal. In the northwest, temperatures with nHs are not usually as extreme compared to normals; in 1953 some stations recorded colder days with mLl/c. For nHl, temperatures are noticeably colder in the southeast than in the west. In Erie, means were approximately 40° F. or 5° to 10° below normal, whereas in Marquette or Fort William they were only 0 to 5° below normal. In Green Bay they were even higher: maxima and minima, respectively, on April 2 were 52° and 32° F. as opposed to 49° and 33° F. in Cleveland, and means on the four nHl days were approximately 5° above normal. A very similar pattern occurs with nHeH. The importance of the cool lakes is clearly illustrated on each of the nHl days; for example, maxima and minima respectively on April 8 were 47° and 39° F. at Milwaukee, but 58° and 38° F. at Muskegon.

The cumulative long term result of these type temperature characteristics is shown in the normal temperature map (Fig. 16A). Temperatures are still quite cool but with less latitudinal gradient than in winter. Southern areas are in the forties and northern areas about freezing. The cold associated with the anticyclonic types is not severe and the high southeastern temperatures of sLl and mLl, though still reflected in the trend of isotherms in Southern Ontario, are partially counteracted by the greater cooling of the east than the west by all three significant high types, n&eH, nHl and even nHs. The lakes being quite cold, most shores, but particularly those of southern Lake Michigan and Lake Erie, are relatively cool for their latitude and the temperature reversal of Upper Michigan has completely disappeared.

Departures of average temperatures from normal temperatures (see Fig. 19), however, are quite significant with variations in type frequencies. In 1955 there were no nHs and many sLl days with the result that temperatures for the entire region were $6^{\circ}$ to $8^{\circ}$ above normal. In 1956 there were a large number of nHs days and also several nHn days; temperatures were $1^{\circ}$ to $4^{\circ}$ below normal for the entire region. In 1954 there was an unusually high number of mLl/ws days and only one day of nHl, and temperatures were well above normal in the southeast.

Precipitation in April is again highest on days of sLl and mLl (e.g. see Table 4). For both types it is widespread, but heavier in the southeast than northwest, and tending to be highest in a variable belt running across the region from southwest to northeast in the case of sLl and west to east for mLl. April 30, 1953 for sLl, April 25 and 26 for mLl/ws, and April 15 and 16 for mLl/c are typical. Precipitation is light with nHs and particularly with nHl. Some showers occur in the south with n&eH, but the north is very dry.

Normal precipitation (Fig. 16B), except for the winter snow belt areas, is slightly greater for April than for January because of the dominance of mLl and sLl. Only the extreme northwest averages less than 2 inches, and most of the southern half of the region has over 2.5 inches. The southeast, supplemented by n&eH, has over 3 inches. Almost every year

TABLE 4.—DAILY PRECIPITATION,* APRIL 1953

| Station | SOUTHEAST S. Ontario St. Thomas | Malton | Durham | NY.Penn.Ohio Buffalo | Rochester | Erie | Cleveland | Toledo | SOUTHWEST Ind.Ill.Wis. Green Bay | Chicago | Milwaukee | South Bend | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Day | | | | | | | | | | | | | |
| 1 | | | | 01 | | 17 | 25 | 23 | T | 26 | 15 | 27 | sLl |
| 2 | 15 | | | | | T | 09 | 01 | | 01 | | T | nHl |
| 3 | 07 | 01 | 09 | | | | 02 | 10 | 16 | 07 | 07 | 12 | mLl/c |
| 4 | 02 | T | 21 | 01 | 01 | 02 | 04 | T | 05 | T | T | T | mLl/c |
| 5 | 02 | T | | T | 01 | | T | | | | | | mLl/c |
| 6 | | | | T | 07 | T | 02 | | | | | | nHl |
| 7 | | | | T | T | | | | | | | | nHl |
| 8 | | | | | | | 03 | 20 | 04 | T | 30 | T | nHl |
| 9 | 51 | 23 | | | T | T | 30 | 51 | 48 | 16 | 26 | 94 | sLl |
| 10 | 04 | T | 29 | 15 | 15 | 33 | 37 | 02 | 144 | T | T | T | sLl |
| 11 | | | | | T | | | | | | T | | sLl |
| 12 | 09 | T | | 05 | 09 | 13 | 22 | 08 | T | T | T | T | gLe |
| 13 | 05 | | | 13 | 06 | 19 | 06 | | | | | | wHs |
| 14 | | T | | | | | T | | 27 | 01 | 01 | 66 | wHs |
| 15 | 68 | 33 | 15 | 01 | | 02 | 27 | 44 | 81 | 60 | 43 | 30 | mLl/c |
| 16 | 14 | 09 | 20 | 52 | 02 | 20 | 10 | 04 | 06 | 12 | 10 | 01 | mLl/c |
| 17 | | T | T | 21 | 11 | 11 | 18 | T | | T | | T | mLl/c |
| 18 | | | | T | T | T | 01 | | T | | | 03 | nHs |
| 19 | 09 | T | 10 | T | 03 | T | 16 | 01 | T | 01 | T | 05 | nHs |
| 20 | 02 | T | | 32 | 24 | 14 | 23 | T | | T | T | | nHs |
| 21 | | | | | | T | 02 | | | | | T | nHs |
| 22 | 02 | 01 | 12 | 05 | 07 | T | T | | T | T | T | | mLl/ws |
| 23 | | | | T | T | T | | | | | | | nHl |
| 24 | 24 | 01 | 51 | 03 | T | 04 | T | 09 | 08 | 17 | 60 | 12 | mLl/ws |
| 25 | 78 | 90 | 74 | 17 | 29 | 22 | 07 | 50 | 104 | 19 | 11 | 32 | mLl/ws |
| 26 | 07 | 12 | 12 | 14 | 12 | 21 | 26 | 03 | 38 | 10 | 08 | 18 | mLl/ws |
| 27 | 06 | 05 | 18 | 19 | 01 | 22 | 03 | 01 | | 11 | | 06 | mLl/c |
| 28 | | | | T | T | T | T | 01 | | 14 | 03 | 06 | n&eH/s |
| 29 | | | T | | | T | 02 | T | 02 | T | 23 | | n&eH/s |
| 30 | 22 | 59 | | 25 | 22 | T | 07 | 16 | 69 | 87 | 44 | 45 | sLl |
| Total | 327 | 244 | 271 | 224 | 150 | 200 | 282 | 244 | 552 | 282 | 281 | 357 | |

*Unit of precipitation is 0.01 inch.

TABLE 4—Continued

| Station | CENTRAL | | | | | | | | NORTH | | | | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower Mich. Alpena | Detroit | E. Lansing | Muskegon | Traverse City | Upper Mich. Escanaba | Sault Ste. Marie | Marquette | Minn.,N.Ont. Duluth | Fort William | Chapleau | North Bay | |
| Day | | | | | | | | | | | | | |
| 1 | | 42 | 25 | 04 | | | | | | | | | sLl |
| 2 | | 01 | | | | | | | T | | | | nHl |
| 3 | 08 | 10 | 10 | 19 | 21 | 22 | 18 | 05 | 57 | 50 | | T | mLl/c |
| 4 | 05 | 01 | | 01 | 16 | 05 | 30 | 35 | T | 01 | 35 | 20 | mLl/c |
| 5 | T | T | T | | 04 | T | 03 | 11 | | | 70 | 05 | mLl/c |
| 6 | T | | | T | | | | | | 02 | | | nHl |
| 7 | | | | | | | | | 02 | T | 40 | | nHl |
| 8 | T | | 10 | 05 | 02 | 08 | | | 23 | 01 | | | nHl |
| 9 | 11 | 57 | 62 | 08 | 15 | 19 | 01 | 04 | 50 | 04 | | 04 | sLl |
| 10 | 19 | 03 | T | 22 | 51 | 56 | 96 | 74 | 18 | | 12 | 62 | sLl |
| 11 | | | | | | T | T | | | | 60 | 12 | sLl |
| 12 | T | T | | | | | T | | | | | | gLe |
| 13 | 01 | T | T | T | 01 | | T | | | | | | wHs |
| 14 | | T | | T | | 04 | | T | T | | | | wHs |
| 15 | 11 | 65 | 22 | 65 | 05 | 111 | 38 | 58 | T | 23 | | | mLl/c |
| 16 | 27 | 22 | T | 21 | 18 | 10 | 18 | 13 | 02 | 01 | 10 | 08 | mLl/c |
| 17 | 08 | 05 | | | 01 | T | 03 | 05 | | 01 | 05 | 08 | mLl/c |
| 18 | T | | | T | T | T | 04 | 11 | 04 | 01 | 10 | T | nHs |
| 19 | T | 05 | T | 16 | 06 | T | T | 22 | T | T | 10 | | nHs |
| 20 | T | 01 | | 03 | T | 01 | T | | | | | 02 | nHs |
| 21 | | | 05 | | | | | | T | | | | nHs |
| 22 | 11 | T | | T | T | 01 | 15 | T | T | 10 | | 46 | mLl/ws |
| 23 | | | | | | | | | | | | | nHl |
| 24 | 01 | 13 | 03 | 13 | T | 01 | | 02 | 56 | | | | mLl/ws |
| 25 | 38 | 61 | 79 | 14 | 74 | 63 | 30 | 44 | 83 | T | | 05 | mLl/ws |
| 26 | 42 | 05 | 15 | 18 | 52 | 33 | 38 | 92 | 03 | | | 38 | mLl/ws |
| 27 | 16 | 03 | | 01 | 05 | T | 01 | T | | | 05 | 49 | mLl/c |
| 28 | | T | | 02 | | | | | | | | 05 | n&eH/s |
| 29 | | 18 | 26 | 24 | | | | | 01 | T | | | n&eH/s |
| 30 | 35 | 20 | 14 | 102 | 15 | 30 | T | 32 | 58 | 01 | | 05 | sLl |
| Total | 233 | 322 | 271 | 338 | 286 | 364 | 295 | 398 | 357 | 95 | 257 | 269 | |

some areas get over 6 inches in the month, but because of the fickleness of both sLl and mLl as to the exact location of their highest concentrations no area averages over 4 inches. For the same reason the total precipitation map for any one year (see Fig. 20) is always characterized by a very irregular pattern of local concentration or dryness.

The combined frequency of sLl and mLl is remarkably constant from year to year. Therefore, little order can be ascribed to the patterns and their variation except the invariably light northern rainfall as opposed to the high southern rainfall with variable concentration. The suggestion of heaviest southern precipitation in 1954 and 1957 is associated with more numerous meH/s days.

July

Summer, in contrast to both winter and spring, is characterized by an outstandingly high frequency of anticyclonic types as compared to cyclonic types. The usual large number of mLl still exist and aLn is also very important, but with the northward shift of circulation all other lows are virtually nonexistent. Of the anticyclonic types, meH, associated with the strong development of the Bermuda High and southeastern upper-level anticyclone, occurs with great frequency and is by far the leading type; but nHl, associated with the cool lakes, is also very common. Other highs occur only irregularly.

Both mLl and aLn bring high temperatures, particularly to the southern half of the region and, except for a few aLn/d, heavy precipitation to much of the region. In contrast, nHl is cool and dry. Summer, however, is very different from other seasons in that heavy precipitation is associated with the dominant anticyclonic type, that is, with meH. Thus, in spite of the higher frequency of anticyclonic types precipitation is generally easily maintained. Temperature with n&eH depends on the position of the front. Days with the front over or south of the Lakes occur with about equal frequency over a number of years.

Highest temperatures for any given year may be recorded on a variety of type days but usually occur with an aLn or, south of the front, with a n&eH/l. In July 1954 (see Table 5) they occurred for most western stations on July 12 or 13 with an aLn, but for the southeast on July 14 with the following n&eH/l. In Sault Ste. Marie, Marquette, and Chapleau, July 29 with another aLn was warmest. On July 2 with n eH/l, maxima and minima south of the front were $94^{\circ}$ and $67^{\circ}$ F., respectively, at Chicago, and $97^{\circ}$ and $60^{\circ}$ F. at Cleveland. North of the front, on the other hand, they were only $62^{\circ}$ and $54^{\circ}$ F. in Green Bay and $74^{\circ}$ and $58^{\circ}$ F. in Buffalo. In Cleveland all days of n&eH/l had maxima over $90^{\circ}$ F.; aLn, just slightly lower. In Chapleau and North Bay, however, n&eH/l reached only the sixties and low seventies as opposed to the eighties on days of aLn. Temperatures for mLl were generally close to normal. Coldest days occurred either with nHl or north of the front with n&eH. In 1954 most stations experienced lowest temperatures between July 7 and July 9 with nHl and the remainder, mainly in the northwest, from July 2 to 4 with n&eH. The extreme temperature lows recorded were on July 8 when Chapleau dropped to a minimum of $36^{\circ}$ F., as opposed to its high of $87^{\circ}$ with an aLn on July 29, and on the following day when Durham in Southern Ontario reached the same degree. On the same days, Cleveland experienced its only maxima of the month in the seventies, while minima dropped to $50^{\circ}$ F. Erie maxima fell to the sixties. However, as the centre of the high moved slightly farther east on the following days, temperatures rose as usual in the west with Chicago

TABLE 5.--DAILY TEMPERATURE, JULY 1954

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTHEAST | | | | | | | | | | | | | | | | |
| S. Ontario | | | | | | | | | | | | | | | | |
| Malton | mx | 84 | 74 | 70 | 77 | 79 | 77 | 70 | 79 | 74 | 76 | 77 | 87 | 89 | 91 | 74 |
| | mn | 58 | 56 | 54 | 51 | 58 | 53 | 54 | 46 | 50 | 50 | 56 | 63 | 59 | 58 | 51 |
| Durham | mx | 80 | 65 | 71 | 76 | 67 | 72 | 64 | 72 | 71 | 76 | 80 | 84 | 81 | 90 | 72 |
| | mn | 53 | 49 | 45 | 45 | 50 | 41 | 47 | 36 | 40 | 45 | 49 | 61 | 53 | 54 | 49 |
| South-ampton | mx | 69 | 61 | 70 | 70 | 69 | 61 | 70 | 59 | 63 | 65 | 69 | 72 | 86 | 74 | 74 |
| | mn | 58 | 54 | 43 | 43 | 47 | 54 | 51 | 45 | 43 | 49 | 46 | 49 | 62 | 59 | 57 |
| St.Thomas | mx | 89 | 84 | 74 | 79 | 67 | 73 | 73 | 72 | 75 | 71 | [illegible] | 86 | 90 | 95 | 79 |
| | mn | 60 | 53 | 54 | 54 | 57 | 45 | 57 | 41 | 43 | 46 | 48 | 56 | 59 | 60 | 56 |
| NY.Penn.Ohio | | | | | | | | | | | | | | | | |
| Buffalo | mx | 90 | 74 | 75 | 84 | 71 | 72 | 72 | 71 | 76 | 80 | 85 | 85 | 92 | 84 | 75 |
| | mn | 64 | 53 | 54 | 58 | 61 | 53 | 56 | 51 | 54 | 54 | 56 | 60 | 70 | 66 | 61 |
| Rochester | mx | 85 | 78 | 75 | 78 | 74 | 78 | 71 | 71 | 75 | 76 | 81 | 86 | 91 | 92 | 74 |
| | mn | 64 | 61 | 57 | 59 | 56 | 52 | 55 | 52 | 50 | 51 | 52 | 54 | 66 | 64 | 60 |
| Erie | mx | 82 | 81 | 70 | 75 | 71 | 72 | 66 | 69 | 74 | 74 | 72 | 90 | 86 | 91 | 72 |
| | mn | 65 | 58 | 60 | 60 | 58 | 53 | 61 | 52 | 50 | 51 | 51 | 57 | 68 | 67 | 63 |
| Cleveland | mx | 88 | 97 | 90 | 93 | 76 | 84 | 70 | 75 | 81 | 90 | 85 | 94 | 93 | 99 | 78 |
| | mn | 70 | 66 | 65 | 64 | 64 | 51 | 58 | 50 | 50 | 54 | 57 | 59 | 73 | 67 | 57 |
| Toledo | mx | 90 | 94 | 69 | 82 | 78 | 80 | 69 | 74 | 79 | 76 | 79 | 94 | 90 | 96 | 79 |
| | mn | 68 | 60 | 63 | 61 | 62 | 55 | 55 | 48 | 54 | 54 | 53 | 65 | 71 | 67 | 61 |
| SOUTHWEST | | | | | | | | | | | | | | | | |
| Ind.Ill.Wis. | | | | | | | | | | | | | | | | |
| South Bend | mx | 84 | 93 | 77 | 80 | 77 | 82 | 75 | 76 | 79 | 77 | 84 | 95 | 87 | 94 | 75 |
| | mn | 65 | 62 | 64 | 62 | 58 | 56 | 55 | 50 | 61 | 62 | 63 | 70 | 69 | 63 | 57 |
| Chicago | mx | 88 | 94 | 75 | 80 | 72 | 86 | 70 | 79 | 84 | 87 | 93 | 97 | 93 | 95 | 79 |
| | mn | [illegible] | 69 | 66 | 67 | 65 | 62 | 59 | 55 | 65 | 68 | 69 | 75 | 75 | 69 | 62 |
| Milwaukee | mx | 82 | 79 | 65 | 78 | 68 | 81 | 66 | 76 | 76 | 69 | 82 | 95 | 87 | 87 | 74 |
| | mn | 62 | 59 | 59 | 60 | 59 | 59 | 55 | 52 | 52 | 66 | 63 | 71 | 69 | 63 | 59 |
| WEATHER TYPES | | mLl/ws | n&eH/1 | n&eH/s | n&eH/s | nHl | mLl/ws | mLl/ws nHl | nHl | nHl | nHl | nHl | aLn/d | aLn/d | n&eH/1 | nHl |

| Station | dy | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTHEAST | | | | | | | | | | | | | | | | | |
| S. Ontario | | | | | | | | | | | | | | | | | |
| Malton | mx | 80 | 78 | 87 | 80 | 85 | 80 | 76 | 81 | 84 | 85 | 90 | 86 | 86 | 73 | 91 | 80.2 |
| | mn | 52 | 55 | 56 | 60 | 64 | 51 | 54 | 58 | 62 | 53 | 59 | 60 | 63 | 65 | [illegible] | 56.3 |
| Durham | mx | 75 | 80 | 82 | 78 | 84 | 74 | 72 | 78 | 81 | 83 | 84 | 78 | 82 | 74 | 81 | 76.4 |
| | mn | 44 | 46 | 57 | 49 | 56 | 60 | 50 | 49 | 45 | 43 | 48 | 51 | 60 | 62 | 67 | 50.7 |
| South-ampton | mx | 65 | 66 | 78 | 79 | 69 | 77 | 70 | 67 | [illegible] | 74 | 74 | 77 | 75 | 72 | 72 | 70.9 |
| | mn | 60 | 50 | 50 | 64 | 58 | 62 | 51 | 50 | 53 | 54 | 56 | 64 | 56 | 63 | 65 | 55.0 |
| St.Thomas | mx | 77 | 80 | 89 | 83 | 84 | 78 | 75 | 77 | 83 | 81 | 86 | 88 | 87 | 72 | 87 | 80.3 |
| | mn | 46 | 48 | 57 | 59 | 57 | 62 | 52 | 45 | 46 | [illegible] | 52 | 55 | 62 | 62 | 61 | 53.8 |
| NY.Penn.Ohio | | | | | | | | | | | | | | | | | |
| Buffalo | mx | 75 | 81 | 81 | 82 | 78 | 81 | 72 | 79 | 80 | 84 | 83 | 80 | 85 | 83 | 84 | 79.5 |
| | mn | 54 | 54 | 64 | 66 | [illegible] | 64 | 57 | 56 | 58 | 61 | 59 | 62 | 67 | 64 | 65 | 59.7 |
| Rochester | mx | 77 | 82 | 85 | 81 | 84 | 79 | 77 | 82 | 82 | 82 | 89 | 89 | 85 | 74 | 90 | 80.9 |
| | mn | 51 | 53 | 65 | 64 | 58 | 64 | 58 | 55 | 58 | 59 | 59 | 62 | 68 | 62 | 65 | 58.8 |
| Erie | mx | 75 | 77 | 81 | 76 | 89 | 77 | 72 | 74 | 73 | 79 | 82 | 87 | 87 | [illegible] | 88 | 78.8 |
| | mn | 49 | 53 | 66 | 63 | 60 | 59 | 57 | 51 | 51 | 56 | 57 | 57 | 66 | 66 | 65 | 58.6 |
| Cleveland | mx | 84 | 89 | 87 | 85 | 91 | 81 | 82 | 81 | 86 | 89 | 91 | 93 | 94 | 82 | 87 | 85.8 |
| | mn | 50 | 53 | 64 | 65 | 63 | 67 | 57 | 51 | 53 | 55 | 57 | 58 | 67 | 69 | 67 | 60.3 |
| Toledo | mx | 81 | 86 | 87 | 87 | 88 | 75 | 77 | 78 | 83 | 84 | 87 | 91 | 93 | [illegible] | 91 | 83.4 |
| | mn | 53 | 56 | 66 | 63 | 63 | 65 | 57 | 55 | 56 | 59 | 59 | 61 | 67 | 58 | 53 | 60.8 |
| SOUTHWEST | | | | | | | | | | | | | | | | | |
| Ind.Ill.Wis. | | | | | | | | | | | | | | | | | |
| South Bend | mx | 82 | 85 | 89 | 87 | 94 | 91 | 82 | 77 | 82 | 82 | 86 | 89 | 88 | 85 | 92 | 83.9 |
| | mn | 52 | 58 | 65 | 60 | 67 | 64 | 60 | 57 | 53 | 59 | 57 | 61 | 67 | 67 | 65 | 61.0 |
| Chicago | mx | 84 | 90 | 94 | 94 | 98 | 78 | 82 | 79 | 84 | 88 | 88 | 93 | [illegible] | 96 | 94 | 86.5 |
| | mn | 63 | 65 | 74 | 68 | 70 | 68 | 65 | 63 | 65 | 65 | 63 | 64 | 69 | 68 | 71 | 66.4 |
| Milwaukee | mx | 82 | 84 | 85 | 83 | 85 | 73 | 76 | 77 | 81 | 80 | 87 | 89 | 82 | 85 | 83 | 79.6 |
| | mn | 59 | 64 | 66 | 64 | 67 | 65 | 64 | 59 | 60 | 60 | 58 | 66 | 69 | 66 | 65 | 62.4 |
| WEATHER TYPES | | nHl | nHl | aLn/w | aLl/b | aLl/b | nHn | nHn | aLn/d | wHl | wHl | wHl | aLn/w n&eH/1 | n&eH/1 | aLn/w | mLl/ws | |

TABLE 5--Continued

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRAL | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alpena | mx | 88 | 71 | 70 | 72 | 74 | 76 | 72 | 73 | 73 | 76 | 75 | 91 | 88 | 87 | 78 | 83 | 81 | 87 | 82 | 84 | 78 | 77 | 82 | 83 | 89 | 91 | 87 | 83 | 81 | 83 | 80.3 |
| | mn | 59 | 51 | 47 | 45 | 45 | 50 | 43 | | 46 | 51 | 47 | 57 | 60 | 62 | 49 | 47 | 49 | | 49 | 64 | 58 | 51 | 50 | 56 | 52 | 52 | 69 | 64 | 63 | 64 | 54.0 |
| Detroit | mx | 88 | 90 | 66 | 81 | 74 | 79 | 70 | 73 | 78 | 74 | 81 | 95 | 92 | 97 | 77 | 81 | 83 | 89 | 85 | 90 | 77 | 77 | 78 | 84 | 85 | [illegible] | 91 | 89 | 82 | 90 | 82.8 |
| | mn | 67 | 59 | 58 | 59 | 61 | 55 | 54 | 48 | 53 | 56 | 55 | 66 | 67 | 65 | 60 | 56 | 60 | 65 | 63 | 68 | 62 | 57 | 56 | 57 | 62 | 59 | 65 | 72 | 69 | 70 | 60.8 |
| E.Lansing | mx | 80 | 85 | 64 | 77 | 73 | 75 | 69 | 71 | 77 | 69 | 73 | 80 | 86 | 8? | 75 | 76 | 80 | 86 | 79 | 80 | 73 | 77 | 76 | 82 | 83 | 86 | 87 | 86 | 87 | 88 | 79.1 |
| | mn | 63 | 58 | 57 | 55 | 60 | 52 | 52 | 43 | 50 | 53 | 60 | 60 | 67 | 61 | 60 | 47 | 51 | 62 | 58 | 66 | 57 | 52 | 53 | 54 | 57 | 57 | 58 | 52 | 64 | 62 | 57.1 |
| Muskegon | mx | 75 | 84 | 64 | 68 | 74 | 75 | 73 | 72 | 78 | 67 | 80 | 83 | 84 | 87 | 73 | 78 | 83 | 84 | 81 | 85 | 80 | 81 | 78 | 80 | 85 | 90 | 86 | 84 | 80 | 86 | 79.0 |
| | mn | 64 | 63 | 56 | 58 | 53 | 53 | 53 | 46 | 48 | 59 | 62 | 69 | 64 | 64 | 57 | 59 | 56 | 65 | 56 | 66 | 62 | 56 | 53 | 53 | 56 | 55 | 59 | 66 | 63 | 63 | 58.8 |
| Traverse City | mx | 72 | 60 | 73 | 75 | 71 | 72 | 63 | 73 | 76 | 72 | 73 | 80 | 80 | 76 | 76 | 73 | 84 | 81 | 85 | 80 | 80 | 78 | 78 | 80 | 83 | 80 | 85 | 87 | 84 | 79 | 73.2 |
| | mn | 56 | 56 | 48 | 53 | 51 | 52 | 48 | 45 | 48 | 59 | 59 | 69 | 62 | 63 | 52 | 45 | 52 | 65 | 54 | 68 | 59 | 52 | 48 | 55 | 52 | 53 | 66 | 69 | 66 | 62 | 56.3 |
| Upper Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Escanaba | mx | 72 | 63 | 66 | 77 | 74 | 62 | 72 | 68 | 69 | 66 | 68 | 91 | 87 | 75 | 76 | 73 | 76 | 81 | 74 | 74 | 77 | 77 | 72 | 77 | 74 | 87 | 74 | 77 | 82 | 78 | 74.9 |
| | mn | 57 | 52 | 51 | 56 | 49 | 55 | 51 | 45 | 55 | 61 | 62 | 66 | 66 | 59 | 54 | 50 | 64 | 54 | 56 | 61 | 55 | 54 | 54 | 54 | 53 | 63 | 66 | 66 | 66 | 57 | 57.3 |
| Sault Ste. Marie | mx | 62 | 61 | 74 | 63 | 68 | 71 | 72 | 69 | 76 | 74 | 70 | 77 | 74 | 66 | 68 | 78 | 73 | 73 | 74 | 74 | 76 | 74 | 77 | 76 | 73 | 85 | 72 | 83 | 85 | 71 | 73.0 |
| | mn | 50 | 45 | 43 | 43 | 46 | 43 | 41 | 44 | 44 | 52 | 51 | 55 | 53 | 47 | 45 | 43 | 50 | 53 | 49 | 53 | 53 | 49 | 43 | 50 | 53 | 55 | 59 | 62 | 62 | 54 | 50.4 |
| Marquette | mx | 67 | 60 | 63 | 67 | 65 | 71 | 61 | 73 | 72 | 74 | 75 | 86 | 86 | 78 | 71 | 77 | 87 | 75 | 83 | 71 | 64 | 70 | 73 | 67 | 80 | 85 | 72 | 75 | 87 | 70 | 73.6 |
| | mn | 50 | 50 | 46 | 52 | 52 | 53 | 46 | 51 | 53 | 59 | 61 | 63 | 69 | 59 | 56 | 58 | 63 | 61 | 58 | 60 | 54 | 49 | 53 | 53 | 53 | 66 | 65 | 64 | 65 | 53 | 53.7 |
| NORTH | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Minn., N.Ont. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Duluth | mx | 63 | 77 | 64 | 73 | 79 | 74 | 72 | 75 | 73 | 72 | 73 | 84 | 83 | 78 | 81 | 78 | 82 | 81 | 87 | 74 | 75 | 72 | 72 | 82 | 85 | 78 | 76 | 72 | 72 | 65 | 76.3 |
| | mn | 49 | 45 | 45 | 55 | 52 | 56 | 51 | 49 | 45 | 52 | 53 | 57 | 65 | 60 | 55 | 57 | 65 | 60 | 53 | 56 | 53 | 50 | 56 | 53 | 55 | 64 | 64 | 58 | 56 | 50 | 54.7 |
| Fort William | mx | 64 | 72 | 70 | 66 | 78 | 76 | 71 | 72 | 64 | 70 | 61 | 86 | 86 | 75 | 80 | 81 | 83 | 76 | 80 | 80 | 77 | 76 | 69 | 81 | 82 | 84 | 76 | 71 | 83 | 71 | 76.0 |
| | mn | 57 | 44 | 40 | 49 | 46 | 50 | 52 | 40 | 44 | 48 | 54 | 54 | 62 | 55 | 45 | 45 | 57 | 58 | 54 | 60 | 51 | 46 | 52 | 55 | 50 | 58 | 63 | 60 | 56 | 50 | 51.4 |
| North Bay | mx | 74 | 62 | 75 | 69 | 66 | 62 | 64 | 64 | 71 | 76 | 69 | 83 | 72 | 60 | 72 | 71 | 75 | 74 | 63 | 67 | 72 | 77 | 78 | 82 | 77 | 77 | 75 | 77 | 77 | 77 | 71.3 |
| | mn | 61 | 54 | 45 | 45 | 54 | 42 | 44 | 43 | 47 | 52 | 56 | 59 | 59 | 44 | 48 | 50 | 61 | 54 | 59 | 51 | 50 | 55 | 53 | 61 | 60 | 57 | 62 | 61 | 64 | 64 | 53.9 |
| Chapleau | mx | 66 | 63 | 75 | 57 | 71 | 62 | 58 | 67 | 68 | 75 | 76 | 80 | 82 | 66 | 70 | 78 | 74 | 71 | 73 | 71 | 64 | 71 | 76 | 78 | 82 | 81 | 72 | 82 | 87 | 63 | 72.4 |
| | mn | 53 | 45 | 44 | 51 | 50 | 49 | 36 | 47 | 43 | 45 | 43 | 62 | 59 | 56 | 40 | 43 | 48 | 59 | 45 | 59 | 43 | 47 | 43 | 43 | 49 | 57 | 52 | 54 | 56 | 55 | 49.5 |
| WEATHER TYPES | | mLl/ws | n&eH/1 | n&eH/s | n&eH/s | nHl | mLl/ws | mLl/ws nHl | nHl | nHl | nHl | nHl | aLn/d | aLn/d | n&eH/1 | nHl | nHl | nHl | aLn/w | aLl/b | aLl/b | nHn | nHn | aLn/d | wHl | wHl | wHl | aLn/w n&eH/1 | n&eH/1 | aLn/w | mLl/ws | |

reaching maxima and minima of 87° and 68° F. whereas Erie recorded only 74° and 51° F.

The characteristic feature of normal temperature distribution for July (Fig. 17A) is a low latitudinal gradient, a feature also characteristic of mHl, n&eH/s, wHl and aIn. Long term averages are in the low seventies in the south and the low sixties in the north. The slightly higher southern temperatures and steeper gradient are maintained by n&eH/l and in the east by mLl. Of particular interest are the much cooler temperatures on the shores of all five of the Great Lakes.

Departures from normal (see Fig. 19) are often significant. However, because of the general conformity of many of the types' isotherm patterns with the normal pattern they are usually remarkably uniform over the region. In 1953 a high incidence of aIn was balanced by an unusually high number of nHs days, and the entire region was very close to normal. In 1954 and 1957 there was a high nHl frequency with much of the region, particularly the east, averaging slightly below normal. Numerous n&eH/s days in 1956, a cool year, were partially balanced in the southeast by an equal number of mLl. In 1955, however, n&eH/l was dominant, both mLl and aIn occurred in fair numbers, and temperatures were well above normal.

Precipitation in July is distinctly concentrated on days of n&eH, mLl, and aIn/w. In 1954, for example (see Table 6), heavy rainfall occurred over much of the region on every day of each of these three types but was very light or nil on all other days. Local amounts with any one type occurrence are often very high. South Bend in 1954 received 2.13 inches over 2 days of n&eH, and 2.62 inches over 2 days of mLl, out of a total 5.82 inches for the month. Similarly, Fort William in July 1955 received .63, .82, and .27 inches on three separate days of n&eH, .40 and

TABLE 6.—DAILY PRECIPITATION,* JULY 1954

| Station | SOUTHEAST | | | | | | | | SOUTHWEST | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S. Ontario Malton | Durham | Southampton | St. Thomas | NY.Penn.Ohio Buffalo | Rochester | Erie | Toledo | Ind.Ill.Wis. South Bend | Chicago | Milwaukee | Green Bay | WEATHER TYPES |
| Day | | | | | | | | | | | | | |
| 1 | | | | | 08 | 04 | T | | | | | | mLl/ws |
| 2 | 01 | | | 53 | 20 | | T | 20 | 125 | 25 | 13 | 66 | n&eH/l |
| 3 | | | | | 32 | | 09 | 36 | 88 | 105 | 78 | 15 | n&eH/s |
| 4 | 01 | | T | | | | T | | | | T | T | n&eH/s |
| 5 | | | | | 08 | T | | | | | T | | nHl |
| 6 | T | 06 | 08 | 09 | 04 | T | T | 23 | 151 | 113 | 247 | 28 | mLl/ws |
| 7 | | | | | 03 | 04 | 04 | 56 | 111 | 95 | 03 | | mLl/ws nHl |
| 8 | | | | | | | | | | | 01 | | nHl |
| 9 | | | | | | | | | | | 31 | | nHl |
| 10 | | | | | | | | | | | 01 | 73 | nHl |
| 11 | | | | | | | | T | 01 | | T | | nHl |
| 12 | T | | | | | | | | | | | | aLn/d |
| 13 | | | | | | T | | | | | T | T | aLn/d |
| 14 | | | | 99 | 31 | 44 | 79 | T | T | T | T | | n&eH/l |
| 15 | | | | | 04 | 06 | | | | | | | nHl |
| 16 | | | | | | | | | | | | | nHl |
| 17 | T | | | 02 | | | | | | | | | nHl |
| 18 | | | T | 04 | T | 02 | 03 | 01 | T | T | 04 | | aLn/w |
| 19 | 02 | 04 | 05 | | | | | | | | | | aLl/b |
| 20 | 24 | T | | 06 | 06 | 36 | | 15 | 50 | 49 | 01 | | aLl/b |
| 21 | | | | | | | | 05 | 48 | 04 | | | nHn |
| 22 | | | | | | | | | | | | | nHn |
| 23 | | | | | | | | | | T | T | T | aLn/d |
| 24 | | | T | | | T | | | | | | | wHl |
| 25 | T | | | 09 | T | | | | | | | | wHl |
| 26 | | | | | | | | | | | | | wHl |
| 27 | T | 46 | 137 | | T | T | | | | | | | aLn/w n&eH/l |
| 28 | | | 02 | | | | | T | 01 | 30 | 19 | | n&eH/l |
| 29 | 34 | 16 | 22 | 33 | 84 | 45 | 32 | 52 | T | 37 | 25 | T | aLn/w |
| 30 | 10 | 96 | 48 | 30 | 08 | T | 24 | 10 | 07 | T | 90 | 112 | mLl/ws |
| Total | 72 | 168 | 222 | 245 | 208 | 141 | 151 | 218 | 582 | 458 | 513 | 294 | |

*Unit of precipitation is 0.01 inch.

TABLE 6—Continued

| Station | CENTRAL | | | | | | | | NORTH | | | | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower Mich. Alpena | Detroit | E. Lansing | Muskegon | Traverse City | Upper Mich. Escanaba | Sault Ste. Marie | Marquette | Minn.,N.Ont. Duluth | Chapleau | North Bay | Muskoka | |
| Day | | | | | | | | | | | | | |
| 1 | T | | | | | | | T | T | | 02 | | mLl/ws |
| 2 | 02 | 29 | 10 | 46 | 01 | 04 | | T | T | | 03 | | n&eH/l |
| 3 | T | 14 | 59 | 109 | | | | 04 | 02 | | | | n&eH/s |
| 4 | | | | T | 02 | | 02 | T | | 09 | 31 | T | n&eH/s |
| 5 | | | | | | | | | | 19 | | T | nHl |
| 6 | | 02 | 05 | 50 | 11 | 11 | 08 | T | 60 | | 69 | 36 | mLl/ws |
| 7 | | 19 | 43 | 04 | | | | | | 48 | T | | mLl/ws nHl |
| 8 | | | | | | | | | | 05 | 15 | 03 | nHl |
| 9 | | | | | | | | | 22 | 15 | | | nHl |
| 10 | | | | 07 | 05 | 08 | | 09 | 51 | | | | nHl |
| 11 | | T | 21 | 03 | 22 | 08 | T | T | T | | T | | nHl |
| 12 | | | | | | | T | | | | 65 | 14 | aLn/d |
| 13 | | | | T | T | | T | T | T | | 14 | T | aLn/d |
| 14 | 02 | 24 | 03 | T | | | T | | | 03 | 03 | 59 | n&eH/l |
| 15 | | | | | | | | | | | | | nHl |
| 16 | | | | | | | | | T | | | | nHl |
| 17 | | | | | | T | T | 01 | | 02 | | | nHl |
| 18 | | 15 | 19 | 10 | | | T | | | 02 | T | | aLn/w |
| 19 | | | | | 01 | T | | T | T | | T | T | aLl/b |
| 20 | 02 | T | | | | | T | T | | 70 | 29 | 06 | aLl/b |
| 21 | | | | | | | T | | | | | | nHn |
| 22 | | | | | | | | | 06 | | | | nHn |
| 23 | | | | T | | 12 | T | 09 | 14 | | | | aLn/d |
| 24 | | | | | | | | | | | | | wHl |
| 25 | | | | | | | | | | 14 | | 11 | wHl |
| 26 | | | | | | | | | | | 02 | | wHl |
| 27 | 61 | | | | | 44 | 10 | 41 | 87 | | | 54 | aLn/w n&eH/l |
| 28 | 55 | | | | | 01 | T | T | 01 | | | | n&eH/l |
| 29 | 23 | 47 | 22 | 35 | | | | T | | | 07 | 04 | aLn/w |
| 30 | 110 | 51 | 44 | 59 | 48 | 141 | 75 | 53 | 08 | 73 | 88 | 74 | mLl/ws |
| Total | 255 | 201 | 226 | 386 | 90 | 229 | 95 | 117 | 270 | 258 | 328 | 261 | |

.35 inch on two separate days of mLl, and 1.23 inches on one day of aLn, or a total of 3.70 inches out of 3.90 inches for that month. However, all three types are very variable in the exact location of their heaviest precipitation and therefore lead to no definite pattern in any month or, for that matter, in the long term average map. As in April, each July (see Fig. 20) some areas receive over 6 inches while closely adjacent areas may have less than 1 inch. Long term averages (Fig. 17B), therefore, are considerably lower than 6 inches. For most stations, however, they are slightly higher than in either January or April, especially in the north and west due to aLn and nmeH/l, respectively. Almost the entire region averages over 2.5 inches and most of it over 3 inches. Some areas receive over 3.5 inches and a few, over 4 inches.

October

In October, as in July, anticyclonic types are more numerous than cyclonic types. There are, however, very significant differences. By far the dominant type is wHl, a dry type with temperatures close to or slightly below normal. Other anticyclonic types occur in fair numbers, but with considerable irregularity. Both nHn and nHs are common in some years, the former more often than the latter, while in other years they do not occur at all. Similarly, the unusual and very warm anticyclonic type neH may or may not occur in large numbers in this month. The dominant anticyclonic types of July, on the other hand, have all but disappeared. Although much less frequent than in July, nmeH does occur occasionally; but with the Lakes relatively warm, nHl never does. Cyclonic types are only slightly more frequent than in July but show a much greater variety. The most common type is aLn; whereas mLl, though still second in frequency, is at its minimum. Other types occur irregularly, with the occasional gLe hurricane being of particular importance.

Highest temperatures in October 1954 (see Table 7), generally in the seventies, occurred on a wide variety of type days for different stations. In the southwest most stations were warmest on the 3rd with a mT1/ws. Chicago and South Bend led with 81° F. In the southeast, aL1 on October 14 had the highest maxima, 85° and 86° F. in Buffalo and Rochester, respectively; but a nEeH/1 on the first of the month had the highest mean temperatures. Other types and days recording high maxima were aLn/d on the 4th in central Ontario, neH and aLn/w on the 9th in Duluth and Fort William, and aL1/a on the 12th[1] in central Michigan. Normally lowest temperatures occur with nHn or nHs, but neither of these types appeared in 1954. Instead, the coldest days were during a rather unusual aL1/d occurrence at the end of the month. Below normal temperatures were also recorded during both occurrences of wH1, October 6-7 and 18-20.

October as a whole is generally warmer than April. Types occurring in both months are slightly warmer in October. In addition, October is largely dominated by mild types. Even wH1 is a relatively mild anticyclonic type; its temperatures are near normal or just slightly below. Only because of its high frequency is it significant along with irregularly occurring colder types in balancing the milder types. In April there are many mL1 and sL1 occurrences, but they are significant primarily for raising only southern temperatures. In October, not only are there still a fair number of mL1 days, but also numerous aLn and neH occurrences,

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[1]In Ontario several stations had highest minima for the month on the 12th, but not maxima as the cold front passed early in the day.

TABLE 7.--DAILY TEMPERATURE, OCTOBER 1954

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOUTHEAST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| S. Ontario | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Kingston | mx | 75 | 67 | 70 | 78 | 57 | 58 | 55 | 57 | 60 | 63 | 73 | 75 | 72 | 77 | 77 | 60 | 55 | 56 | 49 | 57 | 61 | 57 | 62 | 63 | 53 | 59 | 54 | 49 | 59 | 61 | 62.4 |
| | mn | 62 | 56 | 52 | 58 | 46 | 42 | 37 | 34 | 43 | 55 | 55 | 50 | 52 | 46 | 60 | 49 | 45 | 40 | 34 | 35 | 31 | 34 | 40 | 44 | 33 | 33 | 33 | 47 | 43 | 37 | 43.6 |
| Malton | mx | 73 | 63 | 77 | 73 | 52 | 53 | 50 | 60 | 70 | 65 | 70 | 71 | 71 | 70 | 72 | 61 | 54 | 50 | 49 | 43 | 51 | 50 | 57 | 70 | 63 | 60 | 60 | 52 | 52 | 42 | 53.7 |
| | mn | 63 | 59 | 56 | 60 | 46 | 37 | 29 | 30 | 53 | 54 | 55 | 61 | 53 | 58 | 46 | 48 | 43 | 37 | 34 | 33 | 38 | 37 | 33 | 42 | 46 | 40 | 41 | 38 | 32 | 42 | 43.8 |
| South-ampton | mx | 57 | 62 | 68 | 60 | 55 | 50 | 46 | 62 | 64 | 64 | 70 | 62 | 67 | 75 | 52 | 49 | 48 | 46 | 50 | 53 | 55 | 56 | 60 | 58 | 64 | 60 | 45 | 52 | 43 | 41 | 56.3 |
| | mn | 54 | 51 | 51 | 55 | 44 | 39 | 30 | 30 | 50 | 52 | 57 | 61 | 57 | 65 | 46 | 44 | 42 | 35 | 39 | 39 | 35 | 31 | 46 | 42 | 40 | 44 | 41 | 39 | 42 | 34 | 44.1 |
| St. Thomas | mx | 76 | 74 | 78 | 75 | 56 | 57 | 50 | 61 | 67 | 67 | 72 | 69 | 73 | 78 | 52 | 50 | 52 | 50 | 49 | 54 | 60 | 61 | 71 | 69 | 63 | 66 | 52 | 52 | 49 | 45 | 62.9 |
| | mn | 64 | 62 | 61 | 53 | 44 | 38 | 25 | 32 | 54 | 61 | 62 | 63 | 53 | 51 | 44 | 40 | 35 | 31 | 30 | 33 | 32 | 34 | 35 | 28 | 42 | 39 | 36 | 29 | 38 | 32 | 42.3 |
| NY.Penn.Ohio | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Buffalo | mx | 74 | 69 | 72 | 75 | 56 | 53 | 49 | 65 | 63 | 68 | 72 | 78 | 72 | 85 | 73 | 54 | 49 | 51 | 43 | 51 | 58 | 59 | 62 | 65 | 63 | 67 | 60 | 53 | 50 | 45 | 61.7 |
| | mn | 65 | 60 | 61 | 55 | 47 | 35 | 32 | 34 | 54 | 61 | 63 | 65 | 56 | 56 | 47 | 43 | 41 | 33 | 35 | 34 | 39 | 37 | 47 | 50 | 46 | 48 | 37 | 37 | 39 | 33 | 46.1 |
| Rochester | mx | 79 | 71 | 73 | 78 | 57 | 55 | 47 | 67 | 63 | 65 | 76 | 82 | 74 | 86 | 71 | 52 | 51 | 52 | 43 | 52 | 57 | 56 | 68 | 65 | 70 | 71 | 53 | 55 | 53 | 45 | 63.0 |
| | mn | 67 | 62 | 61 | 54 | 46 | 43 | 32 | 31 | 51 | 63 | 61 | 65 | 53 | 52 | 53 | 44 | 42 | 36 | 35 | 32 | 36 | 34 | 42 | 41 | 39 | 47 | 33 | 34 | 43 | 36 | 45.2 |
| Erie | mx | 74 | 75 | 76 | 73 | 60 | 56 | 49 | 64 | 70 | 68 | 78 | 81 | 70 | 83 | 74 | 54 | 50 | 52 | 49 | 53 | 55 | 54 | 66 | 65 | 69 | 66 | 60 | 55 | 50 | 32 | 62.1 |
| | mn | 63 | 63 | 64 | 56 | 43 | 41 | 35 | 33 | 53 | 60 | 65 | 64 | 60 | 63 | 43 | 40 | 39 | 36 | 34 | 33 | 40 | 35 | 49 | 45 | 43 | 47 | 44 | 37 | 37 | 32 | 46.2 |
| Cleveland | mx | 80 | 84 | 75 | 77 | 66 | 60 | 58 | 56 | 75 | 62 | 81 | 81 | 80 | 81 | 52 | 51 | 56 | 52 | 53 | 56 | 59 | 67 | 69 | 74 | 71 | 65 | 62 | 56 | 49 | 40 | 64.5 |
| | mn | 67 | 64 | 63 | 65 | 52 | 45 | 38 | 37 | 56 | 61 | 63 | 64 | 64 | 58 | 42 | 39 | 41 | 37 | 42 | 36 | 41 | 40 | 44 | 45 | 44 | 54 | 40 | 33 | 35 | 32 | 47.8 |
| SOUTHWEST | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ind.Ill.Wis. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Bend | mx | 75 | 78 | 81 | 75 | 60 | 57 | 56 | 62 | 74 | 71 | 71 | 73 | 45 | 53 | 53 | 53 | 57 | 60 | 65 | 71 | 71 | 65 | 61 | 58 | 65 | 61 | 58 | 55 | 46 | 38 | 62.0 |
| | mn | 59 | 66 | 64 | 58 | 47 | 38 | 32 | 42 | 59 | 62 | 63 | 59 | 40 | 38 | 33 | 30 | 31 | 36 | 35 | 40 | 39 | 42 | 45 | 35 | 42 | 45 | 35 | 32 | 33 | 31 | 43.6 |
| Chicago | mx | 69 | 80 | 81 | 73 | 65 | 53 | 58 | 58 | 77 | 68 | 70 | 73 | 77 | 72 | 51 | 50 | 56 | 48 | 54 | 62 | 64 | 68 | 72 | 73 | 67 | 62 | 58 | 57 | 49 | 40 | 63.2 |
| | mn | 62 | 64 | 68 | 64 | 52 | 49 | 44 | 47 | 43 | 63 | 64 | 60 | 50 | 47 | 42 | 41 | 40 | 38 | 42 | 36 | 40 | 41 | 45 | 44 | 43 | 49 | 39 | 35 | 33 | 29 | 47.3 |
| Milwaukee | mx | 60 | 71 | 78 | 70 | 59 | 53 | 54 | 54 | 76 | 66 | 71 | 72 | 73 | 70 | 54 | 50 | 52 | 49 | 51 | 53 | 59 | 69 | 70 | 71 | 70 | 60 | 50 | 55 | 42 | 38 | 60.2 |
| | mn | 54 | 58 | 64 | 58 | 43 | 44 | 46 | 49 | 54 | 58 | 56 | 54 | 49 | 45 | 39 | 41 | 39 | 39 | 36 | 33 | 41 | 39 | 39 | 44 | 73 | 44 | 37 | 34 | 32 | 29 | 44.2 |
| Green Bay | mx | 55 | 59 | 61 | 64 | 49 | 52 | 54 | 52 | 65 | 56 | 63 | 72 | 63 | 56 | 52 | 52 | 49 | 46 | 52 | 57 | 64 | 66 | 71 | 70 | 66 | 49 | 49 | 58 | 41 | 35 | 56.3 |
| | mn | 48 | 50 | 53 | 48 | 40 | 38 | 29 | 43 | 51 | 51 | 51 | 43 | 45 | 41 | 34 | 33 | 32 | 29 | 27 | 30 | 34 | 33 | 42 | 38 | 41 | 38 | 33 | 37 | 30 | 25 | 38.5 |
| WEATHER TYPES | | n&eH/1 | n&eH/1 | mLl/ws | aLn/d | n&eH/s | wHl | wHl | neH | neH aLn/w | mLl/ws | mLl/ws | aLl/a | wHl sLl | sLl | gLe/h | gLe/h | gLe/h wHl | wHl | wHl | wHl | wHl | wHs | wHs | aLn/d n&eH/1 | n&eH/1 | sLl | sLl wHl | aLl/d | aLl/d | aLl/d | |

TABLE 7--Continued

| Station | dy | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | A° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CENTRAL | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Lower Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Alpena | mx | 74 | 57 | 75 | 64 | 63 | 51 | 53 | 61 | 62 | 60 | 69 | 74 | 67 | 69 | 69 | 49 | 50 | 50 | 55 | 52 | 60 | 69 | 60 | 71 | 72 | 68 | 50 | 57 | 53 | 39 | 60.6 |
| | mn | 50 | 43 | 48 | 43 | 41 | 38 | 26 | 30 | 45 | 48 | 48 | 49 | 56 | 44 | 45 | 36 | 35 | 30 | 31 | 30 | 40 | 33 | 36 | 33 | 38 | 37 | 37 | 30 | 33 | 32 | 38.8 |
| Detroit | mx | 72 | 77 | 78 | 78 | 61 | 57 | 51 | 53 | 74 | 70 | 72 | 74 | 75 | 79 | 54 | 48 | 40 | 51 | 51 | 57 | 61 | 67 | 71 | 73 | 70 | 65 | 57 | 54 | 40 | 41 | 62.4 |
| | mn | 65 | 62 | 63 | 61 | 47 | 42 | 39 | 43 | 53 | 62 | 64 | 63 | 57 | 54 | 42 | 42 | 38 | 34 | 34 | 35 | 30 | 39 | 43 | 46 | 44 | 54 | 40 | 35 | 36 | 34 | 46.6 |
| E.Lansing | mx | 67 | 70 | 79 | 72 | 55 | 56 | 56 | 55 | 74 | 70 | 69 | 73 | 75 | 72 | 52 | 47 | 50 | 51 | 52 | 53 | 65 | 67 | 72 | 73 | 71 | 61 | 55 | 55 | 47 | 44 | 61.3 |
| | mn | 56 | 61 | 63 | 55 | 45 | 37 | 32 | 39 | 55 | 62 | 63 | 60 | 50 | 50 | 43 | 39 | 35 | 35 | 31 | 32 | 38 | 35 | 42 | 43 | 42 | 43 | 36 | 33 | 34 | 31 | 43.6 |
| Muskegon | mx | 66 | 69 | 74 | 67 | 53 | 53 | 55 | 53 | 68 | 66 | 67 | 72 | 70 | 73 | 55 | 49 | 51 | 49 | 53 | 56 | 62 | 63 | 64 | 61 | 65 | 59 | 53 | 55 | 48 | 38 | 52.9 |
| | mn | 53 | 59 | 61 | 53 | 44 | 37 | [illegible] | 42 | 53 | 61 | 61 | 60 | 57 | 49 | 45 | 39 | 36 | 34 | 28 | 30 | 39 | 34 | 45 | 40 | 40 | 45 | 35 | 41 | 35 | 31 | 43.5 |
| Traverse City | mx | 57 | 59 | 70 | 66 | 54 | 50 | 55 | 54 | 62 | 60 | 64 | 60 | 67 | 72 | 52 | 45 | 46 | 45 | 52 | 56 | 57 | 67 | 63 | 77 | 60 | 53 | 47 | 54 | 46 | 38 | 56.7 |
| | mn | 49 | 50 | 57 | 49 | 40 | 37 | 25 | 33 | 51 | 52 | 53 | 52 | 45 | 47 | 44 | 40 | 35 | 33 | 27 | 28 | 34 | 31 | 43 | 42 | 37 | 38 | 36 | 34 | 32 | 30 | 40.1 |
| Upper Mich. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Escanaba | mx | 53 | 57 | 57 | 65 | 49 | 50 | 51 | 54 | 60 | 54 | 57 | 68 | 65 | 51 | 53 | 49 | 47 | 45 | 51 | 55 | 62 | 60 | 72 | 58 | 59 | 40 | 50 | 51 | 43 | 34 | 52.7 |
| | mn | 43 | 48 | 51 | 43 | 35 | 35 | 30 | 48 | 49 | 44 | 50 | 51 | 43 | 40 | 29 | 35 | 34 | 32 | 33 | 35 | 37 | 49 | 45 | 45 | 37 | 34 | 37 | 32 | 24 | 21 | 39.9 |
| Sault Ste. Marie | mx | 52 | 60 | 55 | 56 | 50 | 48 | 51 | 55 | 54 | 59 | 54 | 62 | 65 | 61 | 51 | 42 | 44 | 44 | 53 | 53 | 60 | 62 | 61 | 61 | 58 | 50 | 40 | 50 | 42 | 35 | 52.3 |
| | mn | 43 | 41 | 48 | 45 | 36 | 31 | 27 | 36 | 40 | 37 | 49 | 48 | 47 | 47 | 41 | 35 | 32 | 30 | 30 | 29 | 37 | 33 | 45 | 39 | 40 | 36 | 32 | 30 | 33 | 26 | 37.1 |
| Marquette | mx | 49 | 56 | 52 | 53 | 46 | 46 | 54 | 60 | 58 | 53 | 52 | 66 | 65 | 48 | 49 | 45 | 52 | 43 | 52 | 52 | 56 | 70 | 63 | 54 | 64 | 43 | 41 | 52 | 43 | 32 | 51.8 |
| | mn | 43 | 46 | 47 | 40 | 37 | 34 | 32 | 44 | 45 | 41 | 40 | 50 | 47 | 44 | 42 | 33 | 34 | 34 | 35 | 34 | 35 | 40 | 45 | 44 | 43 | 37 | 36 | 36 | 32 | 26 | 39.3 |
| NORTH | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Minn.,N.Ont. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Duluth | mx | 45 | 55 | 55 | 50 | 42 | 46 | 54 | 48 | 62 | 51 | 49 | 59 | 52 | 47 | 46 | 52 | 38 | 48 | 54 | 55 | 61 | 65 | 63 | 52 | 49 | 38 | 52 | 45 | 33 | 31 | 49.5 |
| | mn | 32 | 36 | 41 | 32 | 28 | 29 | 32 | 42 | 45 | 45 | 46 | 46 | 42 | 38 | 37 | 34 | 24 | 22 | 27 | 27 | 30 | 43 | 43 | 40 | 37 | 30 | 25 | 30 | 26 | 22 | 34.0 |
| Fort William | mx | 46 | 55 | 54 | 54 | 48 | 48 | 52 | 52 | 64 | 50 | 53 | 54 | 53 | 46 | 42 | 47 | 48 | 54 | 62 | 56 | 60 | 62 | 64 | 47 | 39 | 40 | 50 | 49 | 34 | 23 | 50.7 |
| | mn | 29 | 31 | 32 | 34 | 22 | 26 | 25 | 44 | 41 | 46 | 47 | 45 | 36 | 31 | 38 | 32 | 23 | 25 | 25 | 24 | 30 | 40 | 40 | 35 | 32 | 27 | 31 | 27 | 23 | 14 | 33.7 |
| North Bay | mx | 56 | 51 | 53 | 65 | 48 | 39 | 42 | 55 | 52 | 54 | 50 | 62 | 62 | 63 | 46 | 41 | 42 | 42 | 50 | 46 | 51 | 64 | 53 | 52 | 44 | 37 | 46 | 43 | 33 | 32 | 50.3 |
| | mn | 50 | 44 | 41 | 47 | 32 | 31 | 35 | 33 | 44 | 44 | 47 | 54 | 52 | 45 | 48 | 43 | 37 | 30 | 31 | 35 | 37 | 29 | 43 | 36 | 37 | 36 | 29 | 29 | 39 | [illegible] | 33.1 |
| Muskoka | mx | 61 | 62 | 63 | 70 | 53 | 47 | 46 | 59 | 58 | 61 | 65 | 65 | 67 | 66 | 65 | 54 | 49 | 47 | 47 | 52 | 62 | 55 | 64 | 62 | 55 | 50 | 44 | 51 | 45 | 45 | 55.8 |
| | mn | 54 | 47 | 45 | 54 | 31 | 33 | 22 | 24 | 48 | 46 | 52 | 53 | 47 | 41 | 49 | 43 | 36 | 23 | 30 | 26 | 31 | 26 | 34 | 30 | 33 | 33 | 36 | 24 | 37 | 31 | 33.3 |
| WEATHER TYPES | | n%eH/1 | n%eH/1 | mLl/ws | aLn/d | n%eH/s | wHl | wHl | neH | neH aLn/w | mLl/ws | mLl/ws | aLl/a | wHl sLl | sLl | cLe/h | cLe/h | cLe/h wHl | wHl | wHl | wHl | wHl | wHs | wHs | ·Ln/d n%eH/1 | n%eH/1 | sLl | sLl wHl | aLl/d | aLl/d | aLl/d | |

and a few n&eH/l days. Conversely, cold types are few and irregular in October, whereas in April nHs is fairly common and nHn, nHl and n&eH/s all occur in some years.

Normal temperatures (see Fig. 18A) are in the low fifties in the south and about forty degrees in the north. Latitudinal gradient and east-west differences are both smaller than in spring. The two dominant types wHl and aLn have fairly uniform temperatures from east to west, except for the effect of modification by the lakes, and also small latitudinal gradients. In addition, mLl and sLl, which are largely responsible for the higher southern and southeastern temperatures in spring, are much less common in October and their differential effects are to a large degree counteracted by neH, n&eH/l and nHn. However, modification by the warm lakes, particularly for anticyclonic types, is again important though not as much as in January. A slight reversal of gradient appears in Upper Michigan, and the cold loops of northeastern Wisconsin, northern Lower Michigan, and south of Georgian Bay have redeveloped. All eastern and southern shores are noticeably mild for their latitude.

Departures from normal are important because of the variability of the more extreme, less common types, in spite of the reliability of the two dominant types. For example, (see Fig. 19), in 1957 there were a fair number of nHn and nHs and almost no cyclonic types; hence average temperatures were below normal, particularly in the south. On the other hand, in 1953 there were no nHs, a number of neH, and a few mLl occurrences and temperatures were above normal. In 1956 neH had a very high frequency and mLl occurred in fair numbers. There were only two days of nHn and none of nHs. Consequently, temperatures were well above normal. In 1954 and 1955 there were no occurrences of nHn and only one of nHs, but also, only one neH; temperatures were close to normal or slightly above.

Precipitation in October is, for the most part, very clearly associated with only certain types. Heavy rain occurs with mLl, sLl, gLe and the occasional naeH or aLl. In contrast, wHl and neH, except for fringe disturbances in the case of the latter, are very dry (e.g. Table 8).

In Table 8, (Daily Precipitation, October 1954), of particular note are the small amounts recorded from the 6th to the 8th with wHl and neH, and especially from the 18th to the 23rd with wHl and wHs. The naeH/l on the 24th and 25th also appears quite dry, but on this occasion the front was fairly far north and few of the stations listed recorded rain. Typical amounts in Northern Ontario were as follows: Atikokan, .04 and .25; Armstrong, .98 and .06; Fort William, .10 and .01; White River, .12 and .41; Biscotasing, .23 and .31; Coniston, .02 and .17; Earlton 0 and .31; and North Bay 0 and .04 inch. South of North Bay there was virtually no rain.

Extremely heavy rainfall also occurred in the same month. On the 3rd, mTl/ws brought over 2 inches and occasionally 3 inches to many stations in the southwest and in central Michigan; another occurrence on the 10th and 11th brought similar amounts again to Chicago and South Bend. Record falls, however, occurred during Hurricane Hazel on the 15th and 16th and the preceding sLl on the 14th. Of the stations listed, Malton, near Toronto, Ontario received the highest amounts: 4.78 inches fell on the 15th and a total of 6.14 inches over the three days. Several stations, however, received even more. Port Credit just west of Toronto had 5.05 inches on the 15th and a total of 6.35 inches. Highest was Brampton, northwest of Toronto with 7.02 inches on the 15th and a total

TABLE 8.—DAILY PRECIPITATION,* OCTOBER 1954

| Station | SOUTHEAST | | | | | | | | SOUTHWEST | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | S. Ontario Malton | Durham | Southampton | St. Thomas | NY.Penn.Ohio Rochester | Erie | Cleveland | Toledo | Ind.Ill.Wis. South Bend | Chicago | Milwaukee | Green Bay | WEATHER TYPES |
| Day | | | | | | | | | | | | | |
| 1 | 75 | 36 | 09 | 39 | | | | | | T | 33 | 02 | n&eH/l |
| 2 | 56 | 134 | 77 | 10 | 150 | | | | T | 01 | 31 | 344 | n&eH/l |
| 3 | 25 | 09 | 04 | 109 | 06 | 26 | 30 | 18 | 150 | 395 | 124 | 28 | mLl/ws |
| 4 | | | | | 01 | 101 | 94 | 20 | 21 | | T | T | aLn/d |
| 5 | T | 02 | 09 | 01 | T | 05 | 97 | 63 | 76 | 86 | 16 | 01 | n&eH/s |
| 6 | 02 | 04 | 02 | 01 | 10 | 01 | T | T | T | | | | wHl |
| 7 | | | | | | | | | | | | | wHl |
| 8 | | T | 01 | 01 | | | 01 | T | 03 | 02 | 06 | 02 | neH |
| 9 | T | 12 | 03 | 24 | T | T | | 09 | 79 | 227 | T | T | neH aLn/w |
| 10 | 32 | 82 | 54 | 80 | 20 | 37 | 60 | 111 | 276 | 394 | 74 | 09 | mLl/ws |
| 11 | 04 | 48 | 32 | 12 | 04 | 16 | 28 | 11 | T | 51 | T | 05 | mLl/ws |
| 12 | 20 | 46 | 19 | 07 | 90 | 127 | 73 | 02 | 16 | 03 | | 01 | aLl/a |
| 13 | T | 29 | 16 | 64 | | T | | | | | | | wHl sLl |
| 14 | 125 | 86 | 70 | 138 | 03 | 16 | 28 | 217 | 110 | 22 | 13 | 48 | sLl |
| 15 | 476 | 309 | 261 | 197 | 143 | 435 | 336 | 07 | 26 | T | T | T | gLe/h |
| 16 | 11 | 50 | 52 | 77 | 23 | 15 | 17 | 07 | 95 | 02 | 03 | 01 | gLe/h |
| 17 | | | 25 | | 06 | 103 | 09 | 04 | 21 | T | T | T | gLe/h wHl |
| 18 | T | | | | 01 | 12 | 49 | | 01 | 15 | 02 | | wHl |
| 19 | | | | | T | | 34 | | | 03 | | | wHl |
| 20 | | | | | | | | | | | | | wHl |
| 21 | | | | | | | | | | | | | wHl |
| 22 | | | | | | | | | | | | | wHs |
| 23 | | | | | | | | | | | | | wHs |
| 24 | | | | | | | | | | | | | aLn/d n&eH/l |
| 25 | | | | | | | T | T | T | | | | n&eH/l |
| 26 | 06 | 21 | 21 | 29 | T | 02 | 02 | T | 01 | 02 | 14 | 49 | sLl |
| 27 | T | 06 | | 03 | 93 | 22 | 04 | T | 10 | T | 02 | 02 | sLl wHl |
| 28 | 04 | 12 | 13 | 09 | | | | T | 10 | T | T | 05 | aLl/d |
| 29 | 04 | 38 | 34 | 02 | 03 | 07 | 10 | 14 | 27 | 03 | T | 03 | aLl/d |
| 30 | | 03 | 37 | 22 | T | 54 | 20 | T | 49 | T | T | T | aLl/d |
| Total | 842 | 927 | 739 | 834 | 549 | 979 | 892 | 504 | 971 | 1206 | 318 | 500 | |

*Unit of precipitation is 0.01 inch.

TABLE 8.--Continued

| Station | CENTRAL | | | | | | | | NORTH | | | | WEATHER TYPES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower Mich. Alpena | Detroit | E. Lansing | Muskegon | Traverse City | Upper Mich. Escanaba | Sault Ste. Marie | Marquette | Minn.,N.Ont. Duluth | Fort William | North Bay | Muskoka | |
| Day | | | | | | | | | | | | | |
| 1 | 08 | 89 | 25 | 08 | T | | | T | 04 | 03 | | 09 | m&eH/l |
| 2 | 02 | 01 | 05 | 71 | 65 | 16 | | | | | 01 | 22 | m&eH/l |
| 3 | 130 | 329 | 208 | 321 | 95 | 09 | 04 | T | T | | 10 | 29 | mLl/ws |
| 4 | T | 43 | 22 | T | T | | 04 | | | | | 02 | aLn/d |
| 5 | | 16 | 29 | 02 | T | | | | | 01 | | 02 | n&eH/s |
| 6 | 01 | T | | | | | 09 | T | | | 04 | 01 | wHl |
| 7 | | | | | | | | | T | 13 | | | wHl |
| 8 | | T | 03 | 11 | | T | | | T | | T | T | neH |
| 9 | 01 | | T | 01 | | 01 | T | T | 01 | | 04 | 08 | neH aLn/w |
| 10 | 07 | 11 | 60 | 14 | 01 | 51 | 126 | 105 | 14 | | 05 | 51 | mLl/ws |
| 11 | 24 | 24 | 05 | 02 | 06 | 03 | 17 | 14 | 15 | T | 18 | 37 | mLl/ws |
| 12 | 26 | 44 | 22 | 06 | 05 | 69 | 27 | 02 | 32 | 18 | 08 | 19 | aLl/a |
| 13 | | 01 | T | | | | | 04 | T | | T | | wHl sLl |
| 14 | 48 | 126 | 42 | 26 | 21 | 95 | 66 | 139 | 24 | 35 | 155 | 151 | sLl |
| 15 | 04 | 39 | 02 | T | 04 | 04 | 03 | 04 | T | T | 122 | 332 | gLe/h |
| 16 | 180 | 11 | 21 | 83 | 112 | 03 | 09 | 14 | | 03 | 54 | 13 | gLe/h |
| 17 | 08 | T | T | 12 | 16 | 03 | T | 35 | | | T | 10 | gLe/h wHl |
| 18 | 02 | | | | T | | | 05 | | | 03 | | wHl |
| 19 | | | | | | | | | | | | | wHl |
| 20 | | | | | | | | | | | | | wHl |
| 21 | | | | | | | | | | | | | wHl |
| 22 | | | | | | | | | | | | | wHs |
| 23 | | | | | | | | | | T | | | wHs |
| 24 | | | | | | | | | T | 10 | | | aLn/d n&eH/l |
| 25 | | | | | | | | 01 | 16 | 01 | 04 | | n&eH/l |
| 26 | | 08 | 10 | 17 | 08 | 23 | 27 | 14 | 03 | | 37 | 14 | sLl |
| 27 | 14 | 17 | 07 | 08 | 21 | 02 | 03 | 01 | | | 01 | 01 | sLl wHl |
| 28 | | | T | | T | 07 | T | 01 | T | 01 | | 24 | aLl/d |
| 29 | 15 | 18 | 22 | 31 | 38 | 03 | 22 | 12 | 03 | T | 20 | 28 | aLl/d |
| 30 | 09 | 02 | 05 | 23 | 05 | 02 | T | 17 | T | 01 | 08 | 02 | aLl/d |
| Total | 479 | 780 | 488 | 636 | 397 | 291 | 407 | 368 | 112 | 86 | 454 | 755 | |

of 8.35 inches for the three days.

Normal precipitation for October (Fig. 18B), however, is much less than in 1954 due to the dominance of the dry anticyclonic types. Nevertheless, with the variety of cyclonic types most areas average between 2 and 3.5 inches, with the greatest amounts falling to the east and southeast of the lakes.

As illustrated by 1954, major deviations from the normal due to the variability of the heavy precipitation types are characteristic of October, particularly in the south and east associated with very rainy mLl occurrences and the gLe hurricanes. Several areas in both 1954 and 1955 had over 8 inches during the month (see Fig. 20) with both years experiencing hurricanes and heavy mLl rainfall. Remarkably dry years also occur. In 1956, the month was very largely dominated by wHl and neH, cyclonic types were at a minimum, and much of the region received less than 1 inch of precipitation. The other two years were close to normal but had rather unusual patterns. In 1955 both east and west had less than 1 inch; however, the central areas had close to 2 inches and the extreme east over 2 inches. Dry nHn, wHl and neH were all frequent, but a few days of mLl brought some rain to central areas, and a gLe, some to the extreme east. In 1957 the dry anticyclonic types dominated the month almost to the exclusion of other types. Nevertheless, precipitation to the lee of the lakes with nHs, along with one day of gLe, kept southeastern amounts well up; with several days of aLn, all areas received at least one inch.

Summary of Seasonal Comparisons and Type Frequency

The highest overall frequency throughout the year of any of the types is maintained by mLl. This type occurs in large numbers in every month except October and in that month it is still important, especially for its occasional very heavy rains. Thus, in all seasons it may be considered as responsible generally throughout the region for the base amount of precipitation and its high reliability; in addition, it contributes to a large degree to the higher temperatures of the south.

Other than mLl, however, each type has definite and strong seasonal concentrations: nHn and nHs in January, and to a lesser degree nHs also in April; sLl in April; nSeH and nHl in July; wHl in October; and aLn, second in total frequency but well behind mLl, in July and October. Combined, cyclonic types have a greater frequency than anticyclonic types in winter due to their variety and in spring due largely to the reliability of mLl and sLl. On the other hand,[1] anticyclonic types are far more common in summer due to the high frequency of nSeH and nHl and almost complete absence of three of the cyclonic types, and again in fall due especially to the very large number of wHl and in spite of a greater diversity of cyclonic types than in either spring or summer. Over the year there are just a very few more anticyclonic than cyclonic days (see Fig. 2).

These concentrations, as well as the more general frequencies, are of fundamental importance to the climate. Although the temperatures of each of the types do vary with the seasons, they maintain roughly the same distribution characteristics throughout the year and also their

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[1]Compare Trewartha's generalization (see above p. 3, or Finch and Trewartha, p. 186) that the greater importance in winter of anticyclonic circulation, as a "condition that is antagonistic to the development of fronts and cyclones", is a factor in the summer maximum of precipitation in humid microthermal climates.

same general relation, either relatively cold or warm, to those of other types. Similarly, precipitation associated with each type falls in approximately equal quantities and with the same distribution characteristics, except for minor differences caused by the changes in lake temperatures, no matter when the type occurs. Type frequencies, therefore, clearly determine not only the day to day character of the climate, but also the distributional differences of average temperature and total precipitation from season to season and year to year.

The normal temperatures of January are particularly cold because of the dominance of very cold types, nHn and nHs, and some years are much colder than others due largely to the frequency variation of nHs. The daily weather, however, is best characterized by the frequent alterations of these cold anticyclones with the wide variety of cyclonic types which bring much warmer temperatures to the south of the region. As a result strong contrasts of average temperatures exist between those areas in the south and especially the southeast which are most influenced by the cyclonic warm sectors, and the northern areas reached by relatively warm temperature only during the occasional aLn while at the same time experiencing extremely low temperatures with both nHn and nHs. Also, at this time of the year the importance of the lakes is at a maximum. The lakes are relatively warm whereas the extremely cold nHs and even nHn have temperatures far below freezing. Thus, the greatest possible contrasts are created. Interior cold loops as well as modification of shores are both clearly evident.

By April sLl and mLl, both important warm sector types, reach a maximum frequency and, in addition, anticyclonic types appear in greater variety and are less severe. Temperatures, therefore, are generally milder, at least in comparison to the extremes of winter, and fluctuations are greatly reduced. Cold waves of nHn and especially nHs do occur, but since continental cold is not as extreme at this season, neither type is quite as cold in relation to normals as in January. On the other hand, mLl and sLl, because of their high frequency, influence April temperatures to such an extent that they, also, both differ from normal temperature slightly less than in January. Latitudinal gradient of normal temperature is still considerable due in particular to mLl and sLl, but the influences of these types in this regard are minimized by the variety of anticyclonic types and aLn which bring more uniform temperature from north to south and never the severe northern cold to oppose the southern warm sectors. Year to year departures of monthly averages from normal, however, are sometimes great since the three dominant types have the most extreme temperatures relative to normal and are all subject to occasional frequency differences. Lake influence is at a minimum because the lakes are cool and the types mild.

In July temperatures are, of course, high. Occurrences of the coldest types, nHn and nHs, are at a combined minimum; hence the high temperatures of mLl, aLn, and n&eH/l are balanced only by the less severe anticyclonic types, n&eH/s, nHl, and wHl. There is even less normal latitudinal gradient than in April due largely to the disappearance of sLl and the great increase of nHl, n&eH/s, and particularly of aLn which brings warm temperatures more frequently to northern areas. The ratio of n&eH/l to n&eH/s is particularly important in creating above or below normal temperatures from year to year. The lakes are cool and noticeably lower temperatures in their vicinity.

October is perhaps the most unusual of the four months. Between one-quarter and one-third of the month each year is dominated by wHl, a mild anticyclonic type. The remainder of the month is divided among a wide variety of types, both cyclonic and anticyclonic, with aLn running a poor second to wHl. For the most part these types are also mild except for a variable number of nHn and nHs. Temperatures, therefore, in spite of a minimum of mLl and only rare occurrences of sLl, average considerably higher than in April. On the other hand, because there are few mLl and sLl, the latitudinal gradient is small as it is in July. Variation from year to year is important because of the irregularity of all but wHl and aLn, which includes the more extreme types. The lakes are quite warm at this time, but so are the temperatures; consequently, only eastern and southern shores are moderately warmed.

The importance of type frequencies to seasonal precipitation is in many cases much easier to interpret because of the association of heavy precipitation with just certain types while others have very little. The Great Lakes Region is noted for the general flatness of its precipitation curve; yet from the study of weather types it is evident that (1) the synoptic origin of this precipitation is far from constant; (2) very significant differences in seasonal distribution do occur from place to place.

It has been pointed out that mLl is responsible throughout the year with few exceptions for at least a base coverage of precipitation for the entire region; the reliability of the total amounts for any month, however, is dependent on a variety of types and their relative seasonal frequencies. In winter reliability is dependent on the diversity of cyclonic types, while in spring it is more dependent on the frequency of mLl and sLl only. In summer there are decidedly fewer cyclones than anticyclones; hence much less precipitation might be expected. However, in this season n&eH, the only rainy anticyclonic type, reaches a very strong maximum. In fall cyclones are again less numerous than anticyclones, even mIl is at a minimum and, in addition, n&eH has virtually disappeared. Precipitation, therefore, is frequently quite low, but occasionally very high because of gLe hurricanes and very heavy falls with the few mLl. Thus, in all seasons except winter, heavy precipitation is dependent on the frontal precipitation of a few cyclonic types all of which are somewhat fickle in the exact location of their concentrations; almost invariably certain local areas receive much more rain than others. Areas with over 6 inches in a month are common but so are areas with less than 2 inches. In winter the diversity of contributing types, none of which bring the extremely high falls such as those of gLe hurricanes or mIl in fall, lead to a more constant distribution and lower maximum amounts.

In January, due to the importance of sLl and gLe, southeastern areas generally receive the most precipitation and the west, at a distinct minimum for the year, the least. Details of the distribution are largely dependent on the influences of the lakes on aLl, sLl and nHs. Snow belt areas of southwestern Ontario and east of Lake Erie average over 3 inches for the heaviest monthly falls but all southern and eastern lake shores have relatively high amounts compared to other areas. In April precipitation is distinctly heavier in the south than in the north due to the dominance of mLl and sLl, and to a lesser extent to n&eH. With the increase of sLl, the entire southeast, except the winter snow belt of southwestern Ontario, averages over 3 inches or slightly more than in January. Southwestern areas also receive more than in January because of the slight increase of n&eH. In July most areas reach a maximum, except again for the snow belt of southwestern Ontario. Northern and western areas, in particular, are much higher; both average over 3 inches as opposed to under 3 inches in spring and winter, and under 2 inches in the west in winter. In the north the increase is due to the large number of aIn/w days; in the west, to the very high frequency of nwH as well as aIn/w. The peak, however, is as usual in the rainy southeast which has over 4 inches. October precipitation is highly variable: hence average figures of this month have limited meaning and present a rather intricate pattern. Most stations record less than in July, except those in the vicinity of Georgian Bay, but due largely to aIn/w still more than in either winter or spring in the north and more than in winter in the west. Lake influence is of some importance again as seen in slightly higher precipitation to the east and southeast of the lakes.

## SUMMARY AND CONCLUSION

The climate of the Great Lakes Region on a comprehensive and regional scale has received surprisingly little attention in the past. In spite of its peculiar nature, due largely to the lakes themselves, only a few studies have been made specifically of the region as a unit. These studies along with statistical continent wide classifications as well as more local, detailed examinations of the elements provide a general conception of the climate, but this is by no means adequate. For the most part the primary concern has been with element averages which bear no direct relation to actual individual occurrences. Variations and deviations are almost invariably pointed out, but even these do not explain the climate. Numerous qualitative attempts have been made to present the required genetic aspects; yet many problems have remained unanswered, while the validity of some conclusions concerning others is open to question. The need, therefore, has arisen for a quantitative genetic climatology of the region.

Modern demands by climatology and meteorology in general at the broader continental or world level have led in recent times to the intensive development of studies directed toward the dynamics of the atmosphere. Unfortunately, however, although much work has been done in this line there is still a great need for the relating of the dynamics to actual regional element occurrences, that is, for a quantitative explanation of the common, experienced weather elements in terms of their genesis. Numerous methods of classifying regional atmosphere behavior have been devised in the past, which might be employed for this purpose in the Great Lakes Region. Of particular note are air mass and recurrent synoptic pattern classifications. A modification of the latter has been selected over the air mass approach because it is more easily adapted to accommodate frontal precipitation and is more easily applied in regional analysis as opposed to station analysis--again because of the frontal problem.

Three criteria form the bases of differentiation of systems representing the weather types of the region: synoptic circulation pattern, direction of the point of origin, and local trajectory relative to the Great Lakes. Such systems are dynamic-synoptic system weather types and are related both to the general circulation and to actual element occurrences. By establishing type frequencies in each season and also the normal element characteristics of each type, the sought-for relation between the dynamics and the elements is drawn and the climate may be analysed at the same time quantitatively and genetically.

In the Great Lakes Region eleven dynamic-synoptic systems are sufficiently distinctive for isolation as weather types. With each type are associated remarkably constant element occurrences, though in some cases slight variations in the detail of the synoptic pattern and, therefore, in the element distribution has necessitated subdivision of the type. On the other hand, differences between the various types and in their frequencies from season to season are quite marked. These differences are clearly reflected in, and in fact explain, the general day to day character of the seasonal climate as well as the distributional details of the averages and deviations of both temperature and precipitation.

The application of dynamic-synoptic system weather types to the Great Lakes region has, of course, revealed certain limitations to the method--all of which have been discussed at some length. Fortunately, however, most of these may with little difficulty be restated as challenges rather than as limitations. In general, there are two main aspects: first, the great amount of exploratory and analytical work necessary; and second, the fact that a sufficiently sound and complete understanding of the general circulation and the dynamics of the atmosphere is just now evolving. In examining the climate of the Great Lakes only four months of the year have been analyzed. The gradation of changing frequencies from month to month cannot be seen and, consequently, interpretations of such seasonal changes as the more rapid warming of some areas than others in spring cannot be made with any confidence. Furthermore, the total observational period was only five years. From the constancy of frequencies and characteristics over that period the conclusions reached may be considered as reasonably valid in relative terms but are less secure when stated absolutely. In the frequency analysis day units have been used; shorter time intervals are necessary to lessen the discrepancies between them and the natural durations of the systems and thus give much greater reliability and accuracy to generalization and comparisons. In short, the result in the case of the first problem has been a less convincing, less quantitative, and more superficial seasonal analysis than is desired.

The second problem, though inherently entering into the seasonal analysis, is perhaps more directly related to the preliminary typing of the system sequences. Many days clearly belong to one type or another, but some are unavoidably of a borderline nature--though remarkably few.

subjectivity, as in all science, cannot be completely avoided, but it can be reduced by using a shorter time interval, and perhaps, more important, by a more detailed understanding of the dynamics of the atmosphere, particularly the jet stream, the general upper-level westerly flow and the transfer of moisture, as related to the genesis of the dynamic-synoptic systems themselves and their characteristics. Such understanding is fundamentally necessary before the method can be presented with absolute accuracy or accepted with complete confidence.

On the other hand, even in its present form this study of the climate of the Great Lakes Region in terms of its genesis by dynamic-synoptic system weather types at least illuminates a logical and practical method for relating the dynamics of the general atmosphere circulation to actual element occurrences. As such it fills the necessary missing link for a new, fully integrated, comprehensive, and coherent framework for climatic synthesis based not on arbitrary values or other related natural phenomena, but on the genetic character of climate itself. The general atmospheric circulation, its constancies and perturbations form the foundation of this framework, and at the same time, because specific and actually occurring elements values are associated with each system, local and regional climates are truly described in terms of the weather as it is experienced rather than in terms of merely abstract mean values. For the Great Lakes Region itself, it provides a new and more quantitative understanding of the general climate of the region, its daily, seasonal, and yearly variations and its variations from place to place.

## BIBLIOGRAPHY

Blair, Thomas A. "Weather Types and Pressure Anomalies", Monthly Weather Review, Vol. LXI, No. 7 (1933), pp. 196-98.

Brunnschweiler, D.H. "Die Luftmassen der Nordhemisphaere", (in German with English abstract), Geographica Helvetica, Heft III (1957), pp. 164-95.

_______. "The Geographic Distribution of Air Masses in North America", Vierteljahrsschr. Naturforsch. Gesellsch. (Zurich), 1952, pp.42-9.

Calef, Wesley and Others. Winter Weather Type Frequencies Northern Great Plains. Technical Report of the Quartermaster Research and Engineering Command, U.S. Army, through a contract study with the University of Chicago. Natick, Mass.: Regional Environments Research Branch, August, 1957.

California Institute of Technology, Meteorology Dept. Synoptic Weather Types of North America. 1943.

Court, Arnold. "Climatology: Complex, Dynamic, and Synoptic", Annals Assoc. Amer. Geog., Vol. XLVII, No. 2 (June 1957), p. 125.

Day, P.C. "Precipitation in the Drainage Area of the Great Lakes, 1875-1924", Monthly Weather Review, Vol. LIV, No. 3 (1926), pp. 85-106.

Dejordjo, V.A. "Weather Types of Central Asia", (in Russian with English Summary), Geophysics, Vol. V, No. 2 (1935), pp. 163-200.

Elliot, R.D. "The Weather Types of North America", Weatherwise, Vol. 2 (1949).

Finch, V.C. and Trewartha, G.T. Elements of Geography. New York: McGraw Hill Book Co., 1949.

Hare, F.K. "Dynamic and Synoptic Climatology", Annals Assoc. Amer. Geog., Vol. XLV, No. 2 (June, 1955), pp. 152-62.

_______. "The Dynamic Aspects of Climatology", Geografiska Annaler, Vol. XXXIX (1957), pp. 87-104.

_______. "The Westerlies", Geographical Review, (to be published July, 1960).

Jacobs, W.C. "Synoptic Climatology", Bull. Amer. Met. Soc., Vol. XXVII (1946), pp. 306-11.

Kendrew, W.G. Climates of the Continents. New York: Oxford Clarendon Press, 1953.

Lautzenhiser, R.E. "Great Lakes Weather," Weatherwise, Vol. VI, No. 1 (February, 1953), pp. 3-6.

Leighly, J. "Effect of the Great Lakes on the Annual March of Air Temperature in the Vicinity," Papers of the Michigan Academy of Science, Arts, and Letters (University of Michigan Press, Ann Arbor), Vol. XXVII (1941), pp. 377-414.

Miller, Austin. "Air Mass Climatology," Geography, Vol. XXXVIII (1953), pp. 55-67.

Mitchell, C.L. "Snow Flurries Along the Eastern Shore of Lake Michigan," Monthly Weather Review, Vol. XLIX (1921), p. 502.

Putnam, D.F. (ed.) Canadian Regions. New York: Thomas Y. Crowell Co.,1952.

Remick, J.T. "The Effect of Lake Erie on the Local Distribution of Precipitation in Winter," Bull. Amer. Met. Soc., Vol. XXIII, Nos. 1 and 3 (1942), pp. 1-4 and 111-17, respectively.

Stone, R.G. "A Modern Classification of Weather Types for Synoptic Purposes," Bull. Amer. Met. Soc., Vol. XVI (1935), pp. 324-26.

_______. "On Some Possibilities and Limitations of Air Mass Climatology," Annals Assoc. Amer. Geog. Vol. XXV (1935), p. 56.

Strahler, A.N. Physical Geography. New York: John Wiley and Sons Inc., 1951.

Thomas, M.K. A Selected Bibliography of the Great Lakes Basin of Ontario. February, 1959. Taken from unpublished Bibliography of Canadian Climate. (Mimeographed.)

University of Chicago, Institute of Meteorology. A Report on Synoptic Conditions in the Mediterranean Area. Chicago: August, 1943.

Wiggin, B.L. "Great Snows of the Great Lakes," Weatherwise, Vol. III, No. 6 (December, 1950).

STATISTICS AND MAPS

Canada, Dept. of Transport, Meteorological Branch. Monthly Record: Meteorological Observations in Canada. 1953-56.

Monthly Weather Review. 1953-57.

U.S., Dept. of Comm., Weather Bureau. Climatological Data. 1953-57.

_______. Daily Weather Map. 1953-57.