74-17,209

SENGENBERGER, David Lester, 1936-
CLIMATIC YEAR REGIONS OF THE WESTERN GREAT LAKES STATES.

The University of Oklahoma, Ph.D., 1974
Geography

University Microfilms, A XEROX Company, Ann Arbor, Michigan

THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

CLIMATIC YEAR REGIONS OF THE WESTERN GREAT LAKES STATES

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

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1973

CLIMATIC YEAR REGIONS OF THE

WESTERN GREAT LAKES STATES

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[illegible]

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DEDICATION

To Margot, Susan, and Sara for a decade of understanding, encouragement and help.

ACKNOWLEDGMENTS

Dr. James Bohland, Assistant Professor of Geography, University of Oklahoma, for his continuing interest and for directing, constructively criticizing, and carefully editing this study.

Dr. Stephen Sutherland, Associate Professor of Geography, University of Oklahoma, for first acquainting the writer with climatic year research methods.

Dr. James Goodman, Associate Professor of Geography, University of Oklahoma, for constant encouragement.

Dr. Harry Hoy, Professor of Geography, University of Oklahoma, for his help.

Dr. Arthur Myers, Associate Professor of Geology, for aiding in the education of a geographer.

Dr. John Morris, Professor of Geography, University of Oklahoma, for his continuing interest over the span of a decade.

The University of Wisconsin System and the Administration of the University of Wisconsin - Stevens Point for financial aid with Teacher Improvement Leaves, a tuition waiver, and released time for pursuit of the doctoral degree.

The National Science Foundation for a Science Faculty Fellowship to broaden the writer's graduate education and to finance this study.

The personnel of the University of Oklahoma Computing Center;

Ross Beier, United States Army; the writer's colleagues in the Department of Geography-Geology, University of Wisconsin - Stevens Point; the graduate students in the Department of Geography, University of Oklahoma; the Meteorological Branch of the Department of Transport; and the State Climatologists in the study area for data, encouragement, help, and suggestions that cannot be enumerated.

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CHAPTER I

INTRODUCTION

Preliminary Comments

This dissertation is an investigation in regional climatology and macro-scale climatic classification. Its purposes are to improve the descriptive accuracy of the Köppen climatic classification system through application of climatic year methodology and to demonstrate the existence and strength of covariation between climatic regions and regional patterns of other selected physical phenomena. The specific research hypothesis tested and research techniques utilized in this study are discussed in detail below (pp. 8-11).

Regional climatologists are concerned with classifying climate, a highly complex natural phenomenon comprised of numerous variables (air temperatures, wind directions, evaporation rates, precipitation amounts and kinds, etc.) that change both through time and space, into a meaningful set of climatic categories. These may then be mapped and utilized in describing and analyzing areal variations in atmospheric states. George Rumney has succinctly defined regional climatology in the following manner:

> From its origins in the science of ancient Greece, climatology has developed along two main lines of investigation, physical

> climatology and regional climatology. ... The second is the study of climates, the discrete and characteristic qualities of the atmosphere of a particular place or places, and ultimately of particular regions on the earth.[1]

F. Kenneth Hare has elaborated this point observing:

> Climatic classification is an essentially geographic technique. It allows the simplification and generalization of the great weight of statistics built up by the climatologists. These figures do not mean much to the geographer unless a way can be found of reducing them into an assimilable form. The real purpose of classification is hence to define climatic types in statistical terms, in which climate as a geographic factor is to be regarded as having definite and uniform characteristics: only by such a classification can rational climatic regions be defined.[2]

Neither classification nor regionalization may be regarded as exclusively the province of regional climatology or geography. The need for both in all branches of systematic human inquiry has been observed by the biologist Simpson who noted in discussion of the need for classification that: "If each of the many things in the world were taken as distinct, unique, a thing in itself unrelated to any other thing, perception of the world would disintegrate into complete meaninglessness."[3] In a discussion of the processes of and need for regionalization and classification in geography David Grigg commented: "The purpose of classification, then, is to give order to the objects studied. Without classification it would be impossible to: 1) Give names to things; 2) To transmit information; 3) To make inductive generalizations."[4]

That no one regional climatic classification system suits all geographical needs is amply demonstrated by both the constant proliferation of new schemes and frequent "tinkering" with older ones. It is obvious the varying needs of a multitude of disciplines and workers demand differing kinds of classifications.[5] Thus it should be claimed any one system is the best for all purposes. It is equally valid to devise new systems for new needs as well as to alter preexisting ones to make them better fit the needs for which they were initially planned or to prepare them to meet additional uses unforeseen by their authors. The only justifiable criticisms that may be leveled against any classification are that it does not do the task for which it was purportedly designed or it has been entirely supplanted by a better system.

In regional climatology there are two basic kinds of climatic classifications, genetic and empirical. The empirical is based on the effects of climate on some other natural phenomena. Flohn has observed that the empirical ones are, " . . . much more important from the practical point of view . . . ."[6]

One of the most widely known empirical systems used in regional climatology and geography is that first developed in its basic structure by Wladimir Köppen in 1900 and subsequently modified several times by its originator with the last version appearing in 1936.[7] The most recent map utilizing the 1936 criteria was published in 1968 while another utilizing one set of widely accepted modifications, including many selected for use in this dissertation, was published earlier in its most revised form in 1954.[8] The simplicity of this system and its ease of use have undoubtedly contributed greatly to its widespread acceptance. Even today its popularity remains undiminished as evidenced by its use in the most widely adopted physical geography and regional climatology texts, frequent employment in regional geographies, and appearance in popular atlases. An exhaustive literature search turned up only two areas of the world, the Soviet Union and China, wherein there has been no recent work using the

Köppen system.[9] In the Köppen system mean monthly temperatures and mean total monthly precipitation amounts may be easily utilized to yield five major types of climatic regions, each of which may be further subdivided into more precisely defined subregions.[10]

Problems of Means and Recurring Climatic Events

On the basis of two prior investigations the writer determined that the use of long-term normal values in the Köppen climatic classification for two regions, the Gypsum Hills of Woodward and Major Counties, Oklahoma, and the State of Wisconsin, yielded misleading results.[11] They were misleading because although the results are quantitatively accurate according to the data utilized, mean values do not reflect the amount of variance in the data.

As an indicator of centrality the sensitive nature of the mean to extreme values makes it a most valuable tool for inferential statistics. Yet, at the same time this very sensitivity, so valuable in many statistical tests, can be a liability for the presentation of some forms of climatological data. What is needed is a less sensitive indicator of centrality that will reflect accurately climatic conditions as they occur most of the time without being affected greatly by the highly infrequent, atypical occurence.

A second major problem for climatic study is that periodically recurring climatic events, such as a period of sub-freezing temperatures, a summer hot spell, or a winter drought, do not always occur during the same one, two, or three month period during a succession of years. An event of this nature may be entirely hidden in the mean monthly values for a period of years by shifting through a range of several months from year to year.

Data for Faribault, Minnesota,[12] (Table 1) illustrate these problems in regard to Köppen's winter dry season classification "w" and his even precipitation classification "f". The driest winter month is January with 0.60 inches; the wettest summer one is June with 4.69 inches. No winter month in the series has less than one-tenth the amount of moisture of the wettest summer month, and, thus, the standard Köppen classification is "f". However, examination of actual data rather than means during a thirty year period shows this station experienced at least one winter month with less than one-tenth the precipitation of the wettest summer one and has had winters with less than one-half the year's precipitation in twenty-nine of the thirty climatic years[13] from April, 1936, to March, 1966 (Table 2). Frequency of month of occurrence of the dry winter months ranged from lows of three and eight years respectively for March and October to highs of sixteen and nineteen years for February and January. It should also be noted that the remaining thirtieth year, 1936-37, although not meeting the "w" classificational criterion of less than one-tenth the wettest summer month's precipitation for at least one winter month, did have only 29 per cent of its total annual precipitation in the winter half year. Random selection of three other years with "w" classifications, 1944-45, 1947-48, and 1958-59, for examination was made and similar percentages of annual precipitation occurred in the winter half year season (Table 3). These data illustrate most convincingly that for Faribault, Minnesota, at least, the designation of the precipitation regime as even, or lacking a seasonal concentration, "f" is in actual

TABLE 1

MEAN MONTHLY PRECIPITATION
FARIBAULT, MINNESOTA
1936 - 1966

Month	Precipitation in Inches
April	2.34
May	3.90
June	4.69
July	3.85
August	4.15
September	3.18
October	1.70
November	1.11
December	0.89
January	0.60
February	0.87
March	1.78

TABLE 2

MONTHLY "w" CLASSIFICATIONS
FARIBAULT, MINNESOTA
1936 - 1966

Number of Years	Number of "w" Months
8	1
8	2
9	3
4	4

TABLE 3

PERCENTAGE OF ANNUAL PRECIPITATION IN WINTER HALF YEAR IN FOUR SELECTED YEARS FARIBAULT, MINNESOTA

Year	Percentage
1936-37	29
1944-45	18
1947-48	18
1958-59	25

practice misleading if not actually in gross error. For this station a characterization of the precipitation regime as winter dry "w" would appear as a closer description of the true nature of such a regime.

When discrepancies, such as the above, are noted criticism of internal consistancy is probably justified. In the face of such internal inconsistancy some, such as C.W. Thornthwaite,[14] discarded the system and devised new ones. Others have attempted to remove the inconsistancies while retaining as much of the system's previously acknowledged utility as possible.[15] Because of the widespread acceptance and use in geography and regional climatology of the Köppen system and its modified successors this writer pursued the latter course. Such improvements were accomplished through the application of climatic year methodology as explained in Chapters II and III to the analysis of the climate of a large, sub-continental sized, multi-state area. This application tested the following research hypothesis.

Hypothesis

Climatic year methodology as applied to the Köppen systems yields more accurate and detailed climatic regionalization than does the Köppen system when it is based on means. "Accurate" connotes that the new regions better fit both the quantitative and verbal definitions of the classification system while the new regions are smaller and more precisely defined allowing for more detailed definition, analysis, and comparison with other physical geographical phenomena. Therefore, the resulting regions may be better explained and understood in terms of their climatic control causal factors, such as air mass types, continentality, pressure systems, etc. Further, it is postulated climatic year regions covary spatially with patterns of other climatic and physical characteristics. These include: natural vegetation, great soils groups, annual number of days with snow cover, annual snowfall, length of the freeze free period, number of days with temperatures above 90°, number of days with temperatures under 32°, total precipitation, number of precipitation days, number of thunderstorm days, continentality, and percentages of possible sunshine in both summer and winter. The existence of a high degree of covariance allows for prediction of the pattern of occurrence of these factors from that of the climatic year regions and will also aid in finding some of the causal controls of the climatic year regions.

Methodology

The above research hypothesis was tested utilizing the following methodology. The climate for each of the 306 selected stations within the study area was classified for each year of the thirty year study period, April, 1936, to March, 1966, using quantitative and letter definitions of a modified Köppen classification system.[16] Climatic years consisting of complete winter and summer half years rather than calendar years were employed to avoid problems of a split winter season, a problem noted with another similar study based on the calendar year.[17] April has been selected as the beginning of the climatic year for reasons of both cultural and physical geography.

Historically and culturally January has not always been considered as the beginning of the year for many purposes. Numerous types of rites of spring rituals in many mid and upper midlatitude cultures, including that of our own, attest to the importance attached to the rebirth of life in the spring season after its apparent demise during the dormant one of winter. Such cultural practices may undoubtedly be traced to the human perceptions of the physical effects of climate upon other aspects of the physical environment.[18] April was specifically designated as the beginning of the climatic year and the summer half year for the following physical reasons. In the northern portions of Minnesota, Wisconsin, and Michigan April is usually marked by the complete disappearance of the winter snow cover and by the start of the short spring season common in this latitudinal and continental position. In Indiana, on the southern margin of the dissertation study area (below Chapter III), the last freezing temperatures in most of the state occur in April.[19] In a study of the state's agricultural seasons Newman divided the year into six temperature seasons. The three warmest ones begin with "late spring," whose beginning is placed in April.[20] April contrasts well with October, chosen as the start of the winter half year. That month is usually marked by the first serious snowfalls of the approaching winter and by the persistence of killing frosts on the northern edge of the study area.[21]

After classifications had been calculated for each station for each climatic year a coded letter symbol was prepared for each station. The coded letter symbol contained all letter symbols for all climatic types found at the station during the thirty year period. Additionally, each letter was assigned a superscript percentage value representing the percentage occurrence of that letter type during the study period.[22] Contained in the classification and coding procedures was provision for incorporation of James Shear's dry climate notation.[23]

His suggestions are simply that from the standpoint of set theory where humid climate sets intersect with dry ones the resultant intersection may be considered as an intersecting subset. Therefore, all humid region thermal and precipitation distribution symbols may be substituted for Köppen's dry region ones to permit greater notational precision and to allow mapping and consideration of thermal regions (sets) and precipitation ones without regard for the interrupting influence of dry region boundaries.

Means and the coded classifications for all stations were used for making a map based on means, element maps ("f", "w", "a", "b", etc.), four yearly maps, and a climatic year region map based on frequency of occurrence. These maps were constructed for purposes of analysis of detailed climatic conditions and for synthesis of climatic regionalization. Regionalization and isoplethic mapping were done with quantitative values derived empirically. The climatic year region map used the concept of majority of letter occurrence (and in a few isolated cases plurality where a majority had not occurred) for designation of climatic year regions.

Qualitative comparisons were employed to find the climatic controls responsible for the element and regional patterns. Testing for degree of covariance with the geographical phenomena noted in the hypothesis was accomplished with contingency analyses between the climatic year regions map and ones for each of the listed physical and climatic factors (below Chapter VI).

REFERENCES

[1]George R. Rumney, Climatology and the World's Climates (New York: Macmillan Co., 1968), p. 1.

[2]F. Kenneth Hare, "Climatic Classification," in London Essays in Geography: Rodwell Jones Memorial Volume, ed. by L. Dudley Stamp and S.W. Wooldridge (Cambridge, Mass.: Harvard University Press for London School of Economics and Political Science, 1951), p. 111.

[3]G.G. Simpson, Principles of Animal Taxonomy (New York: Columbia University Press, 1961), p. 2.

[4]David Grigg, "The Logic of Regional Systems," Association of American Geographers Annals, LV (1965), 469.

[5]Two such new systems differing greatly from each other are those by Werner Terjung, "Physiologic Climates of the Conterminous United States: A Bioclimatic Classification Based on Man," Association of American Geographers Annals, LVI (1966), 141-79; and Carl Troll and Karlheinz Paffen, "Karte der Jahreszeiten-Klimate der Erde," Erdkunde, XVIII (1964), 5-28. Minor modification of the Köppen system is represented by such works as Edward A. Ackerman, "The Köppen Classification of Climate in North America," Geographical Review, XXXI (1941), 105-11; and James A. Shear, "The Polar Marine Climate," Association of American Geographers Annals, LIV (1964), 310-17.

[6]Hermann Flohn, Climate and Weather (New York: McGraw-Hill Book Company, 1969), p. 163.

[7]Wladimir Köppen, "Versuch einer Klassifikation der Klimate, vorzugweise nach ihren Beziehungen zur Pflanzenwelt," Geographische Zeitschrift, VI (1900), 593-611, 657-79; W. Köppen, "Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf," Petermanns Geographische Mitteilungen, LXIV (1918), 193-203, 243-48; W. Köppen and Rudolf Geiger, Klimakarte der Erde (Gotha: Justus Perthes, 1928); W. Köppen, Grundriss der Klimakunde (Berlin and Leipzig: W. deGruyter, 1931); and W. Köppen, "Das Geographische System der Klimate," Part C, in Handbuch der Klimatologie, I (Berlin: Verlag von Gebrüder Borntraeger, 1936), 1-44.

[8]Glenn T. Trewartha, An Introduction to Climate (4th ed.; New York: McGraw-Hill Book Company, 1968), pp. 394-95; and G. Trewartha, An Introduction to Climate (3rd ed.; New York: McGraw-Hill Book Company, 1954), Pl. I.

[9]A few such examples in each category include: Clyde P. Patton, Charles S. Alexander, and Fritz L. Kramer, Physical Geography (Belmont, California: Wadsworth Publishing Co., Inc., 1970); Arthur N. Strahler, Physical Geography (3rd ed.; New York: John Wiley and Sons, Inc., 1969);

R.G. Barry and R.J. Chorley, Atmosphere, Weather, and Climate (New York: Holt, Rinehart and Winston, Inc., 1970); Howard J. Critchfield, General Climatology (2nd ed.; Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1966); Clarence E. Koeppe and George C. DeLong, Weather and Climate (New York: McGraw-Hill Book Company, 1958); Harold Fullard and H.C. Darby, eds., Aldine University Atlas (Chicago: Aldine Publishing Company, 1969), p. 7; Norman J.W. Thrower, ed., Man's Domain: A Thematic Atlas of the World (New York: McGraw-Hill Book Company, 1968); Preston E. James, Latin America (4th ed.; New York: Odyssey Press, 1969); Otis P. Starkey and J. Lewis Robinson, The Anglo - American Realm (New York: McGraw-Hill Book Company, 1969). Arthur A. Wilcock discusses the uses of this system at greater length in "Köppen After Fifty Years," Association of American Geographers Annals, LVIII (1968), 12-28.

[10]See Appendix A for regional and subregional types of the Köppen system as used throughout this study.

[11]David L. Sengenberger, "The Gypsum Hills of Woodward and Major Counties, Oklahoma" (unpublished M.A. thesis, University of Oklahoma, 1964), pp. 45-58; and D.L. Sengenberger, "Climatic Years and the Climates of Wisconsin" (unpublished typewritten research paper prepared for Dr. S.M. Sutherland, University of Oklahoma, 1967, and presented under the same title at the Spring Meeting of the Southwest Social Science Association - Southwest Division of the Association of American Geographers, Dallas, Texas, 1968).

[12]All monthly precipitation and temperature data, except that for Wisconsin and Canadian Stations, was obtained from Monthly 1009 Summary Data cards prepared by the U.S., National Oceanic and Atmospheric Administration, Weather Bureau. A sample card is enclosed as Appendix B. Wisconsin data was summarized from U.S., Departments of Agriculture and Commerce, Weather Bureau, Climatological Data: Wisconsin, Vols. XLI-LXXI (Washington, D.C.: Government Printing Office, 1936-66). Canadian data was punched in 1009 card format by the writer from information in Canada, Department of Transport, Meteorological Branch, Monthly Record: Meteorological Observations in Canada (Toronto, 1936-66). Precipitation and temperature values as collected and published by the United States Weather Bureau and the Canadian Meteorological Branch are in inches and degrees Fahrenheit and are so utilized throughout this study.

[13]See footnote 1, Chapter II below.

[14]C. Warren Thornthwaite originated two systems. These are outlined in "The Climates of North America According to a New Classification," Geographical Review, XXI (1931), 633-55; "The Climates of the Earth," Geographical Review, XXIII (1933), 433-40; and "An Approach Toward a Rational Classification of Climate," Geographical Review, XXXVIII (1948), 55-94.

[15]Wilcock alluded to this utility when he stated, "Even in the world of advanced data processing there will still remain the need,

broadly termed pedogogic, for displaying a first-order general pattern." Wilcock, "Köppen," p. 28.

[16]All classification was done with automatic data processing equipment of the University of Oklahoma Merrick Computer Center. See Appendix A for specific quantitative definitions of all criteria as used for this study.

[17]This problem was noticed by the writer in Henry M. Kendall's paper, "Notes on Climatic Boundaries in the Eastern United States," Geographical Review, XXV (1935), 117-24 and is discussed in Chapter II below in connection with the topic of the "Climatic Year."

[18]It is pertinent to note that January, used as the start of the year in many climatological and meteorological studies, seems to have mainly cultural significance as the start of the year. There are no physical reasons for its use that this writer has been able to discern. From the geographical standpoint several other months would seem to have more logic behind their use in a regional climatological study such as this. For an entertainingly written, enlightening discussion about the cultural consideration of the beginning and ending dates of seasons and years in the United States during the late eighteenth and early nineteenth centuries see Eric Sloane, The Seasons of America Past (New York: Wilfred Funk, 1958). The selection of April, as the beginning of the summer half year in the Great Lakes States, was also supported by Stephen S. Visher. Personal letter, S.S. Visher to David Sengenberger, March 1, 1966.

[19]Lawrence A. Schaal, "Climate," Indiana Academy of Sciences Proceedings, (July, 1966), p. 164.

[20]James E. Newman, "Bioclimate," Ibid., p. 174.

[21]University of Wisconsin, College of Agriculture, Experiment Station, Climate at the University of Wisconsin Experimental Farms, by Arthur Peterson and Marvin W. Burley, Research Report 17 (Madison: College of Agriculture, December, 1964); Stephen S. Visher, Climatic Atlas of the United States (Cambridge: Harvard University Press, 1954), pp. 82-83, 233.

[22]An example of such a coded classification is: $D^{100}w^{68}f^{32}a^{57}b^{43}$. Its meaning is that all years were humid continental "D", precipitation distribution was winter dry "w" in 68 per cent of the years and even "f" in the remaining 32 per cent, and summers were long and hot "a" 57 per cent of the time and warm "b" in 43 per cent. A superscript notation of frequency of occurrence by deciles was first suggested to the writer by Stephen Sutherland, Associate Professor of Geography at the University of Oklahoma, in his course Regional Climatology, February 19, 1964.

[23]James A. Shear, "A Set-Theoretic View of the Köppen Dry Climates," Association of American Geographers Annals, LVI (1966), 508.

CHAPTER II

CLIMATIC YEAR STUDIES: A REVIEW

Introduction

Richard J. Russell may be credited with originating the climatic year[1] method for regional climatology.[2] Since its introduction this research method has been employed in varying ways in a number of regional climatic studies of which this dissertation is one. Numerous refinements have been made and new concepts added by several investigators. As the literature of these efforts was reviewed, however, two serious problems were repeatedly noted. First, as no review nor even a comprehensive bibliography relating to this subject had been published many writers have either made errors previously corrected by someone else or have unnecessarily repeated earlier discoveries. Second, although some writers make bibliographic reference to other works it would appear these were not closely examined. If a comprehensive review of the subject, such as Wilcock's on the Köppen system,[3] had existed such problems might not have occurred. For these reasons as well as the fact this dissertation synthesizes innovations of many of the earlier studies with original ideas of this writer it is advantageous to review earlier works in the field. Such a review may also meet the needs of others in climatic year research by preventing needless duplication of effort.

Critical examination of the previous studies can be most effectively made through the chronological approach. The chronological approach may serve to detail the development of key concepts and methodological innovations. More importantly it also serves other purposes at the same time. It acts as a framework to outline geographical diffusion of this methodology as well as its application to the practical analysis of the climate of geographical regions of the world. Lastly, such an approach effectively shows how climatic year studies relate to both geography and climatology.

Early Efforts

Climatic year methodology was devised by Richard Russell to eliminate the concealment effect of both periodic and nonperiodic climatic flucuations caused by the exclusive use of normals in the determination of Köppen climatic regions.[4] This study of California climates abandoned the use of normals in favor of annual calendar year data to define the core regions and transitional zones of that state's arid and semiarid climates. A Köppen climatic classification was calculated by Russell for each station for each calendar year of his study period. In this fashion he was able to show the degree of fluctuation from year to year of the areal extent of climatic regions. Thus, the dynamic nature of such regions was graphically demonstrated. Although the existence and importance of climatic fluctuations were acknowledged, it remained for Russell to demonstrate their existence and significance to the specific aspects of a climatic classification system.

From California Russell turned his attention to the illustrative use of his climatic year methodology for a similar problem involving distribution of Köppen first order thermal regions in the United States.[5] Tropical, mesothermal, and microthermal core regions and their broad transitional zones were identified and mapped. Indeed, it may be noted this paper anticipated James Shear's later set-theoretic view for the blending of humid region thermal notation with that of subhumid regions.[6] Although Russell apparently did not recognize the set-theoretic concept as he did not discuss the point, he implicitly utilized it. This was accomplished by discussing and mapping the three first order temperature regions and their transitional zones directly across semiarid and arid regions.[7]

Henry Kendall applied the concept of climatic year methodology to the United States east of the western cordilleras.[8] Kendall's contributions were threefold. First, he suggested the term "year-climate" to define the mapped climates for any one year.[9] Second, he mapped all boundaries for all year-climates on one map to show the extent of transition zones and to present a composite of all successive year-climates.[10] This second innovation has been widely reproduced and the technique applied at other scales.[11] A third innovation was only partially made. Kendall stated:

> The boundary between A and C climates and that between the C and D climates are defined in terms of the average temperatures of the coldest month of the winter season. Consequently it becomes necessary to consider the winter months of two successive calendar years in the construction of the map of each year-climate and not the winter months of any one calendar year. In order to avoid reduplication of any extreme winter season on successive maps it was arbitrarily decided to date the winter season by the January of each calendar year. For example, the 1914 map uses the winter season of 1913-1914 for the determination of the C/D and the A/C boundaries. The B/H [dry/humid] boundary, however, was determined in each instance for the months of January through December.[12]

Although Kendall recognized the inconsistancies inherent in the calculation of thermal boundaries between "A" and "C" and between "C" and "D" climates from split winter data he continued to use calendar year data for construction of dry/humid region boundaries. It would appear that calculation of the dry/humid boundary value ought to have been based on the same twelve month data set (precipitation and temperature) as was used in determination of thermal class boundaries. If one maps a year-climate for a particular year using calendar year data in one portion of the map for some boundaries and climate year data from a different set of twelve months for other boundaries in another portion of the same map fallacious impressions and conclusions are certain to result. Unfortunately, this was the case with Kendall's eighteen year-climate maps.[13] This is a critical point because from a causal standpoint temperatures can be inversely related to precipitation amounts. Unusually high monthly temperature maxima frequently coincide with monthly precipitation minima because, among other reasons, of the lack of reflective cloud cover. The converse is also significant. Below normal monthly temperatures frequently correspond with unusually high monthly precipitation amounts and a high degree of cloud cover. Thus, calculation of boundary values is intimately involved in this question for annual and seasonal precipitation amounts are directly utilized in formulae with temperature data from the same annual and seasonal periods (below Appendix A).

Although at this time, 1935, neither Kendall nor Russell had worked with the problems of humid region secondary and tertiary letters in a climatic year context, logically the methodology would be so extended if it were as valid and powerful an investigative tool of regional climatic analysis as these two investigators seem to have believed. Determination of these two letters involves similar comparisons and calculations as those of the humid/dry and "A", "C", and "D" boundaries. For these reasons then, system internal consistancy demands either calendar year data only or climate year data only. As Kendall recognized, the use of calendar year data leads to the problems of winter thermal region determination. The solution for avoidance of the problems of split winters is the complete use of climate year data and total avoidance of calendar year data. This will preserve the complete seasonal temperature and precipitation regimes as integrated entities. Climate year data as explained below in detail (p. 28) are utilized in this dissertation.

Clarification, Refinement, and Expansion

Following a ten year lapse, perhaps partially explained by the disruptions of the Second World War, Russell returned to publishing the results of climatic year research.[14] Again he devoted his energies to the regional climates of one large state, Texas. Although not explicitly stated in the paper, use of calendar year data was implicit in the classification process of ninety-one stations for the period 1914-1931. However, Russell now added the idea of regionalizing climates on the basis of differing frequencies of occurrence of year-climates. Classification, itself, was done only with the primary and secondary letter positions for both humid and subhumid climates. Introduced for the first time was a process of coding year-climate frequencies to permit the recognition and mapping of homogeneous regions. This procedure led to mapping twelve distinctive climatic regions. The presence of the first primary and secondary letters in the coded classification denotes more than 50 per cent frequency for each while that of the remaining letters indicates less than 50 per cent for each.[15] Omitted was any recognition of an even probability for two climatic types or of the possibility of no climatic type attaining as much as 50 per cent although either situation has a strong probability of occurrence in such a pronounced climatic boundary region as Texas.

In the following decades climatic year methodology, appearing in a variety of differing types of research efforts, spread to Japan, Great Britain, and India. Initiating this new group of studies was that by Sekiguchi (sic) in 1951 in Japan.[16] Although the paper was published only in Japanese a concise English abstract, maps, and tables do provide useful information concerning the nature of the study and its conclusions. The author mapped year-climates of Japan using data from a number of stations for an extended period of time (approximately fifty years). These were compared with average Köppen conditions. His year-climate frequencies identified four core regions: "Cfa", "Cwa", "Dfa", and "Dfb"; while standard Köppen maps show only two: "Cfa" and "Dfa". In addition an "s" frequency of at least once per decade occurred at most stations and "b" occurrences were frequent in one district. The core region of "f" was on the Asiatic side of Japan, whereas cores of "w" appear in the interior of the nation on easterly mountain slopes and in spots on the Pacific coast.[17] The abstract does not mention other climatic types nor is there any information whether calendar or climate year data were used for classification. Particularly noteworthy in this study was the extension of year-climate classification, regionalization, and mapping to the tertiary letter position.

In the following year Jack Villmow made a detailed study of the tertiary letters "a" and "b" with an investigation of their boundary in the eastern United States.[18] Despite the apparent use of calendar year data for calculating and mapping year-climates no error of the type previously discussed (above pp. 17-19) is introduced because in the Northern Hemisphere neither "a" nor "b" relies on any comparison with winter conditions.[19] Both are exclusively based on mean monthly summer temperatures. Villmow mapped the "a"/"b" line for each calendar year on one map as Kendall had previously done with the primary letter.[20] Rather than using frequency of occurrence for points (station locations) as Russell and apparently Sekiguchi had done[21] he made a series of cartographic linear interpolations halfway among the numerous year-climate boundary lines along each of a group of selected meridians. As this boundary is generally latitudinal in the eastern United States his cartographic innovation gave apparently satisfactory results. This paper showed the boundary to be in a position well to the north of its previously mapped representation. As drawn here it also extends westward well into subhumid regions. The author noted this was done because humid years occasionally may occur there.[22] And, thus, the as yet unstated set-theoretic idea continued.

The Provinces of British Columbia and Alberta in western Canada were the subjects of the next climatic year study. George Rheumer completed a doctoral dissertation in geography at the University of Illinois in 1953 which was the first monograph-length climatic year investigation.[23] Additionally, it was the first study to make complete, explicit utilization of climate year data. The year selected starts in October and ends in September. Although Rheumer did not explain why he did not use calendar year data he did justify the beginning and ending months of this climate year by noting the existence of winter as the dominant season in most of western Canada.[24] For the second time Russell's 1945 system of coded notation for indication of percentages of occurrence for year-climates was utilized.[25] With the exception of noting "B" year frequency, however, Rheumer failed to explicitly state either percentage or absolute frequency of occurrence of any year-climate types.[26] The purpose of this study was a general investigation and analysis of regional climatic conditions in western Canada. None-the-less, a quite detailed regionalization of climatic year methodology was achieved. The author utilized data for 61 stations for 35 years and that for 373 stations with varying, unstated, shorter periods.[27] A set of synthetic data consisting of averaged temperature and precipitation values from two to four stations was produced in a hypothesized fashion to illustrate idealized conditions in each climatic year region. The data sets for all regions were included in an appendix.[28] This study, based as it was on large amounts of climatic data for a large region, must be acknowledged as a major contribution.

Stanley Gregory produced the first published climatic year study of a continental area.[29] Unlike his predecessors Gregory went against the trend of employing ever denser station networks for gaining finer detail. Only data from forty-five stations were used for studying most of the continent of Europe. His research objectives were twofold. First, he mapped Köppen's climates for a thirty year period using averages for one map and year-climate data for the second. Both maps and the accompanying discussion demonstrate a better fit of the boundaries as calculated with climatic year methods than do the more traditional averages maps. The author noted the phenomenon observed by almost all climatic year investigators that, "the consideration of individual years prevents undue weight being given to years of exceptional conditions, and this may lead to quite considerable differences in boundary location . . . ."[30] The second and principal aim of the study was the application of the methodology to an attempt to show direction and degree of a hypothesized climatic fluctuation or change. This was accomplished by mapping five overlapping thirty year periods from 1871-1940 using year-climate data for each period. Because Gregory was strongly interested in the European position of the "C"/"D" boundary it appears unfortunate he did not recognize the inconsistancy of using calendar year data for its calculation. This is especially striking as he did make specific note of Villmow's paper wherein the problem had previously been noted.[31]

Fukui's investigation of climates in eastern and southeastern Asia was the next major climatic year study.[32] The thrust of this paper was finding the degree of fluctuation or stability of climatic regions in this part of the world. For this purpose the author selected and classified year-climates for 164 stations. Unfortunately, while some stations had records of 71 years the majority had much shorter records (20 years or less).[33] Fukui's work resulted in two important findings. First, through isoplethic mapping of the "BS"/humid boundary at intervals of 0, 50, and 75 per cent annual "BS" occurrence the semiarid climate core and its transition zones were mapped for eastern Asia.[34] Also, both the core "A", "C", and "D" climates and their transition zones were similarly delineated.[35] A second finding was that noted both previously and subsequently by most writers, "Generally the normal or average climate does not coincide with the . . . most frequently experienced climate."[36] Fukui specifically identified several stations where the average climate occurred only 3 per cent of the time. This recurring theme runs repeatedly through most of the literature.

Dayal completed a brief climatic year investigation in 1962 of aridity in northwestern India using data for the decade 1950-1959 from twenty-five stations.[37] In addition to drawing ten year-climate maps Dayal extended the technique of finding boundary location. He placed a median arid/semiarid boundary by finding a series of midpoint positions for it by interpolating cartographically among the year-climate boundaries along both selected meridians and parallels. Conclusions of the paper were that although the desert region did fluctuate in size through the decade, especially in its eastern and western dimensions, no long-term expansion, contraction, nor migration of the region could be discerned.[38]

As the author was directly concerned with aridity boundaries it is most unfortunate he did not use reordered climate year data. This reordering is highly significant in an aridity study because Köppen's aridity formulae use mean annual temperatures in comparison to total yearly rainfall. Also, seasonal precipitation distribution is vital in selecting the proper boundary formula. As climate year data were not used the boundaries on the year-climate maps are open to considerable doubt concerning both their validity and reliability. The study is open to one other criticism. As Dayal was trying to establish the existence or non-existence of an increase in desert size one decade seems a rather short period base on which to try to establish climatic trends.

Sutherland's 1962 study was the first to use computer technology in a climatic year context to speed the classification process.[39] The general thrust of this study was to delineate and define climatic regions in the Missouri River basin by climatic year methodology and to investigate those physical controls responsible for the areal differences. Also noted were specific weather conditions and types within the outlined regions. For regional differentiation an improved form of coded notation similar to Russell's[40] was utilized to sum yearly climatic conditions at each point. Within the notation the first letter of each group indicated a "predominance."[41] It is clear it could signify a plurality as well as a majority.[42] The presence of a single letter in either the primary, secondary, or tertiary position was employed to show "nuclear" climate.[43] As both Villmow's and Rheumer's papers were noted it appears surprising the problem of calendar versus climate year data was omitted.[44]

While a description of climates in the Missouri River basin was presented, the major contribution of this study was its pioneering application of the modern electronic computer to the data processing problems of regional climatology.[45] Such a procedure greatly expands the time and space potentials for climatic studies.

Sutherland and Doerr published a study of Oklahoma[46] which for the first time applied climatic year methodology to Thornthwaite's as well as to Köppen's classification.[47] Calendar year maps of both systems calculated with a computer were drawn and compared with standard maps of both systems. The authors noted the great annual variations of climatic conditions as shown and observed that sequential study of year-climate maps shows the locations of core areas. However, as calendar year data were employed the accuracy of each year-climate map for either system is open to doubt. Also, one may question the conclusion that, " . . . a sequential set of annual (year-climate) maps . . . is probably more meaningful in regional climatology than are regions based upon means or frequencies."[48] This is true as far as means are concerned. However, presentation of frequencies on a summation map should present a picture of variability as well as year-climate maps. Rheumer's and Sutherland's regional maps of western Canada and the Missouri River Basin demonstrated this though a more numerical expression of frequency may be necessary.[49] Also, widespread use of Kendall's summation map would appear as an additional refutation of this conclusion.[50]

Several important advancements were presented. All stations and periods of record utilized were specified. Significantly it was shown climatic year methods may be extended to regional systems other than Köppen's. For the first time complete notation was made of all definitional criteria. Most importantly, computer technology was published and shown to have useful applications to some of the problems of regional climatology.

Fukui's 1965 study again used climatic year methodology to continue the analysis of secular movements of climatic areas started four years earlier.[51] This analysis was expanded to the continental areas surrounding the North Pacific Ocean. Tables were presented showing percentages of Köppen climatic types and the mean classification at each station. Because Fukui found so many deviations from the normal he was led to investigate the areal variations of this phenomenon. Indicies were constructed for each station showing degree of stability or instability of its climate. Stability was considered to exist when less than three climatic types had occurred.[52] Regions of stability and instability were mapped and compared with maps showing frequency of occurrence of surface fronts.

Several significant findings were noted. Regions of greatest instability were found to coincide with principal frontal formation zones. Second, Köppen's major boundary lines tended to coincide with these frontal zones. For the first time in climatic year studies it was observed that dynamic climatic classification based on frontal occurrence reaches much the same results. Finally, the pattern of climatic change appeared to be more meridional than zonal and was probably caused by relationships between alternations of maritime and continental airmasses. Fukui must be credited for linking the results of regional and dynamic climatological studies. His conclusions could prove illuminating for those who have dismissed regional climatology in general and the Köppen system in particular.[53]

Other climatic year research efforts since that time have been sporadic and unpublished and consist of two Master's theses and one research paper presented to a professional meeting.[54] Taylor's Oklahoma study was noteworthy in several respects. It continued the trend of using dense, long-term record station networks. This was the first study to include a complete computer program. Where modifications from generally accepted classification procedures were used they were defined and their derivations explained.[55] Maps of mean conditions, year-climates, and individual elements ("C", "B", "w", etc.) were presented with verbal analysis of each.

As a substantial part of the study was concerned with individual year-climates it is unfortunate the writer failed to calculate them from climate year data. The element analysis maps and discussions contain another inconsistancy. This was the use of class limits of varying sizes that do not appear to have been derived from any type of standard statistical transformation.[56] A third problem noted is in the mapped pattern of "w" year occurrence. The most intensive development of this condition is centered on the north-central border of the state with a crescentic pattern of decreasing intensity radiating outward. The pattern appears truncated on the western side because consideration of precipitation distribution during "B" years was omitted.[57] However, Taylor's general conclusions remain valid. Oklahoma was shown to have quite variable climatic conditions, a conclusion that does not appear when means are employed, and also that there was a distinct geographical distribution of this variability.

The last climatic year study to be reviewed is Sengenberger's.[58] It is of importance to this review for several techniques that are employed in this dissertation were introduced. For this study all data were reordered into climate years that began in April of one year and ended in March of the next. This was done to avoid the split winter season problem discussed in Chapter I and in the beginning of this chapter. The selection of April and October was done for essentially the same reasons as used in this dissertation (above Chapter I). Two additional techniques introduced were the extension of Russell's coding technique into the form adopted for this dissertation and the inclusion of provision for the use of Shear's dry climate notation.[59]

The coded classifications were used for the construction of element analysis maps of precipitation distribution and summer types. Analysis of the coded classifications and the element maps led to a climatic regionalization that recognized four kinds of discrete climatic regions in Wisconsin. Each had 50 per cent or more occurrence for each letter of its symbolization. In conclusion the regions were compared to actual station climatic data, verbal definitions of the Köppen system, and to general climatic control factors. These four climatic year regional types were shown to have a better fit to those three factors than do the "Dfa" and "Dfb" regions as usually depicted on averages maps. Also, it was observed that the improvements in descriptive accuracy appeared to obviate the need for drastic alteration of the Köppen system with extensive definitional alteration of older symbols and addition of entirely new ones such as proposed by some regional climatologists.[60]

Summary

Specific techniques of climatic year methodology used in this dissertation whose development has been reviewed above may be briefly summarized as follows: 1) use of a dense station network with long term records; 2) climatic classification for each year; 3) classification with computer; 4) reordering of data into climate year order; 5) use of Shear's set theory modifications; 6) use of coded classifications; 7) mapping of year-climates, individual letter elements, and climatic year regions; 8) comparison of climatic year regions with control factors; and 9) comparison of climatic year regions with regional patterns of other selected aspects of the physical environment.

REFERENCES

[1]The following definitions are used throughout this dissertation: "climatic year" - the methodology of calculating a climatic classification on the basis of data from one year, also the regions drawn on the basis of this methodology; "year-climate" - the mapped climate of one year; "calendar year" - the twelve month period from January through December; and "climate year" - the twelve month period from April through the following March, or generally any consecutive twelve month period other than January through December used in climatological research.

[2]"Dry Climates of the United States: II, Frequency of Dry and Desert Years 1901-20," University of California Publications in Geography, V (1932), 245-74.

[3]Arthur A. Wilcock, "Köppen After Fifty Years," Association of American Geographers Annals, LVIII (1969), 12-28.

[4]Russell, "Dry Climates," pp. 245-74.

[5]Richard J. Russell, "Climatic Years," Geographical Review, XXIV (1934), 92-103.

[6]James A. Shear, "A Set-Theoretic View of the Köppen Dry Climates," Association of American Geographers Annals, LVI (1966), 508-18.

[7]Russell, "Climatic Years," p. 98.

[8]"Notes on Climatic Boundaries in the Eastern United States," Geographical Review, XXV (1935), 117-24.

[9]Ibid., p. 120 [10]Ibid., p. 123.

[11]One such example is found in Trewartha, An Introduction to Climate (4th ed.), p. 245.

[12]Kendall, "Notes," p. 120. [13]Ibid., pp. 118-19.

[14]Richard J. Russell, "Climates of Texas," Association of American Geographers Annals, XXXV (1945), 37-52.

[15]Ibid., pp. 48-51.

[16]Takeshi Sekiguchi, "On the Year Climate in Japan," Geographical Review of Japan, XXIV (1951), 175-85. This writer's surname is reported as Sekiguti in: Japanese Progress in Climatology, II (1965), p. 1 and in Association of American Geographers, Directory of the Association of American Geographers: 1970 (Washington, D.C.: A.A.G., 1970), p. 272.

[17]Sekiguchi, "Year Climate in Japan," p. 185.

[18]"The Position of the Köppen Da/Db Boundary in Eastern United States," Association of American Geographers Annals, XLII (1952), 94-97.

[19]*Ibid.*, p. 95. [20]Kendall, "Notes," pp. 117-24.

[21]Russell, "Texas," pp. 48-51; Sekiguchi, "Japan," pp. 175-85.

[22]Villmow, "Eastern United States," p. 97.

[23]"Climate and Climatic Regions of Western Canada" (unpublished Ph.D. dissertation, University of Illinois, 1953).

[24]Ibid., p. 1. [25]Russell, "Texas," pp. 175-85.

[26]Rheumer, "Canada," p. 156. [27]*Ibid.*, p. 3. [28]*Ibid.*, pp. 161-65.

[29]"Climatic Classification and Climatic Change," *Erdkunde*, VIII (1954), 246-52.

[30]*Ibid.*, p. 247. [31]Villmow, "Eastern United States," pp. 94-97.

[32]Eiichiro Fukui, "The Secular Movement of the Major Climate Areas of Eastern Asia," *Geographical Studies Presented to Professor Taro Tsujimura in Honour of His 70th Birthday* (publisher and place of publication unknown, 1961), pp. 298-312.

[33]*Ibid.*, pp. 309-10. [34]*Ibid.*, pp. 302, 311. [35]*Ibid.*, pp. 305, 312.

[36]*Ibid.*, p. 312.

[37]"The Variation in Köppen's BW/BS Boundary in N.W. India," *Indian Geographical Journal*, XXXVII (1962), 83-86.

[38]*Ibid.*, p. 86.

[39]"Climate and Climatic Regions of the Missouri River Drainage Basin" (unpublished Ph.D. dissertation, University of Illinois, 1962), p. 1.

[40]Russell, "Texas," pp. 175-85.

[41]Sutherland, "Missouri Basin," p. 119. [42]*Ibid.*, pp. 119-29.

[43]Sutherland defines a "nuclear" place as, " . . . one which experiences a single climatic type during the entire period for which the region is being classified." *Ibid.*, p. 118.

[44]Sutherland, "Missouri Basin," pp. 117, 130; Villmow, "Eastern United States;" Rheumer, "Canada."

[45]The author was able to classify year-climates for 562 United States and 6 Canadian stations by processing 150,000 Monthly 1009 Summary Data cards. Though the length of the period of record was not stated a volume of cards of this magnitude should cover a period of approximately 25 years. This would yield over 14,000 individual climatic year classifications! Sutherland, "Missouri Basin," pp. 2-3, 5.

[46]Arthur H. Doerr and Stephen M. Sutherland, "Variations in Oklahoma's Climate as Depicted by the Köppen and Early Thornthwaite Classifications," Journal of Geography, LXIII (1964), 60-66.

[47]Ibid., pp. 65-66. [48]Ibid., p. 66.

[49]Rheumer, "Canada;" Sutherland, "Missouri Basin."

[50]Kendall, "Notes," p. 123.

[51]Eiichiro Fukui, "Secular Shifting Movements of the Major Climatic Areas Surrounding the North Pacific Ocean," Geographical Review of Japan, XXXVIII (1965), 323-42.

[52]Ibid., p. 341.

[53]See, for example, the comment of Douglas Carter that, "Preference for the older classification [Köppen's] . . . cannot be supported on grounds of its intellectual adequacy. The Köppen system has degenerated into a dogma," as quoted from "Farewell to the Köppen Classification of Climate" (Abstract), Association of American Geographers Annals, LVII (1967), 784. A similar, enigmatic criticism was the conclusion of Stephen Sutherland that, "Inasmuch as the [climatic year] classification [method] is predicated upon the concepts of Köppen so does Russell's system fail to be purely climatological," as quoted from "Missouri Basin," p. 158. In addition to Fukui's work noted above both Rumney's and Hare's comments (above Chapter I, pp. 1-2) might be appropos to such criticisms.

[54]John W. Taylor, Jr., "A 'Climatic Years' Study: Oklahoma, 1931-1965" (unpublished M.A. thesis, University of Oklahoma, 1966); June M. Winans' "Climatic-Year Study of Michigan" (unpublished Master's thesis, Eastern Michigan University, 1966) is not available for review; David L. Sengenberger, "Climatic Years and the Climates of Wisconsin" (paper presented at the annual meeting of the Southwest Division-Association of American Geographers - Southwest Social Science Association, Dallas, Texas, Spring 1968).

[55]See, for example, Taylor's discussion of the problem of classifying "f", "s", and "w" in "Oklahoma," pp. 10-14.

[56]For example, in the discussion of frequency of yearly occurrence of dry climates class limits used were: 0, 1-3, 4-6, 7-10, 11-14, and 19-27. Ibid., pp. 98-99.

[57] *Ibid.*, pp. 104-05. [58] Sengenberger, "Climates of Wisconsin."

[59] Shear, "Set-Theoretic View," pp. 508-18.

[60] An example of one type of new system is that of Glenn Trewartha. G.T. Trewartha, A.H. Robinson, and E.H. Hammond, *Elements of Geography* (5th ed., rev.; New York: McGraw-Hill Book Company, 1967), pp. 128-96, Plate 2. The fundamental structure remains that of Köppen, but so many changes have been made that other work becomes largely obsolete in the terms of the new scheme.

CHAPTER III

REGIONALIZATION AND CLASSIFICATION METHODS

Study Area

The Western Great Lakes States have been selected as the geographical base for testing the application of climatic year methodology for the regionalization of climates (above Chapter I). The core area consists of the states of Illinois, Indiana, Michigan, Minnesota, and Wisconsin. These five states include almost one-tenth (9.44 per cent) the area of the conterminous United States and stretch over twelve degrees of latitude and fourteen degrees, forty-five minutes of longitude.[1] In order to establish regional climatic boundary trends and to facilitate finding nuclear climates varying sized bordering areas of Manitoba, Ontario, North Dakota, South Dakota, Iowa, Missouri, Kentucky, and Ohio were also examined (Fig. 1). This area was chosen because its diversity of climatic conditions and their yearly variations would allow for a good test of the hypothesis (above Chapter I).

Seven major midlatitude low and two high pressure tracks, greatly differing seasonal air masses, a location and situation in the interior of the North American continent, and the presence of the three largest Great Lakes all combine to make a set of greatly differing regional and temporal climatic conditions.[2] The northerly portions of the Western Great Lakes States lie in the core of the continental climates of the

WESTERN GREAT LAKES STATES

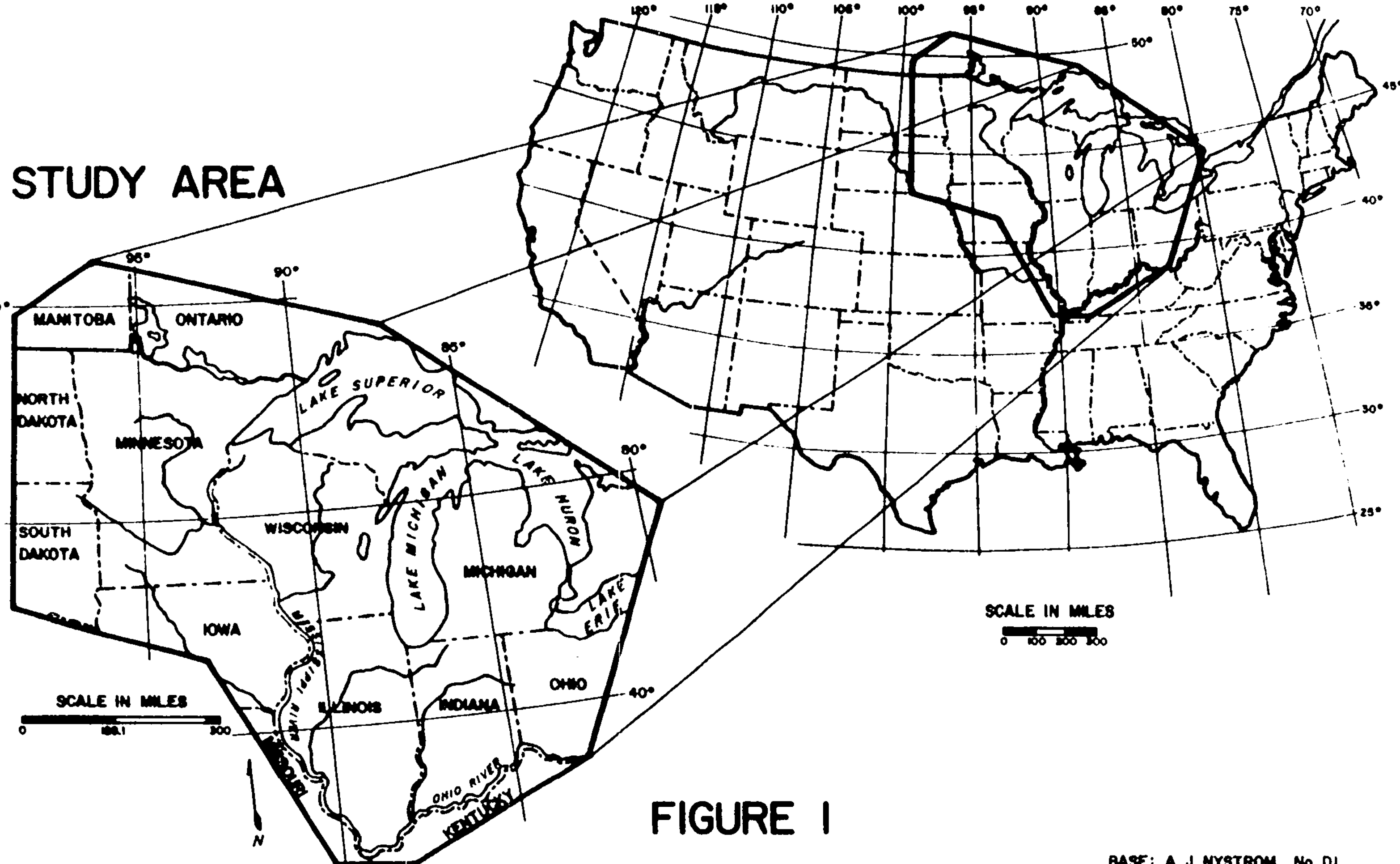

FIGURE I

BASE: A. J. NYSTROM No. DI

United States, whereas the southerly ones are on the margins of the subtropical climates. The west not infrequently has subhumid conditions.[3] Present Köppen system maps based upon normals show three climatic regions here: "Cfa", "Dfa", and "Dfb".[4] However, much of the area has a definite winter dry season that shifts from month to month throughout the winter half year from year to year, as well as occasional summer dry conditions that also behave in a similar fashion.[5] Also, from preliminary analysis it was known other climatic types, including "D-c" and "BS", occur on a yearly climatic basis though their frequency does not appear in published form. Until the yearly climates had been classified it was difficult to predict the regional types that might be expected to appear.

Station Network

The network of stations used in the classification was selected within the study area on the basis of four constraints. First, the network had to be as dense as possible in order that climatic boundaries could be reliably drawn and spatial climatic changes of great difference identified. The second constraint was the existence of a continuous, unbroken record for each place to insure that ficticious climatic regions would not be invented. The third constraint was use of a sufficiently long period of observations so as to include the climatic variability that would be expected over several decades. Finally, because of the large amounts of data required for a study of this nature it was deemed important that the data be in format suitable for automatic data processing.[6]

Because both the United States Weather Bureau and Canadian

Meteorological Branch have laboriously collected and published immense quantities of primary climatological and meteorological data for numerous locations within the area these two agencies were utilized as the data source.

Sample stations were selected to form a network. Within the network distances between any two stations did not exceed sixty miles. Two types of exceptions to this procedure were necessary. In sparsely inhabited areas the distance constraint was relaxed because of the absence of reporting stations. In some more densely settled regions temporal gaps in the data necessitated a coarse network pattern. The densest portion of the network is in Wisconsin where data from the writer's previous work was available. Most areas of that state have no more than forty miles between reporting points. In all 306 stations form the point network (Fig. 2). Their names and identification numbers are listed in Appendix C.

Study Period

Data for a period of thirty-five years as advocated by Conrad and Pollak,[7] was initially established as the temporal length for the study. However, examination of the data revealed too many data gaps between 1931 and 1935. Consequently, the study period was reduced to thirty years (April, 1936, to March, 1966, inclusive). This reduction did not reduce the validity of the analysis for it still meets Conrad and Pollak's dicta that a period should exceed ten years and ought to be about twenty-five to thirty-five years in length.[8]

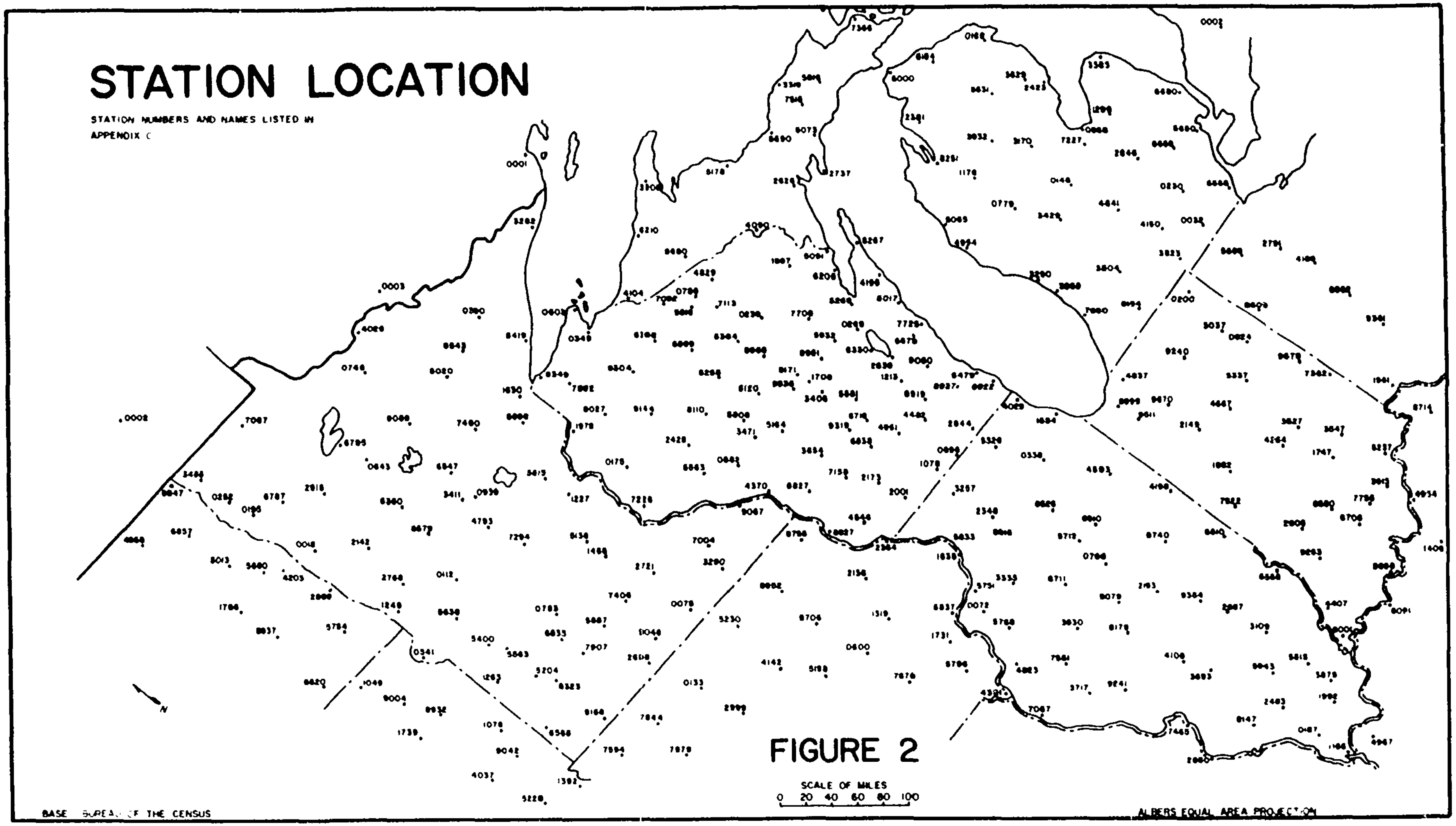
STATION LOCATION
STATION NUMBERS AND NAMES LISTED IN
APPENDIX C
SCALE OF MILES
0 20 40 60 80 100
N
BASE BUREAU OF THE CENSUS
ALBERS EQUAL AREA PROJECTION

FIGURE 2

Data Processing Methodology

Because of the large amounts of data used in the study the use of an electronic computer was necessary. The computer program was written in Fortran IV-G Level for initial use and testing on the I.B.M. 1130 computer at the University of Wisconsin - Stevens Point. Subsequently, program modifications were made to fit the program to the I.B.M. 360/50 computer of the University of Oklahoma where the actual run was made.[9]

Prior to the transformation to magnetic tape the data were sorted and counted to verify chronological order and station number validity. Where possible missing data from Canadian stations[10] and from first order U.S. Weather Bureau stations[11] were added to supplement the original data.

The program performed the following operations. First, all monthly temperature and precipitation values were reordered into climate year form (above Chapters I and II) and printed together with new yearly temperature means and precipitation totals. Köppen classification symbols were then calculated and printed for each year for each station. Thirty year monthly and annual means were established for calculation of a normal Köppen symbol for each station for the thirty year study period. Lastly, a summation table for each station was printed containing a count of the number of times each annual Köppen classification symbols had occurred.

Data print-out sheets were examined for error or inconsistancy in the data or in the calculation of Köppen symbols. In some cases symbols had not been computed because of missing or incomplete data.

For some of these interpolation was possible and missing symbols were calculated by hand. For others symbols had to be corrected or deleted because they had been calculated on the basis of faulty data. In both cases the symbol summation tables following each station's data were altered to reflect these corrections. Finally, all summation tables were converted from numerical frequencies of symbol occurrence to percentages.

Coded Classification and Mapping

After verification and extension of computer calculations a table of coded classifications for all stations in the study area was compiled (above Chapter II). Each coded classification contained all individual letter types found at the station together with a percentage value for each letter indicating the percentage of occurrence of that particular letter type (Appendix D). This table facilitated the drawing of four kinds of maps for further analysis (below Chapter IV).

One map of mean Köppen conditions and a set of annual year-climate maps were based on the mean and annual values of the corrected computer print-out.[12] Each map was constructed by plotting the Köppen letter symbol for each station onto the map. Upon completion of the symbol plotting boundary lines were drawn to separate homogenous regions from each other. Another map set was then constructed showing frequency of occurrence of mesothermal, microthermal, and semiarid microthermal years; winter dryness and even precipitation distribution; summer dryness; and summer types. This map set was constructed by plotting percentages of occurrence of each of the designated qualities for each station on its appropriate map. Isopleths were drawn based upon arithmetic levels to divide the data into regular, mutually exclusive classes of a size appropriate to the data. In those cases where frequency of occurrence was highly infrequent, as in the cases of "s" and "c", class limits were as close as 3.3 (3.35) per cent. Where the quantity varied greatly, as in the cases of "a", "b", "f", and "w", class limits were much wider. The guiding purposes for the selection of class limits in all cases were those of identification of area of occurrence, finding regions of nuclear and transitional conditions, and noting direction and strength of rates of change. The last type of map drawn was a climatic year region map on which each delineated climatic region had a frequency of occurrence of 50 per cent or greater for each named letter type (special notation was made of small, exceptional areas in which one letter type had only a plurality of occurrence rather than a majority).

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[2]*Ibid.*, p. 53; Sverre Petterssen, Introduction to Meteorology (3rd ed.; New York: McGraw-Hill Book Company, 1969), pp. 201, 206; Bernhard Haurwitz and James M. Austin, Climatology (New York and London: McGraw-Hill Book Company, Inc., 1944), Pls. XVI and XVII; Stephen S. Visher, Climatic Atlas of the United States (Cambridge, Mass.: Harvard University Press, 1954), pp. 360-76.

[3]Kendall, "Notes," p. 123; Goode's World Atlas, p. 53.

[4]Petterssen, Meteorology, p. 286.

[5]Sengenberger, "Climates of Wisconsin."

[6]In some cases, for first order U.S. stations prior to 1949 and all Canadian stations, compatible machine format data were not available.

[7]Victor Conrad and L.W. Pollak, Methods in Climatology (2nd ed., rev.; Cambridge, Mass.: Harvard University Press, 1962), p. 240.

[8]*Ibid.*, p. 241.

[9]Input data was card image form on magnetic tape. Transformation of data from Monthly 1009 Summary Data cards was accomplished by personnel of the University of Oklahoma Merrick Computer Center. Detailed information concerning these programs for both the I.B.M. 1130 and 360/50 may be obtained from the writer at the Department of Geography, University of Wisconsin - Stevens Point, Stevens Point, Wisconsin 54481 or from the Department of Geography, University of Oklahoma, Norman, Oklahoma 73069.

[10]Canada, Department of Transport, Meteorological Branch, Monthly Record: Meteorological Observations in Canada (Toronto, Ont., 1933-66). Canada, Department of Transport, Meteorological Branch, Annual Meteorological Summary for Fort William/Port Arthur, Ontario; Annual Meteorological Summary for London Airport, London, Ontario; and Annual Meteorological Summary for Winnipeg, Manitoba (Toronto, Ont., 1969).

[11]Michigan, Weather Service, Climate of Michigan by Stations (rev. ed., East Lansing: Michigan Weather Service, 1966). U.S., Departments of Agriculture and Commerce, Weather Bureau, Climatological Data: Illinois, Indiana, Iowa, Kentucky, Minnesota, Missouri, North Dakota, South Dakota (Washington, D.C.: Government Printing Office and Asheville, North Carolina: Department of Commerce, Weather Bureau, 1936-66).

[12]Where possible when data were missing interpolations were made.

CHAPTER IV

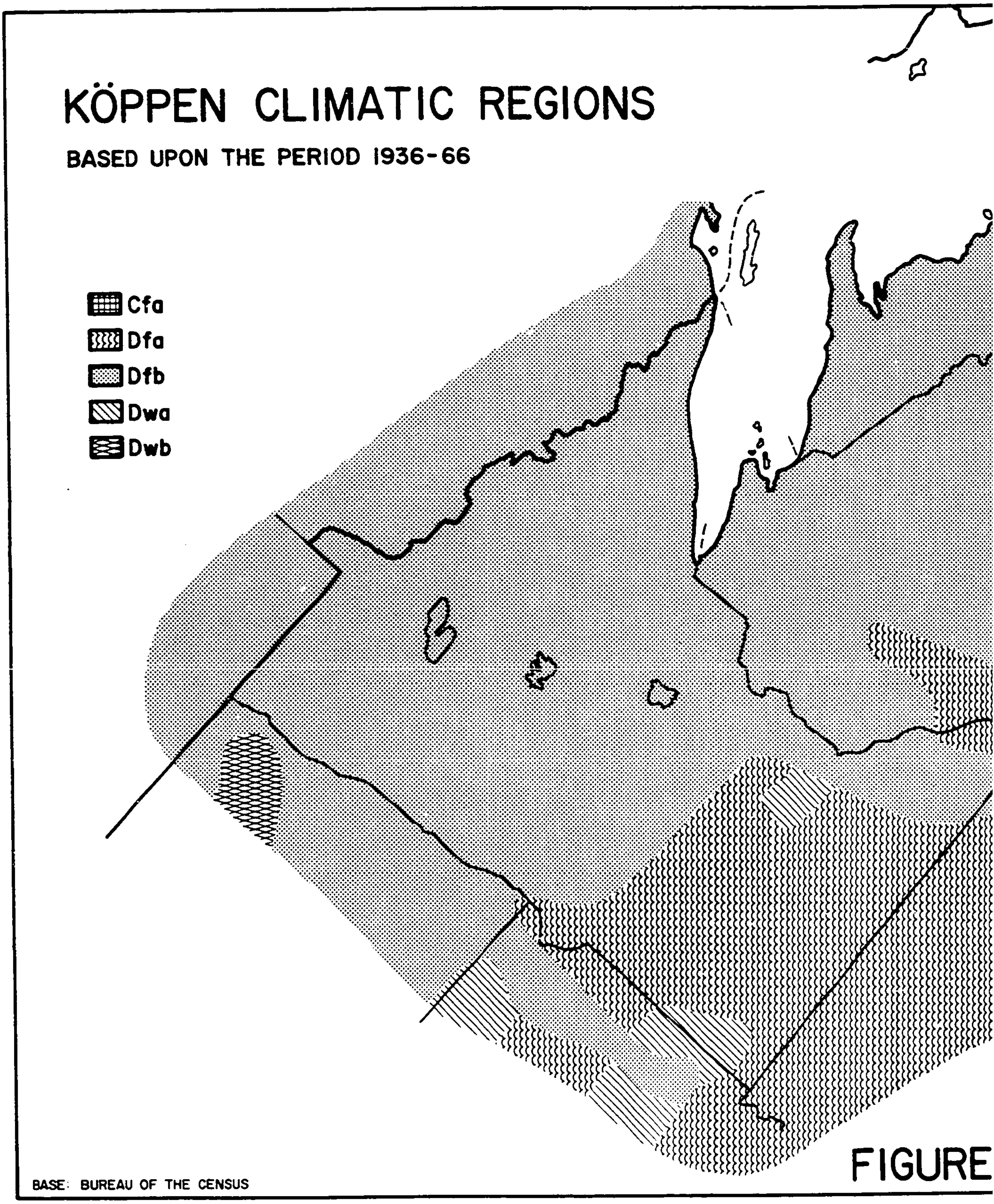
CLIMATIC YEAR REGIONS: A REGIONAL ANALYSIS AND SYNTHESIS

Introduction

For comparative purposes in this chapter the "Köppen Climatic Regions" map (Fig. 3) was prepared with thirty year mean data from all stations utilized in this study. Although it shows a few differences from widely circulated similarly drawn world maps[1] such differences are most minor. These may be explained by the use of a much greater number of stations for the preparation of Figure 3 than is customarily used for comparably sized areas of world maps.

Differences may be seen in Lower Michigan, along the Wisconsin-Minnesota boundary, in east-central Wisconsin, and in eastern South Dakota.[2] In Michigan "Dfb" extends far to the south both along the eastern shore of Lake Michigan and in the east-central part of the state. The southern "Dfb" limit in both instances is the southern state boundary. Areas of "Dfa" appear extended north of their usually mapped locations in eastern and west-central Michigan.[3] Further west a narrow tongue of "Dfb" extends southward along the Wisconsin-Minnesota boundary into north-eastern Iowa while a "Dfa" one projects northward along the western shore of Lake Winnebago.

The only major observable difference is in the northwest where


KÖPPEN CLIMATIC REGIONS
BASED UPON THE PERIOD 1936-66
Cfa
Dfa
Dfb
Dwa
Dwb
BASE: BUREAU OF THE CENSUS
FIGURE

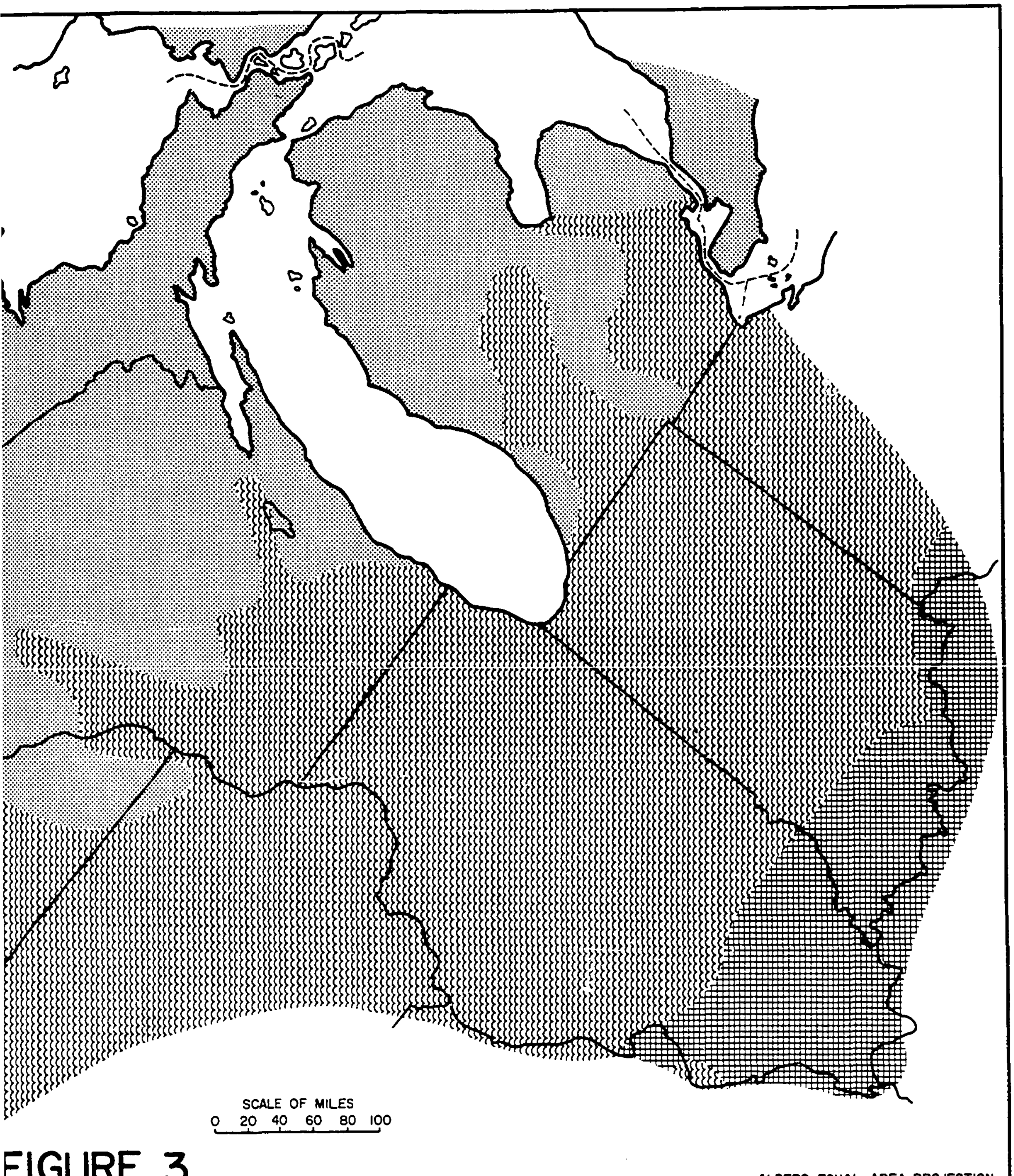


FIGURE 3

ALBERS EQUAL AREA PROJECTION

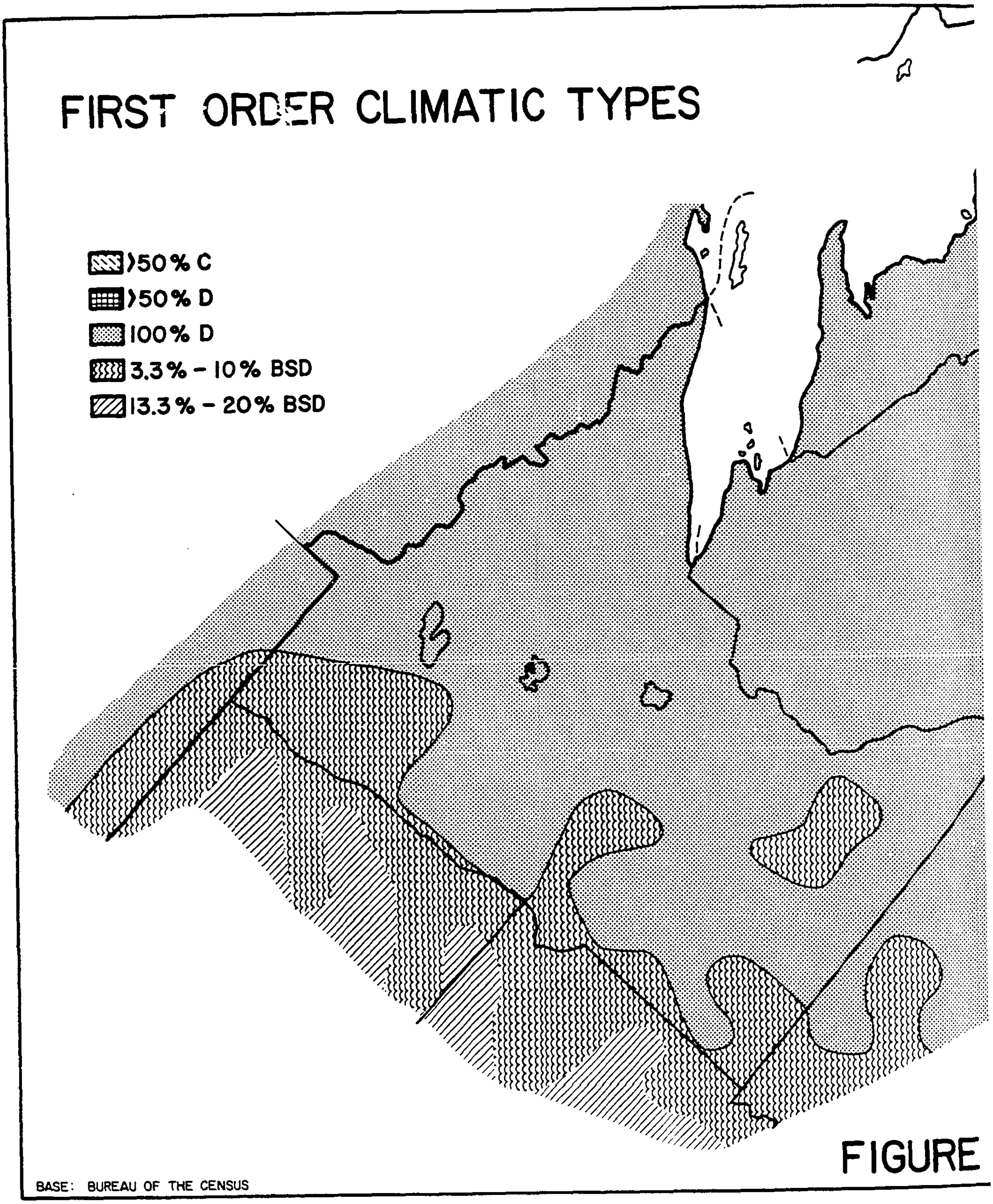
five scattered patches of "Dwa" and "Dwb" have been mapped in Minnesota and the eastern Dakotas. These are indicators of a generally unrecognized major region of winter dry precipitation distribution conditions.[4] As demonstrated below climatic year analysis methods have greater discriminatory powers to detect such phenomena and to do it in greater detail.

Element Analysis

Identification of climatic nuclear (core) regions and their transition zones is accomplished here with element analysis. This method has also been used in construction of climatic year regions. Element analysis consists of mapping regional differentiation for each Köppen letter element by percentage of yearly occurrence during the study period.[5] As outlined in Chapter III the percentage values for one letter for all stations were entered on a base map and isopleths drawn to differentiate among the differing values.

Mesothermal, Microthermal, and Steppe Regionalization

Within the Western Great Lakes States and their bordering area three types of first order letter climatic years, humid mesothermal, humid microthermal, and steppe microthermal, have occurred (Fig. 4). Regional mapping of "C" and "D" was done with isopleths of 50 and 100 per cent while that for "BSD" was accomplished with 0 and 10 per cent ones. Five regions were outlined: 1) 50 per cent and greater "C" (with the balance "D"), 2) 50 per cent and greater "D" (with the balance "C"), 3) 100 per cent "D", 4) 3.3 to 10 per cent "BSD" (with the balance "D"),


FIRST ORDER CLIMATIC TYPES
>50% C
>50% D
100% D
3.3% - 10% BSD
13.3% - 20% BSD
FIGURE
BASE: BUREAU OF THE CENSUS

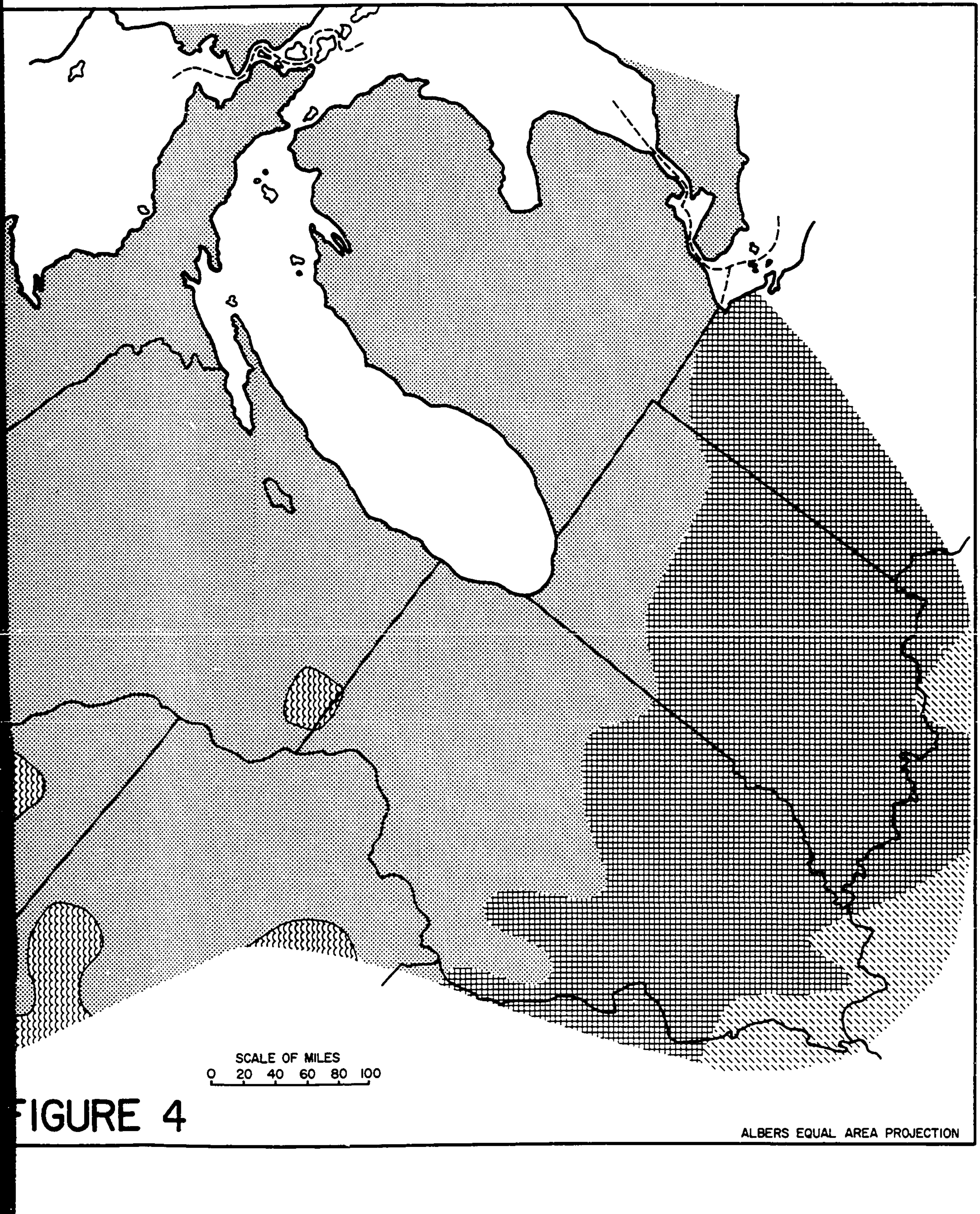


FIGURE 4

and 5) greater than 10 per cent "BSD" (with the balance "D").

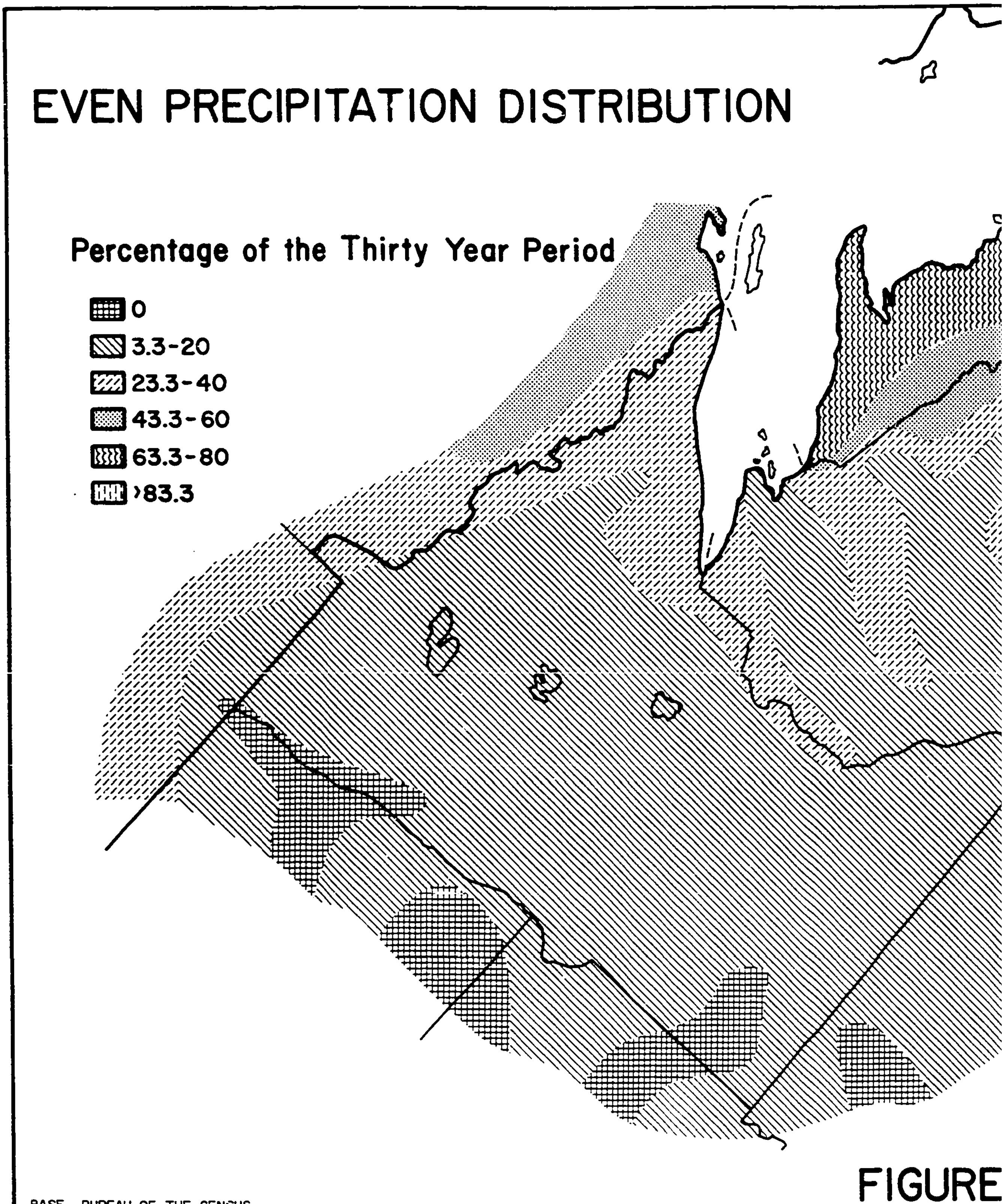
The outlined zone of 100 per cent "D" in the northern part of the study area is obviously part of the nuclear "D" region of the northern portions of the North American continent. Its southerly edge is almost latitudinal stretching west-southwest from the western end of Lake Erie to the southeastern Iowa boundary.[6] Lying on the extreme southern margin of the study area is a region of greater than 50 per cent occurrence of humid mesothermal "C" conditions. This is the transitional "C" region of central North America, transitional in the sense that it is assumed a core region of 100 per cent "C" climatic years exists in the southeastern United States outside the mapped area. As this "C" transitional zone occupies such a small amount of territory within the study area (the extreme southern tip of Illinois) it is of only peripheral interest to this study. Between the small "C" transitional zone to the south and the core "D" region on the north lies the large "D" transitional region. This completely occupies western Ohio, all of north-central, central, and southern Indiana, and central and most of southern Illinois. It does not occur in southeastern Iowa.

In terms of cool season thermal conditions the greatest percentage of the study area has nuclear (100 per cent) microthermal "D" climate. This is observed in south-central Canada, the eastern Dakotas, northern and eastern Iowa, Minnesota, Wisconsin, Michigan, northern and north-central Illinois, and northern and northwestern Indiana.

An additional consideration here is examination of humid/subhumid conditions. Figure 4 clearly shows some occurrence of "BSD" years. These are neither widespread nor frequent. Minnesota and Wisconsin are the only states in the core of the study area to have experienced semiarid microthermal "BSD" years. Two stations in Minnesota have experienced a maximum of 6.6 per cent "BSD" years while ten other Minnesota stations and one in Wisconsin have had a 3.3 per cent occurrence. This is not a chance phenomenon. Similar semiarid microthermal year frequencies are found in Iowa to the south and increased frequencies are observed in the eastern Dakotas (as much as 33.3 per cent at the westernmost station).[7] Frequencies of 3.3 or 6.6 per cent "BSD" years in Minnesota and Wisconsin may seem of minimal importance. Nonetheless, they are of more than passing interest to those engaged in agriculture or the maintenance of domestic water supplies in those states.[8]

Precipitation Distribution Regimes

Although Köppen normals maps (including Figure 3) universally identify the study area as having even precipitation distribution climatic year methodology indicates rather different regimes. Figure 5 was prepared to show the distribution and frequency of "f" years. Less than half the area experiences even as much as 43.3 per cent "f" years. There is no core region of 100 per cent occurrence, and only four stations, all in Michigan, had 83.3 per cent or more of such years. The center of "f" years lies in Michigan, northwestern Ohio, northern and west-central Indiana, and east-central Illinois. In most cases high "f" year frequency is found in association with Lakes Erie, Huron, Michigan, and Superior. Frequencies decrease noticeably to the west and northwest across Illinois, Wisconsin, and Minnesota and reach minimums in western Minnesota, northwestern Iowa, and the eastern Dakotas. A slight indication



EVEN PRECIPITATION DISTRIBUTION
Percentage of the Thirty Year Period
0
3.3-20
23.3-40
43.3-60
63.3-80
›83.3
BASE. BUREAU OF THE CENSUS

FIGURE

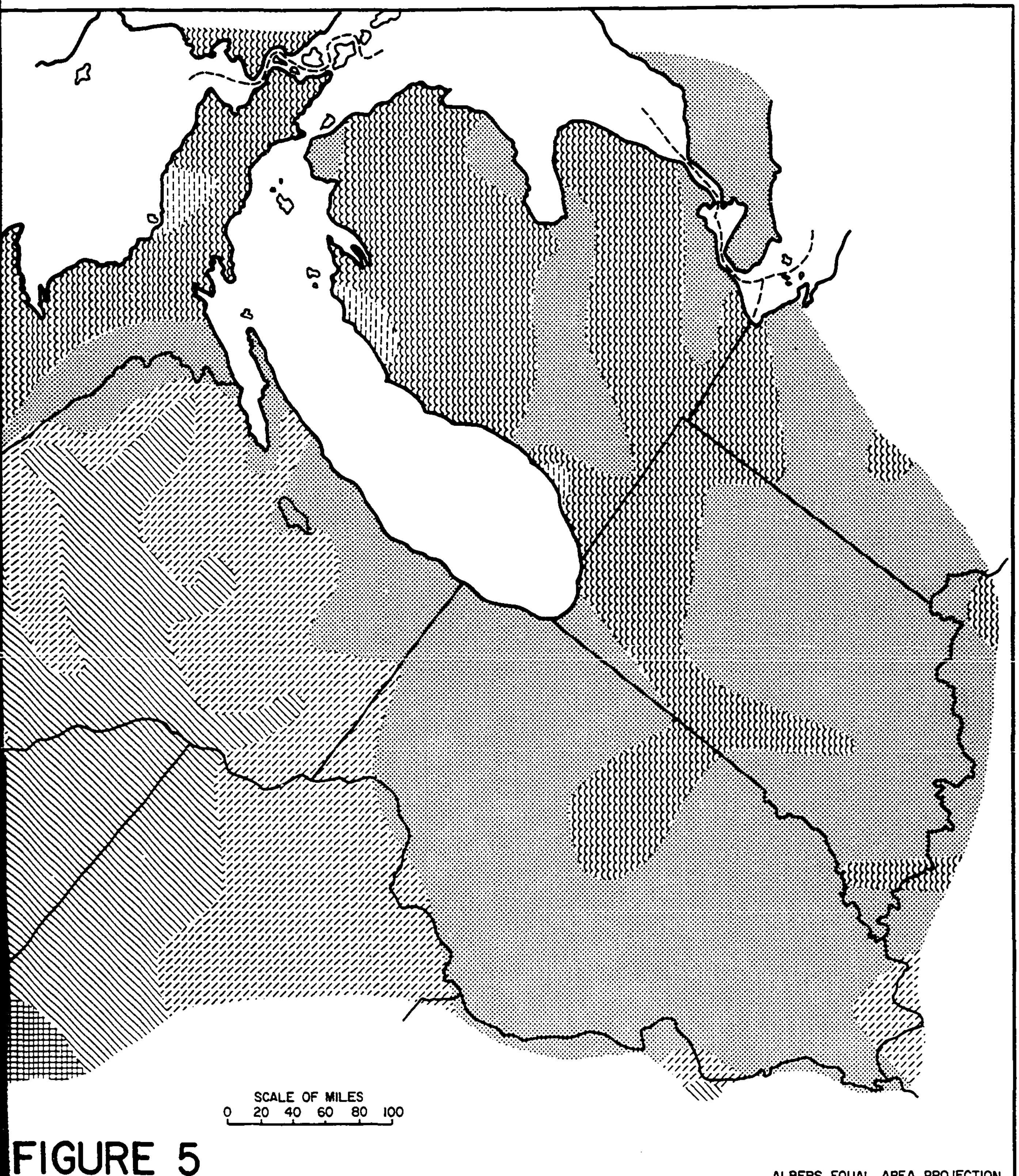
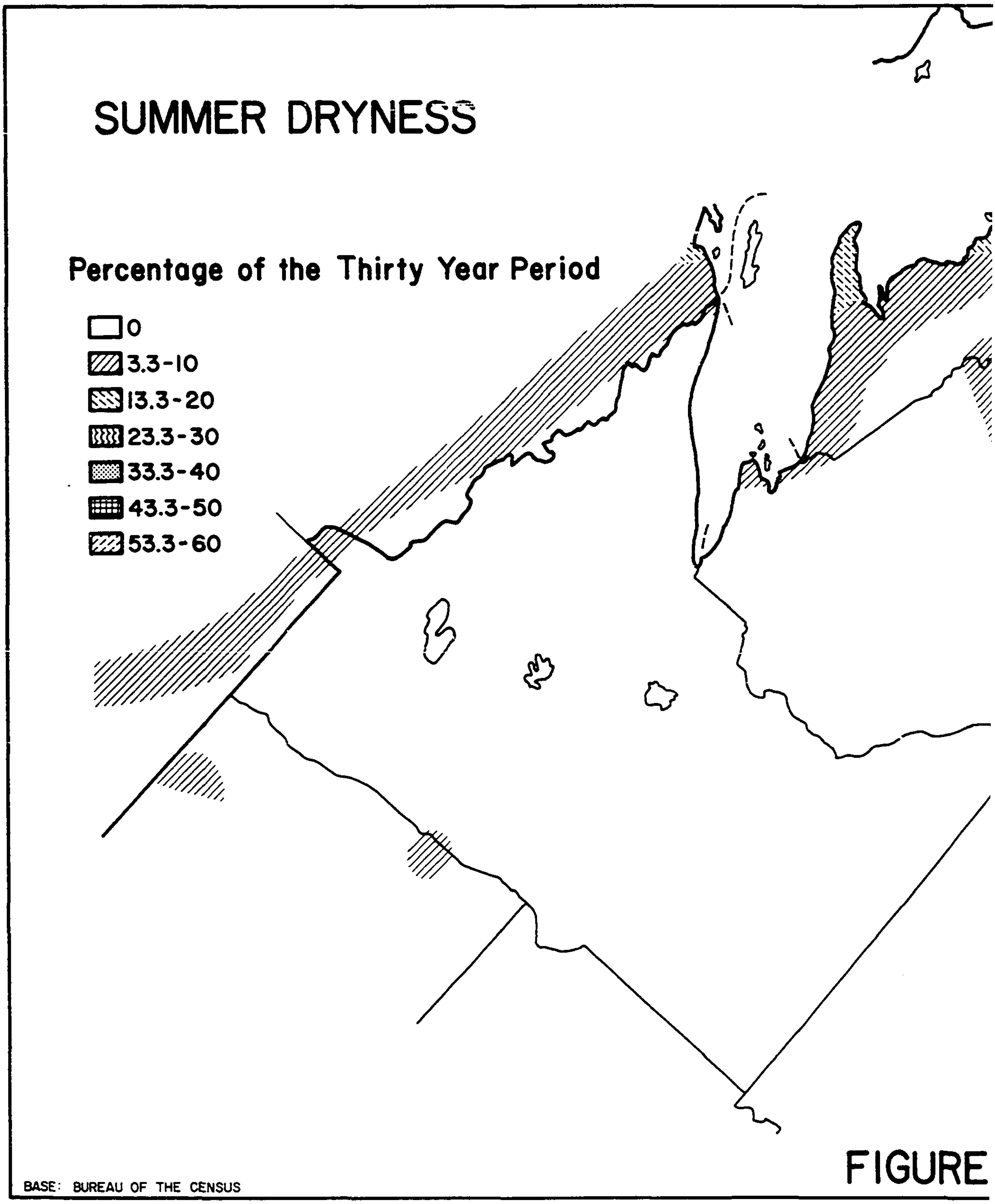


FIGURE 5

of decrease in "f" years is observed in southern and southwestern Illinois. A questionable tendency toward increase is observable in southern Indiana, central Ohio, and in parts of northern Kentucky.

Figures 6 and 7 present a summarization of summer dry and winter dry distribution and frequency. Of the two regimes, the summer dry is less frequently occurring and more restricted geographically. Through most of the eastern and southeastern portions of the study area summer dry years occur typically with frequencies of 3.3 to 30 per cent. Greatest frequencies occur in southern Indiana and Illinois and in northern peninsulas surrounded by waters of the Great Lakes. The three zones of greatest frequencies of "s" years, exceeding 30 per cent, are in the Niagara Peninsula of Ontario and in southernmost Indiana and Illinois and bordering portions of Kentucky. In only one of the localities, extreme western Kentucky and an adjacent sector in southern Illinois, does "s" attain a frequency of greater than 50 per cent. The summer dry regime does not occur with great frequency in most of the Western Great Lakes States area. Nonetheless, its presence can be of critical importance and ought to be recognized. Low summer rainfall amounts can be the cause of disasterous crop failure and domestic water shortages, and in the heavily forested parts of the area potentially dangerous forest fire conditions can be initiated.

The winter dry regime "w" is much more widely distributed and also occurs more frequently (Fig. 7). Every station utilized in the study has experienced at least one winter dry year (3.3 per cent occurrence) during the 1936-66 period. Two states in the core of the dissertation area and three states and one province on its periphery have "w"


SUMMER DRYNESS
Percentage of the Thirty Year Period
0
3.3-10
13.3-20
23.3-30
33.3-40
43.3-50
53.3-60
BASE: BUREAU OF THE CENSUS

FIGURE

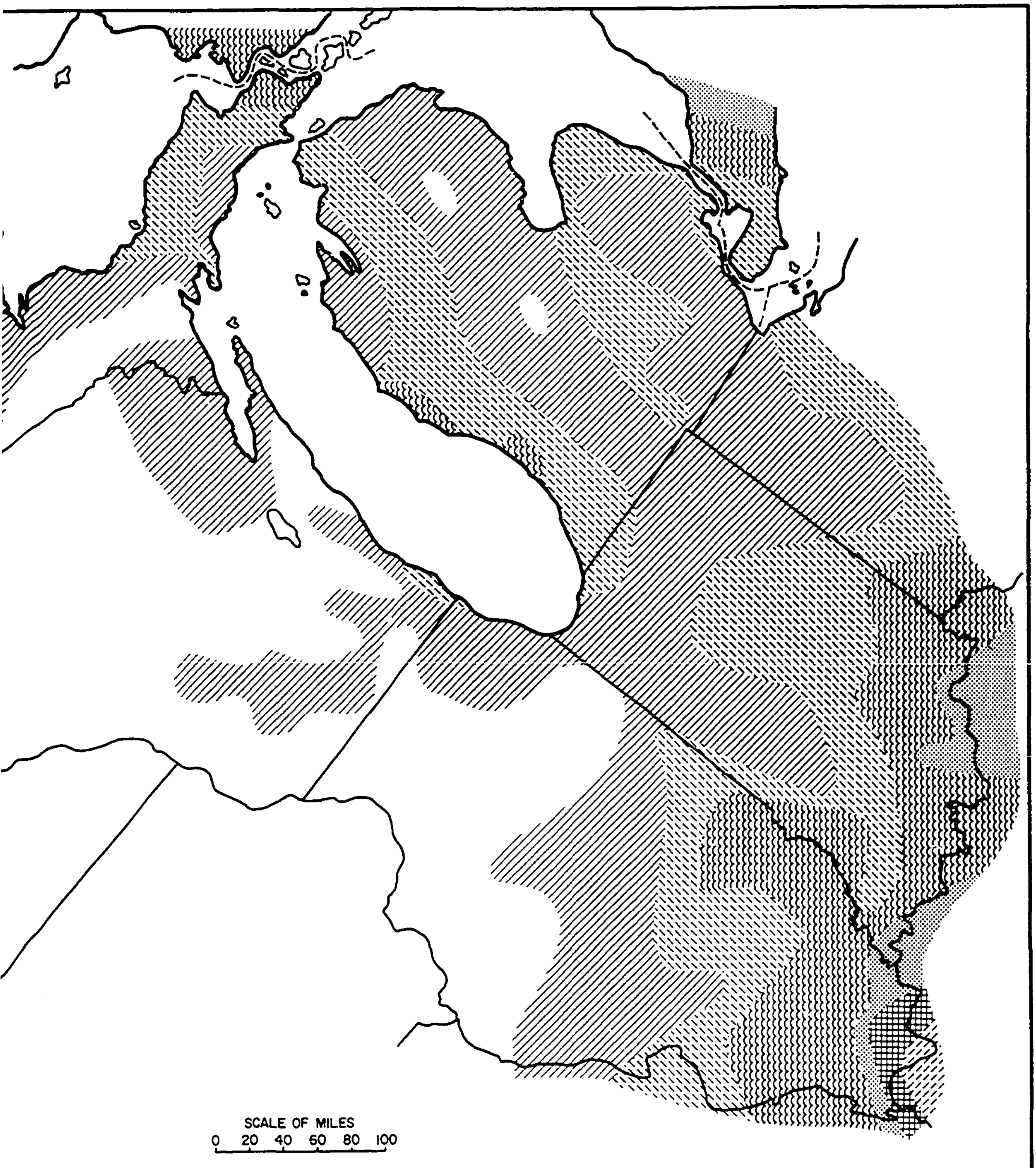
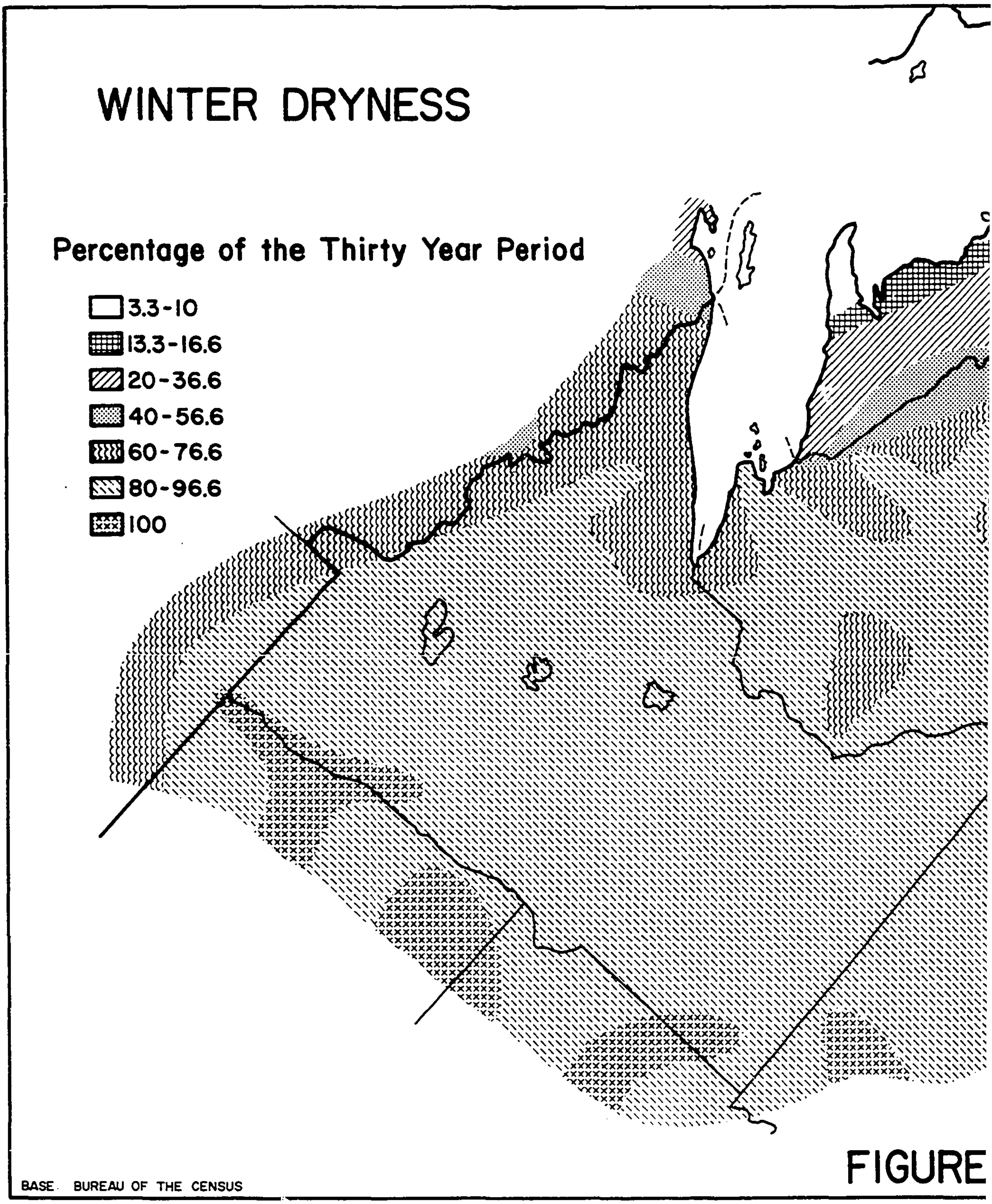


FIGURE 6



WINTER DRYNESS
Percentage of the Thirty Year Period
3.3-10
13.3-16.6
20-36.6
40-56.6
60-76.6
80-96.6
100
BASE BUREAU OF THE CENSUS

FIGURE

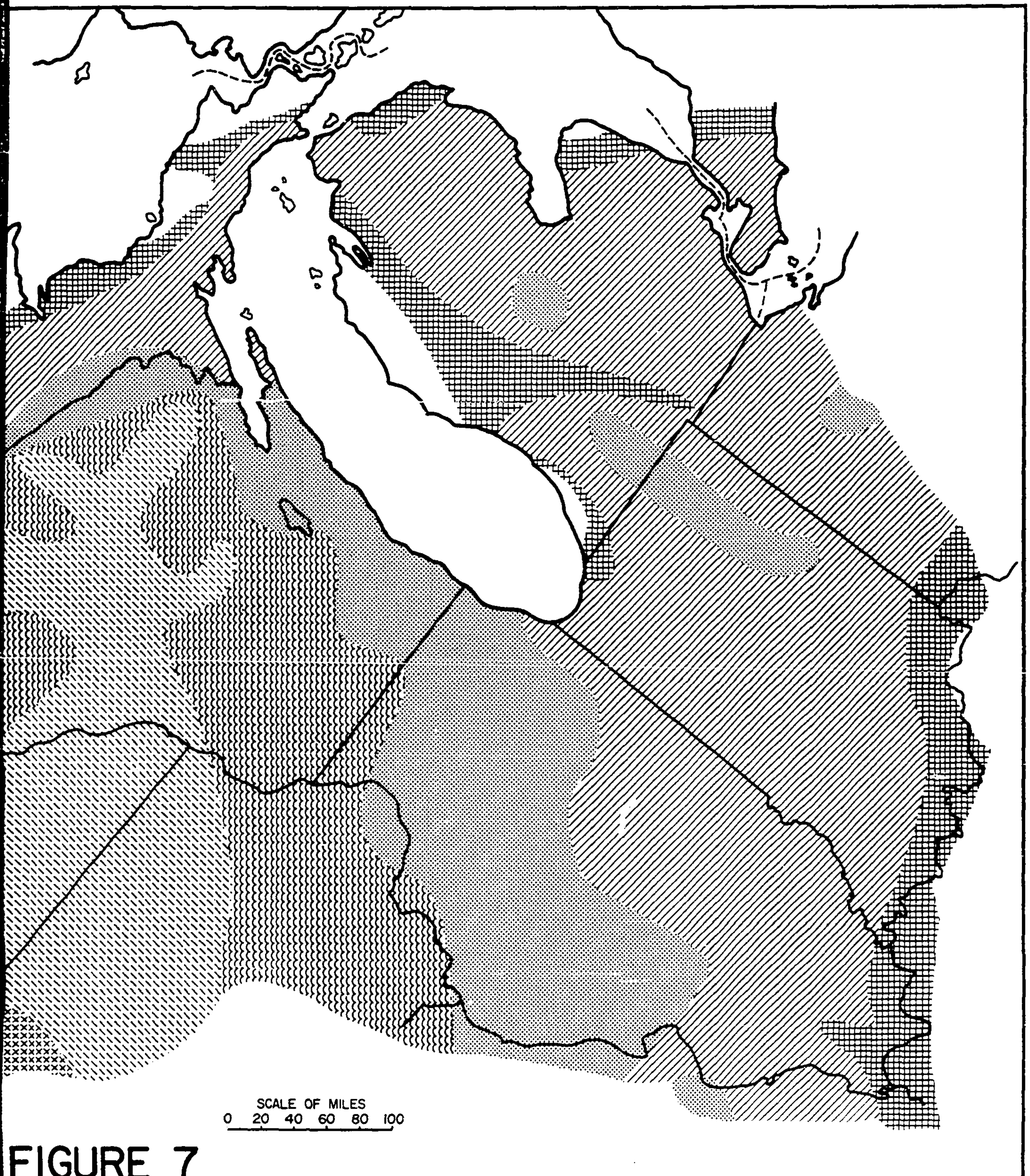


FIGURE 7

frequencies of 50 per cent or greater. In the remaining states and province, with the exception of Kentucky, areas with minimum frequency of 40 per cent are apparent. Three geographic characteristics of the winter dry pattern are evident from the distribution. First, frequencies increase almost uniformly to the northwest, especially in the western half of the study area. Large portions of Wisconsin, Minnesota, Iowa, southeastern Manitoba, and the eastern Dakotas have had "w" winters in 80 per cent or more of the thirty year period; frequency of 100 per cent may be seen in Minnesota, both Dakotas, and Iowa. A second characteristic is that decreases may be noted toward the north in Canada, the northeast, and the southeast. Even in most of these locations, however, frequencies are still as high as 20 to 36.6 per cent as may be observed in Indiana, western Ohio, and Michigan. The last pattern characteristic is that within the central and north-central portions of the study area. Here an irregular pattern of low frequencies, especially apparent in Michigan, appears along the shores of the Great Lakes.

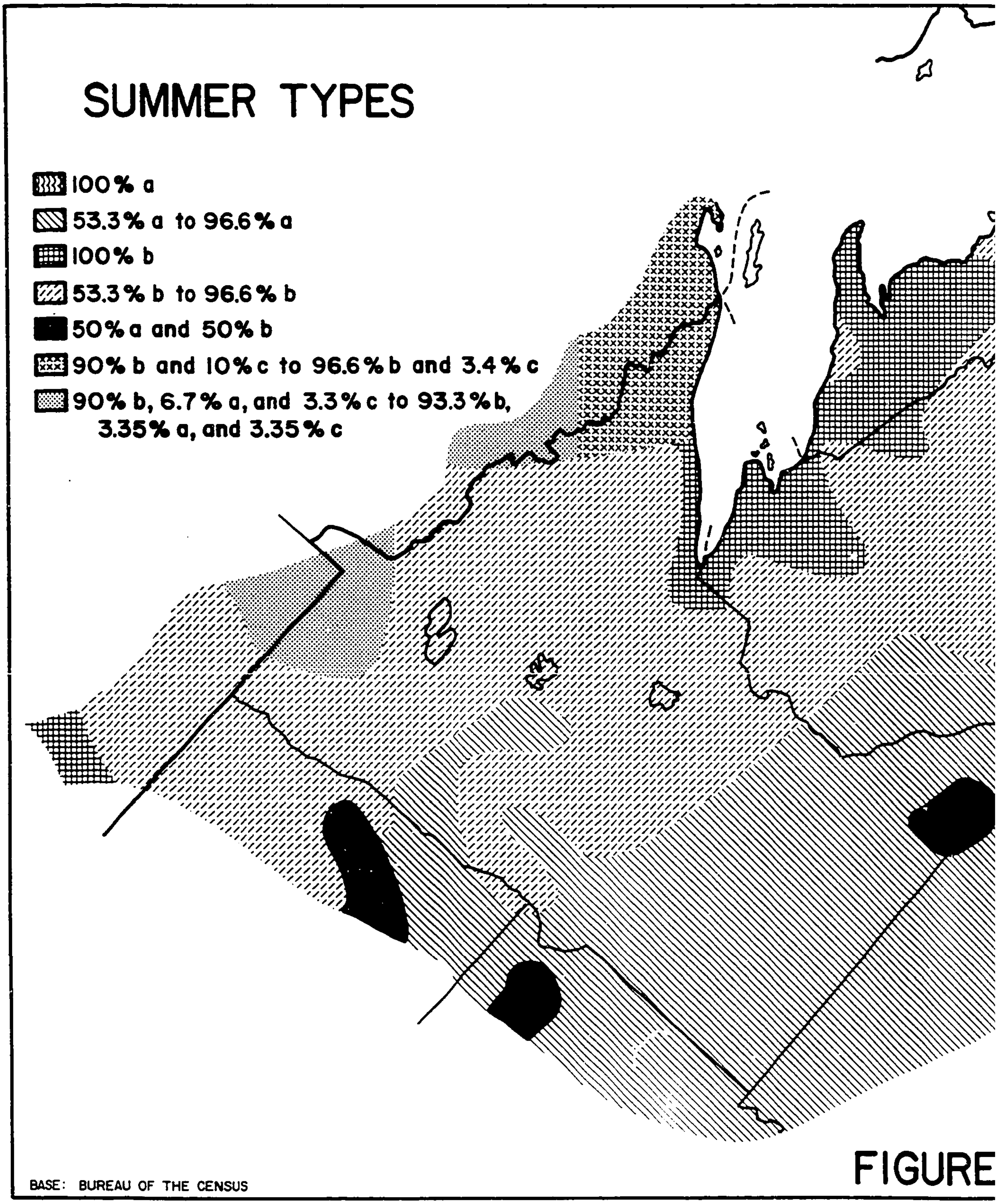
The detection of a widespread region of winter dry conditions is an important result of climatological research. The existence of this regime is only barely hinted by the use of standard Köppen procedures (i.e. the use of means)(Fig. 3). Such a regime should be recognized for its significance to the soil water balance, disruption or lack of disruption to transportation systems, and even to the economics of man's recreation activities.[9]

Summer Characteristics

Most of the study area experiences either hot "a" or warm "b" summer temperature regimes (Fig. 8). Only rarely does the cooler "c" summer occur. It should be observed that the 50 per cent "a"/"b" isopleth closely approximates, but does not completely duplicate, the position of a mean "a"/"b" boundary (Fig. 3). Because monthly temperatures have less variance than monthly precipitation totals these results were not unexpected.

The relationships and patterns of "a" and "b" were examined because these types are the most prevalent. Figure 8 illustrates the position of the 50 per cent "a"/"b" isopleth for comparison with the "a"/"b" normals boundary of world maps.[10] The greatest differences between these two lines are in Lower Michigan and in southeastern and east-central Wisconsin. These differences are simple ones of degree of detail and reflect the large number of stations used in this study. Both locations are close to the Great Lakes. The significance of this locational factor is examined in Chapter V.

A second important isopleth is the 100 per cent "a" boundary in the south. It outlines the nuclear hot summer region which includes most of Illinois, southern and southwestern Indiana, southeastern Iowa, eastern Missouri, northern Kentucky, and the southwest corner of Ohio. To the north, surrounding Lake Superior on the west, is the 100 per cent "b" (in some cases both "b" and "c") isopleth.[11] Within this boundary summers are warm, rather than hot, and occasionally short. Included here are only small parts of northeastern Minnesota, southwestern Ontario, and northern Wisconsin together with most of the Upper Peninsula of Michigan. In the Western Great Lakes States the nuclear "b" (and "b"-"c") region is very restricted in extent.


SUMMER TYPES
100% a
53.3% a to 96.6% a
100% b
53.3% b to 96.6% b
50% a and 50% b
90% b and 10% c to 96.6% b and 3.4% c
90% b, 6.7% a, and 3.3% c to 93.3% b, 3.35% a, and 3.35% c
BASE: BUREAU OF THE CENSUS

FIGURE

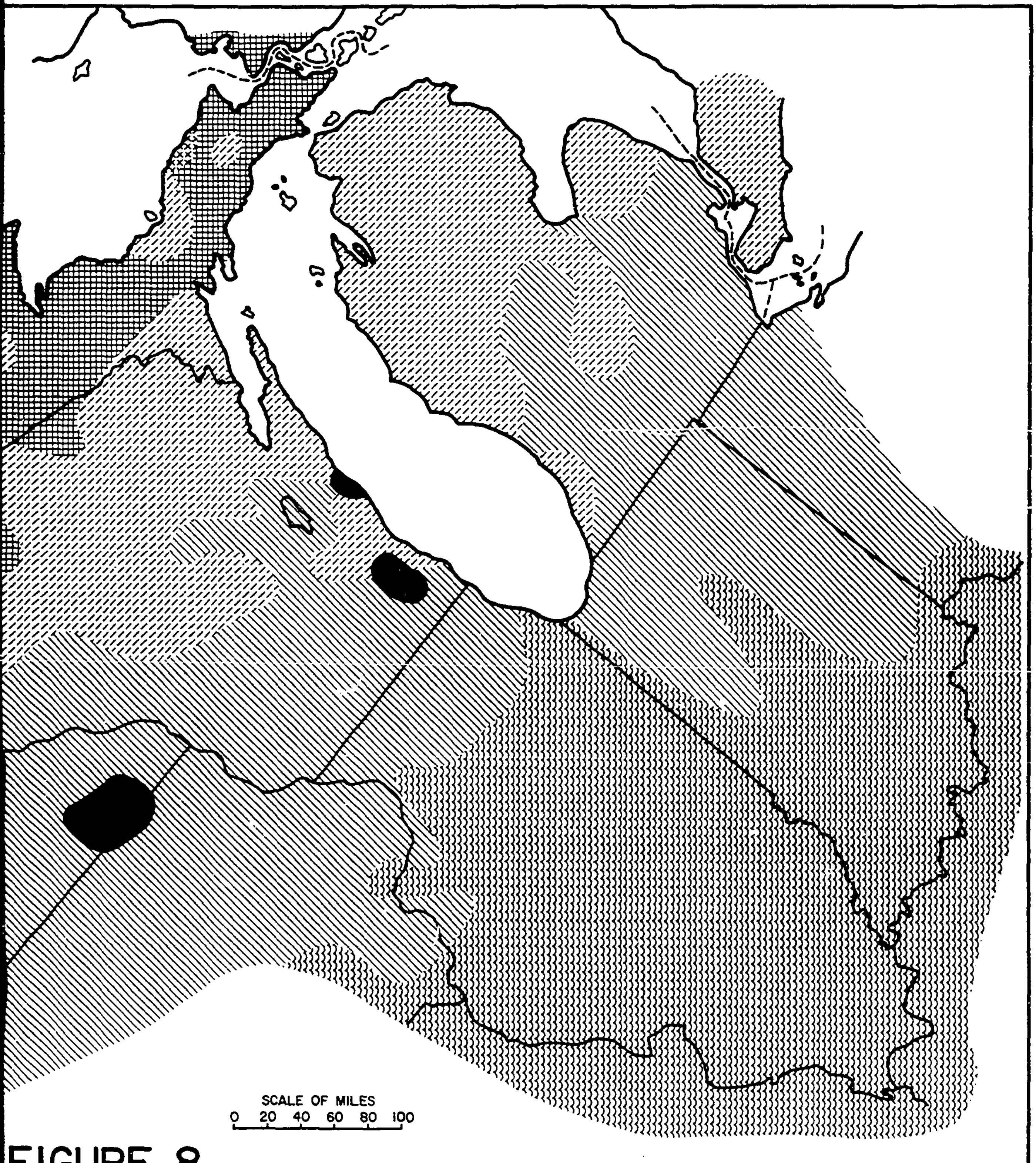


FIGURE 8

ALBERS EQUAL AREA PROJECTION

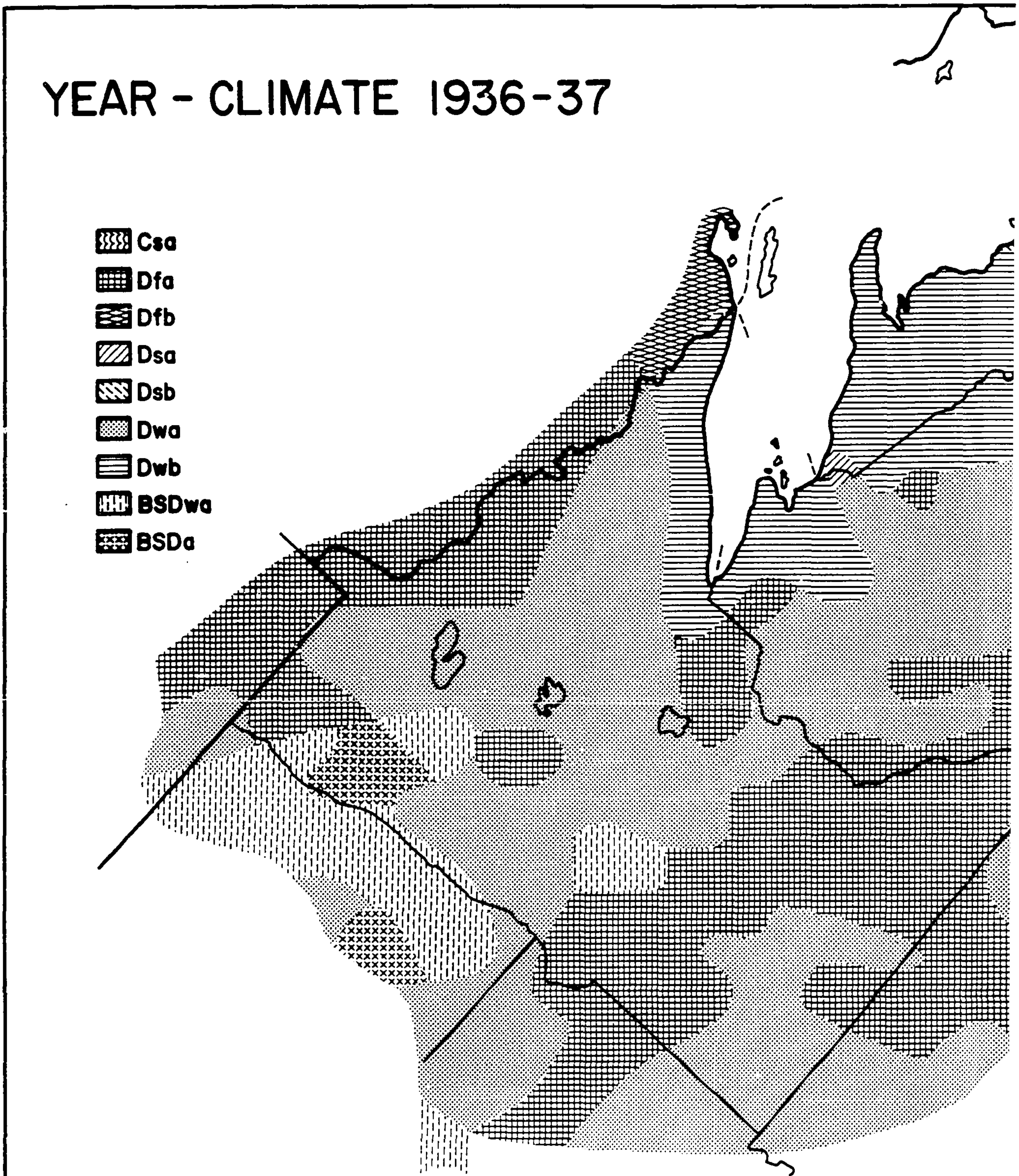
The third summer type "c" as stated above is a most unusual event in this area. Only two stations in southwestern Ontario, two in Minnesota, and one in Michigan have experienced this summer type. Three had one "c" year each (3.3 per cent), one had two years (7.4 per cent), and one, Lakehead, Ontario, had three (10 per cent). The actual years of occurrence were not the same for these stations as a group. There is no readily apparent temporal pattern, and the only apparent spatial one is proximity to Lake Superior and/or extreme northerly position.

Between the "b" (and "c") nuclear region of the north and the "a" one of the south two transition zones have been differentiated. The "a" transition zone consists of a grouping of those areas which had a majority of "a" summers (53.3 per cent to as much as 96.6 per cent) and a minority of "b" ones. To the north lies the "b" transition zone (53.3 per cent to as much as 96.6 per cent "b"). Along the boundary between these two zones in Wisconsin and North Dakota are three small areas of 50 per cent "a" and 50 per cent "b" occurrence. Additionally, there are two similar areas within the "a" transition zone in southeastern Minnesota and northeastern South Dakota. Within the five state core of the dissertation area the "a" and "b" transition zones are the most widespread summer type regions.

Year-Climates

Specific examples of most climatic types experienced in the dissertation area may be illustrated with year-climate maps. Four years were selected for mapping here. Figures 9-12 are not meant to portray either extreme nor "average" conditions though this has happened in some

YEAR - CLIMATE 1936-37



BASE: BUREAU OF THE CENSUS

FIGURE

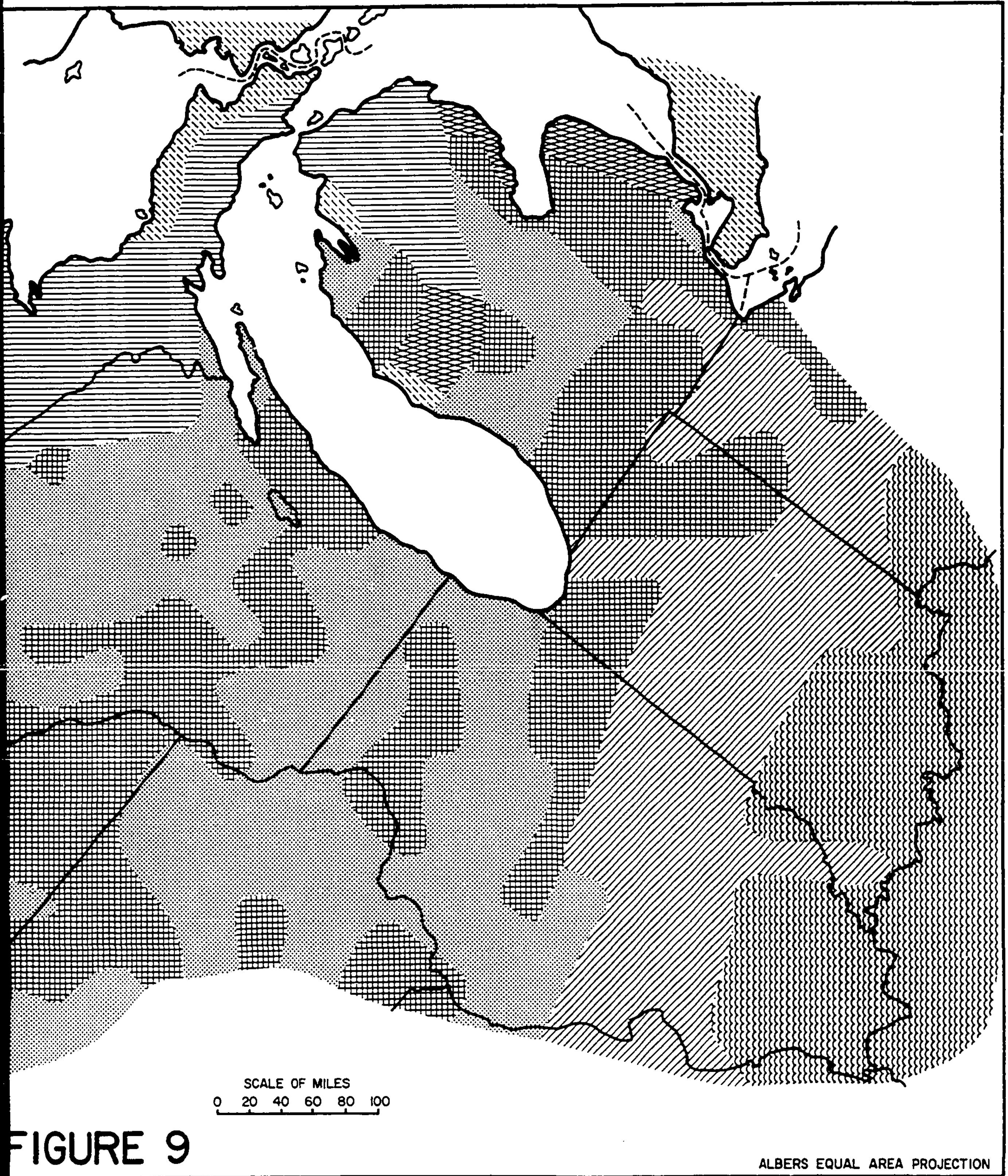
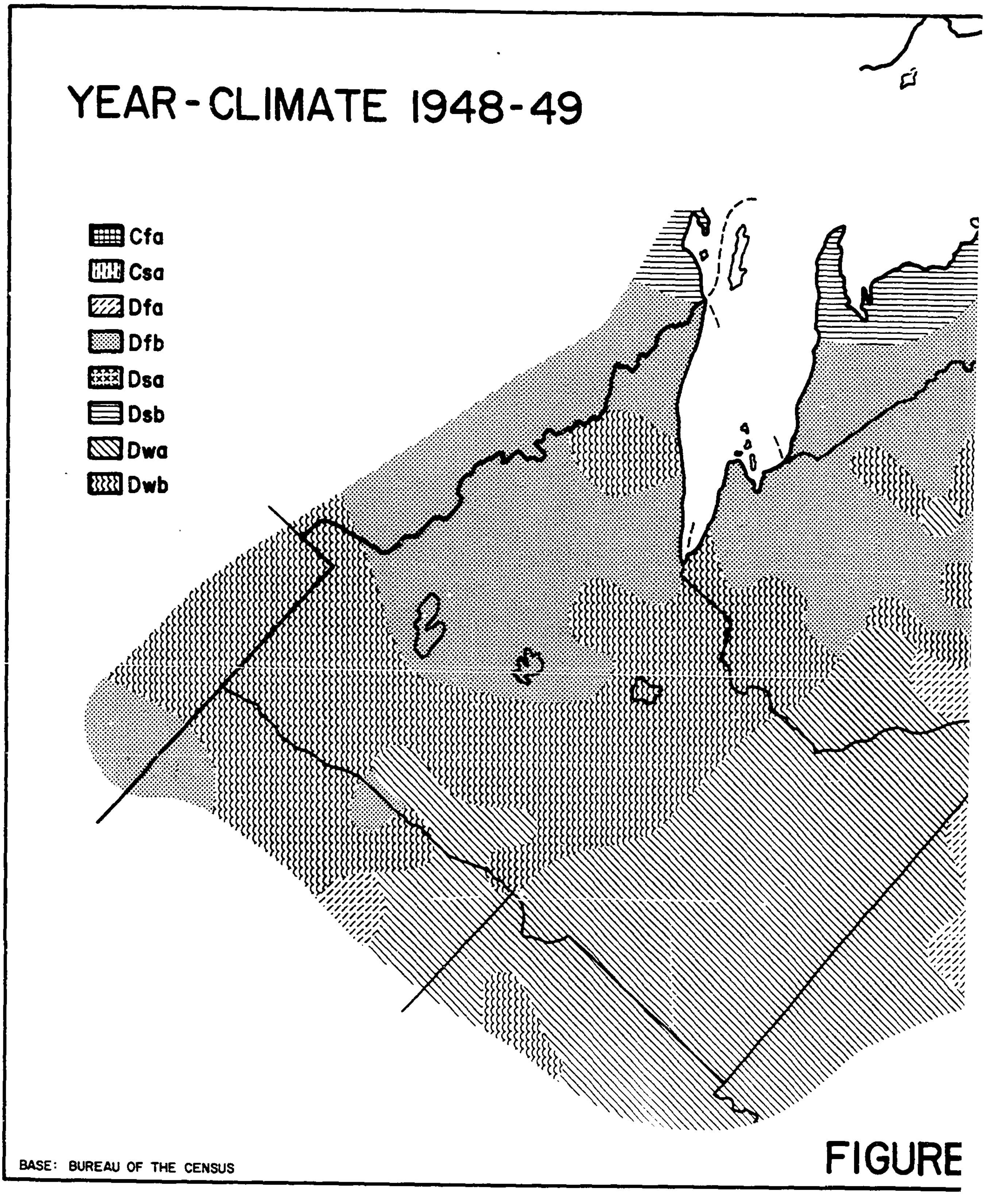
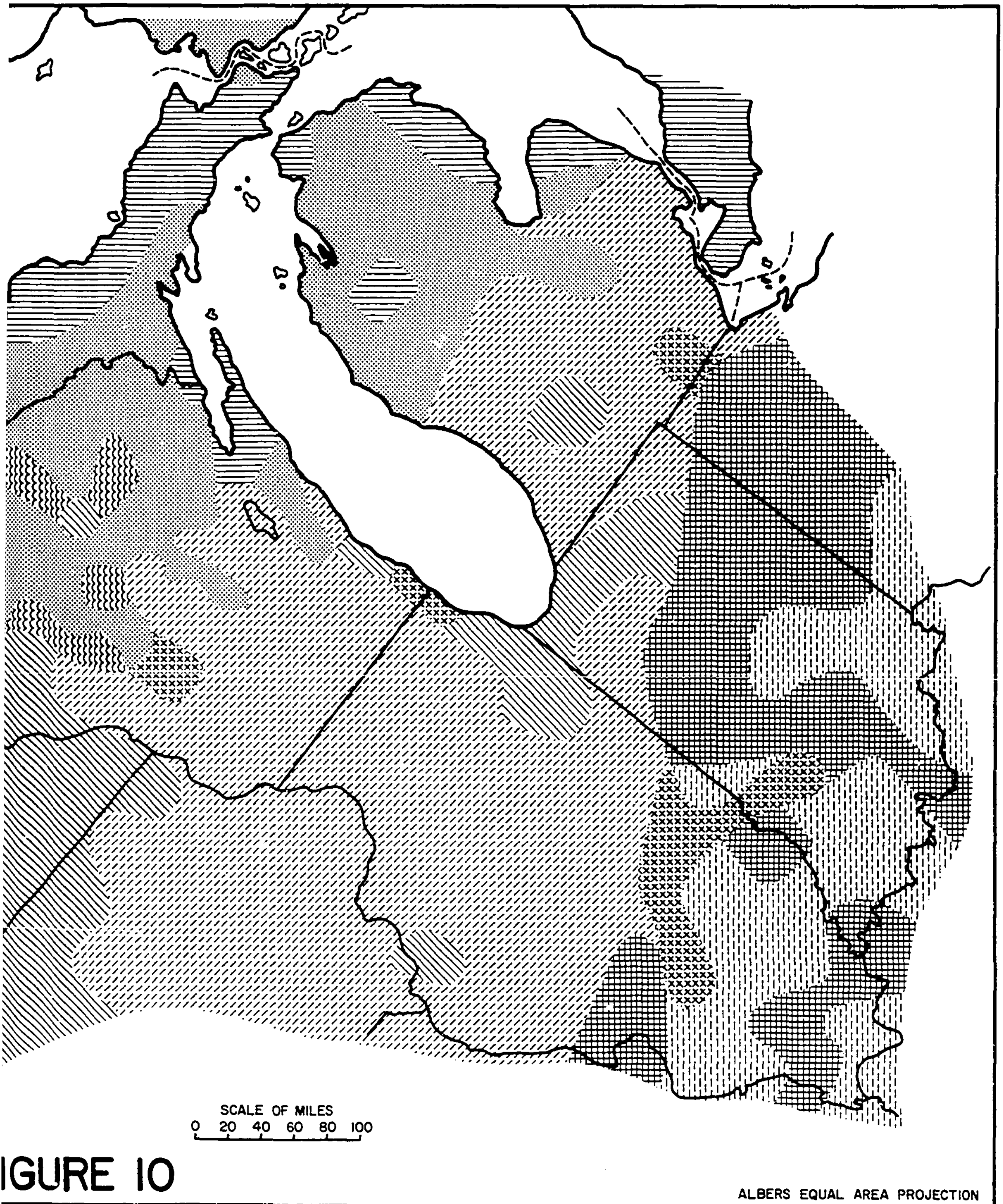


FIGURE 9



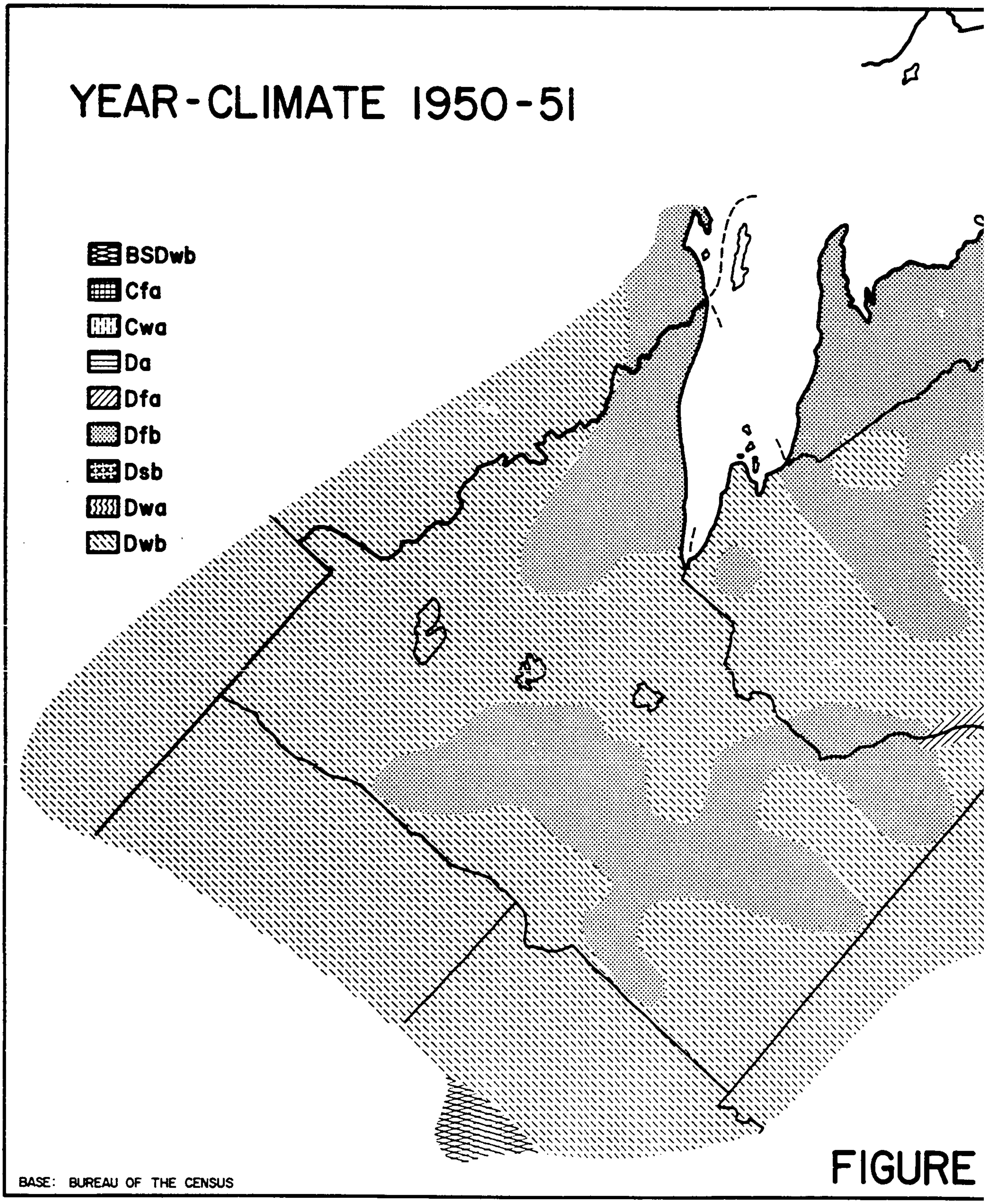
YEAR-CLIMATE 1948-49
Cfa
Csa
Dfa
Dfb
Dsa
Dsb
Dwa
Dwb
BASE: BUREAU OF THE CENSUS

FIGURE



IGURE 10

ALBERS EQUAL AREA PROJECTION


YEAR-CLIMATE 1950-51
BSDwb
Cfa
Cwa
Da
Dfa
Dfb
Dsb
Dwa
Dwb
BASE: BUREAU OF THE CENSUS
FIGURE

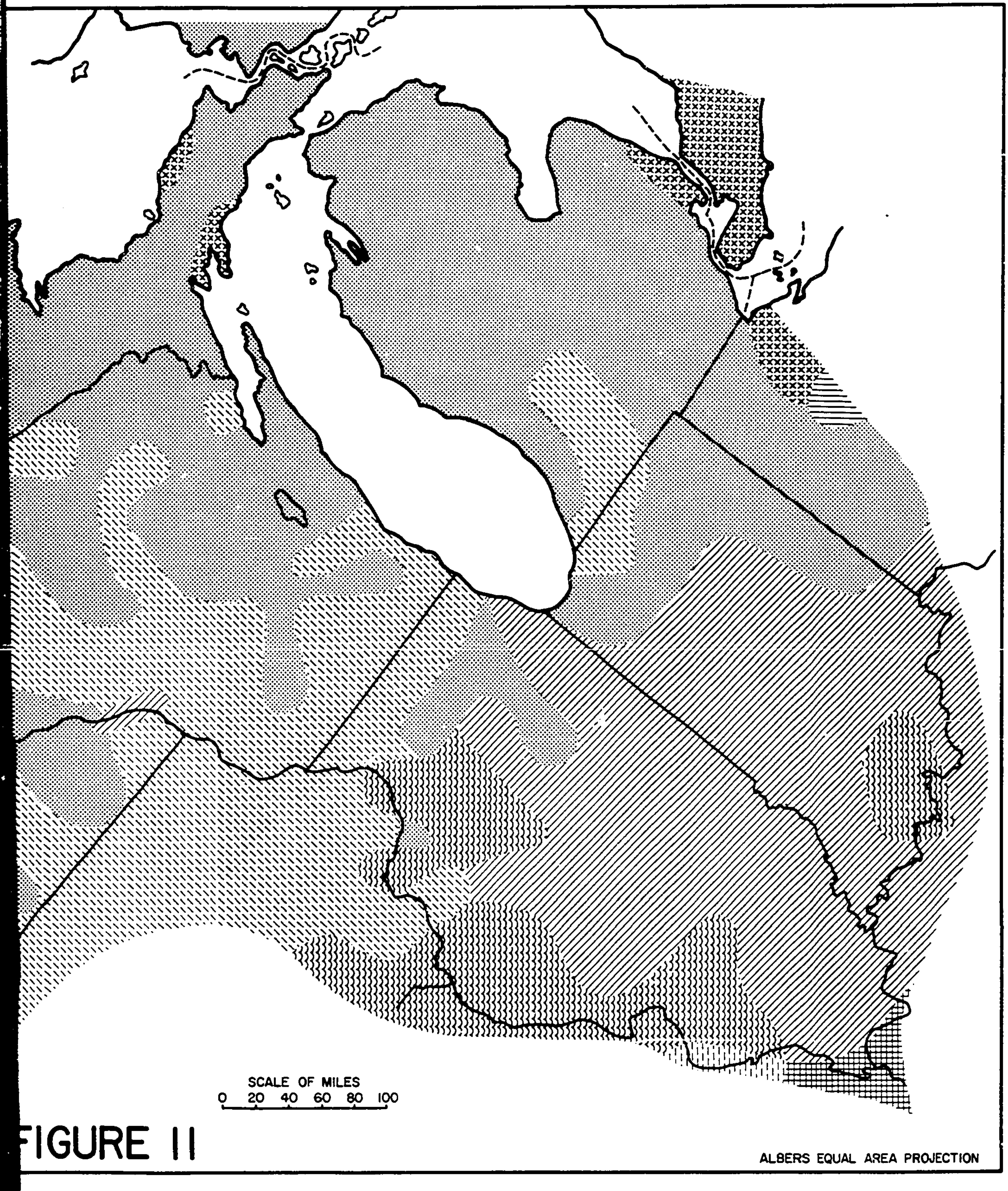
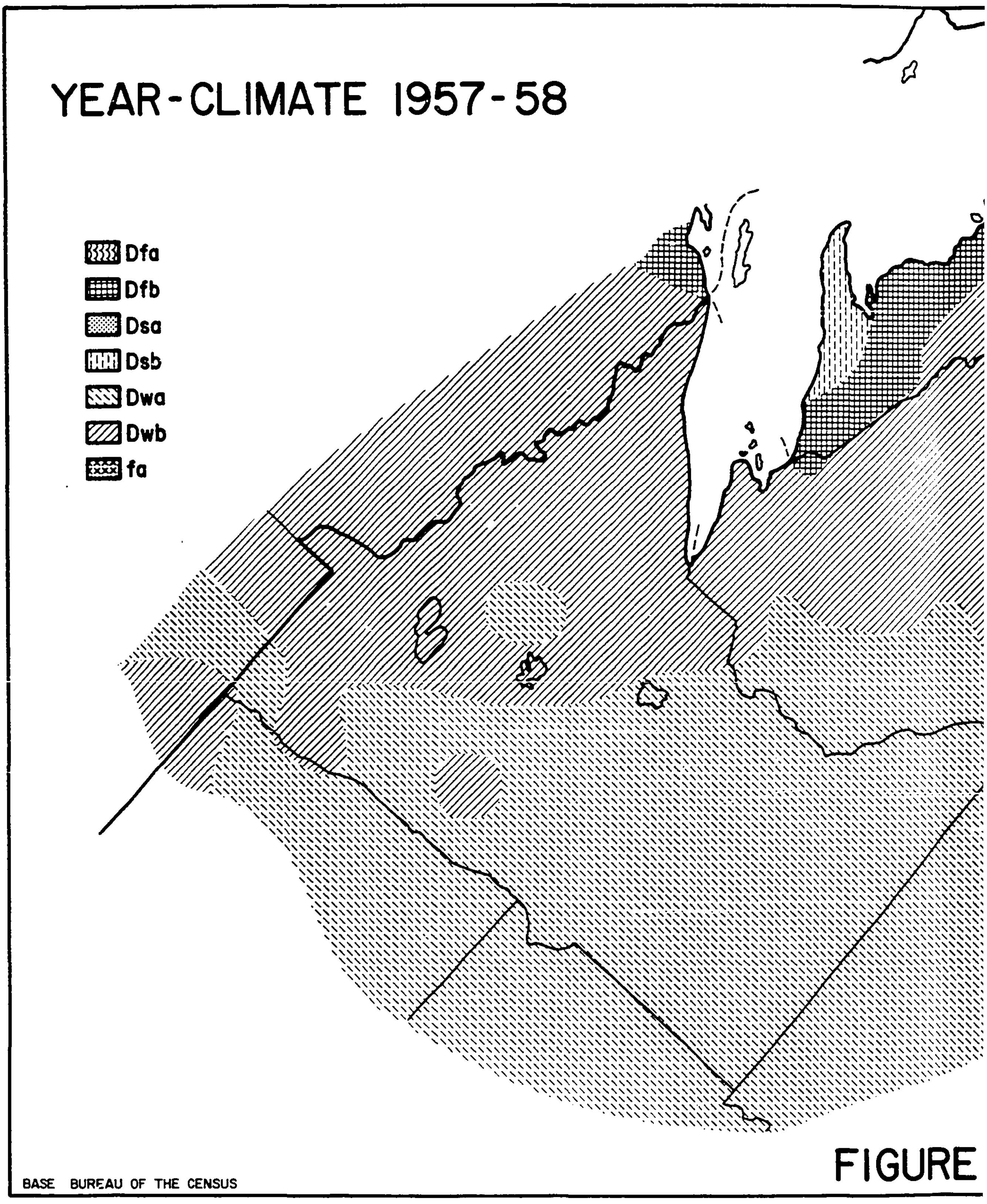


FIGURE 11


YEAR-CLIMATE 1957-58
Dfa
Dfb
Dsa
Dsb
Dwa
Dwb
fa
BASE BUREAU OF THE CENSUS

FIGURE

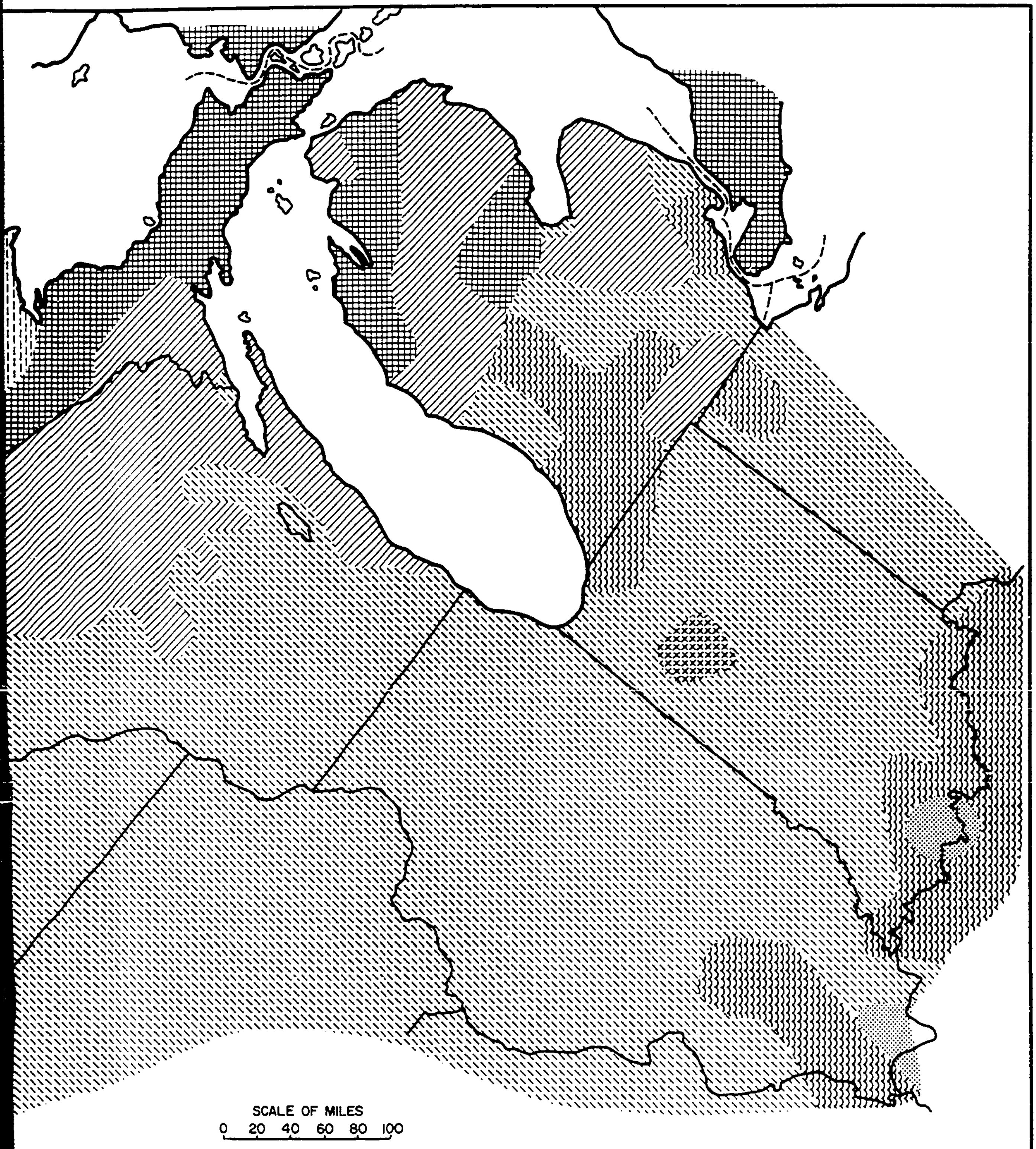


FIGURE 12

ALBERS EQUAL AREA PROJECTION

instances.[12] Selection of the mapped years was made to show much of the range of climates that may be expected in the Western Great Lakes States. The first three year-climate maps (Figs. 9-11) are almost mosaics showing wide diversities of climatic types over short distances; whereas the fourth (Fig. 12) has just a few, large homogenous regions.

The mapped 1936-37 climatic year (Fig. 9) contains several items of interest. The "C" climates, indicative of a mild winter, were extended slightly more northerly than usual. Unusually extensive dry summer climates (both "Csa" and "Dsa") lay in a broad band from southeastern Michigan southwesterly across Indiana and Illinois to Missouri. Additionally, "Dsb" could be found in small spots in both northern Lower Michigan and the Upper Peninsula. The summer was long and hot even as far north as northwestern Lower Michigan, northern Minnesota, southwestern Ontario, and southern Manitoba. An important factor this year was the existence of a microthermal steppe region in western Minnesota and eastern North Dakota.

The map for 1948-49 (Fig. 10) portrays a somewhat different set of conditions. The mild winter "C" climates lay even further north than they did in 1936-37. Dry summers again occurred in the southeasterly portions of the area. During this year, however, they were more extensive in northeastern Lower Michigan and the Upper Peninsula. Other scattered patches of similar conditions could be found in northeastern Illinois, eastern and southwestern Wisconsin, and near the Great Lakes in Ontario. The distribution of "a" and "b" summer types had a more usual pattern with cooler "b" summers occurring from central Lower Michigan across central Wisconsin, central Minnesota, and into North Dakota. The winter dry precipitation regime, somewhat more restricted than frequencies normally indicate, occurred extensively only in northwestern Iowa; central, southern, and western Minnesota; and the Dakotas. A zone of even precipitation distribution was centered in Michigan, Wisconsin, eastern Iowa, and northern and central Illinois.

The third year-climate map for 1950-51 (Fig. 11) showed a great contraction in the mild winter "C" area. It could be found that year only in the far southern tip of Illinois and small adjacent regions of Kentucky and Missouri. The summer was cool over much of the study area with "a" summers extensive only in Illinois and central and southern Indiana. Dry summers were almost absent, appearing as small patches only in Ohio and Michigan. Over most of the area precipitation regimes were about evenly balanced between even distribution and winter dry conditions. Although significant exceptions may be seen "f" was concentrated in the east and north whereas "w" conditions were more numerous in the west and along a narrow corridor centered on the Wisconsin-Illinois boundary.

The last year-climate map presented is that for 1957-58 (Fig. 12). Microthermal or "D" climate was complete. No "C" climates occurred this year. Summer types "a" and "b" were distributed close to their expected positions. The even precipitation regime could only be found on the southern margins of the area and in Michigan. Summer dry conditions were even more restricted occurring only on the Keweenaw Peninsula and in two small locations on the southern boundaries of Indiana and Illinois.

Local and general circulation patterns are partially responsible for the climatic characteristics depicted in Figures 10-12. Three aspects of the winter circulation for 1948-49 were significant to the year's climatic regions. First, the western end of the Bermuda high extended far to the west bringing maritime tropical air deeper into the interior of North America than normal. Second, the westerlies were weaker than normal permitting penetration of the warm, moist Gulf air to the north. Third, the track of Arctic origin anticyclones was more northerly than usual and/or at times went into the Colorado Plateau. Additionally, cyclonic tracks were north of their usual locations. The combination of these factors in general accounts for the warm ("C") winters in the southern portions of the Western Great Lakes States and widespread even ("f") precipitation distribution of 1948-49 (Fig. 10).[13]

Circulation patterns for the 1950-51 winter differed from those described above and as a result the winter was colder and drier in the western portion of the study region. The salient feature of this winter's circulation was a strong mid-Atlantic ridge that deflected the typical Hudson Bay-Mississippi Valley trough to the west. This allowed deeper penetration by continental polar air into the area. In January a well developed polar high pushed cold air far to the south of its usual position. In the western part of the study area winter dry precipitation distribution ("w") was enhanced by a well developed high over the Great Basin (Fig. 11).[14]

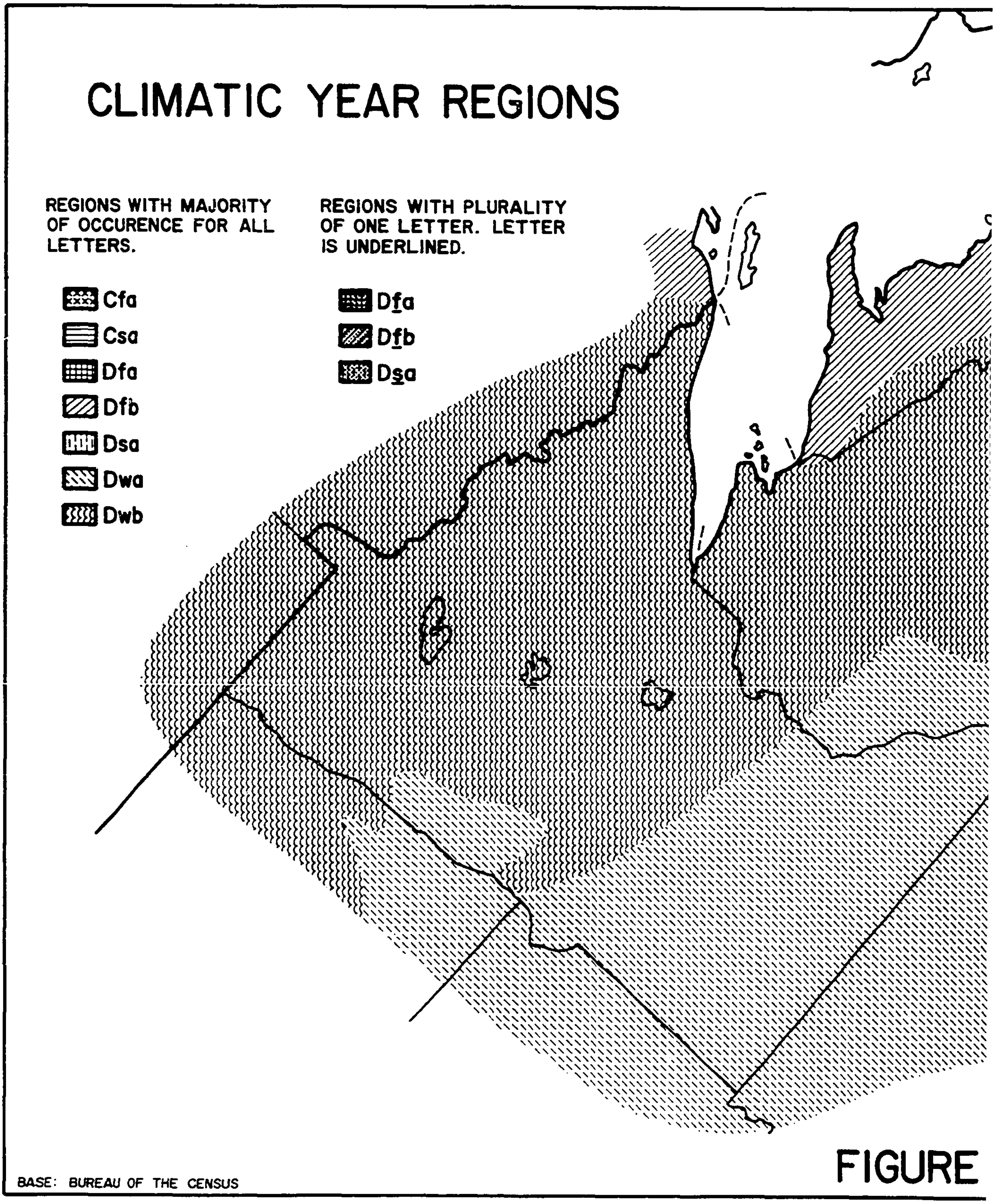
The winter of 1957-58 (Fig. 12) was the coldest, driest period analyzed. Through most of the winter season Arctic high pressure was centered over the Yukon while a trough lay over the southeastern United States. The westerlies and subpolar jet stream were deflected far to the south of their usual position blocking the northward movement of cyclones.

Northwesterly air flow and lack of cyclonic storms promoted southward penetration of cold, dry air masses. These synoptic conditions were to a large measure responsible for the absence of "C" climates in the Western Great Lakes States and for the extremely arid winter ("w").[15]

Climatic Year Regions

One of the two major goals of this dissertation was the synthesis of a descriptive Köppen based climatic regionalization that exclusively used climatic year classifications derived directly from observational data. Such a regional synthesis was to be based upon the principle that each mapped climatic region must be representative of actual annual climatic conditions for the study period to the greatest practical extent. An important additional criterion was simplicity. The regionalization must be compatible with previous Köppen regionalization efforts. Therefore, the use of the usual Köppen symbolization as modified by Shear was continued in an only slightly changed form. These constraints precluded attempts at trying to indicate occurrence of all climatic types that had taken place at each reporting station except in ancillary element analyses. Such efforts would have produced such a plethora of small regions in an area of this size that the generalizing function of regionalization would have been negated. The use of the Table of Coded Classifications (Appendix D) and the element analysis maps (Figs. 4-8) permits almost any additional degree of detail that might be desired by one who has studied the "Climatic Year Regions" map (Fig. 13).

As finally mapped each climatic year region has a majority of climatic year classifications of the designated individual letter types


CLIMATIC YEAR REGIONS
REGIONS WITH MAJORITY OF OCCURENCE FOR ALL LETTERS.
Cfa
Csa
Dfa
Dfb
Dsa
Dwa
Dwb
REGIONS WITH PLURALITY OF ONE LETTER. LETTER IS UNDERLINED.
Dfa
Dfb
Dsa
BASE: BUREAU OF THE CENSUS

FIGURE

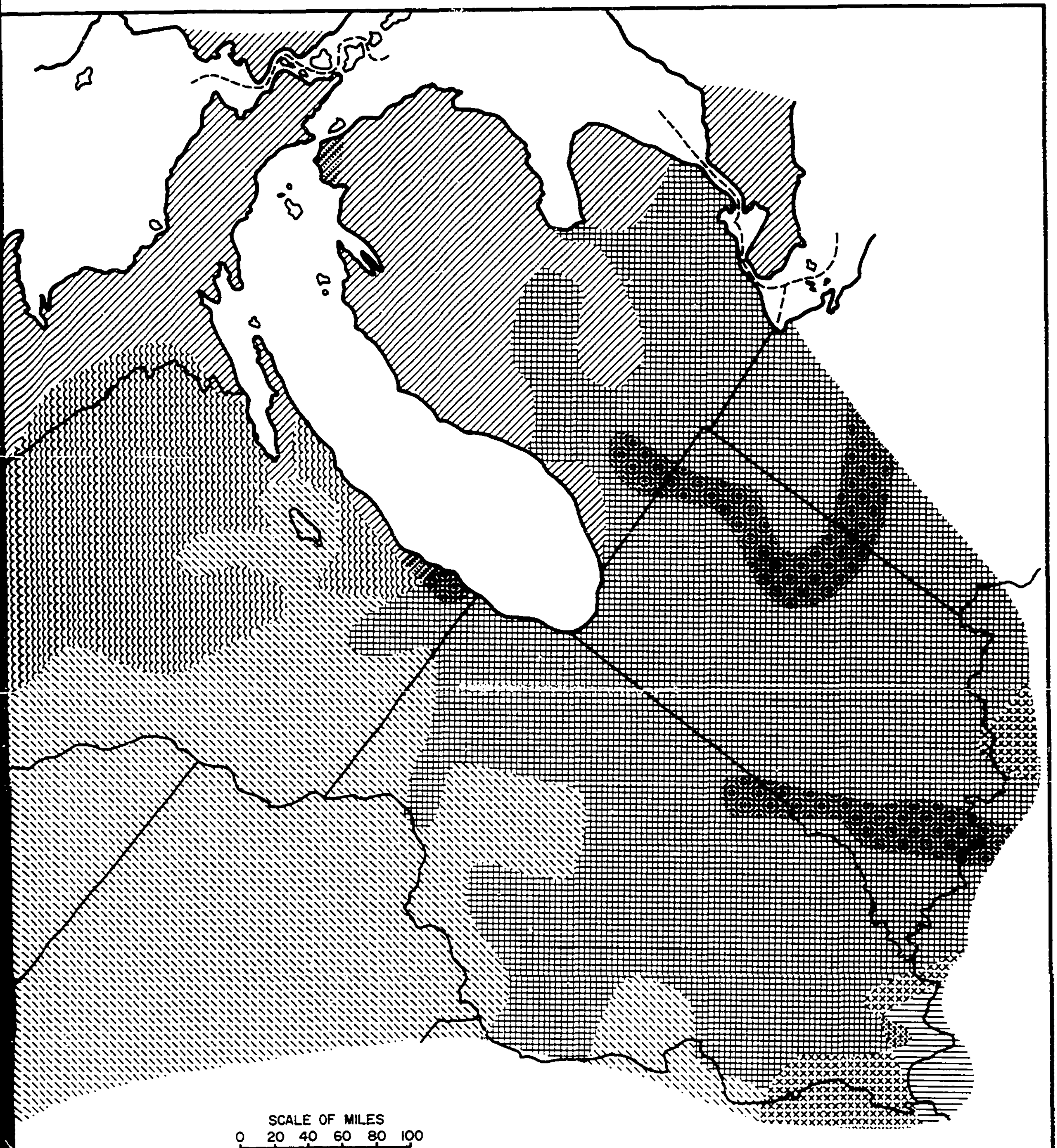


FIGURE 13

except as noted immediately below. In six small outlined regions an underlined letter symbol represents only a plurality.[16] This procedure met the constraints listed above. Köppen symbolization was retained and each region is defined as in that system. The use of majorities (and in a few cases pluralities) conveys to the reader the types of climatic characteristics that occur more than half the time. As can be observed on Figure 13 there are only a few small regions where a particular climatic characteristic type did not prevail during a majority of the study period. In these cases a plurality was used as the modal expression as to which characteristic among several was the most commonly occurring.

Comparison of the "Climatic Year Regions" map (Fig. 13) with that of "Köppen Climatic Regions" (Fig. 3) shows several differences. The most obvious is in the western half of the area where the major regional climatic types now mapped are "Dwa" and "Dwb". These two regions include the eastern Dakotas, Minnesota, northern and eastern Iowa, northwestern and southwestern sections of Illinois, and most of Wisconsin, except the Lake Michigan littoral. A second kind of difference is contraction in the area covered by "C" climates. Climatic year frequencies support "C" classification only in parts of northern Kentucky and extreme southern Illinois. Lastly, small regions of "Csa" and "D<u>s</u>a" may be seen in southern Illinois and Indiana. Although parts of the eastern half of the study area did not change their classifications, an element analysis of them does indicate that even in those regions there has been a variety of climatic conditions during the thirty year study period.[17]

Figure 13 shows seven kinds of climatic year regions in the core and bordering areas of the Western Great Lakes States: "Dfa", "Dfb", "Dwa", "Dwb", "Cfa", "Csa", and "Dsa". One station from each region has been selected for inclusion in Table 4. Choice of stations was done basically to obtain complete data sets with few or no gaps. For this reason the sample stations may not be regarded as completely representative of their respective regions. Information for each station in Table 4 includes a Climatic Year Regional Classification, a Coded Climatic Classification, complete thirty year monthly and annual temperature and precipitation means together with an average Köppen classification symbol based on that data, and climatic year data from two selected years with climatic year classifications similar to that of the regional classification.

The use of mean data gives a classification of "Dfa" for Crawfordsville, Indiana. The summation of conditions for its thirty individual climatic years as represented in the coded classification shows "D" and "a" predominant with frequencies of 90 and 96.7 per cent respectively. Precipitation distribution does not show such a dominance of one regime. An even distribution occurred in 60 percent of the years, "w" took place in more than a third (36.7 per cent), and one year (3.3 per cent) was summer dry. The data from two specific "Dfa" years show temperature and precipitation patterns similar to those of the means.

The Upper Michigan station of Ironwood had a "Dfb" climate. During the entire period all winters were "D" while nine of every ten summers were "b". Precipitation distribution was evenly distributed more often than in Crawfordsville. The second most frequent precipitation regime was "w". This is to be expected as there is a rapid change to dominant winter dry conditions to the southwest of Ironwood (Fig. 7). Only one of the two sample climatic years, 1948-49, showed much difference from

TABLE 4

CLIMATIC YEAR REGION STATION DATA

Station - Crawfordsville, Indiana

Climatic Year Regional Classification - Dfa

Coded Climatic Classification - $D^{90}C^{10}f^{60}w^{36.7}s^{3.3}a^{96.7}b^{3.3}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	51.5	62.4	71.7	75.3	73.9	66.7	55.7	41.4	30.7	27.9	30.9	39.4	52.3	
1936-66	Prec.	4.31	4.42	4.92	3.93	3.29	3.03	2.69	2.90	2.18	2.67	2.22	3.20	39.75	Dfa
Climatic Year	Temp.	57.4	66.4	72.2	76.9	75.6	71.6	59.3	44.3	38.3	29.2	28.2	43.7	55.3	
1941-42	Prec.	2.37	2.89	4.53	1.89	2.59	1.79	4.90	3.59	1.10	1.51	4.01	3.37	34.54	Dfa
Climatic Year	Temp.	44.4	55.5	67.8	74.0	71.8	70.0	55.2	41.3	28.8	22.7	31.6	36.7	50.0	
1961-62	Prec.	6.58	3.22	8.01	2.61	2.12	3.81	2.85	2.55	1.58	4.81	1.94	3.34	43.42	Dfa

Station - Ironwood, Michigan

Climatic Year Regional Classification - Dfb

Coded Climatic Classification - $D^{100}f^{70}w^{26.7}s^{3.3}b^{90}a^{10}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	40.5	53.5	62.3	67.7	65.9	57.2	47.2	30.7	18.2	12.8	15.1	25.2	41.4	
1936-66	Prec.	2.60	3.95	4.61	3.64	4.18	3.70	2.28	3.03	1.92	1.74	1.79	2.07	35.51	Dfb
Climatic Year	Temp.	37.7	52.2	63.6	69.4	66.0	54.4	47.0	26.4	19.4	23.8	17.6	22.8	41.7	
1943-44	Prec.	3.41	3.26	4.63	2.54	3.37	1.97	2.81	4.33	1.39	1.38	1.95	4.67	35.71	Dfb
Climatic Year	Temp.	45.4	52.8	62.0	69.1	67.9	61.6	47.2	33.9	18.7	18.1	14.7	24.2	43.0	
1948-49	Prec.	2.69	.46	2.82	2.32	1.58	3.83	1.15	2.89	1.39	2.14	1.45	1.49	24.21	Dfb

TABLE 4 - Continued

Station - Aledo, Illinois

Climatic Year Regional Classification - Dwa

Coded Climatic Classification - $D^{100}w^{60}f^{40}a^{100}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	51.0	62.4	68.7	72.4	74.0	66.1	55.2	40.0	28.6	22.5	27.3	37.5	50.5	
1936-66	Prec.	3.83	3.90	4.46	3.82	3.01	3.37	2.57	1.87	1.72	1.72	1.44	2.78	34.50	Dfa
Climatic Year	Temp.	51.0	60.6	69.0	75.8	72.8	60.8	49.0	36.5	32.9	23.1	17.3	35.7	48.7	
1957-58	Prec.	5.33	4.43	3.24	2.93	2.21	1.83	3.01	2.58	3.76	.77	.46	.40	30.95	Dwa
Climatic Year	Temp.	50.1	66.9	70.6	73.6	71.1	64.0	53.7	41.1	36.0	16.6	27.1	41.1	51.0	
1965-66	Prec.	6.33	3.34	3.85	2.73	9.34	6.62	.71	1.54	2.77	1.69	.88	1.58	41.38	Dwa

Station - Virginia, Minnesota

Climatic Year Regional Classification - Dwb

Coded Climatic Classification - $D^{100}w^{76.7}f^{23.3}b^{93.3}a^{6.7}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	40.2	53.1	62.0	67.8	65.6	55.6	45.2	26.5	12.9	8.2	11.8	24.8	39.5	
	Prec.	2.43	2.93	4.00	39.0	3.89	3.31	1.74	1.66	.89	.83	.67	1.22	27.47	Dfb
Climatic Year	Temp.	36.7	55.2	62.6	68.8	66.1	56.4	41.0	32.0	23.6	5.1	15.8	19.3	40.2	
1939-40	Prec.	.58	3.93	3.89	.65	6.89	1.58	2.10	.12	.34	.43	.79	1.29	22.59	Dwb
Climatic Year	Temp.	37.8	55.4	62.5	64.8	65.7	54.6	45.8	32.1	13.8	12.6	4.9	26.9	39.7	
1962-63	Prec.	2.54	4.29	2.67	4.20	2.26	2.51	.30	.36	.37	.15	.29	.97	20.91	Dwb

TABLE 4 - Continued

Station - Anna, Illinois

Climatic Year Regional Classification - Cfa

Coded Climatic Classification - $C^{51.7}D^{48.3}f^{50}w^{26.7}s^{23.3}a^{100}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	57.1	66.6	74.7	77.8	77.2	70.3	60.5	46.4	36.5	34.0	38.2	46.5	57.2	
1936-37	Prec.	4.97	4.86	4.29	3.31	3.86	3.77	2.57	3.67	3.00	3.93	3.99	4.96	47.21	Cfa
Climatic Year	Temp.	57.0	66.4	77.0	79.5	78.8	66.0	57.8	45.6	35.2	38.4	42.5	45.4	57.5	
1943-44	Prec.	3.32	10.24	4.95	2.28	3.56	5.55	1.95	2.35	2.92	1.35	4.45	4.85	47.77	Cfa
Climatic Year	Temp.	52.5	66.5	72.7	77.2	77.3	67.2	60.2	39.8	38.2	40.1	42.6	45.3	56.5	
1951-52	Prec.	2.80	2.60	7.86	2.61	4.07	6.13	4.28	7.42	4.34	3.35	3.89	8.13	57.48	Cfa

Station - Lovelaceville, Kentucky

Climatic Year Regional Classification - Csa

Coded Climatic Classification - $C^{76.7}D^{23.3}s^{55}f^{34.6}w^{10.4}a^{100}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	58.6	67.4	75.6	78.5	78.0	71.1	60.5	47.5	38.7	36.4	39.9	47.4	58.3	
1936-66	Prec.	4.44	4.52	3.92	3.34	3.20	3.05	2.57	4.08	3.66	4.99	4.26	5.18	47.22	Cfa
Climatic Year	Temp.	53.6	68.2	76.8	80.8	82.6	75.0	58.2	43.0	40.2	39.8	38.3	43.0	58.3	
1936-37	Prec.	4.65	.86	2.10	3.43	.25	3.02	3.60	3.74	5.77	17.60	2.25	1.80	49.07	Csa
Climatic Year	Temp.	56.4	66.7	81.7	80.1	77.7	69.0	54.2	47.5	40.5	41.9	43.1	52.2	59.2	
1952-53	Prec.	4.47	3.59	.08	2.95	3.72	3.70	1.02	2.55	4.80	4.41	2.86	6.89	41.04	Csa

TABLE 4 - Continued

Station - New Burnside-Creal Springs, Illinois Climatic Year Regional Classification - Dsa

Coded Climatic Classification - $D^{53.3}C^{46.7}{}_s{}^{41.4}{}_f{}^{34.5}{}_w{}^{24.1}{}_a{}^{100}$

		Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Year	Class
30 Year Means	Temp.	56.9	66.1	74.3	77.6	77.0	69.8	60.0	45.7	36.8	34.3	37.9	45.9	56.9	
1936-66	Prec.	4.80	4.98	3.91	3.59	3.53	3.09	2.86	3.63	3.23	4.46	3.71	4.88	46.68	Cfa
Climatic Year	Temp.	55.4	70.0	78.2	77.9	78.3	71.5	58.8	48.1	31.2	31.4	38.4	55.6	57.9	
1944-45	Prec.	6.29	4.53	.96	.33	2.25	1.14	.87	2.04	4.09	2.12	7.39	11.75	43.76	Dsa
Climatic Year	Temp.	60.0	66.4	74.2	76.6	75.8	68.4	54.2	45.1	42.8	32.2	27.3	39.3	55.2	
1957-58	Prec.	7.49	12.19	4.30	3.31	.63	1.01	4.45	8.60	7.17	3.15	1.45	5.29	59.04	Dsa

the means. The precipitation total for that year was 11.30 inches less than the mean and one summer month, May, was quite dry with .46 inches of rain. This month's summer rainfall figure would have given an "s" classification if the summer half year had not had more than half the year's precipitation.

Aledo, in northwestern Illinois, was an example of a "Dwa" station. In this case climatic year classification yielded a different result from the mean approach. Although both "D" and "a" had frequencies of 100 per cent "f" occurred in only 40 per cent of the years. Winter dry conditions were more frequent, occurring 60 per cent of the time. As precipitation patterns at Aledo resemble those in the "Dwb" region at Virginia, Minnesota, both stations are examined together below.

Virginia, classified "Dfb" by conventional means, had a "Dwb" by climatic year methods. As expected in this continental and latitudinal location all years were "D" while summers were "b" by a wide margin ("b" - 93.3 per cent, "a" - 6.7 per cent). As at Aledo the main difference in classification between the two methods is in precipitation distribution. At Aledo 60 per cent of the years were "w"; at Virginia the comparable figure was 76.7. The balances of the years at both stations were "f". The use of means showed only 35 per cent of the year's precipitation fell in the winter half of the year at Aledo; in Virginia the corresponding figure was only 26 per cent. The two sample years from Aledo had 35 and 22 per cent of the annual precipitation in the winter half year. Both years had two winter months with precipitation amounts less than one-tenth as much as the wettest summer months. The dry months in the two years were February and March and October and February respectively. It may be noted that the driest month of the year as shown by means is February with 1.44 inches. The February values of both sample years were substantially lower (.46 and .88 inches).

Virginia has as just noted 26 per cent of the year's precipitation in the winter half year when means are used for the measurement. In the two sample climatic years lesser values of 22 and 11 per cent were recorded. The climatic year 1939-40 had three months (November, December, and January) with precipitation values that allow for "w" classification. Precipitation amounts for the three noted months were .12, .34, and .43 inches. The second sample climatic year, 1962-63, had five months (October through February) allowing "w" classification! Monthly precipitation values for the five months varies from .15 to .37 inches.

Within the dissertation area only three stations were placed in a "Cfa" climatic year region. Sample data from one, Anna, Illinois, is included here. This station is also classified "Cfa" with the use of means. Frequency of winter type showed only a slight dominance of "C" (51.7 per cent "C" versus 48.3 per cent "D"). One half the years had "f" precipitation, 26.7 per cent had "w", and "s" had 23.3 per cent. This "s" value was much higher than in the rest of the Western Great Lakes States. This summer dryness tendency is stronger only in the small bordering "Csa" and "Dsa" regions. Within the means and the two sample years the precipitation distribution regime has no clear tendency toward either a dry season nor toward a seasonal concentration. The means show 53 per cent of the annual precipitation in the summer half year; climatic year 1943-44 had 62 per cent in the same period; 1951-52 had only 45 per cent. Both summer and winter are warm here. Summer temperatures reach the upper

70's whether one looks at the means or sample years. Winter lows are in the mid to upper 30's. The "D" frequency of 48.3 per cent does show, however, that freezing temperatures do occur often enough to indicate this region is only marginally "Cfa".

The last two regions represented, the "Csa" and "Dsa", are also small in geographical extent here. Sample station data are provided by Lovelaceville, Kentucky for "Csa" and New Burnside-Creal Springs, Illinois for "Dsa". Both locations are classified "Cfa" with mean data. There are two principal differences between the two represented regions. The "Dsa" is colder in winter and has only a plurality of "s" years rather than a majority. This is the only major climatic region of the seven in the dissertation area to have only a plurality for one of its letters. The "Dsa" region is small in extent because it is not a distinctively different regional climatic type in this part of North America. Rather, it represents an intersecting area between a hypothesized "Csa" climatic year region to the south, "Dfa" to the north, and "Dwa" to the northwest. Summers at both sample stations were consistantly long and hot. Neither location had a single "b" year during the thirty year period. Lovelaceville did have "C" winters more than three-quarters of the time. This is the greatest such concentration of "C" year occurrence of the sample stations presented here. New Burnside-Creal Springs shows a slight majority of "D" years, indicative of its border location. Sample year data for both stations show summer precipitation concentrations of only 29 and 45 per cent at Lovelaceville and 35 and 49 per cent at New Burnside-Creal Springs. Means show 47 and 51 per cent respectively for the two stations. Five of the six lowest summer month precipitation amounts for the sample years at the two locations were less than one inch.

Summary

In conclusion one may note a definite geographical pattern to the climatic year regions of the Western Great Lakes States as they have been outlined in this chapter. The major finding of climatic year regionalization was the discovery and mapping of significantly large regions of the winter dry climates "Dwa" and "Dwb" in large parts of the western portions of the study area. A second result of this type analysis was a considerable reduction in the area occupied by "Cfa". Additionally, small regions of "Dsa" and "Csa" were found to border the study area on the south.

Item analysis added to the climatic year regionalization in three distinct ways. The winter dry precipitation distribution regime "w" existed outside the "Dwa" and "Dwb" regions to some degree throughout most of the Western Great Lakes States. Although the summer dry regime "s" is common in only two small regions in the southern part of the study area it does occur on a limited basis in numerous locations. Lastly, semiarid conditions, although admittedly of rare occurrence, have taken place and because of their implications for agriculture and other human activities must be recognized as a climatic problem.

REFERENCES

[1]Glenn T. Trewartha, The Earth's Problem Climates (Madison, Wis.: The University of Wisconsin Press, 1966), Plate. This is the most recent Köppen map that shows United States state and Canadian provincial boundaries.

[2]There is an additional difference on the edge of the study area in Missouri. Data from Crystal City-Festus has gaps that may be responsible for "Dfa" classification.

[3]The terms "usual", "unusual", and "expected" as used in this chapter refer to comparison with published Köppen maps, the writer's "Köppen Climatic Regions" map (Fig. 3), or the "Climatic Year Regions" map (Fig. 13). Context of use determines which map is being compared.

[4]These regions have been specifically noted and discussed by Stephen M. Sutherland in "The Dwa and Dwb Climates in the United States," (paper presented at the annual meeting of the Oklahoma Academy of Science, Norman, Oklahoma, Spring 1964); made available through the courtesy of its author.

[5]Exact percentage data from which element maps have been drawn are listed in Appendix D.

[6]It is interesting to observe that the 100 per cent "D" isopleth lies close to the position of the original Köppen "C"/"D" boundary which was based on the 26.6° January isotherm. Koeppe and DeLong, Weather and Climate, Pl. II.

[7]This condition was discerned in a slightly different fashion by Thornthwaite who mapped most of Minnesota and northern Iowa as a "Moist Subhumid Climate." He also mapped the eastern and central portions of the Dakotas as "Dry Subhumid." Espenshade (ed.), Goode's World Atlas, p. 53.

[8]An expanded discussion and bibliographies concerning man's continuing interest in climates and climatic conditions from several standpoints, including the economic, are contained in W.R. Derrick Sewell, Robert W. Kates, and Lee R. Phillips, "Human Response to Weather and Climate," Geographical Review, LVIII (1968), 262-80.

[9]Maps of seasonal precipitation amounts and distribution only do show this phenomenon. For example, see Espenshade (ed.), Goode's World Atlas, p. 52. Also, see n. 8.

[10]Trewartha, The Earth's Problem Climates, Pl.

[11]Whereas "b" and "c" are differentiated from "a" on the basis of one summer month's temperature "b" and "c" use a period of several months representing the length of the summer period. For this reason "c" may be considered a shorter version subset of "b" for the purpose of differentiating regions of cool or warm summers from those with hot ones.

[12]The two year-climate maps for 1950-51 and 1957-58 have small regions of "Da" and "fa" respectively. These two symbols represent regions with missing data. In the first instance the writer was able to interpolate that the area was humid microthermal with a long hot summer. Precipitation distribution could not be deduced. In the second instance precipitation distribution was even and the summer was long and hot, but winter characteristics could not be determined.

[13]William H. Klein, "This Winter's Unusual Weather and Circulation," Weatherwise, II (1949), 36-37.

[14]William H. Klein, "The Weather and Circulation of the Winter of 1950-51," Ibid., IV (1951), 38-39 and 46.

[15]Howard M. Frazier, "The Weather and Circulation of October 1957," Monthly Weather Review, LXXXV (1957), 341-49; Charles M. Woffinden, "The Weather and Circulation of November 1957," Monthly Weather Review, LXXXV (1957), 367-72; James F. O'Conner, "The Weather and Circulation of January 1958," Monthly Weather Review, LXXXVI (1958), 11-18; William H. Klein, "The Weather and Circulation of February 1958," Monthly Weather Review, LXXXVI (1958), 60-70; and Raymond A. Green, "The Weather and Circulation of March 1958," Monthly Weather Review, LXXXVI (1958), 100-107.

[16]Thus, the map designation of "Dfa" shows majorities of "D", "f", and "a" years. The symbols "D$\bar{f}$a" also represents majorities of both "D" and "a" years but only a plurality of "f" ones. It should be cautioned that the particular symbol designation for a given climatic year region may not imply a majority of actual climatic year occurrences of the complete symbol type. It is true most coded classification (Appendix D) have been derived from such conditions, but a few have not.

[17]The writer had expected to find and delineate at least a few small regions which had experienced only one climatic type during the study period. None were found, however.

CHAPTER V

REGIONAL CLIMATIC CONTROLS

Introduction

In Chapter IV climatic year regions were shown to form somewhat different patterns than do Köppen climatic regions computed from means. Analysis was made of the gross distribution patterns of temperature and precipitation values within Köppen system definitions to outline both core and transitional zones of specified letter types. It was felt that both the climatic year region pattern and the element patterns exist in their spatial positions because of interactions among a number of geographically identifiable physical controls on the earth's surface and in the lower troposphere.

General Considerations

Ultimate explanation for both meteorological and physical climatic synoptic events lies in the basic planetary energy balance and in the dynamics of the general circulation at all levels of the atmosphere. Short term climatological and meteorological forecasting is presently achieved reasonably well for large regions by the application of hydrodynamic and thermodynamic principles to given synoptic situations in the general circulation. Additionally, short and long term climatic singularities may be understood through synoptic analysis of the general circulation at all levels in the troposphere.[1]

Within regional climatological analyses the general circulation is observed as establishing many of the general parameters within which specific climates develop in particular regions and areas. The general circulation itself, however, is not independent of either surface conditions or perturbations in the lowest levels of the troposphere. All three of these physical features are interacting parts of the complex mechanisms of the planetary energy balance system.[2] At the subcontinental scale of this study the most significant aspects of the general circulation for long term periods in the Western Great Lakes States are the existence of the strongest mid-tropospheric westerlies at 38° N. in winter and at 48° N. in summer together with the polar front and the polar front jet stream in the upper troposphere.[3] Within the troughs and waves of this system along the polar front and the polar front jet are generated the surface perturbations (cyclones and anticyclones) that directly affect the climate of central North America through their advection of air masses and their triggering of precipitation from those air masses. Once formed the cyclones tend toward tracks to the northeast while the anticyclones tend to move to the southeast; both systems steered by upper currents in the westerlies along the polar front.[4] Analysis of the general circulation can give only a broad view of causes for general climatic conditions in the Western Great Lakes States.[5] For this reason other factors must be examined for explanation of the detailed long term climatic patterns established in this study. These factors are those geographically distributed physical controls responsible for the set of continuing differences in the areal and temporal distributions of temperature and precipitation at the earth-atmosphere interface. Controls discussed below include latitude, elevation, air masses, pressure systems, the landmass of North America, major relief features, the oceans and the Great Lakes, and local topography.

Temperature

Latitude

The fundamental cause of gross thermal variation within the study area, as elsewhere on the planet, is latitudinal difference in insolation. Because the greatest amount of insolation is received at low latitudes and the least amount at higher ones temperature is partially a function of latitude. Climatic year regions in the study area (Fig. 13) reflect this functional relationship. Both Figures 4 ("First Order Climatic Year Types") and 8 ("Summer Types") have basic patterns of warmer winters and longer, warmer summers in the south than in the north.

Data from Cairo, Illinois (37° north latitude), and Roseau, Minnesota (48°51' north latitude) are illustrative of these phenomena. Median January temperatures (1936-66) were 37.5° (mean 36.4°) and 4.4° (mean 2.6°) at Cairo and Roseau respectively; July medians for these two stations were 80.6° (mean 80.7°) and 67.7° (mean 68.3°).[6] Cairo had a median of seven and one-half months with mean temperatures of 50° or greater; Roseau had only five.

A last latitudinally related thermal factor is the northward rate of decrease in temperature. Theoretical decrease in average monthly temperatures in January between 30° and 45° north latitude is 1.91° per degree of latitude; the comparable July decrease is 1.0°.[7] The actual temperature decreases per degree of latitude between Cairo and Roseau for January and July, computed from the above noted medians, were 2.2° and 0.8°.[8]

Elevation

Although elevation is not of major importance in this area some elevational influence is evident in two aspects of temperature. First, there are slight effects on local thermal boundary line orientation ("C"/"D" and "a"/"b" and ["c"]). Such irregularities are also influenced by local topography and they are considered under that control factor (below pp. 92-95). A second influence is on the general location of boundaries considered in their entirety.

Prior to discussion of general boundary locati ns a few points should be noted. Both general elevational differences and elevational maxima and minima are not great here. Maximum and minimum elevations in the core states are 2301 feet in Minnesota and 279 feet in Illinois.[9] These elevations allow for maximum theoretical regional temperature differences of approximately 4.0° in January and 5.3° in July.[10] Such conclusions are speculative as both elevations are extreme points and are not regionally representative.

For purposes of climatic regional differentiation station elevations are more representative as they tend to be located at those elevations where most of the population and economic activities are located. Maximum and minimum station elevations are 1745 feet in Minnesota and 314 feet in Illinois.[11] Regional theoretical temperature differences attributable to elevation alone based on the above station elevations are only

2.9° in January and 3.6° in July.[12]

General boundary location may be examined as a partial function of elevation using the above theoretical considerations. The "C"/"D" boundary, the average 32° cold month isotherm, is located in southern Illinois near Cairo (Fig. 4). In January the elevation of 314 feet at Cairo causes an approximate decrease in actual temperature of 0.59° below corrected sea level temperature. As average temperature decrease by latitude in January at Cairo is 1.91° per degree of latitude the effect of elevation theoretically has shifted the "C"/"D" boundary to the south about eighteen minutes of latitude (approximately twenty miles).[13]

Consideration of the location of the "a"/"b" boundary, usually the July 71.6° isotherm, yields a similar result that differs only in degree. Because of both topography and the effect of the Great Lakes it is difficult to isolate the elevational effects in lower Michigan and extreme eastern Wisconsin. In both localities the boundary is frequently meridional rather than zonal. In most of Wisconsin and Minnesota, however, the boundary is generally zonal and elevation is not so obscured as a control. In these two states station elevations near the "a"/"b" boundary vary between 800 and 1200 feet.[14] In the north-central portion of the study area the July lapse rate when calculated with the noted elevations gives corrected sea level temperatures 2.22° to 3.34° warmer. Average temperature decrease per degree of latitude in this area is 1.0°. Thus, elevation may be postulated as causing an approximate southward displacement of the "a"/"b" line $2^{\circ}13'$ to $3^{\circ}20'$ (153 to 230 miles).[15]

The last effect of elevation discussed here is its relationship to the "c" type summer. Five stations had a total of eight "c" summers.

In all cases the average monthly temperatures of three months were 50° or greater. Temperatures of the fourth warmest months of the eight individual climatic years were 47.6°, 47.9°, 48.0°, 48.6°, 49.3°, 49.8°, 49.9°, and 49.9°. Reduction of these actual temperatures to sea level by the application of a spring/fall lapse rate raises all of these monthly temperatures above 50°.[16] For all eight cases elevation alone appears as the physical control responsible for "c" summers in the Western Great Lakes States.

Air Masses and Pressure Systems

The principal, direct determinants of general temperature characteristics at any given point at any given moment in time are the physical properties of the air mass present over that point. Although the writer was unable to find a body of literature utilizing quantitative analysis of air masses for regional climatic differentiation[17] Bergeron's concept of the air mass[18] is nonetheless a useful qualitative tool.

Within the study area three air masses are most common. These are maritime tropical, continental polar, and continental arctic. Somewhat less frequent in occurrence is maritime polar air.[19] Specific locations for and general thermal characteristics of these air masses may be traced to their origins in the pattern of the general planetary circulation. Noteworthy in this pattern are the locations of the semipermanent pressure cells of the lower troposphere for within these cells are formed the air masses. Conspicuous features of the January pressure pattern over North America are the high pressure cell (>1026 mb.) in northwestern Canada over the Mackenzie Valley and a similar one (>1022 mb.) centered over southern Idaho and northern Utah. Additionally, slightly less intense high pressure (>1020 mb.) occurs as a ridge from the Mackenzie Valley south and southeastward through the Great Plains and the Midwest, west of the Great Lakes, to the southeastern and southern United States. This ridge connects with the western end of the oceanic Azores high pressure cell (> 1020 mb.). Low pressure occurs only off the west coast into the Aleutian low (< 1002 mb.) and off the east coast into the Icelandic low (< 999 mb.). One small, less intense (< 1018 mb.) continental low forms east of the Rockies in eastern Colorado and northeastern New Mexico.

July shows an almost complete reversal of the pressure pattern. Low pressure centers are found over the Canadian archipelago (< 1006 mb.) and the southwestern United States (< 1008 mb.). A trough (1012-1016 mb.) crosses the Great Plains, upper Midwest and Great Lakes, and Hudson Bay. The oceanic Pacific and Azores (Bermuda) highs (> 1023 mb.) are separated by the continental low pressures over North America. The western extension (> 1017 mb.) of the Azores high extends over much of the southeastern United States as far north as central Illinois and Indiana and westward to the Mississippi Valley.[20]

Figure 14 ("Air Masses in Central North America") outlines mean air mass positions and trajectories for January and July. For the winter season (January) in the Western Great Lakes States the coldest air mass is the continental arctic. Source region for this air body is the arctic snow and ice fields of northern and northwestern Canada. Formation occurs under high pressure conditions which favor extremely low temperatures at the surface with inversion common.[21] Divergence results in a southward export of this air mass into Minnesota, upper Michigan, and the

AIR MASSES IN CENTRAL NORTH AMERICA

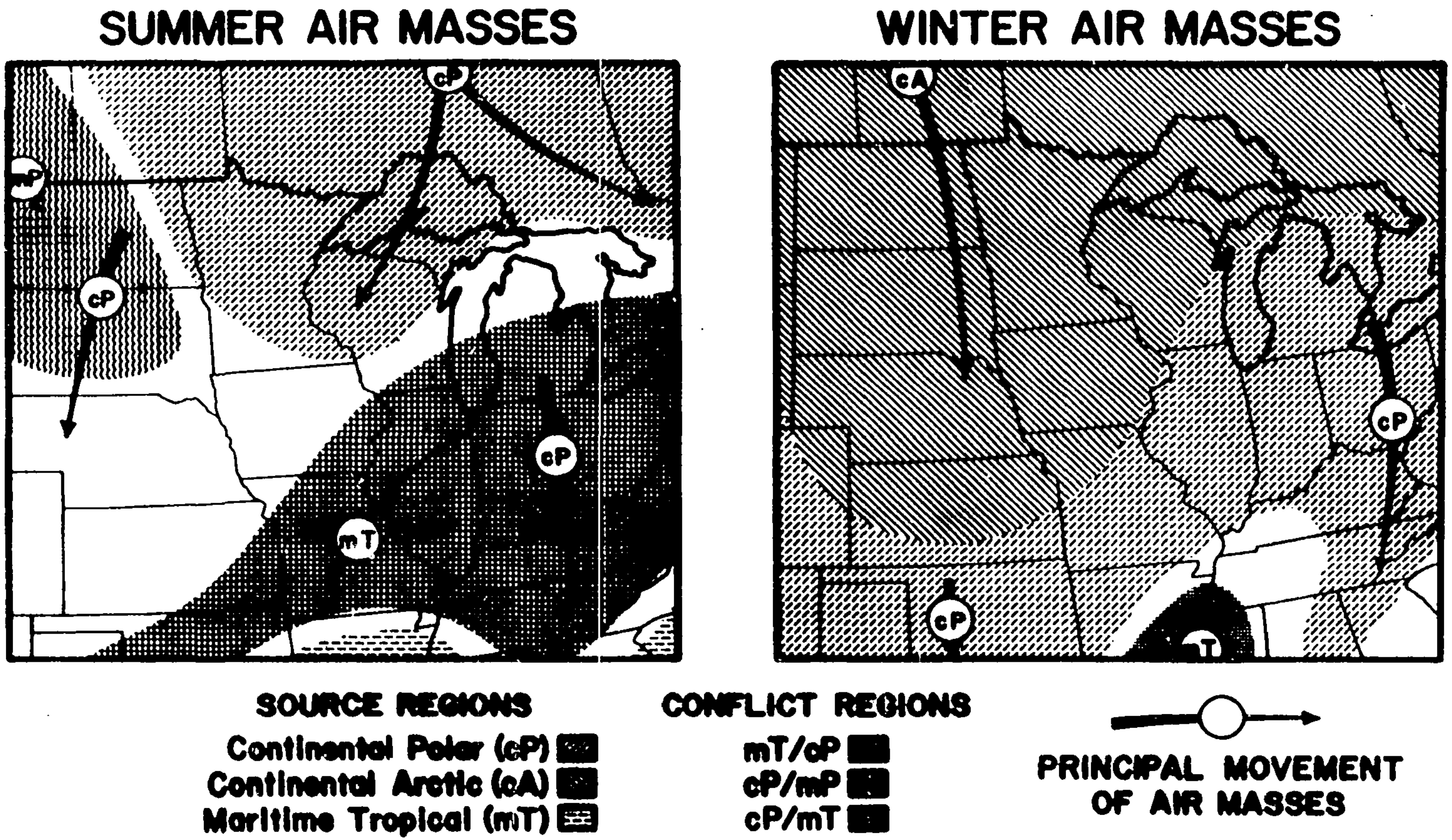


FIGURE 14

northwestern two-thirds of Wisconsin.[22] Within this area lack of major topographic barriers and the uniformity of the snow cover favor little surface modification of this air mass type.

The continental polar air mass differs only in slight degree from the continental arctic type.[23] Source region for this second type is to the south and southeast of the region of continental arctic dominance in southeastern Wisconsin, lower Michigan, Indiana, and Illinois. Conditions of formation for this air mass are under less intense high pressure, in places on the lee side of the Great Lakes or close to its shores, and over a thin snow cover. At the southern edge of the continental polar source region the permanent snow cover completely disappears.[24] There are two effects on thermal climatic regionalization caused by these two air masses that may be seen in this type of study. First, most of the area always experiences "D" winters. Second, the position of the 100 per cent "D" isopleth (Fig. 4) is slightly further north in Indiana than it is in Illinois. This may be related to either the modifying effect of the Great Lakes (below pp. 90-92) on continental polar air or to a slightly more northerly importation of maritime tropical air in Indiana than in Illinois.

Maritime tropical air is of only secondary importance during the winter in determining thermal climatic boundary location in the study area. Source region for this air mass is in the weak, western end of the Azores high over the warm waters of the Gulf of Mexico. Great amounts of sensible heat are absorbed into the air mass. Ascension promotes convective mixing of heat to great height.[25] Thus, this air mass stands in strong thermal contrast with the cold continental polar and arctic air bodies of the continental interior. Although maritime tropical air normally lies to the south of the study area during the winter season (Fig. 14) the frequent passage of easterly and northeasterly moving cyclones in a band from southern Wisconsin and central lower Michigan to central Illinois and northwestern Indiana[26] draws warmer maritime tropical air far to the north of its usual January location into Illinois, Indiana, and southern portions of lower Michigan and Wisconsin. Many of these cyclones originate in the Colorado low (above p. 84). Regional winter effects of these northward incursions of warm air masses are reflected in the positions of both the 50 per cent "C"/"D" isopleth and the 100 per cent "D" one (Fig. 4). At least as far north as northern Kentucky and southern Illinois maritime tropical air masses occur often enough to assure above freezing mean monthly temperatures in more than half the winters. Across most of Indiana and much of Illinois effects of this warm air mass type may be seen in at least occasional "C" classification.

The mean July air mass pattern (Fig. 14) is one of much greater influence by maritime tropical air. This air mass is frequent over Indiana and Illinois as well as the southern parts of Wisconsin and lower Michigan. Source region for the maritime tropical air mass in summer as in winter is the Gulf of Mexico. In summer the warmer sea surface warms the air mass to a greater degree than in winter. Anticyclonic maritime tropical air is drawn more frequently and much more deeply into the continent in July by both the continental low pressure trough (above p. 84) and by midlatitude cyclones. These July cyclones follow a set of tracks from central Michigan and Wisconsin northward to Lake Superior, a position north of the winter set.[27]

Continental polar air is the most frequent air mass in the northern portions of Wisconsin, upper Michigan, and much of Minnesota in July. This air mass has its origin in central Canada. In summer absence of snow cover and much greater amounts of insolation make this a much warmer air mass than in winter. Weak anticyclonic circulation restricts cloudiness allowing insolation to warm the earth which in turn warms the air mass by radiation.[28] However, higher latitude, numerous lakes and swamps, and dense forest cover do restrict continental polar air in its source region from attaining extremely high temperature values. In contrast to winter the thermal gradient between maritime tropical Gulf air and that of continental polar origin is weak.

Summer air mass patterns are partially reflected in the configuration of summer types (Fig. 8). In most of Illinois and much of Indiana mean monthly summer temperatures always over 71.6° show dominant warm air mass control. The slightly cooler air masses from the north penetrate too infrequently and dominate the area for periods of time too short in length to significantly lower warmest month average temperatures. Northward "b" summers increase in frequency. From central lower Michigan westward to central Minnesota the 50 per cent "a"/"b" boundary approximately outlines that area within which continental polar air masses are more frequent than maritime tropical ones.

Air masses, cyclones, and anticyclones are neither fixed in place nor thermal characteristics. Their daily, seasonal, and annual patterns of occurrence and effects on temperature distribution vary dynamically. Such variations are the major cause of thermal climatic fluctuations as they have been noted and mapped by this climatic year classification study. The use of indicies of frequency for those letters representing thermal characteristics reaffirms the dynamic nature of thermal climates.

Major Relief Features

Two groups of North American relief features, the high western cordilleras and the interior lowlands, have an indirect influence on thermal characteristics here. Their influence lies in their blocking and funneling of air masses. Maritime air masses from the North Pacific are almost completely prevented from entering the Western Great Lakes States by the Coast Ranges, Cascades, Northern Rockies, and the Canadian Rockies. Almost all of the few Pacific maritime air masses that do penetrate the interior of the continent are so modified as to be indistinguishable from continental polar ones.

Unmodified Pacific air masses if permitted to penetrate the interior would be expected to modify temperatures and decrease continentality. One might especially find some "C" years occurring much farther north than they do. The cause for this would be by either some modification or replacement of winter continental polar air masses by maritime polar ones. In summer cooler "b" climates would probably frequently replace "a" ones as cooler Pacific air masses displaced warmer Gulf ones.

The interior lowlands have opposite effects from those of the cordilleras. From the Arctic shore of Canada to the Gulf of Mexico no major topographic barrier exists. The entire central portion of the continent is open for the unrestricted northward and southward movement of air masses. The continental arctic and polar air masses of winter are permitted to penetrate southward from their source regions to dominate climates as far southward as Illinois, Indiana, and Ohio. This is one of the lowest latitude locations for "D" climates on the earth.[29] In summer warm maritime tropical Gulf air may move unimpededly to the north reenforcing the warmth developed by continentality. Lack of topographic barriers in winter causes climates to be dominantly under air mass control. The presence of "C" or "D" climatic years in their transition zone in any particular year is primarily dictated only by strength and movement that year of air masses unhindered by topography.

Continentality and the Great Lakes

Large land masses and water bodies have differing effects on temperatures. Because of their low specific heat large land masses increase both diurnal and yearly temperature ranges; water bodies with much higher specific heat reduce them. Among the more widely accepted quantitative measures of the differing effects of land and water on yearly temperature regimes is V. Conrad's coefficient of continentality.[30] This coefficient is stated as a percentage value ranging from 0 (total marine control) to 100 (total continental control). Two published maps show the distribution of continentality values for all or a substantial portion of the study area.[31]

Glenn Trewartha's map was drawn with 5 per cent increments for the conterminous United States and the southern Canadian provinces. Although highly generalized it does show significant isoline bending in the vicinity of the Great Lakes. Greatest continentality values, in excess of 60 per cent, were found along and north of the North Dakota-Manitoba boundary. In the United States high values, in excess of 50 per cent, occur as far south as northern Kansas and northwest Missouri. To the east of this region, however, the higher value isolines appear noticeably deflected away from the Great Lakes.

Richard Kopec's map of the Great Lakes region (including approximately half this writer's study area), because of the use of continentality increments of 1 per cent, presents a much more detailed pattern for shore areas. Kopec's conclusions are pertinent to this investigation. After noting the Great Lakes region is surrounded by high values of continentality to the west, north, and northeast he observed, " . . . the Great Lakes project as an outlier of low continentality into a region that would, in their absence, undoubtedly represent the center of continentality for North America."[32] His map shows isolines paralleling the shores of Lakes Superior, Michigan, and Huron; the shallow western end of Lake Erie has the isolines perpendicular to the shores indicating much lesser control by this lake. Western and southern lake shores have higher values than easterly and northerly ones.

Comparison of the above noted patterns of continentality values with that of "a", "b", and "c" frequencies (Fig. 8) shows similarities in several locations. The first is the 100 per cent "b"-"c" region, which spatially coexists in areas of depressed continentality values surrounding Lake Superior and the north shore of Lake Michigan. It is theorized these two lakes cool atmospheric temperatures in their immediate vicinity sufficiently to prevent the attainment of "a" summer temperatures at any time. Western Wisconsin, most of Minnesota, North Dakota, and southeastern Manitoba have both higher continentality values and greater frequency of "a" summers than to the east near the lakes. In the south the region of 100 per cent "a" summers extends most northerly in Illinois. This same area is also an outlier of the high continentality values from the west.[33] Michigan and Indiana have both lower continentality values and greater percentages of "b" years than areas to the west.

Local Topography

Effects of local topography on size and shape of temperature regions vary both according to scale of the investigation and by the amount and kinds of lesser relief features present. In detailed studies local topography may be observed as a climatic control most often along boundary lines because relatively minor temperature differences will cross selected boundary values and shift a specific station location into another climatic region. Most boundary values were originally chosen to characterize the cores of climatic regions rather than their edges. At least three meteorological effects of differences in local relief, air drainage, elevation, and presence or absence of barriers to air mass movement, can induce both slight increases and decreases in mean temperatures for individual stations and thereby cause irregularities in boundary line position.

Such topographically related irregularities in boundary location may be observed along the southern edges of both the 100 per cent "D" (or "BSD") and the 50 to 96.7 per cent "D" regions (Fig. 4).[34] In the former case three southerly prongs of 100 per cent "D" are associated from west to east with slight uplands[35] next to or between the valleys of the Mississippi, Illinois, Sangamon, Iroquois, and Wabash rivers.

To the east this boundary is deflected northward indicating occasional warmer winters in the Lake Maumee glaciolacustrine plain; cooler winters are restricted to the northwestern edge of the plain in the Fort Wayne, Wabash, and Mississinewa end moraine areas. The most complex area of variation in local relief is in the Illinois, Kentucky, and Indiana border region. Climatically this is a transition zone between domination of colder winters to the north and warmer ones to the south. The combination of transition zone and topographic differences results in an irregular 50 per cent "C"/50 per cent "D" boundary. Southern Illinois and the portion of Kentucky adjacent to southeastern Indiana experience somewhat warmer winters in the Mississippi-Ohio floodplain and the Bluegrass region of Kentucky. The rougher hill lands of southern Indiana and northwestern Kentucky have more frequent colder ones.

Occurrence of summer conditions ("a", "b", and "c") (Fig. 8) also tends to follow local relief along selected boundaries. The northern limit of 100 per cent "a" summers is deflected southward in eastern Indiana by the presence of several morainic uplands; it bends sharply northward in west-central Indiana in the vicinity of Indianapolis and Kokomo following a smoother, lower till-outwash plain; in western parts of the state it is again bent southward outlining another region of moraines. Almost all Illinois has 100 per cent "a" summers. The region is outlined on the north almost perfectly latitudinally. Exceptions are the Chicago and Moline areas. The Chicago region is in the glacial Lake Chicago plain which has elevations slightly lower than the rest of northern Illinois. The warm areas southwest of the city are in the Des Plaines and Illinois River valleys. Moline, at the confluence of the Mississippi and Rock Rivers, may be influenced by air drainage into these two valleys.

The northern edge of the region with a majority of "a" summers is a highly irregular boundary. Many of its irregularities appear related to local relief. This is illustrated well in lower Michigan southwest of Saginaw Bay where the region is deeply penetrated from the north by a ridge of greater than 50 per cent "b" values. This ridge generally follows proglacial lake plains and the Shiawassea River valley. In the southwestern corner of the state is the most southerly presence of a majority of "b" summers. This region, open to Lake Michigan on the west, is in low, proglacial lake plains backed on the east by uplands of end moraines.

The continuation of this boundary is just as complex in Wisconsin. Major penetrations of cooler summers from the north are found in two localities. The first, in the eastern part of the state, is a morainic upland bordering Lake Michigan.[36] It is difficult to tell whether the slight elevation of the moraines or lake effect is more significant here. The second locality, in the western part of the state, is mostly smooth lowlands of proglacial Lake Wisconsin and outwash plains. To the west in Minnesota the only apparently complex boundary configuration is in the western part of that state. In the vicinity of this meandering boundary exist numerous lakes in association with the broad Altamont and Gary end moraines. Because of complex local relief, the many lakes, and a less than adequate station network the boundary as drawn here is highly conjectural.

In the vicinity of Lake Superior, with few exceptions, summers are still cooler. The lake is almost entirely surrounded by an area which rarely experiences hot summers. Topographically the coolest regions are most common in two kinds of areas. Coolest summers in Minnesota and northwestern Wisconsin occur in the Lake Superior Lowland and in the highest uplands along the Ontario border. Farther east in northern Michigan the cooler summers are coincident with uplands. Within this same region those locations, such as Ontanagon, Munising, and Newberry, that have had a few slightly warmer summers are found in sheltered valleys or swampy lowlands. There are two major irregularities along the southern edge of the region of cooler summers. A southward projection of cooler summers occupies the highest section of the Superior Upland; a northward extension of warmer ones south of Ironwood occurs in a section of the upland with slightly lower elevations.

Precipitation

The Köppen system only measures precipitation indirectly. One indirect measure is a comparison of total annual precipitation with annual mean temperature to differentiate between regions of precipitation deficiency and ones with surplus. A second consists of comparisons of seasonal amounts with total yearly ones to outline regions with pronounced seasonal deficits. The following analysis of precipitation climatic controls is therefore limited to only those controls responsible for water deficit and surplus and for seasonal precipitation distribution as these are defined by the Köppen system.

Continents and Oceans

Central to understanding precipitation in this area is consideration of basic planetary land-water distribution. Because the Western

Great Lakes States lie in the heart of North America they are subject to continental rainfall amounts and distribution. Rainfall totals are high nowhere in the area; distribution is in most cases concentrated in the warm season. The one major source of water vapor for central North America is the Gulf of Mexico.[37] Absence of this body of warm water would undoubtedly cause much drier conditions than those that actually prevail.

Air Masses and Pressure Systems

Most of the study area always has humid climates. Infrequent semiarid years occur only in the northwest in Minnesota and Iowa (Fig. 4). Maritime tropical air masses penetrate deeply into the interior of North America in summer to supply an abundant quantity of water vapor to all the Western Great Lakes States.[38] The frequent passage of midlatitude cyclones, their associated fronts, and general overrunning together with the advance and retreat of the polar front in the summer season provide the necessary mechanical mechanisms to lift and cool the above noted moist air (above pp. 84-89) to usually produce enough precipitation for humid climates throughout the entire area.

Infrequent interruptions of this pattern have produced a few semiarid years in Minnesota and Iowa. Such conditions occur with increasing frequency to the west, outside the study area in the Great Plains. The easternmost boundary of semiarid years is generally longitudinal though not perfectly so. Air mass and pressure system control is evident in this longitudinal arrangement[39] as is outlined below.

Precipitation means, medians, and individual yearly amounts decrease northwesterly across most of the area. In western Wisconsin and Minnesota the rate of decrease becomes greater in a westerly direction. As just noted semiarid years begin to occur in Minnesota. This phenomenon is caused by either of two types of interruptions to the usual summer air mass and pressure system pattern in the west. One interruption is when summer lows are on the Alberta track.[40] In this case warm season rains are more northerly than usual causing summer precipitation values in the western portions of the Western Great Lakes States to be depressed. A second interruption to the normal pattern occurs when summer subtropical highs extend inland aloft. In this instance modified dry maritime polar air is brought to the area.[41] Both these interruptions to the usual air mass/pressure patterns when strong enough are responsible for steppe years as summer is the season of usual maximum rains.[42]

Seasonal precipitation distribution (Figs. 5, 6, and 7) is also clearly a function of air mass and pressure conditions. Winter dryness is characteristic in northwestern Iowa, Illinois, Wisconsin, and Minnesota and is caused by seasonal differences in air masses and pressure systems. In winter continental arctic and continental polar air masses, both of which have only slight moisture content, are the usual air masses present (Fig. 14).[43] Winter midlatitude cyclones, the principal precipitation triggering mechanisms, take tracks most frequently to the south and east converging in northern Indiana and southern lower Michigan.[44] In summer conditions are altered. Although maritime tropical air masses from the Gulf of Mexico are a great distance from their source region and tend to take trajectories toward the east[45] they, nonetheless, do occasionally penetrate this far to the northwest and bring modest amounts of water vapor. Summer lows occur often enough in most years to trigger rains over these states.[46, 47]

In contrast with the western portion of the study area even precipitation distribution dominates the east (Fig. 5). Here, too, air masses and pressure systems are the primary determinants of the annual precipitation regime. Differences from the western pattern are mostly ones of degree. Maritime tropical air masses, closer to their Gulf of Mexico source region, contain a greater amount of water vapor and, because of their northeasterly trajectories (Fig. 14), dominate the climate of the east more frequently than they do in the west. Most importantly, through most of the year, storm tracks converge here to provide frontal lifting to produce abundant precipitation from the already moist air.[48]

Although most of the east is most often characterized by even precipitation distribution there are two substantial areas wherein summer dry conditions occur with enough frequency to make an examination of their causal factors necessary (Fig. 6). The first such area is in southern Illinois, southern Indiana, and adjacent portions of Kentucky and southwestern Ohio. Air masses and especially pressure systems appear responsible for the origin of this region. A complex of physical causes has been advanced by Trewartha to explain the rainfall regime of this region.[49] First, in July and August the area lies under a pressure ridge with a dry air flow. Second, divergence or only a weak convergence exists. This is not favorable for convection in the moist maritime tropical air mass present. Third, there is a lack of afternoon sea breeze convergence and tropical disturbances present further south near the Gulf coast. Fourth, winter and early spring lows in association with the polar front are frequent producing heavy, widespread rains.[50] Fifth, in late summer and early fall the polar front and travelling lows have moved to their most northerly position. Also, at this same time the Bermuda high (above p. 84) extends into the area. Although the above noted physical conditions occur in only a minority of years when they are favorably combined dry summers are produced in the southerly parts of the study area.[51]

The Great Lakes

A second region of occasional summer dry conditions surrounds parts of Lakes Superior, Michigan, Huron, and Erie in the Province of Ontario and States of Michigan, Wisconsin, Illinois, Indiana, and Ohio. These areas are all conspicuous by their close proximity to the shores of the Great Lakes. In addition to the presence of summer dry conditions the northwestern portion of the Lakes area is marked by even precipitation distribution. Both conditions are attributable in large measure to two physical effects of the Great Lakes.

In summer the lake surfaces are cooler than the adjacent land surfaces. Air masses that travel over these cooler water surfaces are given an added measure of stability that decreases temporarily their ability to produce precipitation.[52] Convection is especially lessened. These effects are most concentrated on the lee (east and northeast) shores of Lake Michigan. The western and southern littorals are affected to a lesser degree and for the most part in a more geographically restricted strip of a few miles in width.

The lakes in winter produce an opposite effect upon air passing over them. The air is colder than the water. In the heat exchange between water and air, water vapor is added to the air and the lower level of the air mass is given a degree of instability.[53] The lee shores of winter are the southern, southeasterly, and eastern. Northern Indiana and Ohio, western lower Michigan, and the Upper Peninsula all receive copious quantities of snow. The western shores of Lake Michigan, lying to windward of prevailing winter winds, have similar, but more restricted snowfall. As a result of both above noted seasonal effects of the lakes large areas that might be expected to occasionally have less winter precipitation than summer have either as much as or more than in summer. Thus, "f" conditions usually prevail together with a few exceptional "s" years.

Major Relief Features and Local Topography

The same major relief features control precipitation amounts and distribution in the same ways in which they control temperature (above pp. 89-90). The western cordilleras block moist, Pacific maritime air masses from reaching the Western Great Lakes States. The two effects of this blocking are to allow the development of a dominant winter dry regime and occasional semiarid conditions in the northwest. The uninterrupted interior lowlands from the Gulf of Mexico to the Arctic Ocean permit the climate of the Western Great Lakes States to be primarily dominated by dry, continental arctic and continental polar air masses and moist, tropical maritime tropical ones of Gulf origin.

Local topography is much more difficult to assess as a control for precipitation than it is for temperature.[54] Examination of Figures 4-7 shows numerous minor irregularities in boundary line orientation and small anomalous spots of differing precipitation distribution conditions from the general regional ones. These are apparently caused by several types of differences in land surface, including distribution of water, hills, plains, cultivated soil, forests, swamps, cities, and so forth. Because of the complexity of local nuances of surface an on-site investigation of each irregularity and anomaly is undoubtedly necessary for adequate analysis of each such problem.

Summary

Analysis of climatic controls and their comparison with climatic year element patterns have shown that these patterns have a physical basis for their characteristics. Three analyses are especially noteworthy. Possibly the most important is that analysis which has given the causal factors for the presence of a winter dry precipitation distribution in the western portions of the study area. Two other analyses should also be emphasized. One noted the physical causes for occasional summer dry conditions in the vicinity of the shores of the Great Lakes and in the southern and southeastern parts of the Western Great Lakes States; a second produced an explanation for occurrence of semiarid years in the west.

Examination of regional climatic controls for both temperature and precipitation demonstrated convincingly that land and water relationships are of fundamental importance in any explanation of climatic conditions in the heart of North America. The sheer existence of the large landmass of North America, its surrounding oceans, the Great Lakes and the interactions among the physical effects of these entities directly cause a majority of the variations among temperature and precipitation patterns. Most of those variations not directly attributable to these factors are probably indirectly related to them.

The Climatic Year Regions (Fig. 13) were the result of a unique combination of controls. Each climatic year region can best be understood in terms of the controls operative on the region's climatic conditions.

The "Dwb" region has one or more winter monthly mean temperatures below 32°, a condition primarily the function of its upper mid-latitude continental interior location, the winter circulation dominated by continental arctic air masses, the blocking of Pacific air masses by the western cordilleras, and winter cooling of air by continental land radiation from snow covered surfaces. The cool summers can also be attributed to upper mid-latitude position and the region's domination by continental polar air masses. Its southern boundary, primarily that of summer type, is somewhat further south than latitude and other factors can account for because of elevation. Precipitation characteristics are low annual amounts and a winter dry regime. Low annual totals are primarily a function of the absence of certain factors. That is, the region is a great distance or is blocked from moisture sources, while at the same time triggering mechanisms (primarily mid-latitude cyclones) are absent during much of the year. Summer rains have their origins in Gulf maritime tropical air, which is uplifted by mid-latitude cyclones and summer convectional activity. Both factors though weak are most frequent in summer as the polar front retreats northward in the warm season.

Controls for the cold winter of the "Dwa" region are similar to those of the "Dwb" region with only a slight difference. Continental polar as well as continental arctic air masses occur throughout the winter. The region's southernmost edge along the Illinois-Missouri boundary is a few miles further south than otherwise might be expected. Elevation effects appear to be chiefly responsible for this southern displacement. Hot summers then are a function of the region's lower latitude together with the more frequent summer domination by warm maritime tropical air masses. Annual precipitation amounts are similar to those in the "Dwb" region except in the east where they are greater. Here there is slightly less distance to the principal moisture source (the Gulf of Mexico), more frequent summer maritime tropical air mass domination, and because the period of cyclonic disturbances is greater, especially in Illinois and eastern Iowa. The region, however, still has winter dryness. Winter air, whether of arctic or polar origin, is quite dry. Winter cyclonic disturbances are infrequent. As noted maritime tropical air masses and cyclones are more frequent in the summer half year, consequently the majority of the precipitation occurs in this season.

In the eastern portions of the Western Great Lakes States "Dfb" and "Dfa" replace the "Dwb" and "Dwa" regions. Some of the controls of the "Dfb" are the same as those of the "Dwb" region. Its high latitude, coupled with its continental interior position and its continental arctic and polar air masses of winter assure cold winter temperatures. Its southern boundary in Michigan is displaced further to the south than that of the "Dwb" region. The Great Lakes provide additional cooling to the summer months. The southern boundary configuration also shows effects of both proximity to the Great Lakes and to local topography. The yearly precipitation distribution is significantly different from that in the "Dwb" region. Winter precipitation amounts are higher while those of summer are lower. This precipitation regime is caused by more frequent passage of cyclones in winter, early spring, and late fall and the effects of the Great Lakes and shoreline orography on atmospheric stability. Winter air masses lose stability over the lakes and drop copious quantities of snow on leeward shores in Michigan where uplift is triggered by shoreline orography (this is most pronounced in the Upper Peninsula). In summer cool lake waters add a degree of stability to air masses passing over them damping precipitation amounts in their immediate vicinity.

South of the "Dfb" region the influence of the Great Lakes as a major climatic control for either temperature or precipitation is rapidly diminished. Only in the northern areas of the "Dfa" region are they still of importance. Here their effects are similar to those observed in the "Dfb" region. The cold winters of the "Dfa" are caused by the high midlatitude protected continental interior position. The southern boundary of the "Dfa" climatic year region is further south than shown on mean Köppen maps (Fig. 3). This is principally because of the effects of a few extremely warm years on average temperatures. It should also be noted both the writer's southern climatic year region boundary and the Köppen mean boundary lie further south than would otherwise be the case if only latitudinal effects were operative. Elevational effects appear responsible for this shift. Summers are long and hot because of both frequent maritime tropical air mass dominance and the radiational heating from continental interior land surfaces. Precipitation amounts are higher than in the previously mentioned climatic year regions because of closer proximity to the Gulf of Mexico. Also, the persistance of maritime tropical air masses in summer, prevalence of summer low pressures which favor convergence, frequent passage of midlatitude cyclones throughout much of the year, and the aforementioned winter Lakes effect in the northern part of the region are important. The highly irregular westermost boundary of the region where it adjoins the "Dwa" region again appears caused by effects of local topography.

Much smaller in its areal extent is the "Cfa" region. Its lower latitude and frequent intrusion of maritime tropical air masses in winter maintain all monthly temperature averages above freezing. Summers are dominated by maritime tropical air. This control, together with that of lower midlatitude continental interior radiational heating assure long, hot summers. Precipitation amounts and distribution are controlled by cyclones, maritime tropical air masses, and the close proximity of the Gulf of Mexico. The region is close enough to the Gulf that maritime tropical air masses dominate during much of the year assuring large total amounts of available water vapor. Although seasonal distribution is designated as even ("f") there is a tendency to a winter maximum. The most important single factor in accounting for the winter precipitation is the more frequent passage of cyclones in the winter half year than in the summer one.

The smallest, somewhat enigmatic, region is the "Csa". It was not anticipated by the writer. Because of its small size and location on the southernmost margin of the study area one can only speculate as to whether or not it is a region of any substantial size.

Two of its characteristics, mild winter and long, hot summer are predictable and may be explained by exactly the same controls as are responsible for the "Cfa" region. The causes for the summer dry precipitation distribution appear to be either those advanced by Trewartha (above pp. 98-99), or, since the size of the region is unknown, they may be attributed to factors (such as local topography or even faulty instrumentation or record keeping) that would require larger scale analysis.

One small spot of "D<u>s</u>a" occurred. It actually represents only one station in the study. Its "D" winter and "a" summer characteristics and their controls are those of the "Dfa" region to the north. Its summer dry precipitation distribution regime (in this case only a plurality) is thought to be controlled or caused by the same factors as are responsible for the "Csa" region to the south. It may be noted that with both the "Csa" and "D<u>s</u>a" regions the writer encountered considerable difficulty with the data. All stations in the mapped regions had so many data gaps that the mapping of their climatic attributes is open to some question.

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[1]A recent example of the synoptic approach is Jay R. Harmon, Tropospheric Waves, Jet Streams, and United States Weather Patterns, Commission on College Geography Resource Paper No. 11 (Washington, D.C.: Association of American Geographers, 1971), pp. 19-36. An older, more extensive example may be found in Sutherland, "Missouri Basin". A continuing series of such treatments for the United States is published in numerous issues of Weatherwise.

[2]Erik H. Palmen and C.W. Newton, Atmospheric Circulation Systems: Their Structure and Physical Interpretation, International Geophysics Series (New York and London: Academic Press, 1969), pp. 84, 93, 96, 344, 345, and 365. Victor Starr has suggested that one interaction may be the maintenance of the general circulation in the middle latitudes by perturbations. The more common explanation is usually given as being just the opposite. Victor P. Starr, "Commentaries Concerning Research on the General Circulation," Tellus, X (1954), 268-272 as cited in Jen-Hu Chang, Atmospheric Circulation Systems and Climates, (Honolulu: Oriental Publishing Company, 1972), pp. 18-19.

[3]Palmen and Newton, Atmospheric Circulation Systems, pp. 92 and 107.

[4]Ibid., pp. 91, 92, 94, 96, 97, 103, 145, 150, 345, 365, and 552.

[5]Such is not the case for a specific synoptic situation. In analysis of singularities the synoptic pattern of the entire general circulation is of critical importance.

[6]It is not claimed these two data sets are totally controlled by latitude as numerous other factors, such as albedo, instrument placement, and physical controls other than latitude, are also partially responsible for the noted thermal characteristics. This may be observed by comparison of data from Cairo and Roseau with mean temperatures by latitude. January and July mean temperatures at 37° N. are approximately 46.3° and 73.5° respectively while at 48° 51' N. they are approximately 23.9° and 69.9°. These data were interpolated from tabular data in U.S., Environmental Science Services Administration and United States Air Force, U.S. Standard Atmosphere Supplements, 1966 (Washington, D.C.: Government Printing Office, n.d.), pp. 153, 157, 161, 165, 173, and 181.

[7]Ibid.

[8]Although arithmetic means and medians may not be tested nor compared statistically together they are close enough in this case to be verbally compared.

[9] "Extreme Points in the United States," Reader's Digest Almanac, 1966, p. 190, citing United States Geological Survey.

[10] In reduction of actual temperatures to sea level equivalents the problem of selection of lapse rate occurs. The "normal" lapse rate of 3.5° is stated in most standard climatological texts as representing the usual decrease with elevation in the lower troposphere. However, lapse rates vary both geographically and seasonally. For this reason the following lapse rates are utilized in this chapter: January - 1.97° in the north and 1.87° in the south; July - 2.78° in the north and 3.93° in the south. E.S.S.A. and U.S.A.F., U.S. Standard Atmosphere Supplements, 1966, pp. 153, 157, 161, 165, and 173.

[11] U.S., Department of Commerce, Weather Bureau, Decennial Census of United States Climate - Climatic Summary of the United States - Supplement for 1951 through 1960 - Minnesota (Washington, D.C.: Government Printing Office, 1964), p. 59. U.S., Department of Commerce, Weather Bureau, Decennial Census of United States Climate - Climatic Summary of the United States - Supplement for 1951 through 1960 - Illinois (Washington, D.C.: Government Printing Office, 1964), p. 58

[12] Above n. 10.

[13] Above, nn. 6 and 10.

[14] U.S., Department of Commerce, Weather Bureau, Decennial Census of United States Climate - Climatic Summary of the United States - Supplement for 1951 through 1960 - Minnesota (Washington, D.C.: Government Printing Office, 1964), pp. 55-60. U.S., Department of Commerce, Weather Bureau, Decennial Census of United States Climate - Climatic Summary of the United States - Supplement for 1951 through 1960 - Wisconsin (Washington, D.C.: Government Printing Office, 1965), pp. 67-72.

[15] Above, nn. 6 and 10.

[16] E.S.S.A. and U.S.A.F., U.S. Standard Atmosphere Supplements, 1966, p. 169.

[17] Minor exceptions are the efforts of Linke, Dinies, and Landsberg as discussed in Helmut Landsberg, Physical Climatology (2nd ed., 4th printing; DuBois, Pa.: Gray Printing Co., Inc., 1964), pp. 227-232. A recent attempt at introducing a quantitative system with example mapping of Australia is represented by John E. Oliver, "A Genetic Approach to Climatic Classification," Association of American Geographers Annals, LX (1970), 615-637.

[18] Sverre Petterssen, Weather Analysis and Forecasting, II (2nd ed.; New York: McGraw-Hill Book Company, Inc., 1956), p. 1.

[19] Trewartha, An Introduction to Climate (4th ed.), pp. 167 and 175-85.

[20]Thomas A. Blair and Robert C. Fite, Weather Elements: A Text in Elementary Meteorology, (5th ed.; Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1965), pp. 141-42. Visher, Climatic Atlas of the United States, p. 155. U.S., Department of Commerce, Environmental Science Services Administration, Environmental Data Service, Climatic Atlas of the United States (Washington, D.C.: Government Printing Office, 1968), p. 79.

[21]A surface temperature of -45° in one such air mass in the arctic is cited by Petterssen in Weather Analysis and Forecasting, II, pp. 10-14.

[22]Outside the study area it is prevalent as far south as Kansas. Canada, Department of Transport, Meteorological Division and National Research Council, Division of Building Research, Climatological Atlas of Canada (Ottawa: National Research Council, 1953), pp. 98-99. E.S.S.A., Climatic Atlas of the United States, pp. 73 and 75. Trewartha, An Introduction to Climate (4th ed.), p. 176.

[23]Many sources do not differentiate between the continental arctic and the continental polar air masses and treat both under the label "continental polar".

[24]Petterssen, Weather Analysis and Forecasting, II, p. 10.

[25]Ibid., pp. 14-15.

[26]Visher, Climatic Atlas of the United States, p. 166.

[27]Ibid., p. 165.

[28]Summer temperatures of 59° and 68° are reported as typical warming in a cP air mass in summer by Petterssen, Weather Analysis and Forecasting, II, p. 33.

[29]The only comparable low latitude location is in east Asia. As it is mapped by means rather than climatic year frequencies the two locations do not correspond perfectly. Glenn T. Trewartha, The Earth's Problem Climates (Madison, Wis.: The University of Wisconsin Press, 1966), Plate.

[30]Ibid., p. 253.

[31]Ibid., p. 254. Richard J. Kopec, "Continentality around the Great Lakes," Bulletin of the American Meteorological Society, XLVI (February, 1965), 55.

[32]Ibid., p. 57.

[33]In another study Kopec used the method of isanomal mapping to determine the effects of the Great Lakes on temperature regimes in their vicinity. This method compares the amount of deviation of actual temperatures from Standard Temperature Distributions by latitude. Isanomal analysis may be done monthly or seasonally as well as annually. The writer found the greatest deviations occur in winter (January) while the effect of the Lakes generally is small in summer. Lake Superior was a summer exception influencing temperatures in its vicinity. Richard J. Kopec, "Areal Patterns of Seasonal Temperature Anomalies in the Vicinity of the Great Lakes," Bulletin of the American Meteorological Society, XLVIII (December, 1967), 884-89.

[34]The following maps were utilized for landform and elevation determinations: National Research Council, Division of Earth Sciences, Glacial Map of the United States East of the Rocky Mountains (1st ed., scale 1:1,750,000; New York: Geological Society of America, 1959); United States, Department of the Interior, Geological Survey, United States Contour Map (edition of 1916, scale 1:7,000,000; Washington, D.C.: Geological Survey, 1957); United States, Department of the Interior, Geological Survey, Louisville - World (North America) (NJ - 16, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1959); United States, Department of the Interior, Geological Survey, Minneapolis - World (North America) (NL - 15, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1955); United States, Department of the Interior, Geological Survey, Lake Superior - World (North America) (NL - 16, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1966); United States, Department of the Interior, Geological Survey, Chicago - World (North America) (NK - 16, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1948); United States, Department of the Interior, Geological Survey, Lake Erie - World (North America) (NK - 17, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1949); United States, Department of the Interior, Geological Survey, Dakotas - World (North America) (NL - 14, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1955); United States, Department of the Interior, Geological Survey, Platte River - World (North America) (NK - 14, scale 1:1,000,000, Washington, D.C.: Geological Survey, 1959); Erwin Raisz, Landforms of the United States, (6th rev. ed.; scale approximately 1:7,500,000, Cambridge, Mass.: Erwin Raisz, 1957); and Espenshade, Goode's World Atlas, pp. 70-71, 78-79, and 80-81.

[35]These uplands are largely end moraines of Illinoian and Wisconsin Age and include the Payson, Buffalo, Hart, Chatsworth, Bloomington, and Normal.

[36]This area is also southeast of Lake Winnebago which may cool temperatures to a slight degree.

[37]Trewartha, The Earth's Problem Climates, p. 261.

[38]Gulf air is the predominant source of moisture east of 97° W.. This is the approximate western boundary of Minnesota. Ibid.

[39]That the boundary is less than perfectly straight is partially attributed to the fact that precipitation surfaces are extremely uneven. Precipitation data whether analyzed geographically or statistically show great areal differences on any given day or in any given year. As the outline of semiarid conditions has been made with individual year data a perfectly smooth boundary was neither expected nor found. Other complicating factors in locating this boundary are caused by the use of the variable Köppen ratios for determining the humid/semiarid boundary. As these ratios use mean yearly temperatures and annual and seasonal rainfall minor differences in any one term at any one given location may or may not result in the designation of humid or semiarid.

[40]Visher, Climatic Atlas of the United States, p. 164.

[41]Trewartha, The Earth's Problem Climates, p. 289.

[42]Ibid., p. 263.

[43]Visher, Climatic Atlas of the United States, p. 162. Dieter H. Brunnschweiler, "The Geographic Distribution of Air Masses in North America," Vierteljahresschrift Naturforschung Gesellschaft Zürich, XCVII (1952), 42-49.

[44]Visher, Climatic Atlas of the United States, p. 166.

[45]Trewartha, The Earth's Problem Climates, p. 259.

[46]Visher, Climatic Atlas of the United States, pp. 164-65.

[47]It is probable that other Köppen studies of this area usually show even precipitation distribution ("f") because means in this area are unduly influenced by a few large values. Eichenlaub, Strommen, and Dickason have investigated this problem with the use of the gamma probability function. Their conclusions are in agreement with this study that means are not representative of the usual yearly precipitation in this area. Both climatic year studies and those based upon the gamma probability function seem better suited to the investigation of the linkages between regional climatology of precipitation and the historical physical climatology of the atmosphere. Val L. Eichenlaub, Norton D. Strommen, and David G. Dickason, "Precipitation Probabilities as Indices of Climatic Variation over the Eastern United States," Professional Geographer, XXIII (October, 1971), 301-07.

[48]Visher, Climatic Atlas of the United States, p. 164.

[49]Trewartha, The Earth's Problem Climates, pp. 293-99. Although Trewartha's discussion is directed at explanation for the depressed summer precipitation conditions of a precipitation region he has designated as the "Subtropical Interior" it is geographically adjacent to the Ohio valley. It is felt that the same conditions are probably present in a weaker form to the north.

[50]One necessary condition for an "s" classification in the Köppen system is at least a three-to-one ratio between the wettest winter month and the driest summer one. Thus, it is necessary to note the conditions for both summer dryness and winter precipitation.

[51]Within the studied area only one station in Kentucky, adjacent to the southernmost tip of Illinois, had more than 50 per cent "s" years.

[52]Sverre Petterssen, Weather Analysis and Forecasting, I (2nd ed.; New York: McGraw-Hill Book Company, Inc., 1956), pp. 326-28. Val L. Eichenlaub, "Lake Effect Snowfall to the Lee of the Great Lakes: Its Role in Michigan," Bulletin of the American Meteorological Society, LI (May, 1970), 403.

[53]Petterssen, Weather Analysis and Forecasting, I, pp. 326-28. Ibid., 403-11.

[54]Above, n. 39.

CHAPTER VI

COVARIATION AND SOME INTERRELATIONSHIPS

Introduction

One aim of physical geography is the search for interrelationships among the factors of man's physical environment. In regional climatology empirical classifications, such as that used in this study, are based on the underlying assumption that climate affects certain other natural phenomena (above Chapter I). Additional aims of classification systems are transmission of information and to permit inductive generalizations to be made. For all of these reasons it was hypothesized in this dissertation that climatic year regions covary in space with other natural phenomena. Such a hypothesis allows the climatic year regions to be extended in their usefulness.

Thirteen variables were selected for comparison with climatic year regions (below Table 5). Natural vegetation and Great Soils Groups were included in the study because it has been so commonly assumed that there is a relationship between them and climate. It should be noted, however, that these assumptions always seem to have been based on qualitative comparisons. Therefore, it was decided to quantitatively test: 1) whether or not there were statistically significant relationships and 2) to measure the strength of such relationships if they were found. All the remaining variables were measures of assorted climatological phenomena. Although none were directly measured by the climatic year methods employed in this study they were compared to the climatic year regions to permit additional generalizations to be made concerning the climatic characteristics of each.

Methodology

The greatest problem found in attempting to measure covariation in this study was finding an appropriate measurement method. This problem was engendered by the use of regions that are nonparametric and are nominally scaled. The basic method chosen for determining statistical significance of hypothesized covariance was the chi-square (X^2) test. Although X^2 is one of the least powerful tests for statistical significance it is uniquely suited to analysis of relationships of nonparametric, nominal variables.[1] Because X^2 values can be made significant by the simple expedient of inflating sample size the total sample was kept constant for all thirteen tests. Additionally, care was taken to use only a moderately sized sample.

The sampling technique was a stratified random one that sampled at a regular interval along a rectangular grid.[2] Stratified random sampling was used because of its obvious asset of being an unbiased sampling procedure. All thirteen tested variables were entered on a series of thirteen uniformly scaled maps. Data from the "Climatic Year Regions" map (Fig. 13) were generalized and placed on a fourteenth map of the same scale as that used for the variables to be tested. The scale of analysis was admittedly a small one. The source maps for all variables tested were selected at scales compatible with that of this study. As this entire study uses a small scale world classification whose purpose is to show basic planetary climatic dimensions maps of other tested variables were chosen that depicted similar macro scale world classifications of natural phenomena. The writer initially planned to use the largest scale maps available. However, it was quickly observed that so many major scale changes and class consolidations would have been necessitated that too many possibilities for sampling error would be introduced. Wherever possible small scale maps which had been scaled down by their original authors were used. Use of larger scale source maps than that used for Figure 13 would tend to invalidate the entire testing procedure.

For each of the thirteen X^2 tests the sampling grid was first placed on the "Climatic Year Regions" map and an ordered listing compiled of the climatic type at each point. Second, the grid was transferred to the map of the variable being tested. Again, an ordered listing was made of the categories of the variable. The completed two column listings of climatic types and the considered variable were used to make frequency counts for placement in standard two way contingency tables for computation of the X^2 statistics. The total sample (N) for each of the thirteen tests was ninety-eight.

Null hypotheses were stated for each of the thirteen X^2 tests. Each hypothesized no areal covariance between climatic year regions in the Western Great Lakes States and regions of difference within each of the thirteen tested phenomena. In all cases the computed X^2 statistic was compared with a standard table of critical values of the X^2 distribution for the appropriate number of degrees of freedom at the .001 level of significance.[3] The computed X^2 values for all thirteen tests exceeded the tabular values and, therefore, all thirteen null hypotheses were rejected.

There are two major problems with the use of X^2 in geography. First, although areal covariation may be established the strength of the relationship is not revealed. Second, as noted above, use of a sufficiently large sample may provide a X^2 value that is statistically significant but not geographically meaningful.[4]

Both problems may be solved with the use of Karl Pearson's coefficient of mean-square contingency (C). Computation of C is accomplished by use of the expression $\sqrt{\frac{\phi^2}{1+\phi^2}}$ in which ϕ^2 (mean-square contingency) equals $\frac{X^2}{N}$.[5] Division of X^2 by N in the computation for ϕ^2 minimizes the effect of inflated sample size on X^2. The coefficient C has three restrictions, one of which may be overcome.[6] The first two are that C, unlike the coefficient of correlation (r), may not be used for regression nor does it have a range between negative one and positive one.[7] The third restriction is that the value of C ranges between zero and a varying, theoretical upper limit that is always less than unity. The upper limit of C, as well as of ϕ^2, is variable depending upon the number of rows and columns in the contingency table from which X^2 was calculated.[8] The solution to this third restriction, as suggested by Pearson, is to obtain a corrected coefficient of mean-square contingency (CC) with an upper limit of unity. This coefficient is calculated by dividing C by the theoretical upper limit for a table of s columns and t rows. This upper limit is the product of multiplication of the two tabular values for number of columns and for number of rows.[9]

Areal Covariation

The high, obtained values of the thirteen corrected coefficients of mean-square contingency (.72 to .91) suggest that all the variables show moderately strong to very strong tendencies toward covariance with climatic year regions (Table 5).

Vegetation and Soils

The strongest relationship found in the groups of thirteen tested variables was that between natural vegetation and climatic year regions (Table 5). Four climatic year regions ("Dfa", "Dfb", "Dwa", and "Dwb")[10] were tested against three vegetation associations (Grass, Broadleaf Deciduous Forest, and Mixed Broadleaf Deciduous - Needleleaf Evergreen and Needleleaf Evergreen Forest) (Table 6). Three of twelve cells contributed more than half the total X^2 value. In all three, observed frequencies exceeded expected ones by wide margins. The three were: "Dfa" - Broadleaf Deciduous Forest, "Dwa" - Grass, and "Dwb" - Mixed Broadleaf Deciduous-Needleleaf Evergreen and Needleleaf Evergreen Forest. Two additional analyses were made with null hypotheses rejected at the .001 level. The first compared two vegetation groups (1. Grass - Mixed Broadleaf Deciduous Forest and 2. Mixed Broadleaf Deciduous - Needleleaf Evergreen and Needleleaf Evergreen Forest) to the summer types "a" and "b". The four cells suggest "a" is closely associated with Grass and Broadleaf Deciduous Forest whereas "b" is more coextensive with the Mixed and Needleleaf Forests. The CC of .89[11] suggests strong covariance between summer types and broad vegetation associations. The second analysis compared precipitation distribution, "f" and "w", with two

TABLE 5

STRENGTH OF COVARIANCE BETWEEN CLIMATIC YEAR REGIONS AND SELECTED PHYSICAL PHENOMENA[a]

Variable	CC
Natural Vegetation	.91
Great Soils Groups	.90
Average Annual Number of Days with Snow Cover (1 inch)	.86
Average Annual Snowfall	.84
Mean Length of Freeze Free Period	.82
Mean Number of Days with Temperatures $\geq 90^{\circ}$	.82
Mean Number of Days with Temperatures $\leq 32^{\circ}$	.81
Total Annual Precipitation	.81
Mean Number of Precipitation Days ($\geq$ .01 inches)	.79
Annual Number of Thunderstorm Days	.78
Continentality	.77
Percentage of Possible Sunshine (June - August)	.73
Percentage of Possible Sunshine (December - February)	.72

[a]Source maps for these tested variables are: Espenshade (ed.), Goode's World Atlas, p. 16; Fullard and Darby, Aldine University Atlas, p. 35; U.S., Department of Agriculture, Climate and Man: Yearbook of Agriculture (Washington, D.C.: Government Printing Office, 1941), p. 728; Ibid., p. 727; U.S., Department of Commerce, Environmental Science Services Administration, Environmental Data Service, Climatic Atlas of the United States (Washington, D.C.: Government Printing Office 1968), p. 31; Ibid., p. 25; Ibid., p. 27; Ibid., p. 43; Ibid., p. 56; Visher, Climatic Atlas of the United States, Fig. 408, p. 167; Trewartha, The Earth's Problem Climates, p. 254; Espenshade (ed.), Goode's World Atlas, p. 53; and Ibid.

TABLE 6

THREE VEGETATION TESTS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Vegetation Associations	.91[a]
2	2 Summer Types	2 Vegetation Associations	.89[b]
3	2 Precipitation Distributions	2 Vegetation Associations	.52[c]

[a]Strongest Relationships - "Dfa" - Broadleaf Forest.
"Dwa" - Grassland.
"Dwb" - Mixed and Needleleaf Forest.

[b]Strongest Relationships - "a" - Grassland and Broadleaf Forest.
"b" - Mixed and Needleleaf Forest.

[c]Strongest Relationships - "f" - No Grassland.
"w" - Grassland.

vegetation types, Grass and Forests. Although the CC is much weaker (.52)[12] two table cells contributed heavily to X^2. The greatest was "f" versus Grass. In this case the observed frequency was substantially lower than the expected. The second greatest cell contributor to X^2 was "w" versus Grass. In this case the observed frequency was much higher than the expected. The results of this subtest tend to add additional credence to the generally accepted notion that grasslands are at least partially induced by seasonal precipitation deficiencies. In view of the weak CC of .52, however, the relationship is theorized to be only a moderate one.

Testing of Great Soils produced the second highest CC in the entire group (.90) (Table 5). Each of the four climatic regions was tested against Chernozem-Prairie, Gray-Brown Podzolic, and Podzol Soils (Table 7). Three cells of the twelve in the contingency table were especially strong contributors to the total X^2 statistic. The Chernozem-Prairie Soils had a much greater than expected frequency in the "Dwa" region. Gray-Brown Podzolic Soils in the "Dfa" and Podzol Soils in the "Dwb" also occurred with much greater than expected frequencies. Two subtests were conducted. In the first "f" and "w" were tested against Chernozem-Prairie and Gray-Brown Podzolic - Podzol Soils.[13] Within the "f" region 41 of 43

TABLE 7

THREE SOILS TESTS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Soils Groupings	.90[a]
2	2 Precipitation Distributions	2 Soils Groupings	.61[b]
3	2 Summer Types	2 Soils Groupings	.89[c]

[a]Strongest Relationships - "Dwa" - Chernozem-Prarie.
"Dfa" - Gray-Brown Podzolic.
"Dwb" - Podzol.

[b]Strongest Relationship - "f" - Gray-Brown Podzolic-Podzol.

[c]Strongest Relationships - "a" - Gray-Brown Podzolic.
"b" - Podzol.

samples were in the Gray-Brown Podzolic - Podzol Soils region. The CC of only .61 reflects the fact that in the "w" region the 55 samples were almost evenly divided between the Chernozem-Prairie and Gray-Brown Podzolic - Podzol Soils regions. The results of this subtest suggest that only when the summer is long and hot is precipitation distribution of great importance in predicting soil groups. Summer types "a" and "b" were compared to Gray-Brown Podzolic and Podzol Soils regions. All 34 "a" samples were in the Gray-Brown Podzolic Soil region. In the "b" region 28 of 35 samples were Podzols.[14] For this second subtest the CC was an expectedly high .89. In this case summer characteristics are important variables. The first test demonstrated that the combination of both precipitation distribution and temperature in the climatic year regions accounts for even more of the soils variation.

Snow

The third tested variable was length of snow cover (Table 5). Prior to investigating snow and climatic year region covariance the writer had theorized that such covariance did exist. However, as the Köppen system does not have any direct snow measures the type and/or amount of relationship was unknown. For this test the four climatic year regions were compared to three length of snow cover ones (11 - 60, 61 - 120, and 121 - 160 days) (Table 8). One of twelve cells ("Dfa" versus 11 - 60 day length of snow cover) accounted for more than one-fourth of the total X^2 value. The contribution of a second cell ("Dwb" versus 121 - 160 day length of snow cover) added almost another fourth of the X^2. The CC of .86 for this variable is indicative of a strong degree of covariance. A second analysis was made between summer types "a" and "b" and snow cover seasons of 10 - 100 days and 101 - 160 days. The CC for this analysis was .85.[15] Slightly less than two-thirds of the X^2 value was accounted for by the two "b" comparisons with almost all the "b" locations associated with longer length of snow cover season. A third analysis attempted to validate the hypothesis that longer snow cover seasons are associated with the "f" precipitation distribution regime

TABLE 8

THREE LENGTH OF SNOW COVER TESTS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Snow Cover Regions	.86[a]
2	2 Summer Types	2 Snow Cover Regions	.85[b]
3	2 Precipitation Distributions	2 Snow Cover Regions	--[c]

[a]Strongest Relationships - "Dfa" - Shortest Season.
"Dwb" - Longest Season.

[b]Strongest Relationship - "b" - Longest Season

[c]X^2 value was not statistically significant. No CC was calculated.

and shorter seasons with the "w" regime. Such appears not to be the case, however, as the null hypothesis had to be accepted at the .001, .01, and .02 levels. It can only be rejected at the .05 level. This is felt to be such a weak rejection level for X^2 that further investigation of the original hypothesis is unwarranted.

A fourth test was made to compare climatic year regions to total amounts of average annual snowfall (Table 5). In this testing climatic year regions were compared to total amounts of average annual snowfall (Table 9). The CC of .84 is only .02 less than the comparable value for length of snow cover. Two of twelve cells contributed more than half the total X^2 value. The "Dfb" region had much greater frequencies of heavy snowfall than expected; "Dfa" had fewer than expected. The addition of two more cells accounts for three-fourths of the X^2. The third had a much lower than expected frequency of low snowfall in the "Dwb"

TABLE 9

FIVE AVERAGE SNOW AMOUNT TESTS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Snow Amount Regions	.84[a]
2	2 Precipitation Distributions	5 Snow Amount Regions	.63[b]
3	"wa" versus "fa"	2 Snow Amount Regions	.64[c]
4	"wb" versus "fb"	2 Snow Amount Regions	.65[d]
5	2 Summer Types	3 Snow Amount Regions	.76[e]

[a]Strongest Relationships - "Dfb" - Heavy Snowfall.
"Dfa" - Light Snowfall.
"Dwb" - Moderate Snowfall.

[b]Strongest Relationships - "f" - Low Snowfall.
"w" - Moderate to Heavy Snowfall.

[c]Strongest Relationships - "wa" - Moderate Snowfall.
"fa" - Low to Moderate Snowfall.

[d]Strongest Relationships - "wb" - Low to Moderate Snowfall.
"fb" - Heavy Snowfall.

[e]Strongest Relationships - "a" - Low to Moderate Snowfall.
"b" - Moderate to Heavy Snowfall.

region while the fourth had a much higher than expected frequency of only moderate snowfall in the "Dwb" region. A ten cell table was constructed to analyze differences in snowfall amounts between "f" and "w". Although snowfall amounts were grouped into five categories a CC of .63 was achieved. The two cells that contributed most heavily to the X^2 were in the lowest snowfall category. The "f" cell had a higher than expected frequency; the "w" one had a much lower than expected frequency. Because of several anomalies in this test the writer extended it. First, "wa" was tested with "fa" in terms of low versus moderate snowfall. A CC of .64 was obtained.[16] Within the "a" region "w" showed an almost exclusive tendency to moderate snowfall amounts; "f", however, was almost evenly divided with about half the observations in a low snowfall area and the other half in a moderate one. Second, "wb" was tested against "fb". The value of .65 was obtained for the CC.[17] Examination of the table and X^2 values showed "wb" to have more than the expected frequency of low to moderate snowfall amounts and a lower than expected frequency of high snowfall amounts; "fb" showed just the opposite tendencies. A final analysis was made of snowfall amounts versus summer types "a" and "b". Summer region "a" had a strongly pronounced tendency toward low to moderate snowfall while summer region "b" had a moderately strong tendency to moderate to heavy snowfall.[18] The overall tendencies toward covariance in this last snow comparison are indicated by a CC of .76.[19]

Temperature

Three major analyses were made of temperature regions (Table 5). The first testing for length of the freeze free period was conducted to validate the hypothesis that there logically is a progression of increasing length of the freeze free period from cooler summer climates to warmer ones. Although .82 is a high CC it suggests that there is a less than perfect areal relationship. For the first test (Table 10) the greatest contribution to X^2 was the one cell of four that compared the shortest freeze free period to "Dwb". The observed frequency was two and one-half times greater than the expected. The second strongest cell compared the longest freeze free period to "Dfa". In this cell observed exceeded

TABLE 10

FOUR TESTS OF LENGTH OF FREEZE FREE PERIOD

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	4 Freeze Free Period Regions	.82[a]
2	4 Climatic Year Regions	2 Freeze Free Period Regions	.82[b]
3	2 Precipitation Distributions	4 Freeze Free Period Regions	.67[c]
4	2 Summer Types	4 Freeze Free Period Regions	.83[d]

[a]Strongest Relationships - "Dwb" - Shortest Freeze Free Period.
"Dfa" - Longest Freeze Free Period.

[b]Strongest Relationships - "Dwb" - Short Freeze Free Period.
"Dfa" - Long Freeze Free Period.

[c]Strongest Relationships - "f" - Long Freeze Free Period.
"w" - Short Freeze Free Period.

[d]Strongest Relationships - "a" - Long Freeze Free Period.
"b" - Short Freeze Free Period.

expected frequencies by two and one-half times. Mean length of the freeze free period was analyzed in three additional ways. Two periods were compared to the four climatic year regions. Almost the entire X^2 value was contributed by the four cells concerned with "Dfa" and "Dwb". One may conclude that "Dfa" and a long freeze free period covary strongly as do "Dwb" and a short freeze free period. Two additional CC statistics were calculated for precipitation distribution and summer type. The value .67 was obtained for precipitation distribution. The summer type value of .83 was somewhat stronger.

Two additional tests were added for comparison of number of hot days ($\geq 90^{\circ}$) and number of cold days ($\leq 32^{\circ}$) with climatic year regions. In both cases qualitative judgement would suggest that a strong degree of covariation ought to exist. However, as neither measure is directly included in the Köppen system the question may be asked as to what degree these factors covary. The warm season temperature analysis was made for annual number of days with temperature equal to or greater than 90° (Table 5). The single largest contributor to X^2 was the "Dfb" - small number of days cell (Table 11). Existence of several moderate or high value cell contributors to X^2 indicates a good degree of covariance among all the regions. Both summer type and precipitation distribution were also examined. The summer type CC was an expectedly high .86. Precipitation distribution, however, was a poor predictor. Its X^2 value was barely significant at .001 and the CC was only .53.

The last temperature analysis was made for annual number of days with minimum temperatures equal to or less than 32° (Table 5). Greatest differences between expected and observed frequencies as they contributed to X^2 were the "Dfa" and "Dwb" cells (Table 12). The "Dfa" region had many fewer cold minimum temperatures than expected; "Dwb" had many more. Two tests were conducted to see whether covariance was greater between summer types or precipitation regimes. The CC for the former was only .61 while its value for the latter was .73.[20] Even distribution "f" had many fewer cold minimum temperatures than expected; the winter dry distribution "w" had more. As neither summer type nor precipitation distribution is a measure in any direct way of cold winter temperatures the lower values of .61 and .73 are not surprising. Nonetheless, both values do indicate some form of relationship, even perhaps an accidental one.

TABLE 11

THREE TESTS OF NUMBER OF DAYS $\geq 90^{\circ}$

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Hot Period Regions	.82[a]
2	2 Summer Types	3 Hot Period Regions	.86[b]
3	2 Precipitation Distributions	3 Hot Period Regions	.53[c]

[a]Strongest Relationships - "Dfb" - Shortest Number of Days Region.
"Dfa" and "Dwa" - Long and Moderate Number of Days Regions.
"Dwb" and "Dfb" - Short and Moderate Number of Days Regions.

[b]Strongest Relationships - "a" - Long and Moderate Number of Days Region.
"b" - Short and Moderate Number of Days Region.

[c]No strong relationships.

TABLE 12

THREE TESTS OF NUMBER OF DAYS $\leq 32^{\circ}$

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	2 Cold Period Regions	.81[a]
2	2 Summer Types	2 Cold Period Regions	.61[b]
3	2 Precipitation Distributions	2 Cold Period Regions	.73[c]

[a]Strongest Relationships - "Dfa" - Short Number of Days Region.
"Dwb" - Long Number of Days Region.
[b]Strongest Relationships - "b" - Long Number of Days Region.
"a" - Short Number of Days Region.
[c]Strongest Relationships - "f" - Short Number of Days Region.
"w" - Long Number of Days Region.

Precipitation

In addition to snow analyses (above pp. 121-124) precipitation was examined in terms of: 1) total for the year; 2) yearly number of precipitation days; and 3) yearly number of thunderstorm days (Table 5). The highest value contributing cell to the X^2 statistic for total precipitation for the year, accounting for almost half its total value, is that representing "Dfa" versus high precipitation amounts (Table 13). In this case observed frequency was three times greater than expected. The second highest cell value is that for "Dfa" and low precipitation.[21] These two cells, of a total of twelve, account for over 60 per cent of the X^2 value. The third, fourth, and fifth highest value cells show a higher than expected frequency for "Dwb" and low precipitation and lower than expected occurrences of both "Dwa" and "Dwb" with high precipitation amounts. One of the writer's hypotheses conceived before the research was begun was that "f" regions have higher than expected precipitation amounts while "w" regions have greater than expected frequencies of small amounts. Contingency analysis only partially confirms this. The CC computed for "f" and "w" versus low and high precipitation amounts is only .60. Because of this low value two additional subtests were performed. The "fa" region was compared to the "wa" one. The result is a CC of .72.[22] The second subtest compared "fb" to "wb". Computed X^2 was so low that the null hypothesis had to be accepted as high as the .02 level. These two subtest suggest that meaningful regional differences in total precipitation occur within the "a" region on the basis of seasonal precipitation distribution, whereas similar differences do not occur within the "b" region.[23] Within the "a" region "f" has significantly greater

TABLE 13

FOUR TESTS OF TOTAL PRECIPITATION

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Precipitation Regions	.81[a]
2	2 Precipitation Distributions	2 Precipitation Regions	.60[b]
3	"fa" versus "wa"	2 Precipitation Regions	.72[c]
4	"fb" versus "wb"	2 Precipitation Regions	--[d]

[a]Strongest Relationships - "Dfa" - Heavy Precipitation.
"Dwb" - Light Precipitation.
"Dwa" - Light to Moderate Precipitation.

[b]Strongest Relationships - "f" is weakly related to Heavy Precipitation.
"w" is weakly related to Light Precipitation.

[c]Strongest Relationships - "fa" - Heavy Precipitation.
"wa" - Light Precipitation.

[d]X^2 value was not statistically significant. No CC was calculated.

than expected frequencies of high precipitation and smaller than expected frequencies of low precipitation. Within the "b" region frequencies of low precipitation amounts are higher than expected; those of high precipitation amounts are lower than expected.

Yearly number of precipitation days ($\geq$ .01 inch) has a reasonably high CC of .79. No strong trends throughout the study area appear in the data, however (Table 14). Two cells for "Dwa" compared with low and high numbers of precipitation days contribute slightly more than half the X^2 statistic. The balance of the statistic is spread rather evenly among ten other cells. Two other tests also tended to confirm

TABLE 14

THREE TESTS OF NUMBER OF PRECIPITATION DAYS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	3 Number of Days Regions	.79[a]
2	2 Summer Types	3 Number of Days Regions	.53[b]
3	2 Precipitation Distributions	3 Number of Days Regions	.70[c]

[a]Strongest Relationships - "Dwa" - Small Number of Days.
"Dfb" - Large Number of Days.
"Dfa" - Large Number of Days.

[b]Strongest Relationships - "b" - Large Number of Days.
"a" - Small Number of Days.

[c]Strongest Relationships - "f" - Large Number of Days.
"w" - Small Number of Days.

the above conclusion. First, "a" and "b" were tested; second, "f" and "w" were used. The two resultant CC statistics (.53 and .70) are both considerably less than .79. The entire analysis suggests that the strongest relationships are that "Dwa" is strongly associated with small numbers of rain days while "Dfa" and "Dfb" are moderately associated with greater numbers of rain days.

The last precipitation analysis was made for yearly number of thunderstorm days (Table 5). Six of eight cells in the first test showed significant deviations between observed and expected frequencies (Table 15). Summer types and precipitation distribution regimes were tested separately to attempt to see whether one factor or the other was distinctly stronger in its contribution to the CC. The subtest for "a" compared to "b" produced a CC of .83.[24] Conclusions from this subtest are that "a" summers have significantly greater numbers of thunderstorm

TABLE 15

THREE TESTS OF NUMBER OF THUNDERSTORM DAYS

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	2 Number of Days Regions	.78[a]
2	2 Summer Types	2 Number of Days Regions	.83[b]
3	2 Precipitation Distributions	2 Number of Days Regions	.39[c]

[a]Strongest Relationships - "Dfa" - Large Number of Days.
"Dwb" - Small Number of Days.
"Dfb" - Small Number of Days.

[b]Strongest Relationships - "a" - Large Number of Days.
"b" - Small Number of Days.

[c]Obtained X^2 was low. Null hypothesis only rejected at .01 level.

days than expected. Comparison of "f" with "w" showed only inconclusive results. The obtained X^2 was so low that the null hypothesis could only be rejected at the .01 level; the calculated CC was only .39.[25]

Continentality and Sunshine

Continentality and percentage of possible sunshine (both summer and winter) were the last three variables to be analyzed (Table 5). Continentality was used previously qualitatively as a control to explain the distribution of climatic year regions (Chapter V). Here it is quantitatively examined to determine to what degree it covaries in space with the climatic year regions (Table 16). A sixteen cell table resulted in a reasonably high CC of .77. Ten of the sixteen cells contributed virtually all of the X^2 value indicating covariance is important in a majority of cells. Eight of the ten were comparisons involving both the lowest and highest continentality values. The six cells that contributed

TABLE 16

THREE TESTS OF CONTINENTALITY

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	4 Continentality Regions	.77[a]
2	2 Summer Types	2 Continentality Regions	--[b]
3	2 Precipitation Distributions	4 Continentality Regions	.88[c]

[a]Strongest Relationships - "Dfa" - Low Continentality.
"Dwa" - Moderate to High Continentality.
"Dwb" - Moderate to High Continentality.

[b]Obtained X^2 was so low null hypothesis could not be rejected.

[c]Strongest Relationships - "f" - Low Continentality.
"w" - Moderate to High Continentality.

least to X^2 are all comparisons of the climatic year regions with intermediate continentality values. The subtest for comparison of only summer types resulted in an acceptance of the null hypothesis at all levels through .20. However, a second subtest for "f" and "w" produced a high CC of .88. The table showed "f" to be strongly associated with higher low continentality values and "w" to be associated with higher ones. The results of continentality testing were surprising though not unexpected. They were surprising because continentality itself is computed with annual temperature ranges and includes no measure of precipitation. However, the results were to be expected if general assumptions regarding relationships of winter air pressures over upper midlatitude continental land surfaces and precipitation amounts are correct.

The CC statistics of .73 and .72 for percentage of possible sunshine for June to August and December to February respectively show slightly weaker areal relationships than the other tested variables (Tables 17 and 18). Despite the slight difference of .01 between the

TABLE 17

THREE TESTS OF POSSIBLE JUNE-AUGUST SUNSHINE

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	2 Amount of Sunshine Regions	.73[a]
2	2 Summer Types	2 Amount of Sunshine Regions	.74[b]
3	2 Precipitation Distributions	2 Amount of Sunshine Regions	--[c]

[a]Strongest Relationships - "Dfb" - Little Sunshine.
"Dwa" - Much Sunshine.
"Dwb" - Little Sunshine.

[b]Strongest Relationships - "b" - Little Sunshine.
"a" - Much Sunshine.

[c]Obtained X^2 was so low null hypothesis could not be rejected.

TABLE 18

THREE TESTS OF POSSIBLE DECEMBER-FEBRUARY SUNSHINE

Test	Variable 1	Variable 2	CC
1	4 Climatic Year Regions	2 Amount of Sunshine Regions	.72[a]
2	2 Summer Types	2 Amount of Sunshine Regions	.25[b]
3	2 Precipitation Distributions	2 Amount of Sunshine Regions	.66[c]

[a]Strongest Relationships - "Dfb" - Little Sunshine.
"Dwa" - Much Sunshine.

[b]Obtained X^2 was so low null hypothesis could only be rejected at .10 level.

[c]Strongest Relationships - "f" - Little Sunshine.
"w" - Much Sunshine.

two seasonal CC values close examination of the two contingency tables and further subtests indicate there are seasonal differences in the areal relationships. One such difference is in the "Dwb" region. In summer sunshine is restricted; in winter, however, the area receives more sunshine than expected. A second seasonal difference is shown by the application of subtests of "a" and "b" and between "f" and "w" for the two seasons. In summer "a" and "b" produce a CC of .74[26] while "f" and "w" produce a X^2 for the null hypothesis that must be accepted at all levels up to .50. Winter has opposite results. The use of a subtest for "f" and "w" results in a CC of .66;[27] one for "a" and "b" produces a X^2 for the null hypothesis that may only be rejected at the .10 level. The resultant CC is a low .25. In summary it may be noted that in summer both "Dfa" and "Dwa" have higher than expected frequencies of great sunshine values. In winter "Dwa" and "Dwb" have greater than expected high sunshine values while "Dfa" and "Dfb" have greater than expected low sunshine values.

Summary

General covariance findings from contingency analysis for all considered variables as compared to climatic year regions in the Western Great Lakes States may be summarized as listed below. The "Dfa" climatic year region has Broadleaf Deciduous Forest Vegetation, Gray-Brown Podzolic soils, a short length of snow cover season, a small annual amount of snow, a short to moderate length freeze-free period, many days of hot maximum temperatures, few days with cold minimum temperatures, a moderate to large amount of total yearly precipitation, a large number of precipitation days,[28] a large number of thunderstorm days, a moderate degree of continentality, and varying amounts of possible sunshine during both summer and winter.

The second climatic year region "Dfb" has Mixed Broadleaf Deciduous-Needleleaf Evergreen and Needleleaf Evergreen Forest vegetation, Gray-Brown Podzolic and Podzol soils, a moderate to long length of snow season, large amounts of snow, a long to moderate length of freeze free season, few days of hot maximum temperatures, moderate to many days of cold minimum temperatures, a moderate amount of total precipitation,[29] a large number of precipitation days, a small number of thunderstorm days, a moderate degree of continentality, and a small percentage of the possible sunshine in both summer and winter.

The third climatic year region "Dwa" has a strong tendency to grass, Chernozem-Prairie soils, a moderate length of snow cover, only small to moderate amounts of snow, a long to moderate freeze-free period, a moderate to long period of high maximum temperatures, a moderate to long number of cold minimum temperatures, a small amount of total annual precipitation,[30] a moderate number of precipitation days,[31] a wide range of thunderstorm days from few to many, a high degree of continentality, and a great percentage of possible sunshine in both summer and winter.

The fourth climatic year region "Dwb" has Mixed Broadleaf Deciduous-Needleleaf Evergreen and Needleleaf Evergreen Forest vegetation, Podzol soils, a long snow cover season, a moderate amount of snowfall, a long to moderate freeze-free period, a wide range of maximum temperature days varying from many to few hot days, many days of cold minimum temperatures, a widely varying number of precipitation days, few thunderstorm days, a high degree of continentality, a small percentage of possible sunshine in summer, and a large percentage in winter.

Two factors must be considered in evaluation of the CC values calculated for the variables in this study. These factors are that accuracy of the entire sampling and correlation procedure depends upon both the scale and reliability of the source maps. Extremely large scale maps tend toward greater detail of isarithms and regions than used in the compilation of the Climatic Year Region map. Also, because C does not work well with large numbers of categories[32] the use of large scale maps tends to be precluded. Reliability of source maps must also be considered. A specific problem in this regard is to avoid maps drawn on the basis of factors other than those stated on the map. For example, it would be a nonsense correlation to compare climatic regions with vegetation ones if the vegetation source map had been partially based upon climate rather than upon vegetation samples. This is a distinct problem because of long held assumptions in physical geography about supposed relationships among climate, vegetation, and soils. Such assumptions may be valid but they generally have not been subjected to a rigorous testing procedure. Because of the above discussion, therefore, care was exercised in this study in the selection of source maps to insure that their scale was amenable to contingency analysis, and that where they did not purport to show climatic data they had not been drawn upon the basis of climatic considerations.

Where covariance has been demonstrated there are distinct advantages to using climatic year regions in the Western Great Lakes States for predicting the distribution of other environmental factors. At many locations only monthly temperatures and precipitation data are collected and published. In such cases climatic year regions may be used as predictors when data concerning the thirteen test variables are unavailable. Also, the existence of strong areal covariation ties this regional climatic classification system closely to physical geography which has as one of its goals the discovery of interrelationships among the factors of the physical environment. The discovery of covariance, itself, opens additional lines of investigation, outside the scope of this dissertation, regarding the causes of the relationships.

REFERENCES

[1]John P. Cole and Cuchlaine A.M. King, Quantitative Geography (London: John Wiley and Sons Limited, 1968), p. 135.

[2]Ibid., pp. 115-16.

[3]Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences (New York: McGraw-Hill Book Company, Inc., 1956), p. 249.

[4]Donald W. Maxfield, "Spatial Distributions and Spatial Association of Quantitative Phenomena" (paper presented at the 68th meeting of the Association of American Geographers, Kansas City, Missouri, 1972), pp. 5-6.

[5]A shortened form, $\sqrt{\frac{X^2}{N+X^2}}$, was used fo· calculations in this chapter.

[6]G. Udny Yule and M.G. Kendall, An Introduction to the Theory of Statistics (14th ed., 4th impression; London: Charles Griffen and Company Limited, 1965), p. 53.

[7]Great Britain, Meteorological Office, Air Ministry, Handbook of Statistical Methods in Meteorology, by Charles E.P. Brooks and N. Carruthers, M.O. 538 (London: Her Majesty's Stationery Office, 1953), p. 240.

[8]Ibid.

[9]Karl Pearson, "On the Measurement of the Influence of 'Broad Categories' on Correlation," Biometrika, Cambridge, IX (1913), 116 cited by C.E.P. Brooks and N. Carruthers, Handbook of Statistical Methods in Meteorology, p. 240. One problem found by this writer is that Pearson's upper limit for a 2 x 2 table (.6368) is less than the value .707 given in several works on statistics for the social sciences. See, for example, Siegel, Nonparametric Statistics for the Behavioral Sciences, p. 201. Because of the widespread use of .707, at least in the social sciences, it has been used by this writer for all 2 x 2 tables. Thus, all 2 x 2 tables yield CC values slightly smaller than those yielded by other tables. Wherever .707 has been used it is noted.

[10]As used in all thirteen tests "Dfa" includes small areas of "Cfa", "Csa", and "Dsa". See Fig. 13 for these exceptions.

[11]The upper limit used in calculation of CC was .707.

[12]Above, n. 11. [13]Above, n. 11. [14]Above, n. 11. [15]Above, n. 11.

[16]Above, n. 11.

[17]Above, n. 11.

[18]The two snowfall regions were differentiated by the 40 inch isarithm.

[19]Above, n. 11.

[20]Above, n. 11.

[21]No such cases occured.

[22]Above, n. 11.

[23]A further subtest was made of "a" compared to "b". Although X^2 was statistically significant at the .001 level the CC of .24 is too small in the writer's opinion to be geographical meaningful as a predictor at the scale of this investigation.

[24]Above, n. 11.

[25]Above, n. 11.

[26]Above, n. 11.

[27]Above, n. 11.

[28]Also there is a large minority of a moderate number of precipitation days.

[29]Also there is a large minority of locations of low precipitation amounts.

[30]Also there is a large minority of moderate amounts of total annual precipitation.

[31]Also there is a large minority of only a small number of precipitation days.

CHAPTER VII

CONCLUSIONS

As stated in the hypothesis (above Chapter I) the purposes for this study were threefold. Briefly, they were to: 1) improve the descriptive accuracy of the Köppen system of regional climatic classification through the use of climatic year methodology, 2) justify the distinctive physical characteristics of each of the climatic year regions by qualitative analysis of areal distributions of climatic controls; and 3) quantitatively establish and measure the strength of hypothesized covariance between climatic year regions and selected kinds of physical geographical phenomena.

With the application of climatic year methodology in the Western Great Lakes States area the writer found, outlined, described, and analyzed four more distinctively different climatic regions than the three conventionally obtained with the use of long-term means. These regions, based essentially on majorities of annual occurrences (in a few cases on pluralities), appear to accurately reflect the most frequent climatic conditions of those differentiated in the Köppen system present in each region. Additionally, the preparation of coded classifications (Appendix D) facilitated an examination of areal variations in annual precipitation distribution regimes, summer types, mesothermal and microthermal winters, and semiarid conditions. If one purpose of classification is to permit transmission of information[1] this study is a success. More precise definition and description of climates were obtained in the study area with climatic year methods than have been done with means in the unmodified Köppen system.

A major ancillary benefit of the use of climatic year methodology was element analysis. This method was directly permitted by the calculation of percentages in the coded classifications. It allowed considerably more detailed examinations of the nuances of temperature characteristics and precipitation distribution regimes in the area than could have been done with the Köppen system as it is usually applied. These examinations were able to note subtle tendencies, directions of change, and regions of strongly developed characteristics.

The element analysis found that a substantial portion of the western part of the Western Great Lakes States has the greatest percentage of its precipitation in the warm season. Also noted was a small area in the south that had a tendency to a summer dry regime. The examination of climatic controls and their interaction provided good evidence for the origin of these conditions. Also, the areal patterns of the controls appeared to satisfactorily explain the regional climatic differences noted in the climatic year regions and in the element analyses. The most prominant control factors found were continentality and the Great Lakes. Their influences were pervasive throughout the study area in explaining the regional differences in annual precipitation distribution regimes. Additionally, they were important in numerous locations in the determination of temperature characteristics.

Three significant additions were made to climatic year methodology in this study. These were addition of set theory modifications to the basic notational structure of the Köppen system, substitution of reordered climatic year data for that of the calendar year, and introduction of a modified Köppen climatic region designated as a climatic year region. The use of set theory modifications permitted the extension of element analysis into those areas that had semiarid conditions in order to study individual climatic element patterns unhindered by extraneous considerations of other relationships. Introduction of reordered climatic year data removed erroneous winter-summer comparisons and allowed accurate calculation of annual Köppen symbols and mapping of real rather than ficticious year-climates. The substitution of the modified climatic year regions for the more usual Köppen regions based on means allowed a greater degree of accuracy in the description of each region based on its statistical history and permitted a greater degree of regionalization by delineating additional regions.

A third aim of this study was an investigation of covariance and strength of relationship between the climatic year regions and each of thirteen selected variables of the physical environment. The purpose of this testing was to establish whether or not climatic year regions could be used to predict geographical patterns of other environmental phenomena. A secondary purpose of the testing procedure was to lay a quantitatively based foundation regarding the relationships of climate, vegetation and soils. Additionally, the results of the quantitative testing procedures add credence to previous qualitative assertions that Köppen climatic patterns covary with patterns of natural vegetation and soils. Within the parameters engendered by the use of the chi-squared distribution of probabilities and the mean-square contingency coefficient for nonparametric data it may be stated that the hypothesized covariances exist. Therefore, within the Western Great Lakes States Köppen climatic regions drawn on the basis of climatic year methodology may be used as predictors of the regional variations of those other elements of the physical environment tested in this study.

The contributions of this dissertation to regional climatology and physical geography have been: 1) an extension of the usefulness of the Köppen system of regional climatic differentiation to more accurately regionalize the climates of the study area, 2) a demonstration of the advantages of an expanded and extended climatic year methodology, and 3) to link the modified Köppen system more closely to physical geography by using it as a predictive tool. It is asserted that these contributions were achieved satisfactorily within the self-imposed constraint of staying within most of the basic definitional criteria of the Köppen system.

A major premise underlying the use of climatic year modifications to the Köppen system in this study was that the modified system and its climatic year regions are better than the original system and its regions. This study and its predecessors (Chapter II) appear to strongly support this contention. The reasons for this conclusion are as follows. The use of means in the original system definitely conceals differing climatic regimes in one region. Climatic year methods separate differing regimes into different regions. The original system has no discriminating power to analyze the strength of each regime. Element analysis in climatic year methodology permits almost any degree of discrimination desired. Although the regions of each system may be qualitatively compared to climatic controls the greater detail of climatic year regions allows more complex comparisons. Lastly, both systems are amenable to contingency analysis. But, as with controls analysis the greater detail of climatic year regions means a greater degree of comparison is possible.

Climatic year methods and climatic year regions have one outstanding advantage over competing, similar, broad scale world climatic classification systems. That is the element of compatibility. The modified system is close enough to the original that work in the original is not made obsolete. Additionally, the new regions in the modified system are easily understood by anyone who knows the original system because so few new terms and definitions have been introduced.

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[1] Grigg, p. 469.

APPENDIX A

KÖPPEN CLIMATIC CLASSIFICATION[a]

Primary Type

"B" Dry

Humid - Dry Boundary Data

1. Even Precipitation[b] $I = 0.44t - 8.5$[c]
2. Winter Dry $I = 0.44t - 3$
3. Summer Dry $I = 0.44t - 14$

$R > I$ = "C" or "D" (Humid Climates)[d]

$R \leq I$ = "B" (Dry Climates)

Secondary Type

"W" - Arid (Desert)
"S" - Semiarid (Steppe)

Arid - Semiarid Boundary Data

$$R > \frac{I \text{ (from 1, 2, or 3 above)}}{2} = \text{"S"}$$

$$R \leq \frac{I \text{ (from 1, 2, or 3 above)}}{2} = \text{"W"}$$

Tertiary Types

"C" or "D"; "f", "w", or "s"; and "a", "b", or "c" are defined as in "C" below.[e]

Primary Type

"C" Humid Mesothermal

Coldest Month < 64.4° and > 32°.[f]

Warmest Month > 50°.

Secondary Type

"w" - Winter Dry. Precipitation in driest month of winter half year ≤ 1/10 amount of wettest month of summer half year. Precipitation of winter half year ≤ 1/2 R.[g]

APPENDIX A - Continued

"s" - Summer Dry. Precipitation in driest month of summer half year $\leq$ 1/3 amount of wettest month of winter half year and $\leq$ 1.6 inches.[h]
Precipitation of summer half year $\leq$ 1/2 R.

"f" - Well Distributed Precipitation. Conditions for neither "w" nor "s" are met.

Tertiary Type

"a" - Hot Summer. Warmest month $\geq 71.6^{\circ}$.

"b" - Warm Summer. Warmest month $< 71.6^{\circ}$ and four or more months $\geq 50^{\circ}$.

"c" - Cool Summer. Warmest month $< 71.6^{\circ}$ and one to three months $\geq 50^{\circ}$.

Primary Type

"D" Humid Microthermal[i]
Coldest Month $\leq 32^{\circ}$.
Warmest Month $> 50^{\circ}$.

Secondary and Tertiary Types

Letter symbols and definitions as in "C" above.

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[a]Except as noted below numerical values for climatic classification as utilized in this study are those of Wladimir Köppen as stated in Handbuch der Klimatologie, Vol. I, Part C, "Das Geographische System der Klimate", ed. by W. Köppen and Rudolph Geiger (Berlin: Verlag von Gebruder Borntraeger, 1936), pp. 1-44, *passim*.

[b]Precipitation is said to be evenly distributed when neither half year, i.e., April - September or October - March, receives as much as 70 per cent of the total annual precipitation. If a half year receives as much as or more than 70 per cent of the total annual precipitation then this is a seasonal concentration for purposes of selecting the proper dry/humid boundary formula; the remaining half year is considered dry. This procedure is in accordance with the suggestions of Preston E. James and Henry M. Kendall in "Notes on Climatic Boundaries in the Eastern United States", Geographical Review, XXV (January, 1935), p. 120.

[c]I = index, t = mean annual temperature, R = total annual precipitation.

[d]Because of necessities in programming for automatic machine

processing of data the writer has found it necessary to add equality (=) to one statement in each pair of "either-or" choices for classification.

[e]In the "B" climates Köppen's tertiary position letters "h" and "k" for thermal indication and "w" and "s" for precipitation distribution are completely replaced by all values and symbols associated with "C" and "D" climates as suggested by James A. Shear in "A Set-Theoretic View of the Köppen Dry Climates", Association of American Geographers Annals, LVI (1966), 508-18.

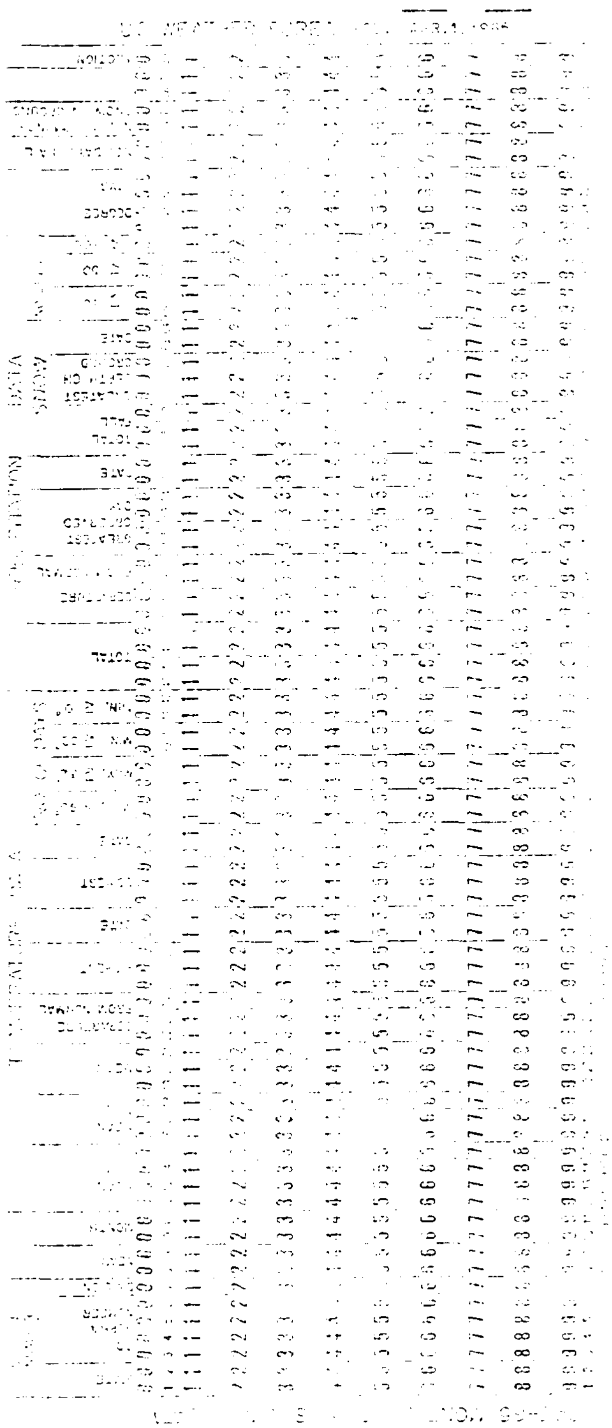
[f]The 32° winter isotherm has been selected as the boundary between the "C" and "D" climates in accordance with the proposal of Richard J. Russell in "Climates of California", University of California Publications in Geography, (1926), pp. 80-81.

[g]To insure logical consistancy for either "w" or "s" to be valid in climatic year classification the writer has added the criterion that the half year in question may have no more than one-half of the total annual precipitation.

[h]Both Köppen's suggestions and those of later writers are ambiguous regarding "s" definition. In Köppen's last major published work the figure of 40 mm. (1.57 in.) is shown in a classification chart whereas 30 mm. (1.19 in.) is mentioned in the text. See Köppen, "Das Geographishe System der Klimate", pp. 22 and 43. Recent use of the rounded figure 1.2 in. appears in Arthur N. Strahler, Physical Geography (New York: John Wiley and Sons, 3rd ed., 1969), p. 267 and in Helmut Landsberg, Physical Climatology (Dubois, Pa.: Gray Printing Company, Inc., 2nd ed., 1960), p. 365. These contrast with the use of the rounded figure of 1.6 in. as utilized in Howard J. Critchfield, General Climatology (Englewood Cliffs: Prentice-Hall, Inc., 2nd ed., 1966), p. 150; Clarence E. Koeppe and George C. DeLong, Weather and Climate (New York: McGraw-Hill Book Company, 1958), p. 194; and Henry M. Kendall, Robert M. Glendinning, and Clifford H. MacFadden, Introduction to Physical Geography (New York: Harcourt, Brace and World, Inc., 1967), p. 360. Because of this continuing confusion the writer has arbitrarily chosen the figure of 1.6 in.

[i]Köppen's primary types "A" (Tropical) and "E" (Polar) and his tertiary type "D-d" (Humid Microthermal-Severe Winter) were neither expected nor found in this study.

APPENDIX B



Monthly 1009 Summary Data Card

APPENDIX C

STATION NAMES AND NUMBERS

Number	Name	Number	Name
	Illinois		**Illinois - continued**
0072	Aledo	9241	Whitehall
0187	Anna	9354	Windsor
0338	Aurora		
0766	Bloomington-Normal		**Indiana**
1166	Cairo		
1584	Chicago (1572, 1582)	0200	Angola
2193	Decatur	0824	Bluffton (0831)
2348	Dixon	1747	Columbus
2483	DuQuoin	1882	Crawfordsville
2687	Effingham	2149	Delphi
3109	Flora	2605	Elliston
3257	Freeport	3037	Fort Wayne
3335	Galva	3527	Greenfield
3693	Greenville	3547	Greensburg
3717	Griggsville	3915	Henryville
3879	Harrisburg	4264	Indianapolis
3930	Havana (3940)	4407	Johnson Farm
4108	Hillsboro	4667	Kokomo (4662)
4198	Hoopeston	4837	LaPorte
4593	Kankakee	5237	Madison
4823	LaHarpe	5337	Marion
5079	Lincoln	6001	Mount Vernon
5326	Marengo	6580	Oolitic Farm
5515	McLeansboro	6705	Paoli
5712	Minonk	7362	Richmond
5751	Moline	7522	Rockville
5768	Monmouth	7755	Salem
5833	Morrison	8698	Tell City
5943	Mount Vernon	8999	Valpariso
6093	New Burnside (1992 Creal Springs)	9240	Warsaw
		9253	Washington
6526	Ottawa	9511	Wheatfield
6558	Palestine	9670	Winamac
6610	Paris	9678	Winchester
6711	Peoria		
6910	Pontiac		**Iowa**
7067	Quincy		
7551	Rushville	0133	Algona
8147	Sparta	0600	Bell Plaine
8179	Springfield	1319	Cedar Rapids
8740	Urbana	1635	Clinton
8916	Walnut	1731	Columbus Junction
9029	Waukegan	2136	Delaware

APPENDIX C - Continued

Number	Name
	Iowa - continued
2364	Dubuque
2999	Fort Dodge
4142	Iowa Falls
4381	Keokuk
5198	Marshalltown (5193)
5230	Mason City
5796	Mount Pleasant
5837	Muscatine
5952	New Hampton
7594	Sheldon
7678	Sigourney
7844	Spencer
7979	Storm Lake
8704	Waterloo (8706)
8755	Waukon
	Kentucky
4954	Louisville
4967	Lovelaceville
6091	Owensboro
7091	St. John (Cecilia 1406)
8714	Williamstown
	Michigan
0032	Adrian
0146	Alma
0169	Alpena
0230	Ann Arbor
0568	Bay City
0779	Big Rapids
1176	Cadillac
1299	Caro
2381	East Jordan
2394	East Lansing (Lansing 4641)
2423	East Tawas
2626	Escanaba
2737	Fayette
2846	Flint
3123	Germfask (Seney 7515)
3170	Gladwin
3290	Grand Haven
3319	Grand Marais
3429	Greenville
	Michigan - continued
3504	Gull Lake
3529	Hale
3585	Harbor Beach
3823	Hillsdale
3858	Holland
3914	Houghton (Calumet 1213, Houghton 3908)
3932	Houghton Lake
4090	Iron Mountain
4104	Ironwood
4150	Jackson
4954	Ludington
5000	Mackinaw
5065	Manistee
5073	Manistique
5178	Marquette
5531	Mio
5558	Monroe
5650	Mount Clemens
5690	Munising
5816	Newberry
6184	Onaway
6210	Ontanagon
6658	Pontiac
6680	Port Huron
7227	Saginaw
7366	Sault Ste. Marie
7690	South Haven
8184	Three Rivers
8251	Traverse City
8680	Watersmeet
	Minnesota
0018	Ada
0075	Albert Lea
0110	Alexandria (0112)
0195	Angus
0252	Argyle
0390	Babbitt
0541	Beardsly
0643	Bemidji
0746	Big Falls
0783	Bird Island
0934	Brainerd (0939)

APPENDIX C - Continued

Number	Name
	Minnesota - continued
1227	Cambridge
1245	Campbell
1263	Canby
1465	Chaska
1630	Cloquet
2142	Detroit Lakes
2698	Fairmont
2721	Faribault
2768	Fergus Falls
2916	Fosston
3282	Grand Marais
3290	Grand Meadow
3411	Gull Lake
3455	Hallock
4026	International Falls
4793	Little Falls
5020	Mahoning Mine
5136	Maple Plain
5204	Marshall
5400	Milan
5563	Montevideo
5598	Moose Lake
5615	Mora
5638	Morris
5887	New Ulm
6360	Park Rapids
6547	Pine River Dam
6565	Pipestone
6787	Red Lake Falls
6795	Red Lake Agency
6835	Redwood Falls
7004	Rochester
7087	Roseau
7294	St. Cloud
7405	St. Peter
7460	Sandy Lake
7907	Springfield
8323	Tracy (8329)
8419	Two Harbors
8543	Virginia
8579	Wadena
9046	Winnebago
9059	Winnibigosh
9067	Winona
9166	Worthington

Number	Name
	Missouri
2031	Crystal City (Festus 2850)
7465	St. Louis
	North Dakota
1766	Cooperstown
2859	Fargo
4203	Hillsboro
4958	Langdon
5013	Larimore
5660	Mayville
5754	McLeod
6620	Oakes
6857	Park River
6947	Pembina
8937	Valley City
	Ohio
1560	Cincinnati
2791	Findlay
4189	Kenton
5664	Napoleon (5669)
8552	Urbana
8609	Van Wert
9361	Xenia
	South Dakota
1049	Britton
1076	Brookings
1392	Canton
1739	Clark
3284	Gelhaus (Webster 9004)
3294	Gettysburg
4037	Howard
5228	Marion
8932	Watertown
9042	Wentworth
	Wisconsin
0175	Amery
0239	Antigo
0265	Appleton

APPENDIX C - Continued

Number	Name
	Wisconsin - continued
0349	Ashland
0603	Bayfield
0696	Beloit
0786	Big St. Germaine
0882	Blair
1078	Brodhead
1213	Burnett
1708	Coddington
1897	Crivitz
1978	Danbury
2001	Darlington
2173	Dodgeville
2428	Eau Claire
2839	Fon du Lac
2844	Fontana
3269	Green Bay
3405	Hancock
3471	Hatfield
3654	Hillsboro
4195	Kewaunee
4370	La Crosse
4482	Lake Mills
4546	Lancaster
4829	Long Lake
4961	Madison
5017	Manitowoc
5091	Marinette
5120	Marshfield
5164	Mather
5255	Medford
5364	Merrill
5479	Milwaukee
5516	Minoqua
5563	Mondovi
5581	Montello
5808	Neillsville
5932	New London
6208	Oconto
6330	Oshkosh
6398	Park Falls
6678	Plymouth
6718	Portage
6827	Prairie du Chien
6838	Prairie du Sac
6859	Prentice
	Wisconsin - continued
6922	Racine
7092	Rest Lake
7113	Rhinelander
7158	Richland Center
7226	River Falls
7708	Shawano
7725	Sheboygan
7892	Solon Springs
8027	Spooner
8110	Stanley
8171	Stevens Point
8267	Sturgeon Bay
8349	Superior
8827	Viroqua
8919	Watertown
8937	Waukesha
8951	Waupaca
8968	Wausau
9050	West Bend
9144	Weyerhauser
9304	Winter
9319	Wisconsin Dells
9335	Wisconsin Rapids
	Manitoba
0001	Brandon
0002	Winnipeg
	Ontario
0001	Lakehead (Fort William-Port Arthur)
0002	London
0003	Mine Centre

APPENDIX D

TABLE OF CODED STATION CLIMATIC YEAR CLASSIFICATIONS

Station Number	Name	Climatic Classification Letters and Percentages[a]	Average (mean) Classifications
		Illinois	
0072	Aledo	D^{100} w^{60} f^{40} a^{100}	Dfa
0187	Anna	$C^{51.7}D^{48.3}$ f^{50} $w^{26.7}$ $s^{23.3}$ a^{100}	Cfa
0338	Aurora	D^{100} f^{50} $w^{43.3}$ $s^{6.7}$ a^{90} b^{10}	Dfa
0766	Bloomington-Normal	D^{100} $f^{63.3}$ $w^{33.3}$ $s^{3.4}$ a^{100}	Dfa
1166	Cairo	C^{80} D^{20} $f^{43.3}$ s^{40} $w^{16.7}$ a^{100}	Cfa
1584 (1572, 1582)	Chicago	D^{100} $f^{53.3}$ w^{40} $s^{6.7}$ a^{100}	Dfa
2193	Decatur	$D^{96.7}C^{3.3}$ $f^{63.3}$ $w^{33.3}$ $s^{3.4}$ a^{100}	Dfa
2348	Dixon	D^{100} f^{50} w^{50} $a^{96.7}$ $b^{3.3}$	Dfa
2483	DuQuoin	$D^{56.7}C^{43.3}$ $f^{56.7}$ $s^{23.3}$ w^{20} a^{100}	Cfa
2687	Effingham	$D^{83.3}C^{16.7}$ f^{50} $w^{33.3}$ $s^{16.7}$ a^{100}	Dfa
3109	Flora	$D^{57.1}C^{42.9}$ f^{56} w^{28} s^{16} a^{100}	Cfa
3257	Freeport	D^{100} w^{60} f^{40} $a^{73.3}$ $b^{26.7}$	Dfa
3335	Galva	D^{100} w^{50} f^{50} a^{100}	Dfa
3693	Greenville	D^{78} C^{22} f^{52} w^{40} s^{8} a^{100}	Dfa
3717	Griggsville	D^{100} f^{56} w^{40} s^{4} a^{100}	Dfa
3879	Harrisburg	$C^{53.3}D^{46.7}$ f^{50} s^{30} w^{20} a^{100}	Cfa
3930 (3940)	Havana	D^{100} $f^{53.3}$ $w^{46.7}$ a^{100}	Dfa
4108	Hillsboro	$D^{86.7}C^{13.3}$ $f^{46.7}$ $w^{43.3}$ s^{10} a^{100}	Dfa
4198	Hoopeston	D^{100} $f^{53.3}$ $w^{33.3}$ $s^{13.4}$ a^{100}	Dfa
4593	Kankakee	D^{100} $f^{53.3}$ $w^{46.7}$ a^{100}	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Illinois - Continued	
4823	LaHarpe	D^{100} $w^{53.3}$ $f^{46.7}$ a^{100}	Dfa
5079	Lincoln	D^{100} $f^{66.6}$ w^{30} $s^{3.4}$ a^{100}	Dfa
5326	Marengo	D^{100} $f^{57.1}$ $w^{39.3}$ $s^{3.6}$ $a^{82.8}$ $b^{17.2}$	Dfa
5515	McLeansboro	$D^{56.7}C^{43.3}$ $f^{53.3}$ $w^{26.7}$ s^{20} a^{100}	Cfa
5712	Minonk	D^{100} $w^{55.6}$ $f^{44.4}$ a^{100}	Dfa
5751	Moline	D^{100} $w^{53.3}$ $f^{46.7}$ $a^{96.7}$ $b^{3.3}$	Dfa
5768	Monmouth	D^{100} w^{50} f^{50} $a^{96.7}$ $b^{3.3}$	Dfa
5833	Morrison	D^{100} f^{60} w^{40} a^{100}	Dfa
5943	Mount Vernon	D^{60} C^{40} f^{50} $s^{26.7}$ $w^{23.3}$ a^{100}	Cfa
6093 (1992)	New Burnside (Creal Springs)	$D^{53.3}C^{46.7}$ $s^{41.4}$ $f^{34.5}$ $w^{24.1}$ a^{100}	Cfa
6526	Ottawa	D^{100} $f^{53.3}$ $w^{46.7}$ a^{100}	Dfa
6558	Palestine	$D^{76.7}C^{23.3}$ $f^{55.2}$ $w^{24.1}$ $s^{20.7}$ a^{100}	Dfa
6610	Paris	D^{90} C^{10} $f^{44.8}$ $w^{34.5}$ $s^{20.7}$ a^{100}	Dfa
6711	Peoria	D^{100} w^{50} $f^{46.7}$ $s^{3.3}$ a^{100}	Dfa
6910	Pontiac	D^{100} $f^{53.3}$ $w^{46.7}$ $a^{96.7}$ $b^{3.3}$	Dfa
7067	Quincy	$D^{96.7}C^{3.3}$ $f^{53.3}$ $w^{46.7}$ a^{100}	Dfa
7551	Rushville	$D^{96.7}C^{3.3}$ $f^{51.7}$ $w^{48.3}$ a^{100}	Dfa
8147	Sparta	C^{50} D^{50} $f^{46.7}$ w^{30} $s^{23.3}$ a^{100}	Cfa
8179	Springfield	D^{100} f^{50} $w^{43.3}$ $s^{6.7}$ a^{100}	Dfa
8740	Urbana	$D^{96.7}C^{3.3}$ f^{60} $w^{36.7}$ $s^{3.3}$ a^{100}	Dfa

APPENDIX D-Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classifications
		Illinois - Continued	
8916	Walnut	D^{100} $w^{56.7}$ $f^{43.3}$ a^{100}	Dfa
9029	Waukegan	D^{100} f^{50} w^{40} s^{10} a^{80} b^{20}	Dfa
9241	Whitehall	$D^{93.3}C^{6.7}$ w^{50} $f^{46.7}$ $s^{3.3}$ a^{100}	Dfa
9354	Windsor	$D^{93.3}C^{6.7}$ f^{50} w^{30} s^{20} a^{100}	Dfa
		Indiana	
0200	Angola	D^{100} $f^{66.7}$ $w^{26.7}$ $s^{6.6}$ $a^{73.3}b^{26.7}$	Dfa
0824 (0831)	Bluffton	$D^{96.7}C^{3.3}$ $f^{57.1}$ $w^{39.3}$ $s^{3.6}$ $a^{86.7}$ $b^{13.3}$	Dfa
1747	Columbus	$D^{76.7}C^{23.3}$ $f^{53.4}$ $w^{23.3}$ $s^{23.3}a^{100}$	Dfa
1882	Crawfordsville	D^{90} C^{10} f^{60} $w^{36.7}$ $s^{3.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
2149	Delphi	$D^{93.1}C^{6.9}$ $f^{53.3}$ $w^{36.7}$ s^{10} $a^{96.7}$ $b^{3.3}$	Dfa
2605	Elliston	$D^{82.1}C^{17.9}$ $f^{53.3}$ $w^{36.7}$ s^{10} a^{100}	Dfa
3037	Fort Wayne	D^{100} f^{50} w^{50} $a^{87.5}$ $b^{12.5}$	Dfa
3527	Greenfield	$D^{83.3}C^{16.7}$ f^{50} $w^{36.7}$ $s^{13.3}a^{96.7}$ $b^{3.3}$	Dfa
3547	Greenburg	$D^{83.3}C^{16.7}$ $f^{55.2}$ $w^{24.1}$ $s^{20.7}a^{90}$ b^{10}	Dfa
3915	Henryville	$D^{72.4}C^{27.6}$ $f^{56.7}$ $s^{26.7}$ $w^{16.6}a^{100}$	Dfa
4264	Indianapolis	$D^{83.3}C^{16.7}$ $f^{53.3}$ w^{30} $s^{16.7}a^{100}$	Dfa
4407	Johnson Farm	$D^{62.1}C^{37.9}$ $f^{62.1}$ $w^{24.1}$ $s^{13.8}a^{100}$	Cfa
4667 (4662)	Kokomo	$D^{93.3}C^{6.7}$ $f^{56.7}$ w^{30} $s^{13.3}a^{100}$	Dfa
4837	LaPorte	D^{100} $f^{75.9}$ $w^{17.2}$ $s^{6.9}$ $a^{96.7}b^{3.3}$	Dfa
5237	Madison	$D^{51.9}C^{48.1}$ $f^{55.6}$ $s^{33.3}$ $w^{11.1}a^{100}$	Cfa
5337	Marion	$D^{96.7}C^{3.3}$ $f^{46.7}$ w^{40} $s^{13.3}a^{90}$ b^{10}	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Indiana - Continued	
6001	Mount Vernon	$D^{55.2}C^{44.8}$ $f^{46.7}$ $s^{33.3}$ w^{20} a^{100}	Cfa
6580	Oolitic Farm	$D^{75.9}C^{24.1}$ f^{60} $w^{23.3}$ $s^{16.7}$ a^{100}	Dfa
6705	Paoli	$D^{73.3}C^{26.7}$ $f^{51.7}$ $w^{27.6}$ $s^{20.7}$ a^{100}	Cfa
7362	Richmond	$D^{93.3}C^{6.7}$ $f^{53.3}$ $w^{26.7}$ s^{20} a^{80} b^{20}	Dfa
7522	Rockville	$D^{93.1}C^{6.9}$ $f^{60.8}$ $w^{32.1}$ $s^{7.1}$ a^{100}	Dfa
7755	Salem	$D^{63.3}C^{36.7}$ $f^{46.5}$ $s^{32.1}$ $w^{21.4}$ a^{100}	Cfa
8698	Tell City	$D^{51.9}C^{48.1}$ f^{43} $w^{28.5}$ $s^{28.5}$ a^{100}	Cfa
8999	Valpariso	D^{100} f^{60} $w^{36.7}$ $s^{3.3}$ a^{80} b^{20}	Dfa
9240	Warsaw	D^{100} $f^{63.3}$ $w^{33.3}$ $s^{3.4}$ $a^{75.9}$ $b^{24.1}$	Dfa
9253	Washington	$D^{65.5}C^{34.5}$ $f^{48.3}$ $w^{27.6}$ $s^{24.1}$ a^{100}	Cfa
9511	Wheatfield	D^{100} $f^{73.3}$ $w^{23.3}$ $s^{3.4}$ a^{80} b^{20}	Dfa
9670	Winamac	D^{100} $f^{62.1}$ $w^{34.5}$ $s^{3.4}$ $a^{86.7}$ $b^{13.3}$	Dfa
9678	Winchester	$D^{96.4}C^{3.6}$ $f^{46.5}$ $w^{39.3}$ $s^{14.2}$ $a^{83.3}$ $b^{16.7}$	Dfa
		Iowa	
0133	Algona	$D^{96.4}(BSD)^{3.6}$ $w^{96.4}$ $f^{3.6}$ $a^{81.5}$ $b^{18.5}$	Dfa
0600	Bell Plaine	D^{100} $w^{73.3}$ $f^{26.7}$ $a^{96.7}$ $b^{3.3}$	Dfa
1319	Cedar Rapids	D^{100} $w^{66.7}$ $f^{33.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
1635	Clinton	D^{100} w^{50} f^{50} $a^{96.7}$ $b^{3.3}$	Dfa
1731	Columbus Junction	D^{100} $w^{66.7}$ $f^{33.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
2136	Delaware	D^{100} $w^{76.7}$ $f^{23.3}$ a^{70} b^{30}	Dfa
2364	Dubuque	D^{100} $w^{72.4}$ $f^{27.6}$ $a^{93.1}$ $b^{6.9}$	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Iowa - Continued	
2999	Fort Dodge	D^{100} $w^{86.7}$ $f^{13.3}$ $a^{93.3}$ $b^{6.7}$	Dfa
4142	Iowa Falls	D^{100} w^{80} f^{20} $a^{76.7}$ $b^{23.3}$	Dfa
4381	Keokuk	D^{100} w^{60} f^{40} a^{100}	Dfa
5198 (5193)	Marshalltown	D^{100} $w^{76.7}$ $f^{23.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
5230	Mason City	D^{100} $w^{96.7}$ $f^{3.3}$ $a^{76.7}$ $b^{23.3}$	Dfa
5796	Mount Pleasant	D^{100} $w^{73.3}$ $f^{26.7}$ $a^{96.7}$ $b^{3.3}$	Dfa
5837	Muscatine	D^{100} $w^{65.5}$ $f^{34.5}$ a^{100}	Dfa
5952	New Hampton	D^{100} $w^{86.2}$ $f^{13.8}$ a^{60} b^{40}	Dfa
7594	Sheldon	$D^{93.3}(BSD)^{6.7}$ $w^{93.3}$ $f^{6.7}$ a^{80} b^{20}	Dfa
7678	Sigourney	$D^{93.3}(BSD)^{6.7}$ w^{69} f^{31} a^{100}	Dfa
7844	Spencer	D^{100} w^{100} $a^{79.3}$ $b^{20.7}$	Dfa
7979	Storm Lake	$D^{96.7}(BSD)^{3.3}$ w^{100} a^{80} b^{20}	Dfa
8704 (8706)	Waterloo	D^{100} $w^{82.8}$ $f^{17.2}$ $a^{86.2}$ $b^{13.8}$	Dfa
8755	Waukon	D^{100} $w^{82.8}$ $f^{17.2}$ $a^{58.6}$ $b^{41.4}$	Dfb
		Kentucky	
4954	Louisville	$C^{53.3}D^{46.7}$ $f^{53.3}$ $s^{36.7}$ w^{10} a^{100}	Cfa
4967	Lovelaceville	$C^{76.7}D^{23.3}$ s^{55} $f^{34.6}$ $w^{10.4}$ a^{100}	Cfa
6091	Owensboro	$D^{57.1}C^{42.9}$ $f^{62.1}$ s^{31} $w^{6.9}$ a^{100}	Cfa
7091 (1406)	St. John (Cecilia)	D^{64} C^{36} $f^{55.2}$ $s^{27.6}$ $w^{17.2}$ a^{100}	Cfa
8714	Williamstown	$D^{66.7}C^{33.3}$ f^{60} s^{30} w^{10} a^{100}	Cfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Michigan	
0032	Adrian	D^{100} $f^{56.7}$ $w^{36.7}$ $s^{6.6}$ $a^{76.7}$ $b^{23.3}$	Dfa
0146	Alma	D^{100} f^{50} w^{50} $a^{63.3}$ $b^{36.7}$	Dfa
0169	Alpena	D^{100} $f^{73.3}$ w^{20} $s^{6.7}$ $b^{96.7}$ $a^{3.3}$	Dfb
0230	Ann Arbor	D^{100} f^{60} $w^{26.7}$ $s^{13.3}$ $a^{73.3}$ $b^{26.7}$	Dfa
0568	Bay City	D^{100} $f^{56.7}$ $w^{33.3}$ s^{10} $a^{73.3}$ $b^{26.7}$	Dfa
0779	Big Rapids	D^{100} $f^{73.3}$ $w^{16.7}$ s^{10} $b^{83.3}$ $a^{16.7}$	Dfb
1176	Cadillac	D^{100} $f^{66.7}$ w^{20} $s^{13.3}$ $b^{89.3}$ $a^{10.7}$	Dfb
1299	Caro	D^{100} f^{60} $w^{33.3}$ $s^{6.7}$ $b^{56.7}$ $a^{43.3}$	Dfb
2381	East Jordan	D^{100} $f^{73.3}$ $w^{16.7}$ s^{10} $b^{86.2}$ $a^{13.8}$	Dfb
2394 (4641)	East Lansing (Lansing)	D^{100} $f^{66.7}$ $w^{23.3}$ s^{10} $b^{56.7}$ $a^{43.3}$	Dfb
2423	East Tawas	D^{100} $f^{59.3}$ $w^{33.3}$ $s^{7.4}$ b^{90} a^{10}	Dfb
2626	Escanaba	D^{100} $f^{63.3}$ $w^{36.7}$ $b^{96.7}$ $a^{3.3}$	Dfb
2737	Fayette	D^{100} $f^{63.3}$ $w^{26.7}$ s^{10} b^{100}	Dfb
2846	Flint	D^{100} $f^{66.7}$ $w^{23.3}$ s^{10} $a^{53.3}$ $b^{46.7}$	Dfb
3123 (7515)	Germfask (Seney)	D^{100} $f^{81.5}$ $s^{11.1}$ $w^{7.4}$ b^{100}	Dfb
3170	Gladwin	D^{100} $f^{62.1}$ $w^{34.5}$ $s^{3.4}$ $b^{83.3}$ $a^{16.7}$	Dfb
3290	Grand Haven	D^{100} $f^{66.7}$ w^{20} $s^{13.3}$ $b^{63.3}$ $a^{36.7}$	Dfb
3319	Grand Marais	D^{100} $f^{77.8}$ $w^{11.1}$ $s^{11.1}$ $b^{96.7}$ $c^{3.3}$	Dfb
3429	Greenville	D^{100} $f^{66.7}$ $w^{26.7}$ $s^{6.6}$ $a^{63.3}$ $b^{36.7}$	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Michigan - Continued	
3504	Gull Lake	D^{100} $f^{46.7}$ $w^{46.7}$ $s^{6.6}$ a^{60} b^{40}	Dfa
3529	Hale	D^{100} $f^{56.7}$ $w^{36.7}$ $s^{6.6}$ $b^{93.3}$ $a^{6.7}$	Dfb
3585	Harbor Beach	D^{100} $f^{73.3}$ $s^{16.7}$ w^{10} $b^{86.7}$ $a^{13.3}$	Dfb
3823	Hillsdale	D^{100} f^{70} $w^{16.7}$ $s^{13.3}$ $a^{56.7}$ $b^{43.3}$	Dfb
3858	Holland	D^{100} $f^{56.7}$ $s^{23.3}$ w^{20} a^{60} b^{40}	Dfa
3914 (1213, 3908)	Houghton (Calumet)	D^{100} $f^{76.7}$ $s^{16.7}$ $w^{6.6}$ b^{100}	Dfb
3932	Houghton Lake	D^{100} $f^{66.7}$ $w^{23.3}$ s^{10} b^{90} a^{10}	Dfb
4090	Iron Mountain	D^{100} w^{50} $f^{46.7}$ $s^{3.3}$ $b^{93.3}$ $a^{6.7}$	Dfb
4104	Ironwood	D^{100} f^{70} $w^{26.7}$ $s^{3.3}$ b^{90} a^{10}	Dfb
4150	Jackson	D^{100} $f^{66.7}$ w^{30} $s^{3.3}$ $a^{63.3}$ $b^{36.7}$	Dfa
4954	Ludington	D^{100} $f^{66.7}$ $s^{23.3}$ w^{10} $b^{83.3}$ $a^{16.7}$	Dfb
5000	Mackinaw	D^{100} $f^{46.7}$ $w^{36.7}$ $s^{16.6}$ $b^{93.3}$ $a^{6.7}$	Dfb
5065	Manistee	D^{100} f^{90} $s^{6.7}$ $w^{3.3}$ b^{70} a^{30}	Dfb
5073	Manistique	D^{100} f^{69} $w^{24.1}$ $s^{6.9}$ b^{100}	Dfb
5178	Marquette	D^{100} $f^{73.3}$ w^{20} $s^{6.7}$ b^{100}	Dfb
5531	Mio	D^{100} $f^{63.3}$ $w^{36.7}$ $b^{96.7}$ $a^{3.3}$	Dfb
5558	Monroe	D^{100} $f^{63.3}$ $w^{33.3}$ $s^{3.4}$ a^{90} b^{10}	Dfa
5650	Mount Clemens	D^{100} $f^{56.7}$ w^{30} $s^{13.3}$ a^{70} b^{30}	Dfa
5690	Munising	D^{100} $f^{83.3}$ $s^{13.3}$ $w^{3.4}$ $b^{96.7}$ $a^{3.3}$	Dfb
5816	Newberry	D^{100} $f^{73.3}$ w^{20} $s^{6.7}$ $b^{96.7}$ $a^{3.3}$	Dfb

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi- fications
		Michigan - Continued	
6184	Onaway	$D^{100}\ f^{76.7}\ w^{16.7}\ s^{6.6}\ b^{86.7}\ a^{13.3}$	Dfb
6210	Ontanagon	$D^{100}\ f^{63}\ w^{33.3}\ s^{3.7}\ b^{92.6}\ a^{7.4}$	Dfb
6658	Pontiac	$D^{100}\ f^{70}\ w^{26.7}\ s^{3.3}\ a^{70}\ b^{30}$	Dfa
6680	Port Huron	$D^{100}\ f^{60}\ w^{30}\ s^{10}\ a^{56.7}\ b^{43.3}$	Dfb
7227	Saginaw	$D^{100}\ f^{60}\ w^{30}\ s^{10}\ b^{66.7}\ a^{33.3}$	Dfb
7366	Sault Ste. Marie	$D^{100}\ f^{63.3}\ s^{26.7}\ w^{10}\ b^{100}$	Dfb
7690	South Haven	$D^{100}\ f^{83.3}\ s^{13.3}\ w^{3.4}\ b^{53.3}\ a^{46.7}$	Dfb
8184	Three Rivers	$D^{100}\ f^{46.7}\ w^{43.3}\ s^{10}\ a^{70}\ b^{30}$	Dfa
8251	Traverse City	$D^{100}\ f^{76.7}\ w^{16.7}\ s^{6.6}\ b^{80}\ a^{20}$	Dfb
8680	Watersmeet	$D^{100}\ w^{56}\ f^{44}\ b^{96.2}\ c^{3.8}$	Dfb
		Minnesota	
0018	Ada	$D^{100}\ w^{100}\ a^{58.6}\ b^{41.4}$	Dfb
0075	Albert Lea	$D^{100}\ w^{82.8}\ f^{17.2}\ a^{80}\ b^{20}$	Dfa
0110 (0012)	Alexandria	$D^{96.7}(BSD)^{3.3}\ w^{83.3}\ f^{16.7}\ b^{63.3}\ a^{36.7}$	Dfb
0195	Angus	$D^{96.7}(BSD)^{3.3}\ w^{96.3}\ f^{3.7}\ b^{89.7}\ a^{10.3}$	Dfb
0252	Argyle	$D^{96.2}(BSD)^{3.8}\ w^{92.3}\ f^{6.7}\ b^{93.1}\ a^{6.9}$	Dfb
0390	Babbitt	$D^{100}\ w^{89.3}\ f^{10.7}\ b^{96.4}\ a^{3.6}$	Dfb
0541	Beardsly	$D^{96.7}(BSD)^{3.3}\ w^{93.1}\ f^{6.9}\ a^{70}\ b^{30}$	Dfa
0643	Bemidji	$D^{100}\ w^{96.7}\ f^{3.3}\ b^{96.7}\ a^{3.3}$	Dfb
0746	Big Falls	$D^{100}\ w^{82.8}\ f^{17.2}\ b^{93.1}\ a^{6.9}$	Dfb
0783	Bird Island	$D^{100}\ w^{80}\ f^{20}\ a^{73.3}\ b^{26.7}$	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi- fications
		Minnesota - Continued	
0934 (0939)	Brainerd	$D^{100}\ w^{90}\ f^{10}\ b^{79.3}\ a^{20.7}$	Dfb
1227	Cambridge	$D^{100}\ w^{83.3}\ f^{16.7}\ b^{58.6}\ a^{41.4}$	Dfb
1245	Campbell	$D^{100}\ w^{92.9}\ f^{7.1}\ b^{62.1}\ a^{37.9}$	Dfb
1263	Canby	$D^{96.4}(BSD)^{3.6}\ w^{92.9}\ f^{7.1}\ a^{93.3}\ b^{6.7}$	Dfa
1465	Chaska	$D^{100}\ w^{93.3}\ f^{6.7}\ a^{76.7}\ b^{23.3}$	Dwa
1630	Cloquet	$D^{100}\ w^{73.3}\ f^{26.7}\ b^{100}$	Dfb
2142	Detroit Lakes	$D^{100}\ w^{90}\ f^{10}\ b^{86.2}\ a^{13.8}$	Dfb
2698	Fairmont	$D^{100}\ w^{93.3}\ f^{6.7}\ a^{83.3}\ b^{16.7}$	Dfa
2721	Faribault	$D^{96.7}(BSD)^{3.3}\ w^{96.7}\ f^{3.3}\ a^{76.7}\ b^{23.3}$	Dfa
2768	Fergus Falls	$D^{100}\ w^{90}\ f^{10}\ a^{66.7}\ b^{33.3}$	Dfb
2916	Fosston	$D^{93.3}(BSD)^{6.7}\ w^{96.7}\ f^{3.3}\ b^{81.5}\ a^{18.5}$	Dfb
3282	Grand Marais	$D^{100}\ w^{75}\ f^{25}\ b^{92.6}\ c^{7.4}$	Dfb
3290	Grand Meadow	$D^{100}\ w^{89.7}\ f^{10.3}\ b^{50}\ a^{50}$	Dfb
3411	Gull Lake	$D^{100}\ w^{86.7}\ f^{13.3}\ b^{73.3}\ a^{26.7}$	Dfb
3455	Hallock	$D^{93.3}(BSD)^{6.7}\ w^{96.7}\ f^{3.3}\ b^{83.3}\ a^{16.7}$	Dfb
4026	International Falls	$D^{100}\ w^{73.1}\ f^{26.9}\ b^{96.2}\ c^{3.8}$	Dfb
4793	Little Falls	$D^{100}\ w^{96.4}\ f^{3.6}\ b^{56.7}\ a^{43.3}$	Dfb
5020	Mahoning Mine	$D^{100}\ w^{84.6}\ f^{15.4}\ b^{96.2}\ a^{3.8}$	Dfb
5136	Maple Plain	$D^{100}\ w^{83.3}\ f^{16.7}\ a^{56.7}\ b^{43.3}$	Dfa
5204	Marshall	$D^{100}\ w^{96.7}\ f^{3.3}\ a^{80}\ b^{20}$	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Minnesota - Continued	
5400	Milan	D^{100} w^{90} f^{10} a^{70} b^{30}	Dfa
5563	Montevideo	D^{100} $w^{96.7}$ $f^{3.3}$ $a^{73.3}$ $b^{26.7}$	Dfa
5598	Moose Lake	D^{100} $w^{96.4}$ $f^{3.6}$ $b^{96.3}$ $a^{3.7}$	Dfb
5615	Mora	D^{100} $w^{83.3}$ $f^{16.7}$ b^{60} a^{40}	Dfb
5638	Morris	D^{100} $w^{93.1}$ $f^{6.9}$ a^{60} b^{40}	Dfb
5887	New Ulm	D^{100} $w^{86.7}$ $f^{13.3}$ $a^{83.3}$ $b^{16.7}$	Dfa
6360	Park Rapids	D^{100} $w^{76.7}$ $f^{23.3}$ $b^{83.3}$ $a^{16.7}$	Dfb
6547	Pine River	D^{100} $w^{93.3}$ $f^{6.7}$ $b^{93.1}$ $a^{6.9}$	Dfb
6565	Pipestone	D^{100} w^{100} $a^{66.7}$ $b^{33.3}$	Dwa
6787	Red Lake Falls	$D^{96.7}(BSD)^{3.3}$ $w^{96.7}$ $f^{3.3}$ $b^{81.5}$ $a^{18.5}$	Dfb
6795	Red Lake Agency	D^{100} $w^{86.2}$ $f^{13.8}$ $b^{96.7}$ $a^{3.3}$	Dfb
6835	Redwood Falls	D^{100} $w^{93.1}$ $f^{6.9}$ $a^{66.7}$ $b^{33.3}$	Dfa
7004	Rochester	D^{100} $w^{86.7}$ $f^{13.3}$ $a^{53.3}$ $b^{46.7}$	Dfb
7087	Roseau	D^{100} $w^{93.3}$ $f^{6.7}$ b^{90} $a^{6.7}$ $c^{3.3}$	Dfb
7294	St. Cloud	D^{100} w^{90} f^{10} $b^{56.7}$ $a^{43.3}$	Dfb
7405	St. Peter	$D^{96.7}(BSD)^{3.3}$ $w^{83.3}$ $f^{16.7}$ $a^{82.8}$ $b^{17.2}$	Dfa
7460	Sandy Lake	D^{100} $w^{86.7}$ $f^{13.3}$ $b^{93.3}$ $a^{6.7}$	Dfb
7907	Springfield	D^{100} $w^{96.4}$ $f^{3.6}$ $a^{85.7}$ $b^{14.3}$	Dfa
8323 (8329)	Tracy	$D^{96.7}(BSD)^{3.3}$ w^{100} a^{80} b^{20}	Dfa
8419	Two Harbors	D^{100} $w^{76.7}$ $f^{23.3}$ b^{100}	Dfb
8543	Virginia	D^{100} $w^{76.7}$ $f^{23.3}$ $b^{93.3}$ $a^{6.7}$	Dfb

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		<u>Minnesota</u> - Continued	
8579	Wadena	D^{100} $w^{93.3}$ $f^{6.7}$ b^{60} a^{40}	Dfb
9046	Winnebago	D^{100} w^{90} f^{10} $a^{66.7}$ $b^{33.3}$	Dfa
9059	Winnibigosh	D^{100} $w^{86.7}$ $f^{13.3}$ b^{90} a^{10}	Dfb
9067	Winona	D^{100} $w^{82.8}$ $f^{17.2}$ $a^{86.2}$ $b^{13.8}$	Dfa
9166	Worthington	$D^{96.7}(BSD)^{3.3}$ $w^{93.3}$ $f^{6.7}$ $a^{63.3}$ $b^{36.7}$	Dfa
		<u>Missouri</u>	
2031 (2850)	Crystal City (Festus)	$D^{59.3}C^{40.7}$ w^{58} s^{21} f^{21} a^{100}	Dfa
7465	St. Louis	$D^{56.7}C^{43.3}$ $f^{46.7}$ $w^{36.7}$ $s^{16.6}$ a^{100}	Cfa
		<u>North Dakota</u>	
1766	Cooperstown	$D^{93.3}(BSD)^{6.7}$ $w^{96.7}$ $f^{3.3}$ $b^{62.1}$ $a^{37.9}$	Dfb
2859	Fargo	D^{90} $(BSD)^{10}$ $w^{93.4}$ $f^{3.3}$ $s^{3.3}$ a^{60} b^{40}	Dfb
4203	Hillsboro	$D^{93.3}(BSD)^{6.7}$ $w^{96.6}$ $f^{3.4}$ $b^{53.3}$ $a^{46.7}$	Dfb
4958	Langdon	D^{90} $(BSD)^{10}$ $w^{83.3}$ $f^{13.3}$ $s^{3.4}$ $b^{93.3}$ $a^{6.7}$	Dfb
5013	Larimore	$D^{89.7}(BSD)^{10.3}$ w^{100} b^{69} a^{31}	Dfb
5660	Mayville	$D^{78.6}(BSD)^{21.4}$ $w^{96.6}$ $f^{3.4}$ a^{50} b^{50}	Dfb
5754	McLeod	$D^{89.7}(BSD)^{10.3}$ w^{100} $a^{58.6}$ $b^{41.4}$	Dfb
6620	Oakes	$D^{92.9}(BSD)^{7.1}$ w^{100} $a^{56.7}$ $b^{43.3}$	Dfb
6857	Park River	D^{80} $(BSD)^{20}$ w^{100} $b^{73.3}$ $a^{26.7}$	Dwb
6947	Pembina	$D^{92.6}(BSD)^{7.4}$ w^{100} $b^{79.3}$ $a^{20.7}$	Dfb
8937	Valley City	D^{80} $(BSD)^{20}$ $w^{93.3}$ $f^{6.7}$ a^{50} b^{50}	Dfb

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classifications
		Ohio	
1560	Cincinnati	$D^{76.7}C^{23.3}$ $f^{56.7}$ $s^{36.7}$ $w^{16.6}$ a^{100}	Cfa
2791	Findlay	$D^{96.7}C^{3.3}$ $f^{53.3}$ $w^{33.3}$ $s^{13.4}$ $a^{76.7}$ $b^{23.3}$	Dfa
4189	Kenton	$D^{96.7}C^{3.3}$ $f^{46.7}$ $w^{43.3}$ s^{10} $a^{79.3}$ $b^{20.7}$	Dfa
5664 (5669)	Napoleon	$D^{93.3}D^{6.7}$ $f^{71.4}$ $w^{21.4}$ $s^{7.2}$ $a^{86.7}$ $b^{13.3}$	Dfa
8552	Urbana	$D^{93.3}C^{6.7}$ f^{60} w^{30} s^{10} $a^{86.7}$ $b^{13.3}$	Dfa
8609	Van Wert	$D^{93.3}C^{6.7}$ $f^{63.3}$ $w^{30.0}$ $s^{6.7}$ a^{90} b^{10}	Dfa
9361	Xenia	D^{80} C^{20} $f^{55.2}$ $w^{34.5}$ $s^{10.3}$ a^{90} b^{10}	Dfa
		South Dakota	
1049	Britton	$D^{67.6}(BSD)^{21.4}$ w^{100} $a^{73.3}$ $b^{26.7}$	Dwa
1076	Brookings	$D^{83.3}(BSD)^{16.7}$ w^{100} $a^{56.7}$ $b^{43.3}$	Dwa
1392	Canton	$D^{93.3}(BSD)^{6.7}$ $w^{96.7}$ $f^{3.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
1739	Clark	$D^{89.3}(BSD)^{10.7}$ $w^{93.1}$ $f^{6.9}$ $a^{63.3}$ $b^{36.7}$	Dfa
3284 (9004)	Gelhaus (Webster)	$D^{96.7}(BSD)^{3.3}$ $w^{96.7}$ $f^{3.3}$ $a^{51.7}$ $b^{48.3}$	Dfb
3294	Gettysburg	$D^{65.5}(BSD)^{34.5}$ w^{100} $a^{83.3}$ $b^{16.7}$	Dwa
4037	Howard	$D^{86.2}(BSD)^{13.8}$ $w^{96.7}$ $f^{3.3}$ $a^{83.3}$ $b^{16.7}$	Dwa
5228	Marion	$D^{83.3}(BSD)^{16.7}$ $w^{96.7}$ $f^{3.3}$ a^{90} b^{10}	Dfa
8932	Watertown	$D^{96.7}(BSD)^{3.3}$ $w^{96.7}$ $f^{3.3}$ $a^{53.3}$ $b^{46.7}$	Dfb
9042	Wentworth	$D^{92.9}(BSD)^{7.1}$ $w^{96.7}$ $f^{3.3}$ a^{75} b^{25}	Dfb
		Wisconsin	
0175	Amery	D^{100} $w^{86.2}$ $f^{13.8}$ $b^{76.7}$ $a^{23.3}$	Dfb

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Wisconsin - Continued	
0239	Antigo	D^{100} $w^{86.7}$ $f^{13.3}$ $b^{86.7}$ $a^{13.3}$	Dfb
0265	Appleton	D^{100} w^{60} $f^{36.7}$ $s^{3.3}$ $a^{63.3}$ $b^{36.7}$	Dfa
0349	Ashland	D^{100} $w^{86.7}$ $f^{13.3}$ b^{100}	Dfb
0603	Bayfield	D^{100} $w^{81.8}$ $f^{13.6}$ $s^{4.6}$ $b^{96.2}$ $a^{3.8}$	Dfb
0696	Beloit	D^{100} $w^{60.7}$ $f^{39.3}$ $a^{96.7}$ $b^{3.3}$	Dfa
0786	Big St. Germaine	D^{100} $w^{78.6}$ $f^{21.4}$ b^{100}	Dfb
0882	Blair	D^{100} $w^{89.7}$ $f^{10.3}$ a^{60} b^{40}	Dfa
1078	Brodhead	D^{100} $w^{65.5}$ $f^{31.0}$ $s^{3.5}$ $a^{72.4}$ $b^{27.6}$	Dfa
1213	Burnett	D^{100} $w^{77.8}$ $f^{22.2}$ $b^{55.6}$ $a^{44.4}$	Dfb
1708	Coddington	D^{100} $w^{86.7}$ $f^{13.3}$ $b^{86.2}$ $a^{13.8}$	Dfb
1897	Crivitz	D^{100} $w^{82.1}$ $f^{14.3}$ $s^{3.6}$ $b^{83.3}$ $a^{16.7}$	Dfb
1978	Danbury	D^{100} $w^{78.6}$ $f^{21.4}$ $b^{79.3}$ $a^{20.7}$	Dfb
2001	Darlington	$D^{96.7}(BSD)^{3.3}$ w^{75} f^{25} $a^{56.7}$ $b^{43.3}$	Dfa
2173	Dodgeville	D^{100} w^{80} f^{16} s^{4} $a^{54.1}$ $b^{45.9}$	Dfa
2428	Eau Claire	D^{100} $w^{76.7}$ $f^{23.3}$ $a^{65.5}$ $b^{34.5}$	Dfa
2839	Fond du Lac	D^{100} $w^{63.3}$ $f^{36.7}$ $a^{56.7}$ $b^{43.3}$	Dfa
2844	Fontana	D^{100} f^{50} w^{50} a^{75} b^{25}	Dfa
3269	Green Bay	D^{100} f^{50} $w^{46.7}$ $s^{3.3}$ b^{60} a^{40}	Dfb
3405	Hancock	D^{100} $w^{83.3}$ $f^{16.7}$ $b^{56.7}$ $a^{43.3}$	Dfb
3471	Hatfield	D^{100} $w^{86.7}$ $f^{13.3}$ $b^{63.3}$ $a^{36.7}$	Dfb
3654	Hillsboro	D^{100} $s^{73.3}$ $f^{23.3}$ $s^{3.4}$ $a^{55.2}$ $b^{44.8}$	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Wisconsin - Continued	
4195	Kewaunee	D^{100} $w^{62.5}$ $f^{37.5}$ $b^{92.3}$ $a^{7.7}$	Dfb
4370	La Crosse	D^{100} $w^{83.3}$ $f^{16.7}$ a^{80} b^{20}	Dfa
4482	Lake Mills	D^{100} $f^{53.3}$ $w^{46.7}$ $a^{66.7}$ $b^{33.3}$	Dfa
4546	Lancaster	D^{100} $w^{76.7}$ $f^{23.3}$ $a^{86.7}$ $b^{13.3}$	Dfa
4829	Long Lake	D^{100} $w^{56.7}$ $f^{43.3}$ $b^{96.7}$ $a^{3.3}$	Dfb
4961	Madison	D^{100} $w^{53.3}$ $f^{46.7}$ $a^{73.3}$ $b^{26.7}$	Dfa
5017	Manitowoc	D^{100} $w^{53.3}$ $f^{46.7}$ b^{60} a^{40}	Dfb
5091	Marinette	D^{100} $f^{56.7}$ w^{40} $s^{3.3}$ $b^{53.3}$ $a^{46.7}$	Dfb
5120	Marshfield	D^{100} $w^{83.3}$ $f^{16.7}$ $b^{86.7}$ $a^{13.3}$	Dfb
5164	Mather	D^{100} $w^{79.3}$ $f^{20.7}$ b^{80} a^{20}	Dfb
5255	Medford	D^{100} $w^{82.8}$ $f^{17.2}$ $b^{89.7}$ $a^{10.3}$	Dfb
5364	Merrill	D^{100} $w^{89.7}$ $f^{10.3}$ $b^{83.3}$ $a^{16.7}$	Dfb
5479	Milwaukee	D^{100} $f^{46.7}$ w^{40} $s^{13.3}$ b^{60} a^{40}	Dfb
5516	Minoqua	D^{100} $w^{89.7}$ $f^{10.3}$ $b^{88.9}$ $a^{11.1}$	Dfb
5563	Mondovi	D^{100} $w^{90.9}$ $f^{9.1}$ $a^{58.3}$ $b^{41.7}$	Dfb
5581	Montello	D^{100} w^{70} f^{30} $b^{53.5}$ $a^{46.5}$	Dfb
5808	Neillsville	D^{100} $w^{83.3}$ $f^{16.7}$ $b^{65.5}$ $a^{34.5}$	Dfb
5932	New London	D^{100} w^{60} $f^{36.7}$ $s^{3.3}$ $b^{55.2}$ $a^{44.8}$	Dfb
6208	Oconto	D^{100} $w^{66.7}$ $f^{29.6}$ $s^{3.7}$ $b^{71.4}$ $a^{28.6}$	Dfb
6330	Oshkosh	D^{100} $w^{53.3}$ $f^{46.7}$ $a^{63.3}$ $b^{36.7}$	Dfa
6398	Park Falls	D^{100} $w^{73.3}$ $f^{26.7}$ $b^{93.3}$ $a^{6.7}$	Dfb

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Wisconsin - Continued	
6678	Plymouth	D^{100} $w^{55.2}$ $f^{41.4}$ $s^{3.4}$ $b^{62.1}$ $a^{37.9}$	Dfb
6718	Portage	D^{100} w^{75} f^{25} $a^{76.7}$ $b^{23.3}$	Dfa
6827	Prairie du Chien	D^{100} $w^{76.7}$ $f^{23.3}$ $a^{93.3}$ $b^{6.7}$	Dfa
6838	Prairie du Sac	D^{100} $w^{76.7}$ f^{20} $s^{3.3}$ $a^{86.7}$ $b^{13.3}$	Dfa
6859	Prentice	D^{100} $w^{73.3}$ $f^{26.7}$ $b^{96.7}$ $a^{3.3}$	Dfb
6922	Racine	D^{100} $f^{48.3}$ $w^{41.4}$ $s^{10.3}$ $a^{83.3}$ $b^{16.7}$	Dfa
7092	Rest Lake	D^{100} $w^{82.6}$ $f^{17.4}$ $b^{92.6}$ $a^{7.4}$	Dfb
7113	Rhinelander	D^{100} $w^{76.7}$ $f^{23.3}$ $b^{93.3}$ $a^{6.7}$	Dfb
7158	Richland Center	D^{100} $w^{73.3}$ $f^{26.7}$ a^{70} b^{30}	Dfa
7226	River Falls	D^{100} w^{80} f^{20} $a^{56.7}$ $b^{43.3}$	Dfb
7708	Shawano	D^{100} $w^{69.2}$ $f^{26.9}$ $s^{3.9}$ $b^{51.7}$ $a^{48.3}$	Dfb
7725	Sheboygan	D^{100} $f^{56.7}$ $w^{43.3}$ b^{50} a^{50}	Dfb
7892	Solon Springs	D^{100} w^{75} f^{25} $b^{86.2}$ $a^{13.8}$	Dfb
8027	Spooner	D^{100} w^{90} f^{10} $b^{75.9}$ $a^{24.1}$	Dfb
8110	Stanley	D^{100} w^{84} f^{16} $b^{80.8}$ $a^{19.2}$	Dfb
8171	Stevens Point	D^{100} w^{69} f^{31} $a^{53.3}$ $b^{46.7}$	Dfb
8267	Sturgeon Bay	D^{100} $f^{53.3}$ w^{40} $s^{6.7}$ b^{90} a^{10}	Dfb
8349	Superior	D^{100} $w^{79.3}$ $f^{20.7}$ b^{100}	Dfb
8827	Viroqua	D^{100} w^{80} f^{20} $a^{62.1}$ $b^{37.9}$	Dfa
8919	Watertown	D^{100} $w^{55.2}$ $f^{41.4}$ $s^{3.4}$ $a^{73.3}$ $b^{26.7}$	Dfa
8937	Waukesha	D^{100} $f^{53.3}$ $w^{46.7}$ a^{50} b^{50}	Dfa

APPENDIX D - Continued

Station Number	Name	Climatic Classification Letters and Percentages	Average (mean) Classi-fications
		Wisconsin - Continued	
8951	Waupaca	D^{100} w^{80} f^{20} a^{60} b^{40}	Dfb
8968	Wausau	D^{100} $w^{76.7}$ $f^{23.3}$ $b^{76.7}$ $a^{23.3}$	Dfb
9050	West Bend	D^{100} $w^{55.2}$ $f^{44.8}$ $b^{56.7}$ $a^{43.3}$	Dfb
9144	Weyerhauser	D^{100} w^{80} f^{20} $b^{86.2}$ $a^{13.8}$	Dfb
9304	Winter	D^{100} $w^{83.3}$ $f^{16.7}$ b^{100}	Dfb
9319	Wisconsin Dells	D^{100} $w^{76.7}$ $f^{23.3}$ $a^{63.3}$ $b^{36.7}$	Dfa
9355	Wisconsin Rapids	D^{100} w^{80} f^{20} b^{60} a^{40}	Dfb
		Manitoba	
0001	Brandon	D^{100} $w^{72.4}$ $f^{27.6}$ b^{100}	Dfb
0002	Winnipeg	D^{100} $w^{66.7}$ $f^{23.3}$ s^{10} $b^{93.3}$ $a^{6.7}$	Dfb
		Ontario	
0001	Lakehead (Fort William-Port Arthur)	D^{100} f^{50} $w^{36.7}$ $s^{13.3}$ b^{90} c^{10}	Dfb
0002	London	D^{100} $f^{53.3}$ $s^{36.7}$ w^{10} $b^{83.3}$ $a^{16.7}$	Dfb
0003	Mine Centre	D^{100} $w^{51.7}$ $f^{44.9}$ $s^{3.4}$ $b^{93.4}$ $a^{3.3}$ $c^{3.3}$	Dfb

[a] Pencentage values are rounded to the closest tenth. Values may appear to vary because data from less than thirty years have been used in some cases.

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