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REGIONAL WINTER CLIMATIC VARIATIONS
ASSOCIATED WITH ATMOSPHERIC CIRCULATION
CHANGE IN THE COTERMINOUS UNITED STATES:
1939 - 1965.

THE UNIVERSITY OF OKLAHOMA, PH.D., 1979

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THE UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

REGIONAL WINTER CLIMATIC VARIATIONS ASSOCIATED WITH ATMOSPHERIC CIRCULATION CHANGE IN THE COTERMINOUS UNITED STATES: 1939 - 1965

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

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By

ROBERT C. BALLING, JR.

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REGIONAL WINTER CLIMATIC VARIATIONS ASSOCIATED WITH ATMOSPHERIC CIRCULATION CHANGE IN THE COTERMINOUS UNITED STATES: 1939 - 1965

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TECHNICAL NOTES

This text was printed using the "SCRIPT" package available at the University of Oklahoma. The package was modified slightly from its original form developed at the University of Waterloo. Throughout the manuscript, "scientific" footnotes were employed. The last name of the author(s) appears first, followed by the year of the publication. Page numbers follow the year only if the material in this paper came from a specific point in a publication.

ABSTRACT

The primary objective of this investigation was to analyze the relationship between a change in the configuration of the general circulation of the atmosphere and associated changes in surface climatic conditions. The major questions raised by such a focus were addressed in three sections. First, changes that occurred in selected climatic elements were explored. Second, alterations in climatic regions were examined. Third, regions were produced based upon the type of climatic fluctuation that was observed.

Two ten year time periods differentiated by contrasting circulation regimes were selected for analysis. Investigators showed that the predominant circulation pattern of the atmosphere was zonal for the period 1939 through 1949 and was meridional from 1955 through 1965. Only winter data were utilized, for the relatively steep latitudinal temperature gradient during low-sun months tends to accentuate changes in regional climatic patterns. All one hundred fifty-one first-order climatological stations in the coterminous United States where continuous climatic data were recorded and published from 1939 to 1965 were included in this study.

Results from discriminant analyses demonstrated that the two carefully selected time periods could be differentiated based upon surface climatic data. Circulation and moisture components changed most significantly with the shift in the circulation pattern. Generally, moisture levels and temperatures for the atmosphere decreased, and wind speeds increased as the flow pattern became meridional. Distinctive spatial patterns existed in composite factor scores of climatic change data which reflected the development of an upper level ridge in the West and an upper level trough in the East during the meridional period.

Large, spatially homogeneous winter climatic regions were developed for each ten year period using principle-components factor analysis and a clustering algorithm. The configuration of these regions appeared to substantially change between the zonal and meridional time periods. Statistically significant differences in the west to east elongation of the resulting regions for the two periods could not be verified.

Regions were developed across the United States based upon the type of climatic variation that occurred with a shift in the general circulation. The results suggested that a fluctuation in the general circulation pattern was associated with regionally homogeneous changes in the surface climatic elements.

The findings of this investigation demonstrated that substantial changes occurred in the climatic configuration in association with a change in the predominant circulation pattern of the atmosphere. The potential applications and implications of the findings were discussed, and suggestions for future research were presented.

REGIONAL WINTER CLIMATIC VARIATIONS ASSOCIATED WITH ATMOSPHERIC CIRCULATION CHANGE IN THE COTERMINOUS UNITED STATES: 1939 - 1965

CHAPTER I

AN INTRODUCTION TO THE PROBLEM

Statement of the Problem

For approximately the first fifty years of this century, the field of climatology was primarily directed towards the collection and presentation of climatological data. The products that often resulted were maps showing the spatial patterns in a wide range of climatic elements gathered for often unspecified time periods. With continuing efforts in climatic classification, maps were generated displaying the spatial arrangements of climatic regions. These maps were published in a number of atlases and books, and in many cases, little effort was made to show that the patterns were less than "fixed" through time. More recent research in climatology has led to models of an atmosphere treated "dynamically" where motions and changes in the system were analyzed.

The goal of this investigation was to determine if a change in the global atmospheric circulation system was associated with a change in the surface climatic regimes, and to identify and analyze regions where the changes took place. Three major hypotheses were tested throughout this investigation:

1. As the circulation of the atmosphere shifted from a zonal to a meridional pattern, changes occurred in the surface climatic elements. Regional patterns in these surface changes should reflect the change in circulation.

2. As the predominant circulation pattern shifted, climatic regions in many areas of the United States changed in shape and size.

3. As the circulation shifted from a zonal to a meridional pattern, homogeneous regions formed based upon surface climatic changes.

The results of tests concerning the first hypothesis are presented in Chapter IV, where calculations were made to determine which of the climatic elements changed in association with a change in the configuration of the circumpolar vortex. The magnitude and significance of their change were calculated, and the spatial patterns of any observed changes were described. Analyses were conducted to determine if the two time periods, one zonal and the other meridional, could be discriminated based upon surface climatic data alone, and to determine if a significant regional pattern existed in the results from the discriminant functions.

To test the second hypothesis, Chapter V explores changes in climatic regions. Climatic regions were determined for each of two time periods and for an average period using a clustering procedure, and the results were mapped. An examination of the maps allowed differences in the regional alignments to be isolated. Shape measurements were utilized to test a hypothesis that climatic regions were more elongated in a west-east direction during the zonal period than in the meridional period, and that a significant change in shape occurred in conjunction with a fluctuation in the configuration of the general circulation.

In Chapter VI, the third hypothesis was tested where regions were produced based upon the changes that occurred in surface climatic conditions. Unlike the other sections of this study which identified patterns in the changes in the various climatic elements or changes in the configuration of climatic regions, this section displays results from attempts to identify regions, based upon cluster analysis, where the climatic configuration changed in unison. These analyses tested the notion that changes in atmospheric circulation produced regionally homogeneous climatic responses.

Background

Few areas of research in climatology have received as much attention in recent years as those dealing with climatic change. Reports from these investigations have filled books, and both professional and popular journals at unprecedented rates. The goals of these studies have been varied, but generally, investigators have attempted to describe the causes and mechanisms of climatic change, or they have attempted to explain the effect of these changes on some specific location, region, or upon some phenomena. Oliver (1973) and Beckinsale (1973) have summarized the leading theories of climatic change, Grove (1969) and Markham (1975) have published climatic change studies emphasizing the effects on specific areas, and Oliver (1973), Smith (1975), and Mather (1974) have discussed the relationship between climate and a variety of activities.

The many theories that have been developed to explain the causes of climatic change that were reviewed by Beckinsale (1973) can be grouped into several categories: extraterrestrial, atmospheric, and terrestrial. Changes in the energy released by the sun, whether in association with the well-known twenty-two year sunspot cycle (Willett, 1951) or through geologic time, were leading explanations of extraterrestrial factors. The work of Milankovitch (1930) has demonstrated a linkage between earth-sun geometry and climatic variations and also falls in this extraterrestrial category.

Changes in the chemical composition of the atmosphere have also been viewed as factors in climatic change. Variations in carbon dioxide, water vapor, volcanic dust, and ozone have all been posed as possible factors in climatic change by a variety of authors (Plass, 1956; Davitaya, 1969; Landsberg, 1970; Schneider and Mass, 1975; and Wexler, 1952) and are leading topics for atmospheric explanations of climatic variations.

Several authors have examined the role of terrestrial changes, including mountain building (Brooks, 1951) and albedo variations (Kukla and Kukla, 1974) as factors in climatic change. Currey (1962) suggested that random fluctuations in climate may be sufficient enough to create change on the magnitude needed to produce glacial epochs.

The very terminology used by various authors continues to provide some confusion to the study of climatic change. Addressing this problem, Landsberg (1975) suggested that the terms revolution, change, fluctuation, iteration, and alteration be given precise temporal connotations. Using Landsberg's terminology, the kind of climatic variation discussed in this paper was a climatic fluctuation, defined with a duration of ten to one thousand years. Throughout this report, these two terms, change and fluctuation, will be interchangably used to describe the variation in climate between two ten year periods.

Although many theories have been developed to explain the causes of climatic variations, and many terms have been incorporated to describe them, many leading atmospheric scientists agreed that climatic fluctuations, whatever the causes, are manifested in the atmosphere's general circulation system (Mitchell _et al._, 1971). Harman (1971) summarized a large amount of work aimed at explaining this general circulation. Simply, the energy imbalance between the lower and higher latitudes drives the general circulation system keeping the earth in an energy equilibrium. Surplus energy, in several forms, is transported from the equatorial regions poleward to the higher latitudes where outgoing radiation exceeds incoming radiation. This energy transport creates the general patterns of wind for the globe. Due to Coriolis deflection acting upon air parcels moving poleward, a band of strong, westerly wind currents forms in the upper atmosphere of the middle latitudes which surrounds the pole. This band lies at the boundary of the cooler, polar air masses on its poleward side and the warmer, tropical air masses on its equatorward side. If the temperature gradient is relatively small between the lower and higher latitudes, these wind currents travel around the globe in a generally latitudinal fashion, referred to as a zonal flow. However, if this temperature gradient steepens, the circular flow forms a sinuous pattern moving around the hemisphere with stronger north-south components, still at the boundary of the polar and tropical air masses. The second configuration is a meridional flow pattern. Whatever the configuration, the wind band, called the circumpolar vortex, significantly affects the weather and climate of the earth's surface, particularly in the middle latitudes where the boundary between the polar and tropical air masses is normally located. The circumpolar vortex tends to persist at some level of equilibruim, but a change in the annual energy balance of the earth, for whatever reason, can force a stepwise change in the configuration of the circumpolar vortex, creating a climatic fluctuation.

The type of climatic conditions found at the surface in association with mean wave positions follow a set of well-known principles. Harman (1971:15) stated:

> In the vicinity of a trough where air flows from higher to lower latitiudes, temperature departures are negative as polar air masses, transported southward by the prevailing northwesterly flow, overspread the region. Beneath the ridge, in contrast, warmer than normal air is advected northward and mean temperature departures are correspondingly positive.

More directly, higher than normal pressures are found in the region dominated by an upper level ridge, lower pressures are found at the surface in the vicinity of the trough.

The mean position of these wave features also affects vertical motions in the atmosphere critical in the precipitation formation processes. Just ahead of the upper level ridge, air flow is in a converging pattern, favoring subsidence of air parcels towards the surface, inhibiting precipitation formation. The subsidence pattern also favors lighter than normal wind speeds. Ahead of the upper level trough, divergence occurs in the upper atmosphere. This condition favors surface convergence and convection, with stronger wind speeds at the surface, increasing the potential for precipitation formation. Increases in the amplitude (north-south dimensions) of the long waves accentuates these vertical motions in the atmosphere. Positive precipitation departures are therefore expected ahead of upper level troughs, and negative departures are expected ahead of upper level ridges. The surface climatological data will reflect these patterns only if these long waves remain relatively stationary for extended periods of time.

The linkage between upper level flow patterns and surface climatic conditions has been studied using a set of physical equations. General circulation models, such as the one developed by Manabe (1969), allow for interactions to occur through different vertical levels in the atmosphere. The construction of a climatic model demands rigorous evaluation of the processes which make up the climatic system. By employing the equation of state for a perfect gas, the First Law of Thermodynamics, the hydrostatic equation, equations of horizontal motion, and equations for the continuity of mass and the continuity of water substance, the basic physical processes occurring in the atmosphere are modeled. Reasonable approximations are calculated from the models for both surface and upper level climatic conditions. The results of the models demonstrated that the connections between upper level flow patterns and surface conditions are not only understood at the descriptive level, but these connections are also understood and established using sound physical principles.

A number of authors have investigated the timing and causes of climatic fluctuations. Kalnicky (1974) presented convincing evidence that the change from a zonal to a meridional flow occurred in the early 1950's. He factor analyzed a time series matrix containing the number of days represented by each of Dzerdzeevskii's forty-one circulation types from January 1, 1899 through December 31, 1969. The eigenvectors calculated were interpreted as zonal or meridional, and factor scores for each year were plotted through time. For both the summer and winter data, a stepwise change in the predominant circulation occurred in the early 1950's. Kalnicky noted that the change in circulation corresponded closely with a shift from warming to cooling in the Northern Hemisphere.

Dzerdzeevskii (1969) reported similar findings to those of Kalnicky. The basis of Dzerdzeevskii's work was in the classification of circulation regimes into "types." He also showed that by the early 1950's, the general circulation of the atmosphere had shifted from a predominantly zonal pattern to one that was meridional. He suggested that this shift was observable in changes in regional patterns of precipitation and temperature which may in turn significantly affect hydrological phenomena.

The noted British investigator, H. H. Lamb, has also studied changes in circulation through time (Lamb, 1966). Lamb examined temperature and precipitation patterns, and described the effects of changes in these elements upon hydrological features in Africa. Construction of pressure anomaly maps led Lamb to conclude that the first half of the 1960's had seen meridional windstreams become more prevalent in the extratropical latitudes of the Northern Hemisphere. He also concluded that there were reasons to expect more variability in seasonal rainfall and temperatures in many regions to accompany the meridional flow pattern.

Wahl and Lawson (1970) published findings that demonstrated that the late 1950's and 1960's appeared to be very similar to a time period 1850 through 1869. By comparing climatological data from thirty-five areas in the United States from the mid-nineteenth century to the 1931 - 1960 "climatic normals" for the same regions, the authors concluded that the earlier period was dominated by meridional circulation. During the 1850's and 1860's, the western states appeared to be relatively warmer than the eastern states. Precipitation values were thought to be less reliable than temperature, but it appeared that the western states were wetter than the eastern ones in the mid-1800's. Spatial patterns in more recent climatic data, a period from 1959 through 1968, strongly resembled the meridional pattern of the 1850's and 1860's.

In an article describing conditions on the American Great Plains over the past eighty years, Borchert (1971) showed that drought continued to occur at intervals of approximately twenty years. The pattern of drought observed through time closely followed changes in the predominant flow patterns which have also fluctuated near this twenty year interval. Borchert reported that the zonal flow dominated in the 1930's; by the early 1950's, the pattern was reported to have shifted back to meridional. Consequential impacts on water availability, soil salinity, crop productivity, and on migration of farmers were noted.

Geographical Approach

Changes in the circumpolar vortex have been studied through a variety of disciplines. Investigators have used these ideas to study geological phenomena (Brooks, 1951), discontinuities in civilizations (Wendland and Bryson, 1974 and Bryson and Murray, 1977), and changes in animal and plant communities (Crisp, 1959). The development of general circulation models for the atmosphere relied heavily on changes in the configuration of the system to balance energy disparities (Smagorinsky, 1971).

The interdisciplinary nature of the study of climatic variation is well suited to inquiry by the geographer interested in climatology. The question that persisted, however, was how should geographers study climatological phenomena in some uniquely geographical way? This topic was debated vigorously in the 1950's; some geographers (Jones, 1950 and Pitts, 1956) argued that climatologists needed to be applied, providing direct input into other geographical studies. Trewartha (1957) argued that climatology was an atmospheric science that should be studied for its own sake. Hare (1966) stated that geographers should view climate in terms of impact on human activities. Terjung (1976) argued that models created in geographical climatology should be linked to the general decision-making process. In this investigation, some attempt was made to indicate the usefulness, in terms of human activity, of the findings.

Studying some phenomenon geographically goes beyond developing the implications of the results to human activity. Geography is fundamentally a study of spatial patterns exhibited by phenomena. Stringer (1972:35-36) stated that the aim of the geographer was to assess the extent to which atmospheric phenomena are manifested regionally. The spatial approach remains the common factor cementing the discipline, not the emphasis on utility. Hence, this investigation generally sought to find spatial patterns in the changes of climatic elements in associated with a fluctuation in the circulation pattern of the atmosphere.

Potential Contributions

Each section in this investigation holds potentially useful contributions, not only to the atmospheric sciences, but to many physical and social studies for which climate is a component. The combined efforts reported in this investigation addressed a fundamental point in much of the research in the field of climatic change: do changes in atmospheric circulation coincide with significant changes in the surface climatic parameters, and do these changes, if observed, display distinctive spatial patterns? It is well established that many cultural activities are linked to climatic elements (Oliver, 1973; Smith, 1975; and Mather, 1974). For example, many models reviewed by McQuigg (1975) related climate to the production of food, water supply and demand, energy consumption, and to commercial and industrial activities. Knowledge regarding which elements have changed and the magnitude of their change is vital in decision-making areas sensitive to atmospheric conditions. Defining regions where the magnitude of change was greatest is useful in establishing indices of risk from climatic fluctuations. Determining which elements change the most may be useful in monitoring the intensity of future climatic fluctuations, or in the interpretation of climatic histories. In that many activities and phenomena have been shown to closely follow the boundaries of climatic regions, isolating changes in the boundaries is an important factor in predicting shifts in the spatial patterns of the phenomena under consideration.

The urgency for studies in climatic variability in connection with national activities was spelled out in the recent United States Climate Program Plan (Interdepartmental Committee for Atmospheric Sciences, 1977). Throughout this Program Plan, the sensitivity of many human activities to climatic conditions was stressed. Climatic variability studies where recent climatic fluctuations were investigated were viewed as important in identifying the key climatic elements of the global system that were sensitive to climatic change, allowing cause and effect hypotheses to be tested. Tests of the numerical models must include simulation of past climates, and results of this study could be used in model verification. Studies displaying regional patterns in climatic change may lead to the identification of interrelationships, through space, existing in the climatic change processes. Information on past climatic fluctuations is also needed in developing the requirements for refining the obsevational network. In sum, the United States Climate Program Plan called for the explicit determination of the nature of climatic fluctuations that have occurred in the United States.

CHAPTER II

GENERAL OPERATIONAL CONSIDERATIONS AND METHODOLOGICAL FRAMEWORK

Operational Considerations

Temporal Considerations

The definition of surface climatic changes between two contrasting circulation regimes required the selection of a time period that had been dominated by two distinctively different circulation types. The time period must have been long enough to give climatic averages significance. The consensus of a group of climatic researchers (Borchert, 1971; Dzerdzeevskii, 1969; Kalnicky, 1974; Lamb, 1966, 1969; and Wahl and Lawson, 1970) supported the conclusion that upper air circulation was zonal during the 1930's, 1940's, and early 1950's. By 1955, the circulation shifted to a meridional pattern that has persisted through the 1970's. For this investigation, ten years, a standard time scale in climatology (Mitchell *et al.*, 1971), of each circulation type was represented. Only winter data (December, January, and February) were utilized in that temperature gradients are steepest in winter from equator to pole, and climatic fluctuations tend to be accentuated during the low-sun months. During the summer, the relatively small horizontal temperature gradient leaves the general circulation in a weak, poorly defined state.

Two study periods were selected primarily on the basis of the work of Kalnicky (1974). One, the zonal period, was defined as the ten years of winter climatic data from December, 1939 to February, 1949; the meridional period began in December, 1955 and continued through February, 1965. This scheme yielded two distinctly different ten year periods, one dominated by a zonal flow, the other by meridional circulation.

Figure 1 displays the modal 500 millibar circulation patterns for the zonal and meridional periods. Often, mean flow calculation smooth out variations occurring from month to month. Over longer periods of time, in this case thirty months of each type of circulation, differences between the zonal and meridional mean prevalent flow patterns would be lost in the averaging process.

The patterns displayed in Figure 1 were developed from an examination of the 500 millibar pressure surfaces for all zonal and meridional months in this study. These pressure maps were published in the <u>Monthly Weather Review</u> until 1950, and then were continually published in

Climatological Data: National Summary. The contour interval for the maps in Figure 1 is approximately fifty meters, with the highest values of the pressure surface found in the southern regions. The magnitude for each contour line was not presented, for these maps display the modal shape of the 500 millibar surface. The mean height of this surface may change from month to month, but only the pattern of the surface was of interest here. The major difference between the two was the large ridge developed over the Rockies and the trough over the eastern one half of the United States during the meridional period.

Selection of Climatic Elements

In many climatological investigations, temperature and precipitation values averaged at the monthly time scale, comprised the data for which the study was based. Ideally, many more variables of the climatic configuration should be included, but too often, the lack of quality measurements through time and space restricted the use of less conventional variables (e.g. solar radiation, evaporation, vorticity). In this study, attempts were made to include some type of measurement from each of the atmosphere's three major components: (1) a measure of vorticity or surface circulation; (2) heat energy; and (3) moisture. Barrett (1970) suggested that these three components, in one form or another, were the basis for most climatological studies. In actual practice, surrogates for each were determined from

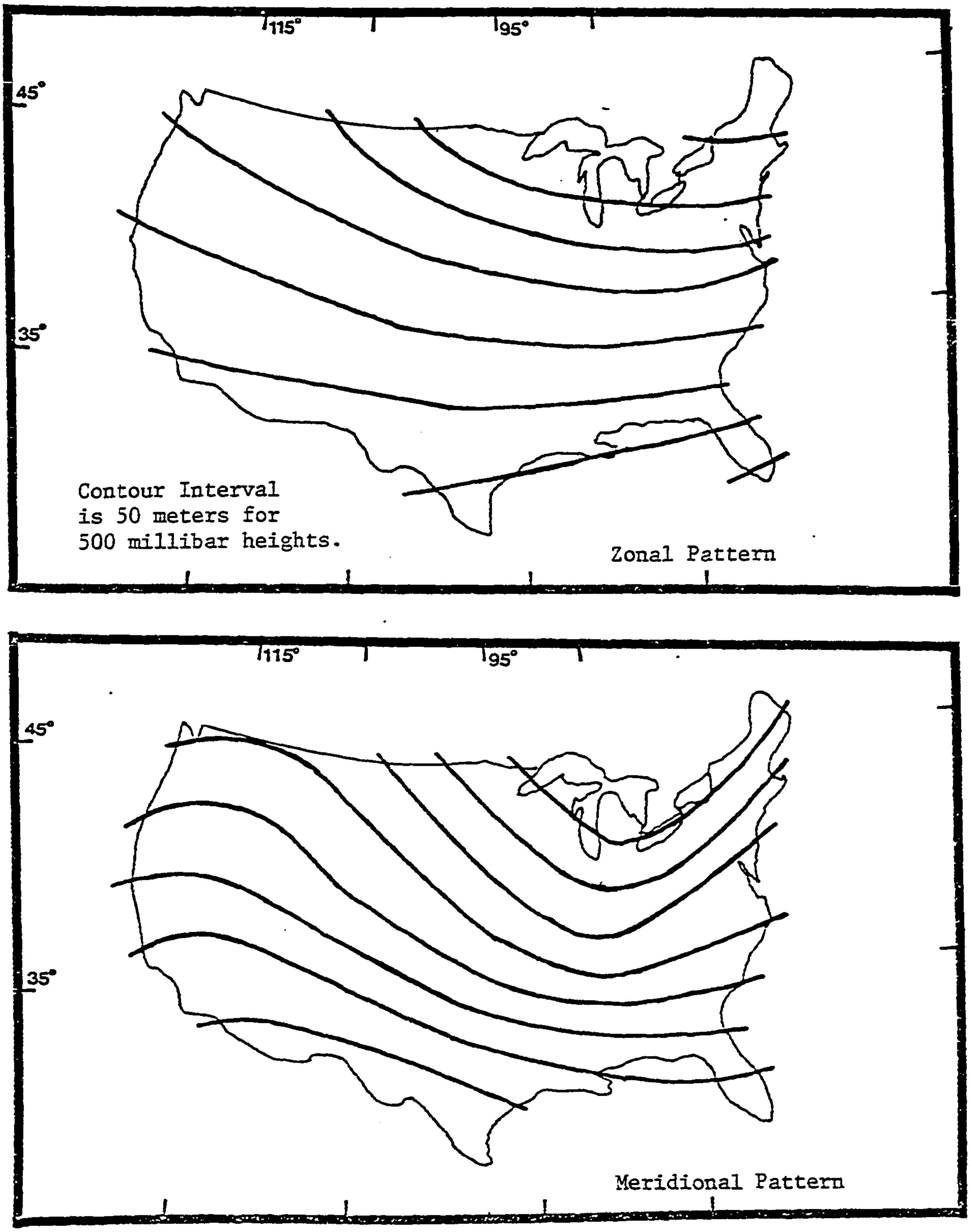


Figure 1: Modal Zonal and Meridional Flow Patterns

the existing data. All data in this study were taken at the monthly time scale, as changes in climate should show up in the monthly averages. Monthly averages also eliminated the fluctuations at smaller time intervals associated with moving short waves that might obscure the pattern of the persistent circulation type.

Three major climatic variables were used as indicators of circulation: (a) barometric pressure; (b) wind speed; and (c) wind direction. Barometric pressure variations were assumed to vary inversely with vorticity (Harman, 1971). Wind speed and wind direction were also combined in vector form to yield a measure of the northerly and westerly components of the wind (Coffin, 1964). Several measures of wind persistence were also computed.

To estimate heat energy, average monthly temperature values were employed. Work by McBoyle (1971) and a pilot study by this investigator showed a high correlation existing between average, maximum, and minimum temperatures. The more commonly used variable, average monthly temperature, was utilized to avoid unnecessary overlap in the measurements.

Three dimensions of atmospheric moisture: (a) relative humidity; (b) total precipitation; and (c) precipitation days were included. Variations in total precipitation, moisture in the atmosphere, and precipitation intensity were obtainable from the measurements.

Data Availability and the Station Network

With the time periods and climatological elements identified, a station network of sufficient density was selected. The coterminous United States provided an excellent surface for testing climatic fluctuations as it falls in the middle latitudes where the circumpolar vortex is often located in the winter months. The result of this location meant that changes in the circulation configuration were likely to be displayed in the surface climatic data, if the hypotheses of this study were correct. The surface was sufficiently large to yield meaningful regions based upon climatic fluctuations, and it contained a variety of topographic features which interacted with the change patterns. A reasonably good network of stations was maintained under government supervision for the length of time required for this study. All first-order climatological stations that continually recorded and published temperature, pressure, moisture, and wind data from December, 1939 through February, 1965 were included, one hundred fifty-one in all (see Figure 2). The data were published in the _Monthly Weather Review_ until 1950 and then appeared in a similar form in _Climatological Data: National Summary_.

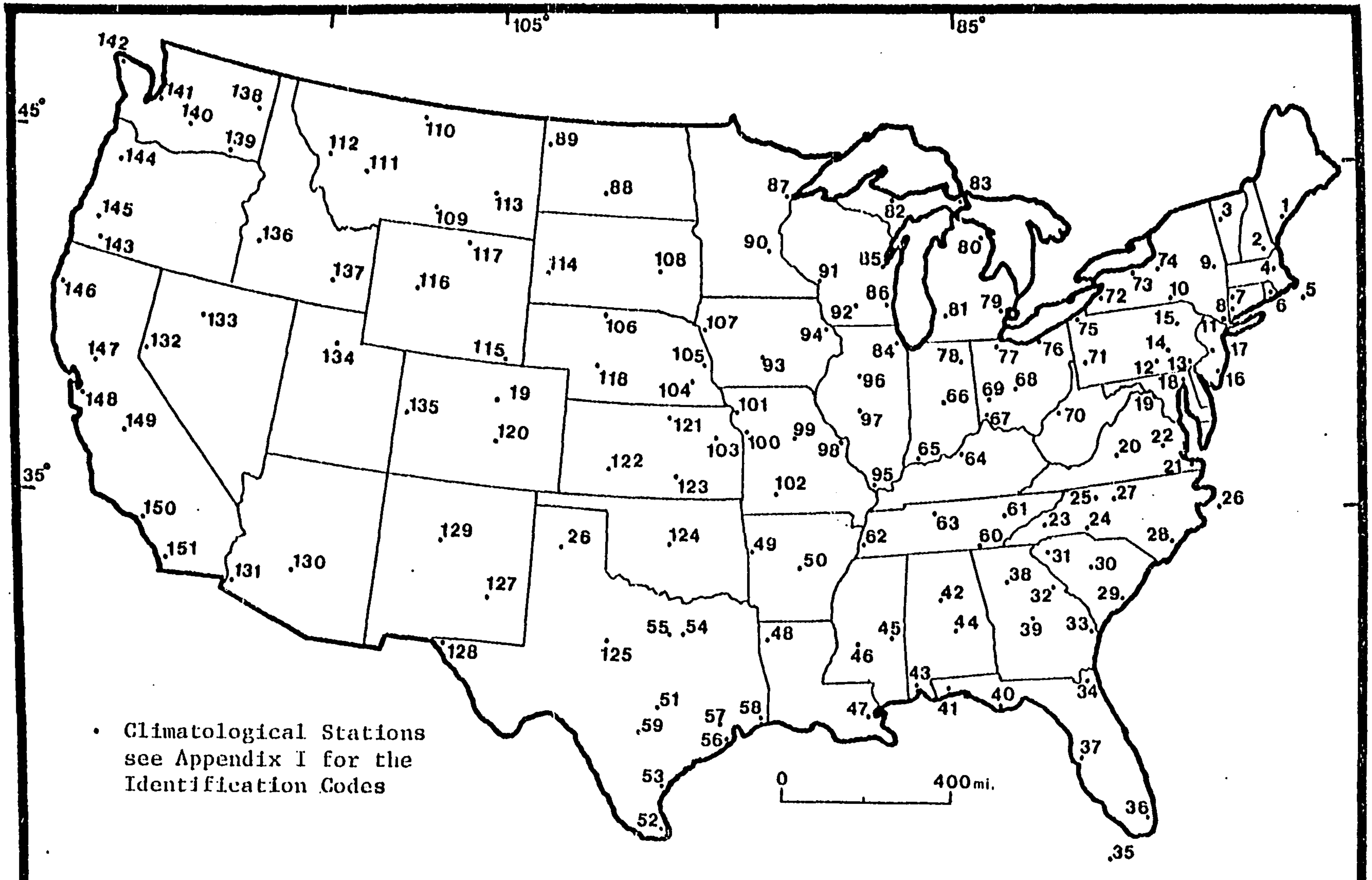


Figure 2: Distribution of First-Order Climatological Stations Used in Analyses

Methodological Framework

Nearest-Neighbor Analysis

To test the notion that the station network was distributed fairly evenly across the continental United States, the nearest-neighbor test was used. This test provided a precise measure of the degree of randomness of the distribution of points within the study area. By examining the nearest-neighbor statistic R, one can determine if the points are clustered (R = 0.0), random (R = 1.00), or uniform (R = 2.15). An R scale can be created using these benchmark values, and point patterns may be described as "approaching random" or "nearly clustered" and so on. From the laws of mathematical probability, the nearest-neighbor statistic was derived as:

$$R = r(A)/r(E)$$

where r(A) was the actual mean distance between climatological stations calculated as:

$$r(A) = [r(1) + r(2) + \ldots + r(N)]/N$$

where r(i) was the measured distance from each station to its nearest-neighbor, and N was the total number of stations. The value of r(E) was the expected mean distance calculated as:

$$r(E) = 1/(2\sqrt{p})$$

where p was the expected density given by:

$$p = N/\text{total area}.$$

For a further discussion on the development and use of this test, see Yeates (1974) and King (1968).

A major concern in this study was that the station network formed a clustered pattern, biasing the findings. Any R value between the random value of 1.00 and the uniform or dispersed value of 2.15 demonstrated that the distribution pattern of the stations was acceptable, assuring that no significant overload entered the study from one region in the United States. The R value determined for the distribution of stations presented in Figure 2 was 1.36, a value demonstrating that the pattern of stations was acceptably dispersed across the United States.

Homogeneity Test

In that many of the records used in this study were from urban locations marked by possible land use changes near the collection site, changes in air quality, or even changes in the collection site location, a test of randomness in the climatic data was performed to be certain that the data for each station were regionally homogeneous. Differential trends in the records were not necessarily linear, therefore, the test must have been capable of detecting non-linear or linear trends. Such a test was described by

Mitchell <u>et</u> <u>al</u>. (1971) where the Mann-Kendall Rank Statistic, T, was computed as:

$$T = [4P/N(N-1)] - 1$$

where N was the number of years in the data set, and P was the statistic calculated as:

$$P = n(1) + . . . + n(N-1)$$

where n(i) was the number of latter terms in a time series that exceeds x(i), the test variable. In other words, to find n(1), compare the value of the first term, x(1), with each term in the series that follows, ending with x(N). The number of times x(1) was exceeded defines n(1). The value of n(2) was determined by comparing x(2) with each successive value in the time series, counting the number of larger terms, and so on until n(N-1) was determined.

For cases where N is ten or greater, the value of T is compared to T(t) with the value:

$$T(t) = 0 \pm t(g) \sqrt{(4N+10)/[9N(N-1)]}$$

where t(g) is the probability point of the Gaussian distribution for a two-tailed test. For example, t(g) is 1.96 for the .05 confidence level and 2.56 at the .01 confidence level. If T is greater than T(t), a significant different trend is established, if T is less than T(t), no differential trend is substantiated.

A problem that was encountered in using this test lies in the computation of T(t). The limit of the T(t) function computed as N, the number of years, increases to infinity is zero. In other words, the significance indicator T(t) becomes very small as the number of years inceases. The same was not true for the equation for which the Mann-Kendall Rank Statistic, T, is generated. Therefore, the test becomes overly sensitive when the number of years in the series increases.

The selection of the correct climatological variable for use in the test was of obvious importance. Peterson (1975) reviewed a great deal of work written on how changing land use in urban areas affects local climates. Temperature has been cited as one variable quite sensitive to changes in the urban landscape. It has the advantage of being more regionally homogeneous through time compared to precipitation measures, making it well-suited for use in the homogeneity test. Mitchell et al. (1971) suggested the use of barometric pressure, as it is a difficult record to keep compared to many variables and is particularly sensitive to changes in the location of the collection site. In this investigation, both temperature and pressure were used to test the records of all one hundred fifty-one stations.

Discriminant Analysis

Discriminant analysis is a multivariate technique used to test the hypothesis that for each station, the years in the zonal group and those in the meridional group could be accurately discriminated based on the appropriate climatic data. From the results of the test, the most discriminating variable was identified, the significance of the discriminant model was computed, and the accuracy of the model was determined. Maps of the most discriminating variable, significance of the model, and the accuracy of the discrimination were produced, and the resulting spatial patterns were analyzed. Some examples were given demonstrating the usefulness of the discriminant functions in analyzing current climatic data.

To derive the needed formulas, the climate data for a given station were broken down into two distinctive groups, one zonal and the other meridional. The discriminant analysis assumed that these were nonoverlapping, distinctive groups. The goal in deriving the discriminant function was to maximize the ratio of the distance between sample means and the standard error within the means. The discriminant function was:

$$Y = b(1)x(1) + \ldots + b(p)x(p)$$

The values for the b coefficients on each variable x were derived using the least squares technique.

In this study where climatic variables were used as discriminating variables, the number of variables necessary to produce an accurate discrimination was often far less than the total number of original variables. A stepwise discriminant analysis technique was therefore used where the "best variable" was picked from the set, and using it alone, the significance and accuracy of the model were computed. The "next best variable" was then entered into the equation in combination with the first. This process continued until all variables were entered or until no improvement in the discrimination was made by adding additional variables. This procedure produced an efficient model with only as many variables included as were needed to yield maximum discrimination. Each year was then reclassified into either the zonal or meridional group based on the optimum discriminant model, and a measure of accuracy was calculated. For a further discussion on discriminant analysis, see King (1969).

Trend-Surface Analysis

Throughout this investigation, a number of isopleth maps were generated displaying the spatial pattern of change in a variety of climatic elements or in the accuracy of discriminant models. At each station location, a number of local factors may have influenced the resulting values for any type of measure, thus introducing random variations, or "noise" into the pattern. In that the maps were constructed to convey general spatial patterns in these data, some type of filtering procedure was required to eliminate "noise" and isolate the more important "signal" or underlying structure in the data. Such a technique is trend-surface analysis, where some given data (z-values) are statistically derived from their x and y position in space. Haggett and Chorley

(1968:196) stated ". . . trend-surface mapping represents an attempt to build up some generalized picture of areal variability in order to test some process-response model."

The construction of the trend-surface fitting may be carried out a number of ways, but the "fitted-regression" method was viewed as most desirable for geographical problems (Haggett and Chorley, 1968). Given an x-value and a y-value for the locations of the stations for which the z-values were representative, multiple regression equations were produced. The relationship can be a linear one in the form:

$$z = a + bx + cy$$

where a, b, and c were coefficients from the regression analysis. This linear equation would produce a flat planar surface which could be "tilted" in space. In many cases, higher order trend fittings would produce a better fit, where the total explained variance (a multiple R squared) increased. A second-order polynomial in two dimensions would be in a form:

$$z = a + bx + cy + dx^2 + exy + fy^2$$

where a, b, . . . , f were partial regression coefficients. The surface formed by the second-order polynomial would be a paraboloid, with only one ridge or valley. Higher order fittings produce greater numbers of inflections on the surface, and generally form a better fit, but the number of terms necessary to produce higher order maps increases exponentially. From the trend-surface fitting, residuals representing the difference between actual z-values and calculated trend-surface z-values can be determined. Spatial patterns in residuals may indicate the existence of local influences creating homogeneous deviations from the general pattern.

One of the problems in using trend-surface analysis was in the determination of the level at which the fit was to be accepted. Lower order fittings often uncover the very basic spatial structure of the data, but the total variance explained by such a surface may be unacceptably low. Higher order fittings may begin to incorporate unwanted "noise", and thus may destroy the justification for using the technique. Experimenting with the technique showed that explained variance added by increasing to the next order falls off sharply after approximately the fourth-order fit; and by the sixth order, the fitting explained a good amount of variance, with local "noise" still apparently absent. Therefore, nearly all the fittings were sixth-order, leaving smoothed patterns where general spatial trends were identifiable.

Principle-Components Factor Analysis

In many of the analyses used in this study, a large number of interrelated variables were used. To uncover the underlying structure of the variables, a principle-components factor analysis was applied. According to Rummel (1970:3), factor analysis "disentangles complex interrelationships among the phenomena into functional unities or separate or independent patterns of behavior and identifies the independent influence or causes at work." Using this technique, large matrices containing many variables can be condensed into just a few significant, interpretable factors, often accounting for most of the variance in the original matrix. The resulting factors are orthogonal, making them ideal for use in a variety of other multivariate techniques.

One of the first problems encountered when using factor analysis was in the selection of the most appropriate factor analysis model. The two most frequently used models are common factor analysis and principle-components factor analysis (Rummel, 1970). The essential difference between the two lies in the assumption regarding the amount of variation of the population explained by the chosen set of variables. The common factor model assumes that only part of the variation in the population is explained by the selected variables, breaking the variance of each into unique and common parts. The principle-components model assumes that all variation in the population is contained within the matrix, with no assumptions about common or unique parts. In this investigation, the factor analyses were not used to directly uncover dimensions of common variance, but were used to define the underlying patterns in the total variance in the data. The principle-components model was used to uncover what Rummel (1970:112) referred to as the "basis dimensions of the data." Rummel (1970:112) also admitted that "often the results of component analysis and common factor analysis are quite similar."

Basically, the principle-components model first calculated a correlation coefficient matrix displaying the intercorrelation within the variables, keeping values of 1.00 in the diagonal. The problem then became one of isolating vectors which summarized the variations found in the intercorrelation matrix. Conceptually, it was possible to locate, in n-space, where n was the number of variables, points representing the correlation of each variable with every other variable. A "best-fit" vector passing through the origin was then calculated which accounted for the greatest amount of variance in the correlation matrix. This vector is called the "primary component" or the "first factor." The degree of association between each variable and the first factor was calculated by taking the cosine of the angle between the first factor and the vector running through the origin passing through the location, in n-space, of the point representing the correlation of the variable in question and every other variable. These cosines for each variable's angle are called factor loadings, and if squared, indicate the amount of variance in the variable accounted for by the factor. The sum of these squares, called the eigenvalue, represented the amount of total variation in the data set accounted for by the first factor.

A second factor was then fitted to the data which was orthogonal (at ninety degrees) to the first principle-component. Loadings and eigenvalues were calculated in the same manner described above for the first factor. A third factor, orthogonal to the first two, was then formed, then a fourth, and so on until n-number of factors were formed.

The last factors formed normally accounted for very small, trivial portions of the total variance. Those factors accounting for significant amounts of variance therefore reduced the number of climatic elements. The point at which a factor was no longer considered significant was determined by the eigenvalue. If the eigenvalue was less than one, indicating that less than one variable's variance was accounted for by the factor, the variance was considered trivial, and the factor was not used in further computations (Yeates, 1974:221). To interpret these factors, the factor axes were rotated in such a way that the factors pass directly through clusters in the vector space. This procedure increased the factor loadings on some variables, allowing for a better interpretation of the factors. Factor scores, which replace the original data for the reduced factor solution, were generated by multiplying the original standardized matrix by the loadings for each factor:

$$ZL = S$$

where Z was the standardized matrix of n observations and m variables, L was the loadings matrix with p components or factors and m variables, and S was the matrix of factor scores with n observations and p components or factors (see Yeates, 1974 and Rummel, 1970 for further discussion).

Numerical Taxomony - Cluster Analysis

In two sections of this study, a method was required to group stations into distinctive climatic regions. Classification has been a major emphasis in climatology with landmark works published by Koppen (for a review, see Wilcock, 1968) and Thornthwaite (1948). In recent years, some attempts have been made towards the development of generic classification systems which avoided problems of the better known Koppen and Thornthwaite systems. Some of these problems were presented by Thornthwaite (1943) and Hare (1951) earlier in this century. McBoyle (1971) showed that the combination of factor analysis and cluster analysis could produce meaningful climatic regions. This system had the advantage of being based upon climatic data alone, and the climatic boundaries derived from the clustering indicate where the climate changed most rapidly.

This same type of procedure, using factor analysis and cluster analysis, was selected for use in this study as the type of data in use, only winter data, were not readily applicable to the Koppen and Thornthwaite systems. Numerical classification using these techniques produced regions based upon atmospheric variables, rather than on how these variables affected some other phenomena. The system also allowed changes in the regional structure, including increases and decreases in the number of regions, with relative ease. Importantly, it provided a consistent system for classification of climatic data throughout the study.

The cluster analysis in use came from the field of numerical taxonomy. Sneath and Sokal (1973:4) defined numerical taxonomy as "the grouping by numerical methods of taxonomic units into taxa on the basis of their character states." Basically, taxonomical techniques group units, in this case climatological stations, according to their degree of similarity. A number of schemes have been developed for taxonomical problems, for similarity, in multidimensional space, can be defined many ways.

The type used in this investigation was an unweighted average linkage clustering where the distance between stations was calculated by a Euclidean distance formula extended into n-dimensions where:

$$D = \sqrt{[a(1)-a(2)]^2 + [b(1)-b(2)]^2 + . . . + [n(1)-n(2)]^2}$$

where D was the distance computed by Euclidean distance, a, b, c, . . . , n represented the variables in use from station 1 and 2. In that the Euclidean formula is based on orthogonal axes, all data were transformed by principle-components factor analysis so that the axes became orthogonal. All data were standardized before entering the model so as to not weight any one variable according to its measurement units. Once two stations were grouped, the centroid in n-space, became the point compared to ungrouped stations, or to computed centroids from other groups. This scheme was seen as desirable by Sneath and Sokal (1971:228) as it smoothed extreme values which distort calculations in other forms of numerical taxonomy.

The successful clustering of the climatological stations resulted in the creation of a phenogram displaying the linkages between the stations. The distance level represented the distance in n-space between the stations or groups of stations. The difficult question then became, at what distance level should the clusters be divided. A level too low produced too many groupings and resulting regions, a distance level too high produced far too few regions for adequate differentiation. Hoel (1960:9) suggested that with more than one hundred stations, between ten and twenty classes were desirable. Therefore, phenon lines, defined as lines of equal distance level, must be passed through the linkage tree dividing the groupings in a consistent, uniform fashion, creating from ten to twenty clusters. This objectively formed the groups, without bias from the investigator. Each of these concepts are illustrated in a sample phenogram in Figure 3.

A cophenetic correlation was calculated for each phenogram in the study as a test for distortion on the phenogram. This measure was a correlation coefficient between actual distances in n-space and implied distances on the

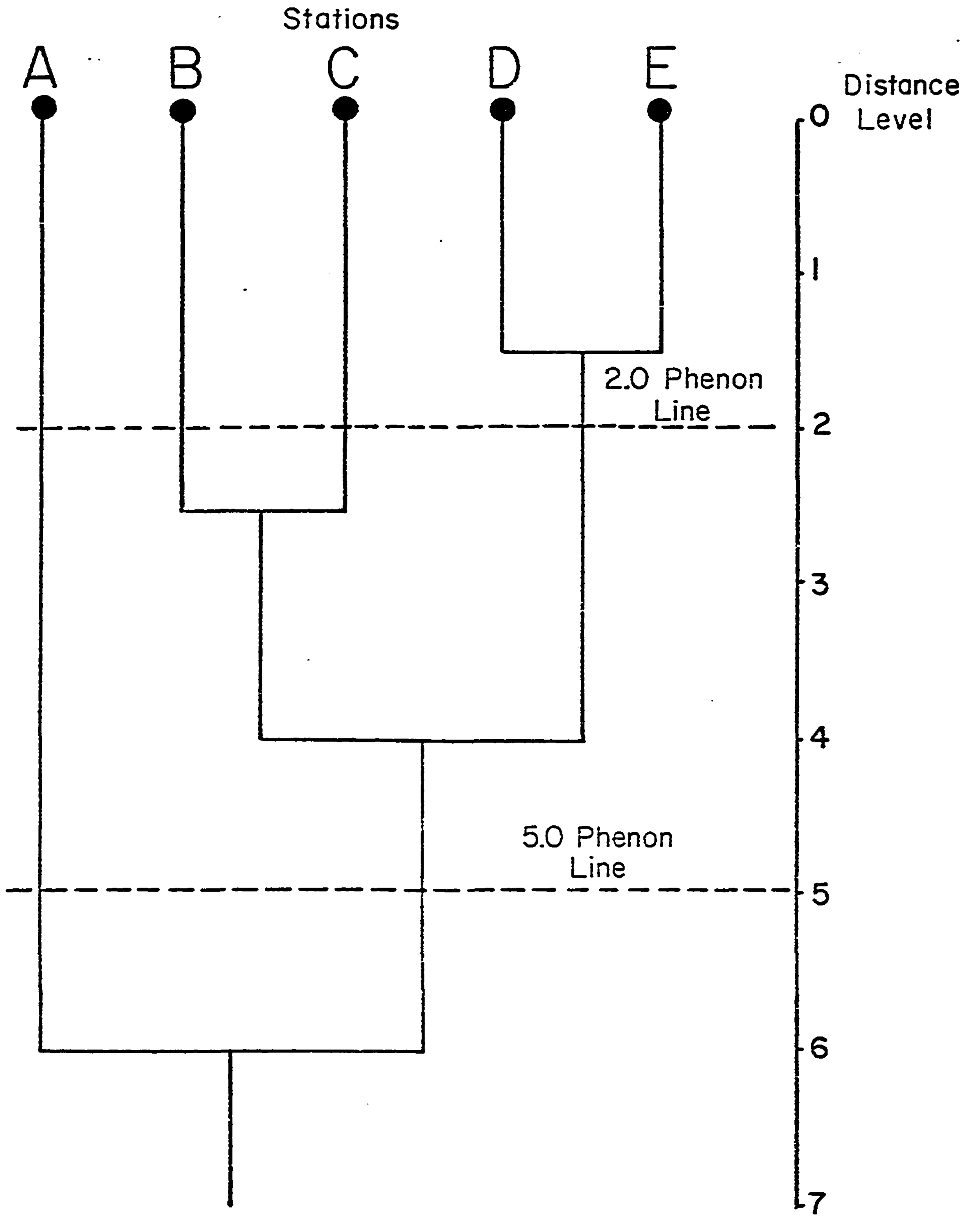


Figure 3: Example of Phenon Lines and Distance Levels on a Sample Phenogram

phenogram. For example, using Figure 3, one could calculate the actual distance from station E to station B or C; the implied distance on the phenogram between station E and station B or C was 4.0. If the correlation between implied and actual distances between stations was 1.00, then no distortion existed, smaller cophenetic correlations indicated greater amounts of distortion.

Shape Analysis

To test the hypothesis that climatic regions significantly change shape in association with a change in the general circulation, measures for shapes of cells, in this case climatic regions, were examined. Haggett and Chorley (1969:70-74) described the measures of shape previously employed in geographical research. Most of the equations given used area, perimeter, and a series of axes to describe the basis characteristics of shape for cells. All of the measures described shape without regard to orientation, a key factor in application to this problem. The hypothesis here was to test whether or not climatic regions were elongated in a west-east direction during the zonal period, and that the shapes significantly changed relative to the west-east orientation. If climatic regions would be equally elongated, but in a north-south direction in the meridional period, the measures suggested by Haggett and Chorley would demonstrate no change in shape. To overcome this problem, a rather simple formula describing shape, S, of a region was employed:

$$S = A(N-S) \ / \ A(E-W)$$

where A(N-S) and A(E-W) were the major axes in the north-south and west-east directions. If climatic regions became less elongated in the west-east direction from the zonal to meridional periods, this shape measure would detect the change.

CHAPTER III

DESCRIPTION OF CLIMATOLOGICAL DATA SETS USED IN ANALYSES

Original Climatic Data

All hypotheses presented in this study were effectively tested only with a base of valid data. These data should be homogeneous through both time and space, minimizing problems of uniformity from one station to the next. All climatic elements must be measured at each selected station and gaps in the data must be minimized. In that the data used in this study ranged in time from December, 1939 to February, 1965, subtle changes in the collection and recording procedure were noted, and steps were taken to correct for any of these changes.

Three measures of circulation were selected from the published data: pressure, wind speed, and wind direction. For barometric pressure, the station pressure, reduced to the mean for each twenty-four hour period, were averaged to yield an average monthly barometric pressure. Station level pressure was utilized instead of reduced sea level pressure for two reasons. First, the pressure measure was used in the homogeneity test which sought to find the significance in changes of the actual station location. Reduced pressures would be insensitive to changes in site, and station level pressures would be extremely sensitive. Second, no sea level pressures were recorded for January and February, 1943. The problem of differing base level pressures through space was not a factor, as this study examined changes through time in the climatic elements. The units used to record barometric pressure were inches of mercury through February, 1944, and millibars from December, 1944 through February, 1965.

Average monthly wind speed was computed from hourly average velocities from December, 1939 through December, 1964, and was recorded in miles per hour. However, the wind resultant speed was the value published for January and February, 1965. This was the value calculated as the length of the resultant wind vector of all daily wind vectors. The resultant wind speeds were generally very low compared to average wind speeds, and were not directly comparable to measures of wind speed. Only if all daily wind directions for a month were equal would the average and resultant wind speeds be equal.

A variety of different scales were used to record wind direction values from 1939 to 1965. From December, 1939 to December, 1948, all prevailing wind directions were recorded by the eight major compass points (N, NE, . . . , W, NW). From January, 1949 through December, 1963, the prevailing wind directions were recorded by the sixteen compass points (N, NNE, NE, ENE, E, . . . , NW, NNW). Beginning in January, 1964, the wind direction values were numerically recorded in units of ten degrees (1, 2, 3, 4, . . . , 35, 36). Figure 4 displays the types of units utilized in describing prevailing wind directions.

A second component of the atmosphere was heat energy. Over the length of time of this study, solar radiation data were so sparse through space that a surrogate, average monthly temperature, was used. Of all the elements included in this investigation, temperature was the most consistently recorded variable. For the entire length of the study period, average monthly temperature was recorded in degrees Fahrenheit.

To estimate moisture in the atmosphere over time, three variables were used: relative humidity, total precipitation, and precipitation days. Mean relative humidity was recorded in percentages for the entire length of the study period. Total precipitation was consistently given in total inches for each month; if only a trace was recorded, the value was assumed to be zero. Snow amounts were melted to yield comparable values with rainfall. Precipitation days were always given as the number of days in each month that a minimum of 0.01 inches of precipitation was recorded.

All data, exactly as found in the published records,

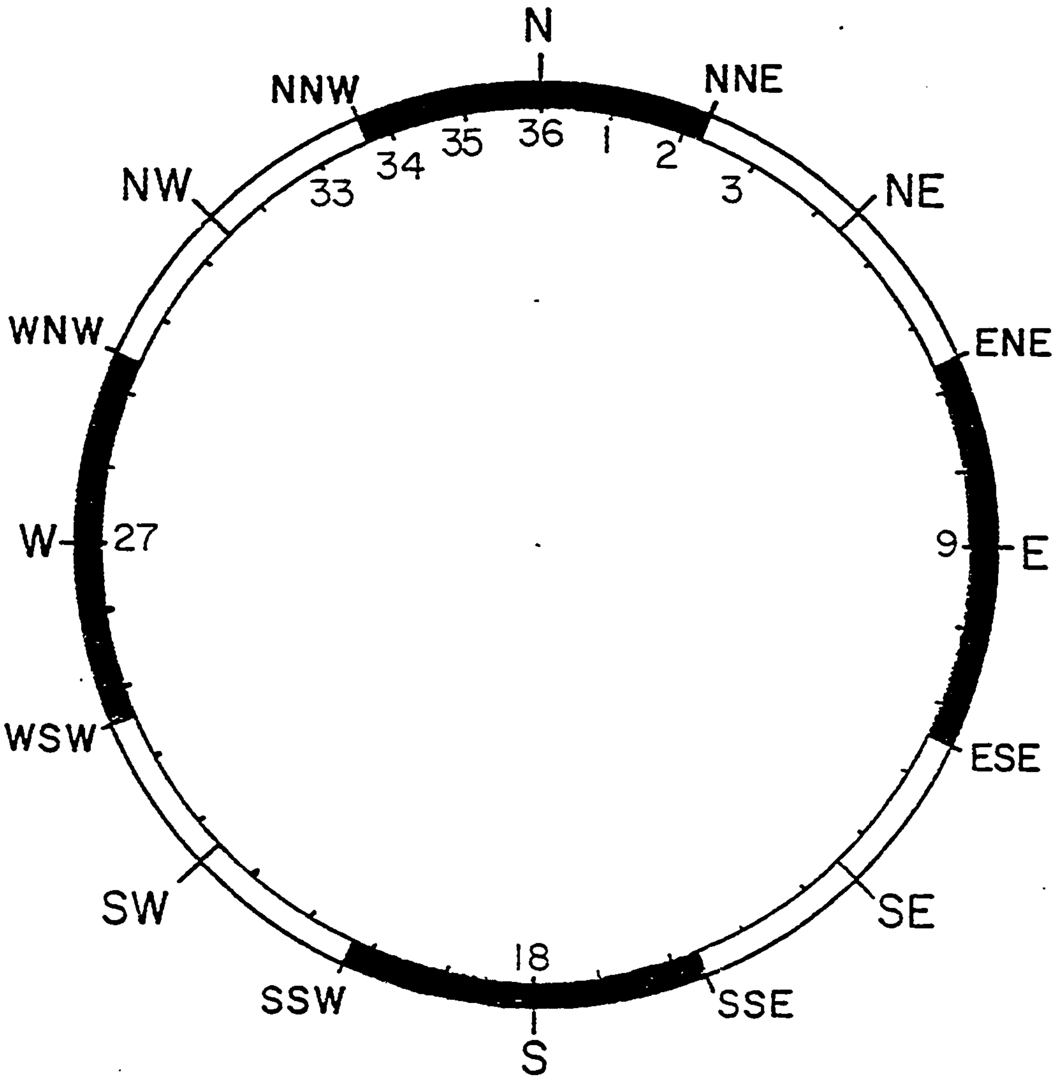


Figure 4: Measurements Used for Wind Direction

were punched onto computer cards, one card for each month for each station. For the zonal years from 1939 to 1949, all circulation, temperature, and moisture values were entered. From December, 1949 through February, 1955, only temperature was included, as these years were only used in some of the homogeneity tests. Using the same format utilized in the zonal period, all variables were entered for the meridional months extending from December, 1955 through February, 1965.

Enhanced Original Climatic Data

Inevitably, the use of published climatic data led to the problems of gaps in the data. Should a station be eliminated if some element was not recorded for a month, or even if some element was consistently missing for several years? Within some predetermined limits, the answer was no. The tradeoff here was in losing the spatial extent of the network to maintain data quality. If a station was eliminated for having any missing values, the station network would literally be reduced to zero. A compromise was obviously necessary. If a station missed more than two complete months of data, or if no reasonable estimate could be made of the missing values, the station in question was eliminated.

The estimation of the missing values could be achieved using a variety of multivariate statistical techniques. Those that could be utilized were restricted to stations included in the study to provide independent variables for predicting missing values. Within the time range of this study, the number of recording stations in the coterminous United States increased forty-one per cent, from one hundred ninety-two in December, 1939 to two hundred seventy-one in February, 1965. The number of nearby stations from which an estimation could be based increased with time. By examining the relationship of a station with a missing element with other nearby stations during months when data were recorded, a reasonable estimate could be interpolated. In the zonal period, thirty months of data were recorded for the one hundred fifty-one stations. With seven original variables, a total of 31,710 measurements were required to complete the set. In all, two hundred fifty-three values were missing (mostly relative humidity and wind direction). This required that 0.8 per cent of the total number of variables were estimated rather than actual published data. In the transitional period where only temperature was required for eighteen months, none of the 2,718 data values were missing. Interestingly, the quality of the data generally decreased with time. Exactly 31,710 meridional data values were required, the same number needed in the zonal set. However, 1,081 values, mostly relative humidity, wind speed, and wind direction measurements, were missing, representing 3.4 per cent of the total needed. In all, 66,138 values were needed for a complete original data set; 1,334 of these were interpolated values, comprising 2.0 per cent of the total. This value was deemed sufficiently low for the purposes of this investigation.

Creation of the enhanced original data set went beyond filling in missing gaps. Two elements, barometric pressure and wind direction, were recorded in different units through the time period used in this study. All barometric pressures recorded in inches were converted into millibars using the conversion formula:

$$P(mb) = 33.864P(in)$$

Only the four significant digits that resulted were recorded into the enhanced data set.

All but one year of the zonal period's wind directions were classified into eight compass points and the meridional period's directions were split between sixteen and thirty-six points. Andrews et al. (1973) stated that little precision was lost by categorizing a variable into as few as five subclasses; therefore, all wind direction data were reduced to eight major compass points. Problems developed as values such as NNE, ENE, ESE, ... , NNW fell directly on the borders created by dividing the measurements into eight major compass points. The wind direction values in these cases were assigned, randomly, to one of the bordering compass directions. Some exactness was lost by reducing the wind direction data, but uniformity was achieved across the time span of the study.

Seasonal Climatic Data

Several tests in this study required data at the season time scale rather than by individual months. For barometric pressure, temperature, relative humidity, precipitation, precipitation days, and average wind speed, this calculation was relatively simple. Taking into account that December and January have thirty-one days and February normally has twenty-eight days, the following formula was applied to weight the monthly values according to days in the month:

$$V(S) = (31/90)V(D) + (31/90)V(J) + (28/90)V(F)$$

where $V(S)$ was the created seasonal value, $V(D)$, $V(J)$, and $V(F)$ were the monthly values for December, January, and February, and the coefficients 31/90 and 28/90 were used as the weights.

Measurements containing a wind direction value proved more difficult and complex to handle. In that the scale used to measure direction was circular rather than linear, problems using normal averaging procedures developed. For example, a wind direction of 359 degrees and one of 1 degree obviously should not average to 180 degrees. Hence, vector representations of wind were used.

To calculate a seasonal wind direction value, the equations suggested by Panofsky and Brier (1958) were used. The east-west, $R(x)$, component and the north-south, $R(y)$

components were calculated as:

$$R(x) = [WS-ES+.707(SWS+NWS)-.707(SES+NES)]/N$$

$$R(y) = [SS-NS+.707(SWS+SES)-.707(NES+NWS)]/N$$

where NS was the weighted sum of all wind speeds with wind with wind direction north, NES was the weighted sum for the northeast winds, . . . , and NWS was the weighted sum of all wind speeds with wind direction northwest, and N was the total number of observations, in this case, three for each season. The resultant wind direction, WD(R) was calculated:

$$WD(R) = \text{Arctan}(R(x)/R(y))$$

resulting in a real value for resultant wind direction for each season in the two study periods. The values were recorded according to these calculations, and were also reduced to eight compass points and recorded.

Measures of the northerly and westerly components of the wind, W(N) and W(W), were computed using formulas suggested by Coffin (1964):

$$W(N) = v\text{Cos}(WD(R))$$

$$W(W) = -v\text{Sin}(WD(R))$$

where v was the average wind velocity, and WD(R) was the resultant wind direction. Another wind speed measure, the resultant wind speed, was also included. This speed was dependent not only on the mean wind velocities, but also on the persistence of the wind. Resultant wind speed was calculated as:

$$W(RS) = \sqrt{R(x)^2 + R(y)^2}$$

The actual persistence of the wind, PER, was calculated from the resultant wind speed measure as:

$$PER = W(RS)/W(AVE)$$

where W(AVE) was the average wind speed for a season. The value of wind persistence ranges from 0.0 indicating an absense of persistence to 1.0 indicating total persistence, or an absolutely constant wind direction for the three months of the season.

In sum, the seasonal climatic data set included averages, all weighted by the days in each month, for barometric pressure, temperature, relative humidity, precipitation, precipitation days, and wind speed. More elaborate calculations produced an average wind direction, northerly and westerly components of the wind, resultant wind speed, and seasonal wind persistence. The ten zonal years and ten meridional years had a full complement of data, the six transitional years contained only seasonal temperature values.

Climatic Change Matrix

To display climatic fluctuation between the two time periods of different circulation, a climatic change matrix was produced. Within this matrix, all elements included in the study were assigned a standardized value indicating the relative amount of change, or adjustment, that took place in conjunction with a change in the general circulation. For most of the elements, calculation of the value was relatively simple, for others, the calculation was somewhat more complex.

Yeates (1974) showed that a standardized value representing the difference between sample means can be accomplished by:

$$t = [X(M)-X(Z)]/\sqrt{S(M)^2/N(M) + S(Z)^2/N(Z)}$$

where X(M) and X(Z) represented the meridional and zonal arithmetic means of some climatic element, S(M) and S(Z) were the standard deviations for the sample, and N(M) and N(Z) were the number of years represented in the sample. The S(M) and S(Z) values were the square roots of the variance v calculated as:

$$v = [\Sigma X^2 - (\Sigma X)^2/N]/(N-1)$$

where the ΣX^2 was the sum of the X squares, ΣX was the sum of the x terms (the values of the climatic elements), and N was the number of years in the sample.

For the following climatic elements, barometric pressure, temperature, relative humidity, total precipitation, and precipitation days, these calculations were carried out with ten zonal years and ten meridional years. A t-value for each element was derived and entered into the matrix.

Only nine meridional years could be used in the calculation of change in the wind measurements, for average wind speed was not recorded in the last season of the meridional period. Hence, for average wind speed, northerly and westerly components of wind, and for the resultant wind speed, ten zonal years were compared to the first nine meridional years to yield a t-score.

Two measures in the change in wind persistence were included in the change matrix. For each year in the study, except for the last meridional year, a wind persistence value was calculated as described in the seasonal data section. It was based on the wind speeds and wind directions for each month for each season. This persistence value based on yearly values fit easily into the t-score calculations, and by comparing the ten zonal years to nine meridional years, a standardized change in winter wind persistence was determined. A second wind persistence value was also included, not based on yearly persistence, but upon persistence of wind through time for each of the calendar months. For example, for the zonal period, a persistence value was calculated for winds in all Decembers, then another for all January months, and then for all February months. An average persistence, weighted by days in the month, was calculated. The same procedures were carried out for the meridional months. Since these values by definition fell between 0.0 and 1.0, and as these values were not in the form to be entered into the t-score formulas, a change in monthly persistence was computed by subtracting the zonal value from the meridional value. The results were of the same magnitude as all other values in the change matrix.

The climate change matrix therefore contained one hundred fifty-one rows, one for each station, and eleven columns containing the values which indicated, in standardized units, the amount of change that occurred between the zonal and meridional periods.

Zonal and Meridional Climatic Means

A final data set was required to test the hypothesis that climatic regions significantly changed shape between the two periods. To develop climatic regions representing conditions in either the zonal of meridional period, climatic means for each period were determined. Only temperature and precipitation values were used as they represented the core variables used in most climatic classification systems. Keeping the parameters upon which these regions were based simple and comparable to other more commonly used classifications was desirable.

For each station, two groups of variables formed this data set. For the zonal period, average temperature and precipitation values were calculated for each month, December, January, and February, from the ten years from 1939 to 1949. The same variables, temperature and precipitation, for each month were also computed for the meridional years, and all results were recorded in this data set.

CHAPTER IV

SPATIAL PATTERNS IN CHANGES OF CLIMATIC ELEMENTS

Results and Analyses of Homogeneity Tests

The Mann-Kendall Rank Statistic (T) was calculated for each station using two variables, temperature and barometric pressure. The test was first utilized to demonstrate that the data for each station were regionally homogeneous in both the zonal and meridional periods. In that the term "regionally homogeneous" may have several interpretations, each station was compared to its nearest-neighbor, its two nearest-neighbors, and to its three nearest-neighbors. At each of these levels of spatial comparison, the 0.01 confidence level was used to test the significance of any differential trends that occurred in the data. Since one hundred fifty-one stations were tested, it became likely that one or two stations may have been incorrectly categorized as having a differential trend due entirely to the confidence level selected.

In the zonal group, using temperature as the test variable, the one nearest-neighbor test scheme produced two stations failing the test - Indianapolis, Indiana, and Dayton, Ohio. When two nearest-neighbors were used to produce the regional standard, no stations displayed differential trends. Jumping to three nearest-neighbors produced two stations with apparent differential trends - Richmond, Virginia, and Cincinnati, Ohio.

Using pressure as the test variable produced different results. Nineteen stations scattered across the United States failed the test when only one nearest-neighbor was used for a comparison. Six stations, including Raleigh, North Carolina, Columbus, Ohio, Marquette, Michigan, Williston, North Dakota, St. Joseph, Missouri, and Fresno, California, showed signs of a differential trend when two nearest-neighbors were used. However, no stations failed the homogeneity test when three nearest-neighbors were used to calculate the regional trend. These results showed that pressure was generally a more sensitive climatic variable to use in this test. It was concluded that all recorded data for the zonal period were regionally homogeneous as no station failed the test when both temperature and pressure values were used in the calculations, and as no stations in either case failed at more than one of the calculation levels.

Within the meridional period, the tests were even more conclusive in determining the adequacy of the data. No stations failed the tests when one, two, or three nearest-neighbors were used to produce the temperature norm. Only Sheridan, Wyoming, failed using pressure and one nearest-neighbor, and only Helena, Montana, failed when two nearest-neighbors were utilized in the computations. With three nearest-neighbors used to represent the regional pressure norms, no station displayed a significant differential trend. In light of these findings, it was concluded that all stations recorded regionally homogeneous data throughout the meridional period.

The results for the entire twenty-six year period showed more stations failing the tests. These findings were expected as the equations used became overly sensitive as the number of years increased. Temperature data were used, and with just one nearest-neighbor, eighteen stations failed the test, with two nearest-neighbors, twelve failed. Surprisingly, when three nearest-neighbors were used, sixteen of the stations appeared to fail the test at the 0.01 confidence level. Even when the confidence level was stiffened so that the probability of a station failing by chance was one hundred fifty-two to one, seven stations continued to fail the test. However, the conclusion based on the homogeneity tests was that all data for the stations were regionally homogeneous within the zonal and meridional periods. The test became extremely sensitive as the number of years increased. An examination of the results showed that no station failed the twenty-six year test and either of the ten year tests. Therefore, all one hundred fifty-one stations were used in the analyses. All stations were the first-order type where maximum care was presumably used to preserve homogeneity of the records through time. Also, various filtering techniques were used to dampen the effect of any real differential that may have occurred. Results from this section also cast some doubt on the usefulness of the Mann-Kendall Rank Statistic in its use for testing longer time periods of data.

Results and Analyses of Discriminant Tests

Discriminant analyses were used to determine if significant climatic differences existed between the zonal and meridional time periods. If they did exist, discriminant functions capable of reclassifying the years into the correct group could be determined. The discriminant functions should be statistically significant, and the number of incorrectly classified years should be at a minimum. Some current data from the extremely meridional winter of 1976-1977 were applied to the discriminant functions. The results provided an index for each station which may be plotted along a zonal-meridional continuum. This procedure demonstrated the usefulness of the equations in situations beyond the time limits of the study periods.

For each station, the years were grouped so that ten zonal years were compared to nine meridional years. The time periods were not equal due to insufficient wind data for the final meridional year. A stepwise discriminant model was used, one run through the model for each station in the study.

Figure 5 displays accuracy results from the one hundred fifty-one stations. In eigthy-five cases, representing fifty-six per cent of all stations, the discriminant functions were able to reclassify every year correctly, that is, each zonal year was classified zonal by the functions and each meridional year was classified meridional. In thirty-three cases, only one year was misclassified; hence, seventy-eight per cent of the discriminant functions reclassied all but one year or less correctly. Nineteen discriminant functions failed to correctly classify exactly two years, eight functions misclassified three test years, five stations displayed four incorrectly classified years, and one station, Atlanta, Georgia, had five misclassified years. An examination of Figure 5 did not immediately produce any distinctive spatial patterns in the data. The models appeared to work well in the northern plains, and possibly the poorest in the lower Mississippi plain.

Continuing with the notion that a distinctive spatial patterns existed in the results, a trend-surface map of the number of misclassified years was generated and dis-

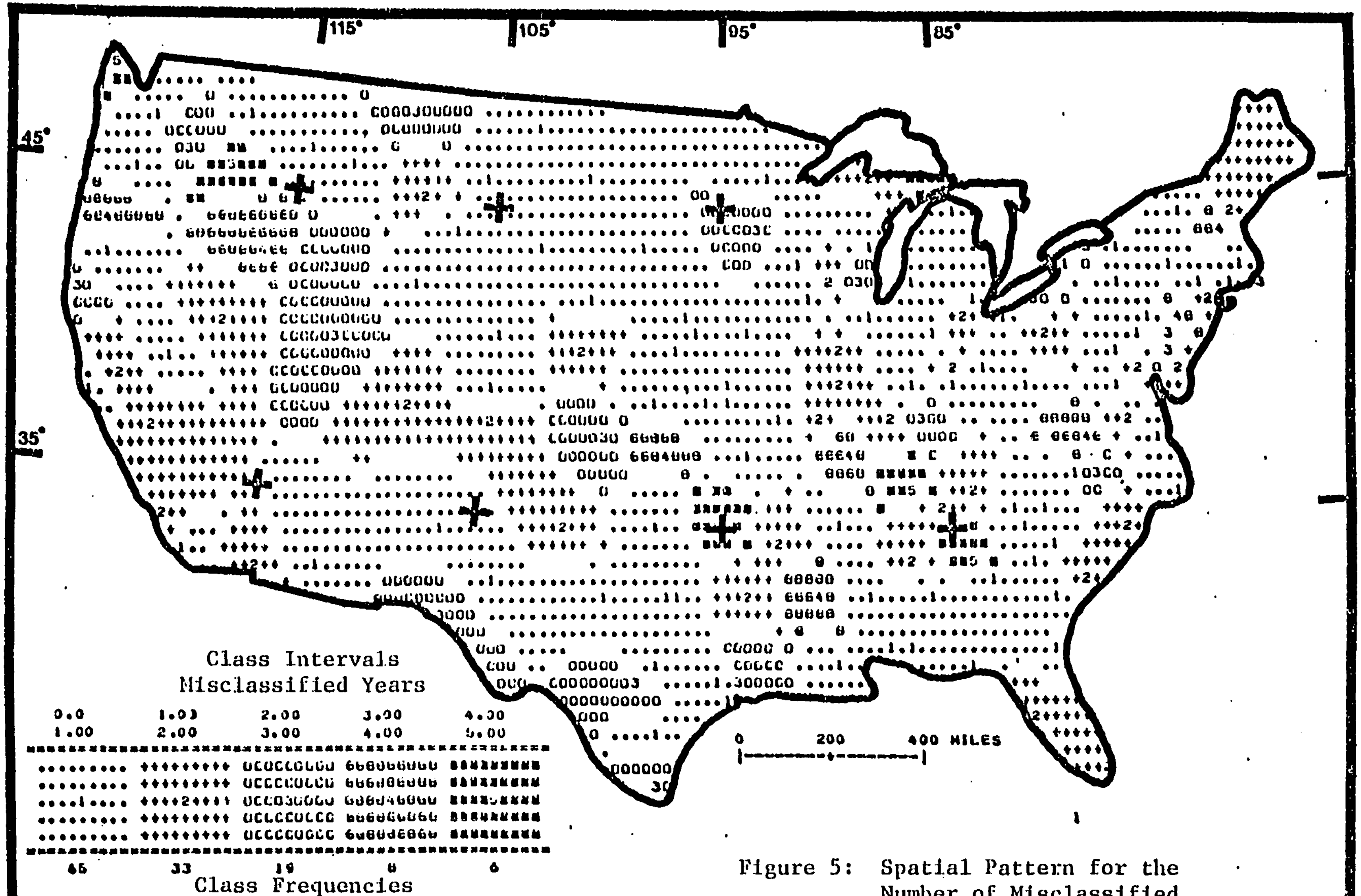


Figure 5: Spatial Pattern for the Number of Misclassified Years

see Appendix III for a discussion of Computer Maps

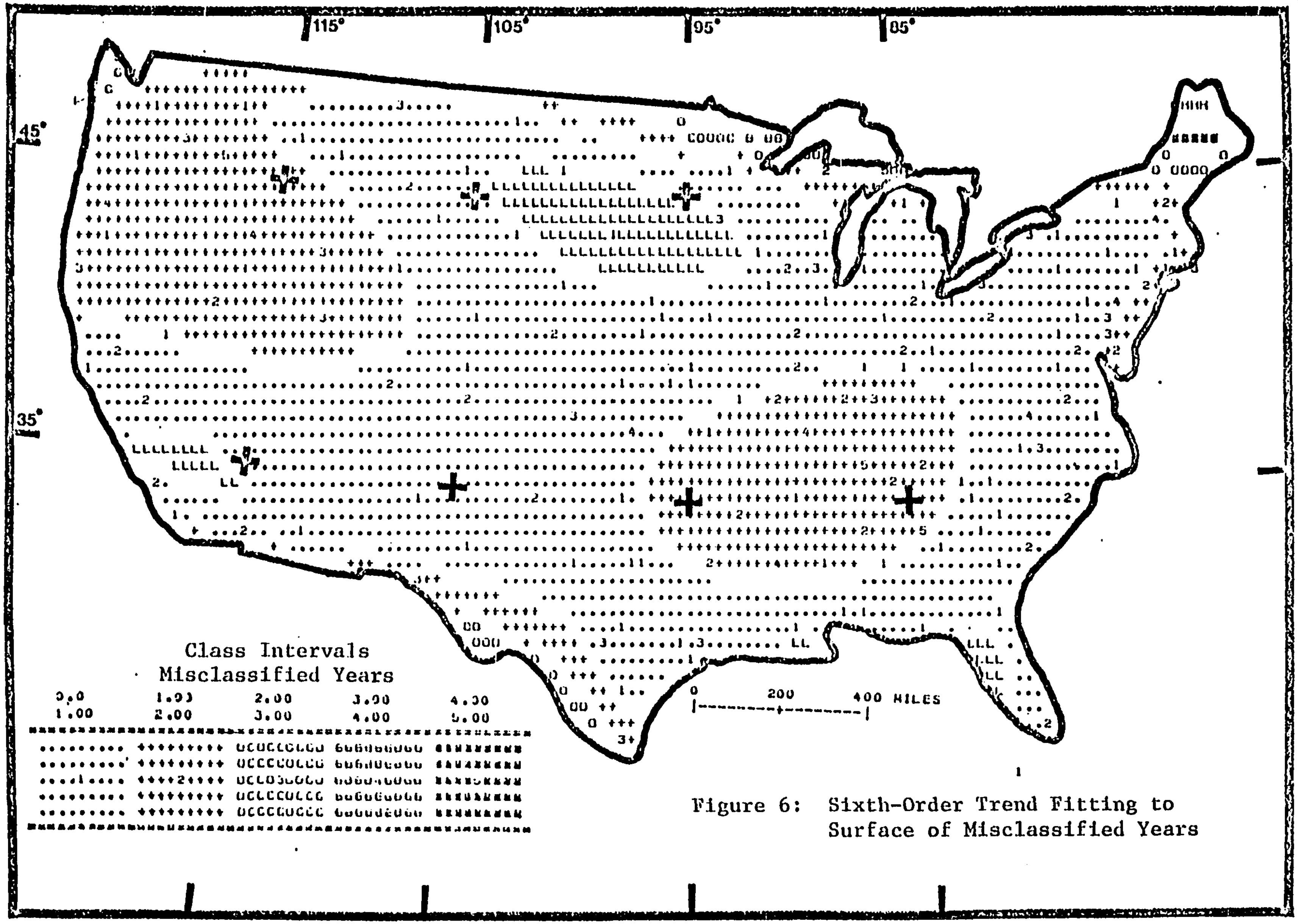


Figure 6: Sixth-Order Trend Fitting to Surface of Misclassified Years

played in Figure 6. This sixth-order trend fitting had a correlation coefficient of 0.44 with the original surface, and therefore explained only nineteen per cent of the total variation displayed in Figure 5. However, it did uncover the underlying patterns in the data. The initial interpretations of Figure 5 were confirmed, the upper plains showed a distinctive pocket where the model separated the zonal from meridional years exceedingly well. Throughout most of the United States, the models did an acceptable job in reclassifying the years. However, two major pockets existed where the models worked poorly; the northwestern corner of the United States and a large region in the south-central United States appeared to be regions where models misclassified the greatest number of years. However, the findings suggested that a change from one circulation type to another may be less consistently pronounced over the northwestern and south-central sections of the United States. The models did not appear to work exceedingly well in the southwest Texas region, or along the Atlantic seaboard from the Boston area southward through Washington. From analysis of these discriminant functions, it appeared that across the United States, the zonal or meridional years could be discriminated based on surface climatic data with accuracy. In all, functions for seventy-eight per cent of the stations could discriminate all but one year, or better, for the selected time period. Some evidence suggested that a few regions in the

United States generally displayed a higher number of misclassified years, implying that in these regions, the impact of circulation changes may be less persistent than in other areas. During either period of predominant circulation, some years for several regions, including the northwestern and south central sections, appeared to produce surface conditions more like those of the other flow type. For example, some zonal years may have produced a flow that was very similar to that of the meridional period for the Northwest. The same type of onshore flow could be produced by either circulation type. The same could be extended to any region where the models worked poorly. However, for most of the United States, the surface climates appeared to substantially change in association with a shift in the general circulation.

Each model was also tested for statistical significance using the F-ratio calculated for each discriminant function. The results are displayed on a proximal map in Figure 7. One hundred thirty-six stations (ninety per cent) were shown to have discriminant functions that were significant at the 0.05 confidence level. Generally the models were statistically significant at the 0.01 and 0.05 confidence levels, with one hundred eighteen (seventy-eight per cent) stations from across the United States falling into this group. In all, one hundred thirty-six of the stations had discriminant functions that were significant at the 0.05

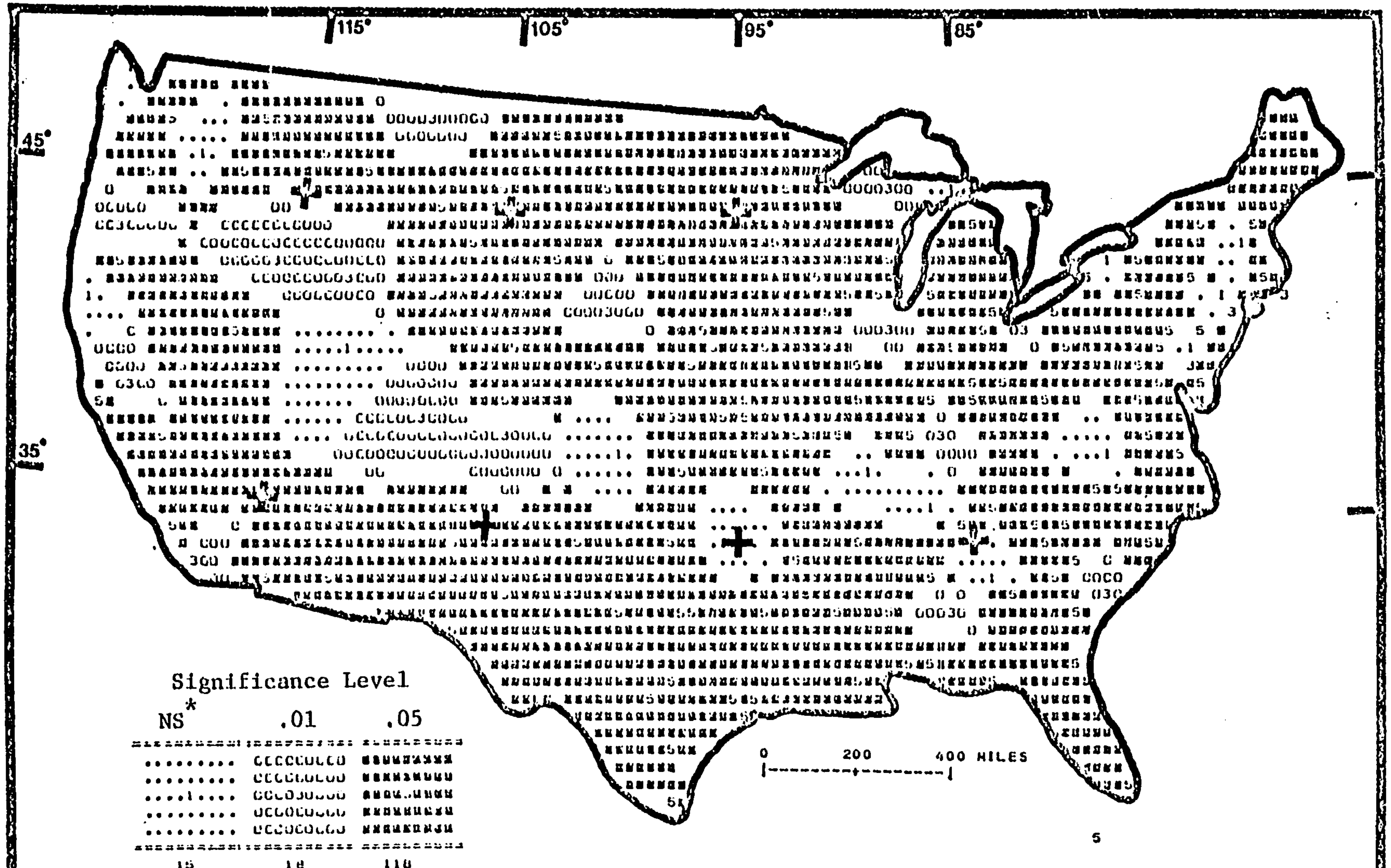


Figure 7: Spatial Patterns in the Significance of Discriminant Functions

*Not Significant

confidence level, and they represented a contiguous pattern broken only in a few isolated areas. It was concluded that the models not only worked with accuracy, but that they were also statistically significant for an overwhelming number of stations.

The stepwise discriminant model was used in the calculations, hence, the first variable picked from the array represented the one that discriminated most efficiently. Once identified, the variable was categorized into the three major components of the atmosphere: circulation, heat energy, and moisture. Circulation variables included barometric pressure and all wind measures, heat energy included temperature, and moisture included relative humidity and both precipitation variables. A map of the most discriminating variable was then produced using the three categories (see Figure 8). Two components, circulation and moisture, clearly dominated the pattern. Sixty-five stations (forty-three per cent) showed circulation variables to be the best discriminators, and eighty-four stations (fifty-six per cent) had moisture variables as the best discriminators. In only two cases did temperature emerge as the most discriminating element. Table 1 displays the results for each variable in these analyses. It may be argued that circulation and moisture categories include more different variables than the heat energy category, creating a better chance for circulation and moisture to be selected, but the findings

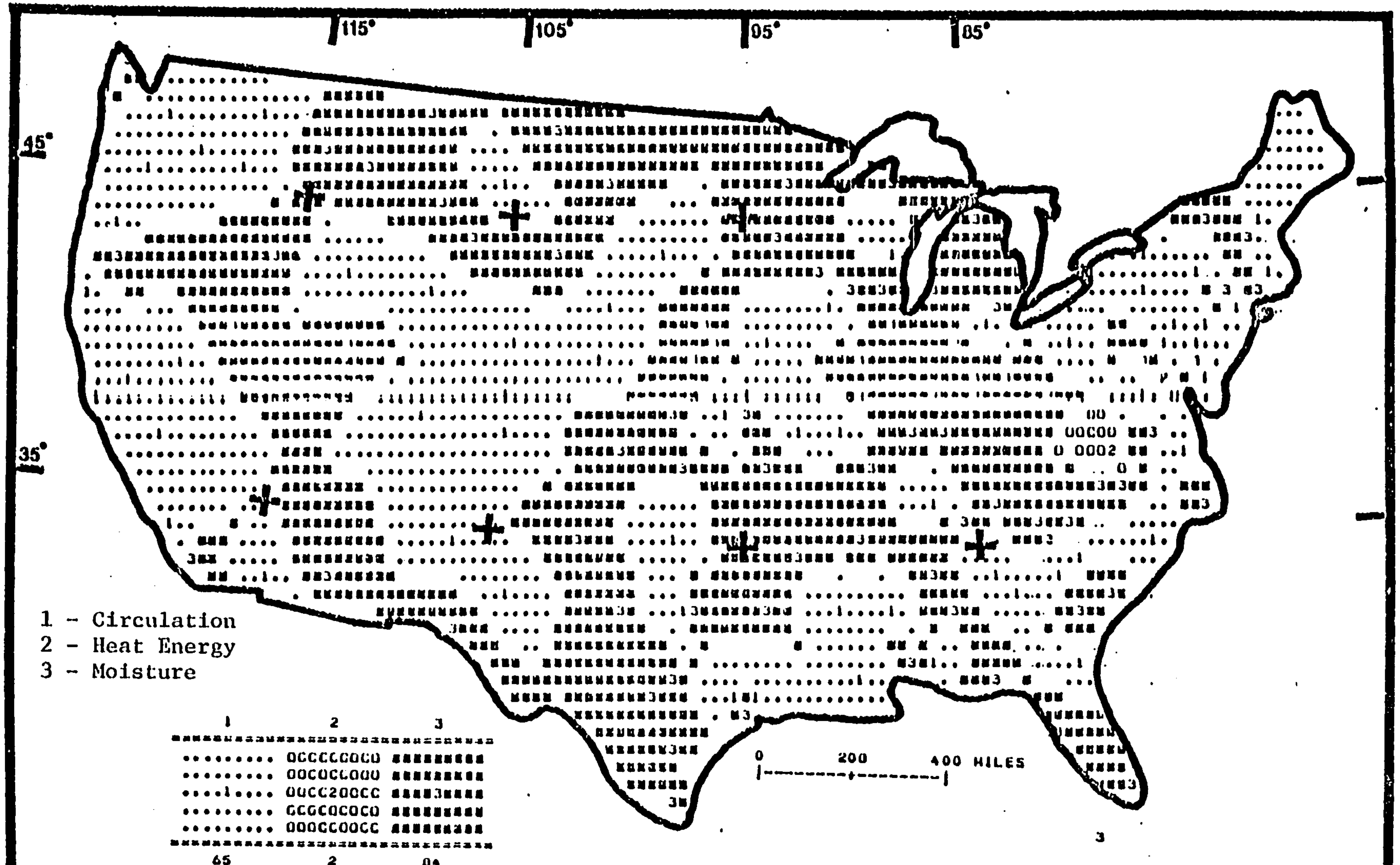


Figure 8: Spatial Patterns of the Most Discriminating Variables

Table 1

Frequency of Occurrence as Most

Discriminating Variable

Atmospheric Component	Climatic Element	Frequency
Circulation	Pressure	7
	Wind Speed	39
	Northerly Wind Component	9
	Westerly Wind Component	10
Heat Energy	Temperature	2
Moisture	Relative Humidity	80
	Precipitation	2
	Precipitation Days	2

here strongly suggested that temperature was not as significantly affected by circulation change as the wind related variables and the moisture components of the atmosphere. Although temperature may be affected by circulation changes, wind and moisture variables appeared to change more significantly in a statistical sense.

Moisture related variables appeared to change more frequently than others across many parts of the United States, particularly in the central region. This was an area ahead of the upper level ridge over the Rockies where subsidence inhibited precipitation formation. The northern High Plains of Montana also showed a number of stations with moisture as the most discriminating variable. The region was located along the storm track only during the meridional period, increasing the precipitation levels. The many erratics in the pattern could be explained using similar reasoning, or the represent cases where other elements remained relatively constant, and small changes in moisture components became the most significant changes.

The pattern of circulation variables as best discriminators was like the moisture pattern in that large homogeneous regions rarely developed. However, the following generalizations were made. Circulation variables appeared to be the best discriminators along the Pacific coast where pressures increased as the western ridge developed in the meridional period. Higher pressures and lower wind speeds could be used to explain the large region in the eastern Rockies and western Plains. The pattern along the Gulf and southern Atlantic coast was caused by increased wind speeds associated with the southern extension of cyclonic storm tracks. Much of the pattern in the Northeast could be explained by decreases in pressure as an increased number of cyclonic storms passed through the region in the meridional time period.

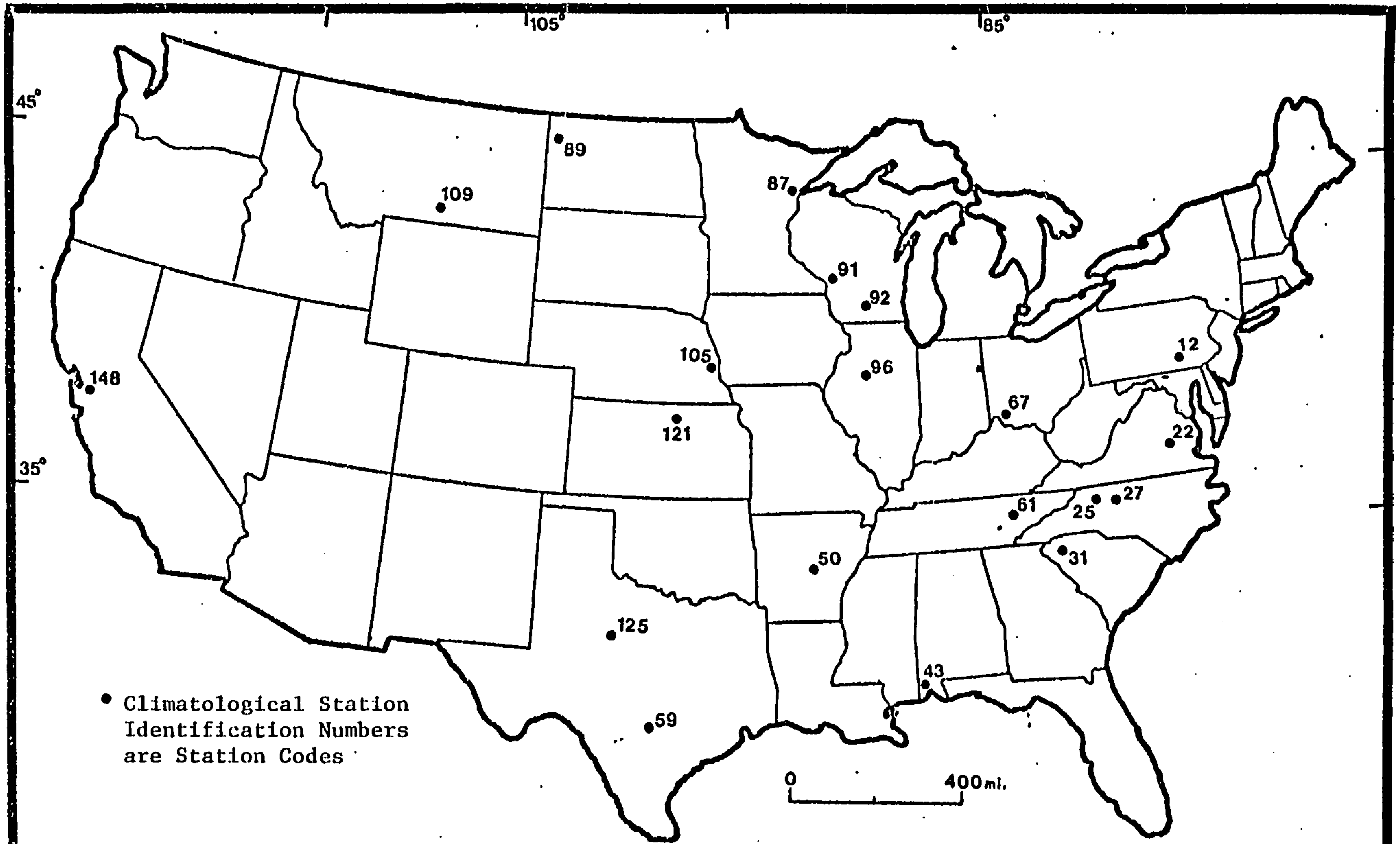
One of the interesting tests for the usefulness of the discriminant functions was one where current data were applied to the models, and the selected year was classified as zonal or meridional at each station. If the type of circulation pattern for the test year was well-known, and if the discriminant models correctly classified the year, the functions may then be shown to have usefulness beyond the time boundaries of the study period. Results from the models may be used to generate indices of zonality or meridionality based on surface climatic data. These may in turn be used to reinforce evidence of future or past climatic fluctuations, and may provide a new index of atmospheric circulation.

The winter of 1976-1977 was one marked by intense meridional flow. Throughout that winter, a strong persistent high pressure ridge was anchored over the Rockies, and a deep low pressure trough in the upper atmosphere persisted over most of the northeastern United States. This situation was associated with one of the most severe winters in history for many northeastern stations, and yet conditions remained relatively mild throughout the western half of the United States (see Taubensee, 1977; Wagner, 1977; and Dickson, 1977). The impact of this situation was overwhelming (see Magnuson, 1977 and Donovan, 1977) and it stimulated a great deal of interest in climatic change research. In short, the winter of 1976-1977 was characterized by an excellent example of intense meridional flow which persisted throughout most of the winter.

Monthly climatological data for this winter was found in <u>Climatological Data: National Summary</u>. It appeared in metric units, unlike the previously published data, and only resultant wind speeds were given in place of average wind velocities. The metric units could easily be converted into English units that were used throughout the study, but missing wind velocities proved to be a handicap. The discriminant functions were all calculated with average wind velocity as a component; therefore, only those stepwise discriminant models not including wind elements were used to test the 1976-1977 data. This left only twenty stations (see Figure 9) for further testing, as the other one hundred thirty-one stations required the use of average wind velocity in their discriminant functions.

The appropriate data were entered into modified discriminant functions for each of the twenty stations. The actual functions and the data entered are listed in Appendix III. In all cases except Williston, North Dakota, the models accurately classified the winter of 1976-1977 as meridional.

The Williston anomaly could be explained in terms of one of the two variables used in the discriminant function, relative humidity. Data to be presented in later sections showed Williston to be in a location where relative humidity values decreased (from 78.9% to 69.0%) as the circulation system shifted to a meridional pattern. Higher than normal values for relative humidity forced the discriminant function to classify the winter as zonal. The 1976-1977 winter



• Climatological Station
Identification Numbers
are Station Codes

Figure 9: Distribution of Selected Stations Used to Test Discriminant Functions With Current Data

was extremely cold in Williston, averaging -10.5 degrees, which was over twenty degrees cooler that the combined zonal-meridional average of 14.5 degrees. Even if moisture in the atmosphere was slightly less than normal during this winter (actually, precipitation was above normal), the extremely cold temperatures would force the relative humidities higher, for the amount of moisture the atmosphere could potentially hold would be very low. The relative humidity value for the 1976-1977 winter was 78.3%, accounting for the incorrect zonal classification. This type of problem points to the need to increase the number and type of variables in use. Only then could this technique of developing surface indices of circulation be perfected.

In thirteen sample cases, the models calculated a very strong meridional value, clearly to the positive side of the meridional average value (see Figure 10). Although the values in use in these models were at the monthly time scale, and as the results produced only a rough estimate of a zonal-meridional index, the findings suggested that more precise values, perhaps weekly means, could be used to generate accurate indices of zonality or meridionality based upon the impact on surface conditions. These values could be used in conjunction with indices of zonality for upper air flow to determine more exact process-response models (Terjung, 1976), identifying a link between upper air and surface changes. If a strong correlations existed between

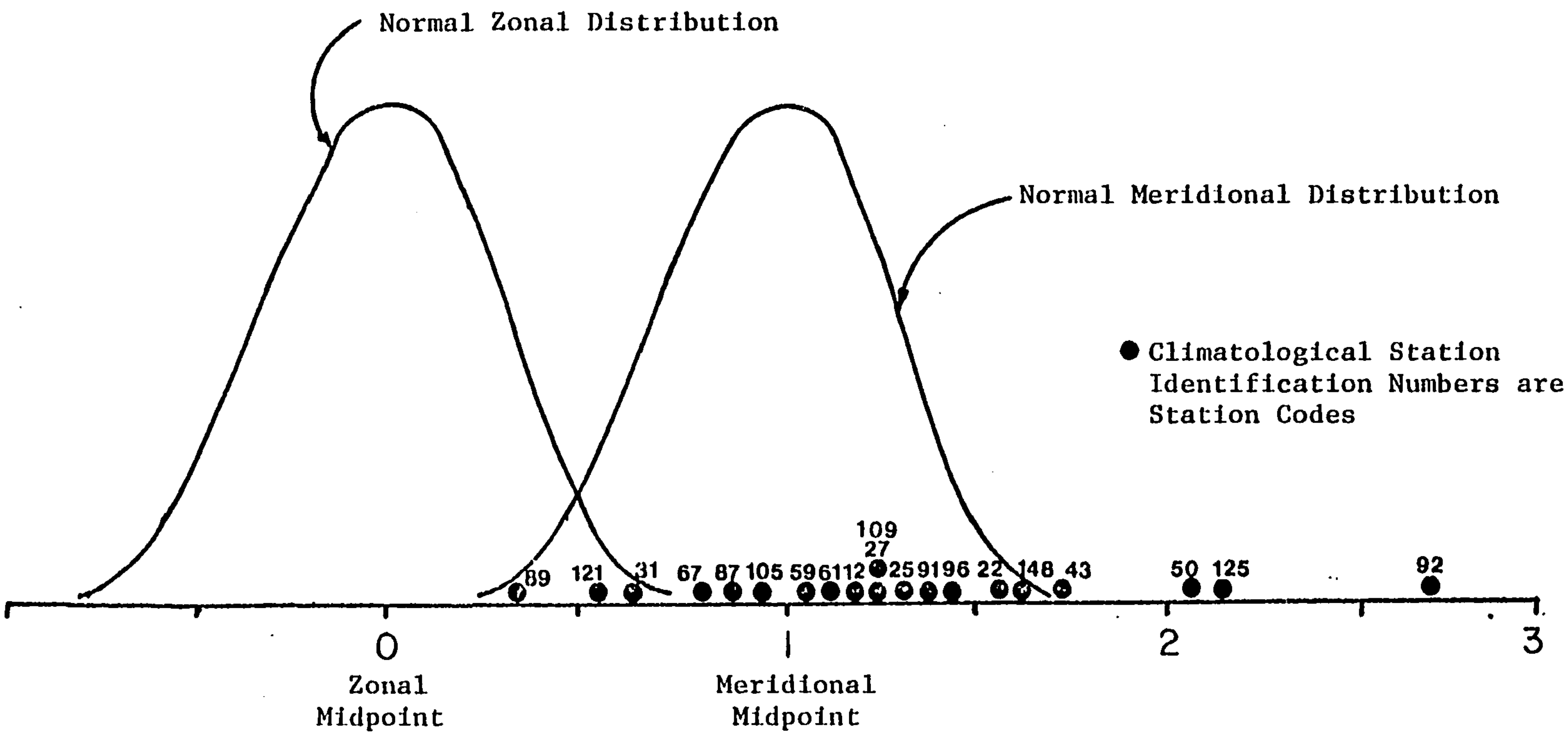


Figure 10: Relative Classification of Stations Along a Zonal-Meridional Continuum

the upper level and surface indices, accurate measures of zonality or meridionality for the upper air flow may be calculated from early surface climatic data. Although this was not the focus of this study, it does seem to be a good base for future research.

The results from the discriminant analyses led to several conclusions. It appeared that throughout the United States, significant discriminant functions could be generated capable of accurately discriminating winter seasons into zonal or meridional circulation types based on surface climatic data. These findings suggested that changes in the upper level circulation did have significant impacts on the surface climatic regimes. By examining the most discriminating variable in each model, moisture and surface circulation variables appeared to be affected most significantly. In only two cases did some other variable arise as the best discriminator. Circulation changes in the upper atmosphere appeared to have greatest impact on moisture and surface circulation, not on temperature. This suggested that moisture and circulation records should be more closely monitored in determining future and past climatic fluctuations. Some current data from the meridional 1976-1977 winter were applied to the models, and findings suggested that indices of zonality and meridionality could be calculated from surface data for any year that appropriate data were available.

<u>Results and Analyses of the Climatic Change Matrix</u>

For eleven climatic elements, values were calculated indicating the amount of change between the zonal and meridional periods. This unit reports the results in two sections; first, the results from the change matrix were generalized for each element, and second, spatial patterns in the results were analyzed. Special attention was given to temperature to produce examples of various interpretations from the data.

General Trends in the Climatic Change Matrix

An examination of the t-scores for each station for temperature showed an overwhelming number of negative values; only sixteen stations, or eleven per cent of the total number, were represented by positve t-score values, indicating an increase in temperature from the zonal to meridional period. In that ten years from both periods were used, yielding eighteen degrees of freedom, the absolute value of t-scores must exceed 2.10 to be significant at the 0.05 confidence level and 2.88 at the 0.01 confidence level. No station showed a significant increase at either level, however fifteen stations displayed a significant decrease at the 0.05 level and four significantly decreased at the 0.01 level. Although most stations did not show a statistically significant decline in temperature, many were approaching significance, and must be interpreted as a real decrease in temperature. The primary use of the t-scores was not to determine statistical significance, but to yield standardized units of change in a variety of climatic elements. Generally speaking, then, average monthly temperatures for the United States appeared to decrease as the circulation shifted from a zonal to a meridional pattern. This seems in line with the findings of others (Kalnicky, 1974; Dzerdzeevskii, 1969; and Lamb, 1966) who showed meridional patterns to be associated with cooler temperatures across the United States.

Some distinctive patterns were also found in the changes in the moisture variables. The t-values calculated for total precipitation showed a divided pattern for the stations; seventy-nine stations (fifty-two per cent) indicated an increase in precipitation amounts, and seventy-two stations showed a decrease in precipitation. Nine of the stations showed a significant decrease and two displayed a significant increase in precipitation amounts (significance at the 0.05 confidence level was used from this point on in this section).

The general pattern for precipitation days was much the same as for total precipitation, with a fairly even split in the sign of the t-values. Seventy-one stations (forty-seven per cent) increased in the number of precipitation days and the remaining eighty stations showed a decrease in the number of precipitation days. Four stations displayed a significant increase, and only one showed a significant decrease.

Interestingly, the t-scores for relative humidity were unlike those of total precipitation and precipitation days. Relative humidity increased in only fifteen station (ten per cent), yet in four of these cases, the change was significant. The remaining one hundred thirty-six stations all displayed a decrease in relative humidity, and of these, one hundred three stations were marked by a significant decrease in this moisture measurement. Therefore, generally across the United States, relative humidity values showed a sharp decline moving from the zonal to the meridional period, implying that less moisture was present in the atmosphere in the meridional period. If temperature had decreased and moisture amount had stayed constant, relative humidity would have increased as it is the ratio between the water vapor in the air and the amount of water vapor that the parcel can hold. Decreases in temperature lower the amount of water that a parcel can hold, which in turn lowers the denominator of the ratio, increasing the relative humidity value. The apparent decrease in both temperature and relative humidity strongly suggested that less moisture was available in the meridional period. Yet, the total precipitation amounts did not show the marked decrease that was expected, suggesting that the precipitation forming processes were more efficient during the meridional period.

These findings may be explained by the changes in the configuration of the wind flow in the upper atmosphere. During the zonal period, the flow moved relatively straight, west to east, across the United States, without forming distinctive troughs and ridges. However, during the meridional period, the ridges and troughs became more predominant. Ahead of the troughs in the upper atmosphere, air currents were diverging, supporting vertical motions in the atmosphere which produce precipitation. This greater upper level support for precipitation during the meridional period provided the key in explaining the apparent situation of less moisture in the atmosphere without smaller precipitation totals.

Some of the findings in the circulation group of variables supported this explanation. Examination of the pressure values in the change matrix showed that sixty-five stations (forty-three per cent) either increased or remained unchanged, while eighty-six stations showed a decrease in the pressure values. Eight of these stations displayed significant increases, three show significant decreases.

Wind velocity t-scores suggested that, in general, wind speeds at the surface tended to increase as the circulation system moved into a meridional pattern. One hundred stations (sixty-six per cent) displayed an increase in wind speed, with forty-seven significantly increasing at the 0.05

confidence level (only seventeen degrees of freedom were associated with the wind measurements as only nine meridional years were represented). Many of these t-values were larger than any others computed for any variable. Four stations, including Dubuque, Iowa, Columbia, Missouri, Topeka, Kansas, and Oklahoma City, Oklahoma, had t-scores greater than ten. Yet, of the fifty-one stations reporting a decrease in wind speed, nineteen values were statistically significant. These findings suggested that surface wind velocities were greatly affected by circulation type, and generally, wind speeds tended to be higher in the meridional period. Many exceptions to this generalization were present.

Values for the resultant wind speeds were somewhat different than the average wind speeds. Surprisingly, seventy-seven stations (fifty-one per cent) showed a decline in the resultant wind speeds from the zonal to the meridional period. Of those, thirteen showed a significant decrease. Seventy-four stations displayed an increase, with fifteen significant values. The increase in the average wind velocities coupled without an apparent increase in the resultant wind speed could be explained by the directional components of the surface winds expected with different circulation types. During the zonal period, the relatively straight pattern, west to east, in the westerlies should give rise to more persistent winds at the surface. In the meridional period, the wind directions were, presumably, less persistent. The average wind speeds in the zonal period may have been less than in the meridional years, but the higher persistence of the wind in the earlier period may have accounted for the relatively high resultant wind speed values.

The actual values calculated for wind persistence reinforced this explanation. Values for wind persistence by years tended to be negative, indicating less persistence in the meridional period. A total of ninety-one stations (sixty per cent) had t-scores which indicated a drop in wind persistence, seventeen had significant decreases. Only four of the sixty stations with positive values had significant t-scores.

Similar results were found when persistence values were calculated for each of the three calendar months. Eighty-eight stations (fifty-eight per cent) showed decreased persistence levels, by months; sixty-three showed an increased level of wind persistence. No measure of statistical significance was indicated as these values were computed by subtracting the average persistence value of the zonal period from that of the meridional period. These findings generally verified the notion that wind persistence levels should decrease as the circulation of the atmosphere shifted from a zonal to a meridional pattern. These findings also help to explain the overall increase in wind speed without a similar increase in the resultant wind speeds.

In analyzing the t-scores for the northerly and westerly components of the wind, the equations that produced these components must be considered. An increase in the average wind speed would increase the absolute value of these measures if the wind directions remained constant. Yet, eighty-two stations (fifty-four per cent) displayed a decrease in the northerly component of the wind, with fifteen of these values found to be significant. Fourteen of the sixty-nine stations with increased northerly components were significant.

The t-scores for the westerly component of the wind were somewhat surprising. Only sixty-seven stations (forty-four per cent) reported decreases in the westerly component of the wind, with thirteen significant values. Of the eighty-four stations having an increase in the westerly component, twenty-three showed statistical significance. Initially, a decrease in the westerly wind component was expected. However, the general increase in wind speed with moderate changes in wind direction led to the general increase in the westerly wind component.

Spatial Patterns in the Climatic Change Matrix

Having examined the general trends in the data, a second set of interesting results came from the analysis of the spatial trends in the data. In the way of example, temperature change values were used to displayed a variety of ways results could be presented and interpretated; principle-components factors were then used to condense the climatic change matrix and the resulting factor scores were mapped. This technique had the advantage of avoiding unnecessary overlap in the presentation of the results.

Using the SYMAP package produced at Harvard University in 1969 (Dougenik and Sheehan, 1975), a variety of options were available for displaying spatial patterns that were assumed to be continuous through space. One of the most widely used methods is the construction of isopleth maps where the data values are entered at specific x and y coordinates, and interpolation is carried out to derive data values at all x and y points within the map boundaries. Figure 11 is one of these simple isopleth maps based on changes in temperature. Interpretation of the pattern was difficult due to the amount of "noise" in the pattern. To uncover and identify the true "signal", a trend-surface fitting was applied to the data.

The first map in this series of trend fittings is presented in Figure 12. The map represented a first-order, linear fit to the temperature change surface. The equation for the fitting was given by:

$$Z = -0.46 - 0.09X + 0.04Y$$

where Z was the calculated temperature change value based on

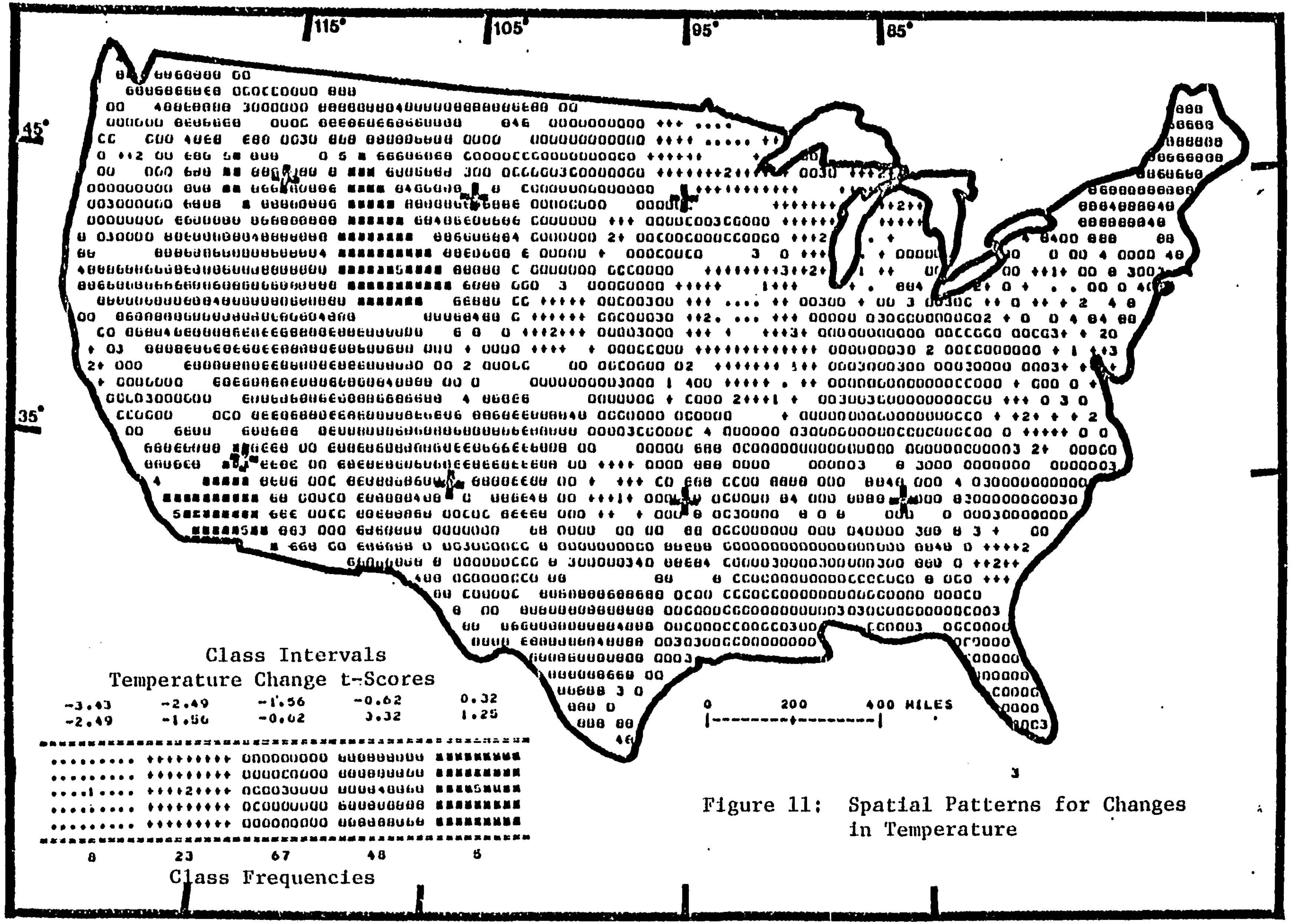


Figure 11: Spatial Patterns for Changes in Temperature

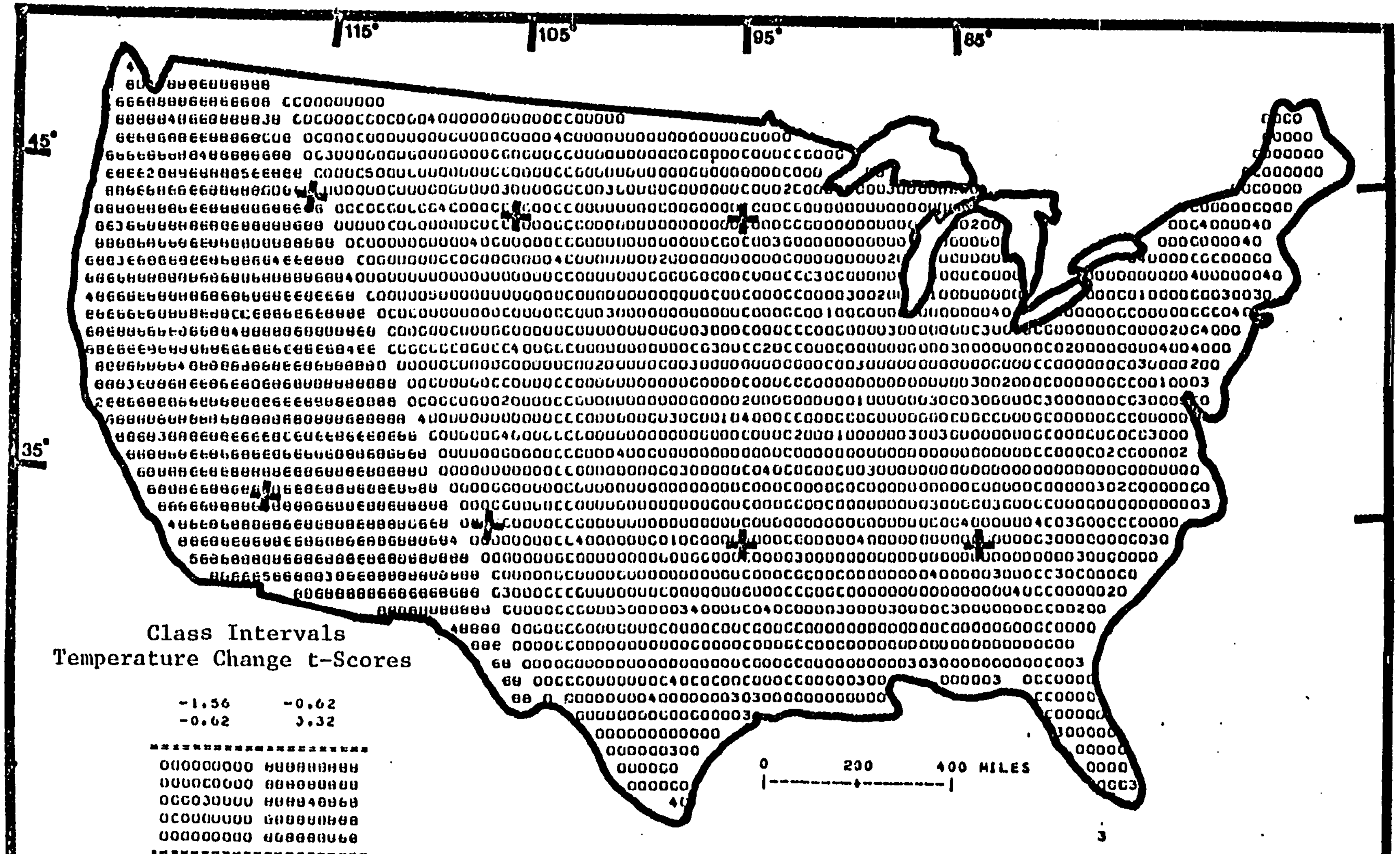


Figure 12: First-Order Trend Fitting to the Surface of Changes in Temperature

the X and Y position of each station. The coefficient of correlation of this fitting was 0.32; squaring this term yielded 0.10 as the coefficient of determination. These values may be interpreted as ten per cent of the total variation of the original temperature change surface that was explained by the first-order fitting. However low this value may have been, it still produced a surface displaying the underlying structure existing in the spatial patterns in the data. Figure 12 clearly showed that in a relative sense, the temperature change values in the West were greater than those in the East, indicating a decrease of temperatures in the East, a relative temperature increase existed in the West.

Figure 13 displays a third-order fitting of the same data. The equation used to calculate the temperature change values was given by:

$$Z = -0.54 + 0.53X - 0.40Y - 0.16X^2 - 0.01XY + 0.16Y^2 + 0.01X^3 - 0.01X^2Y + 0.01XY^2 - 0.02Y^3$$

where Z was again the approximated temperature change value, X and Y were the coordinates of the stations. The resulting surface had a correlation of 0.55 with the original surface, and therefore explained thirty-one per cent of the total variance of that surface. The map displayed in Figure 13 showed the same general pattern seen on Figures 11 and 12, with highest values, indicating a relative increase in temp-

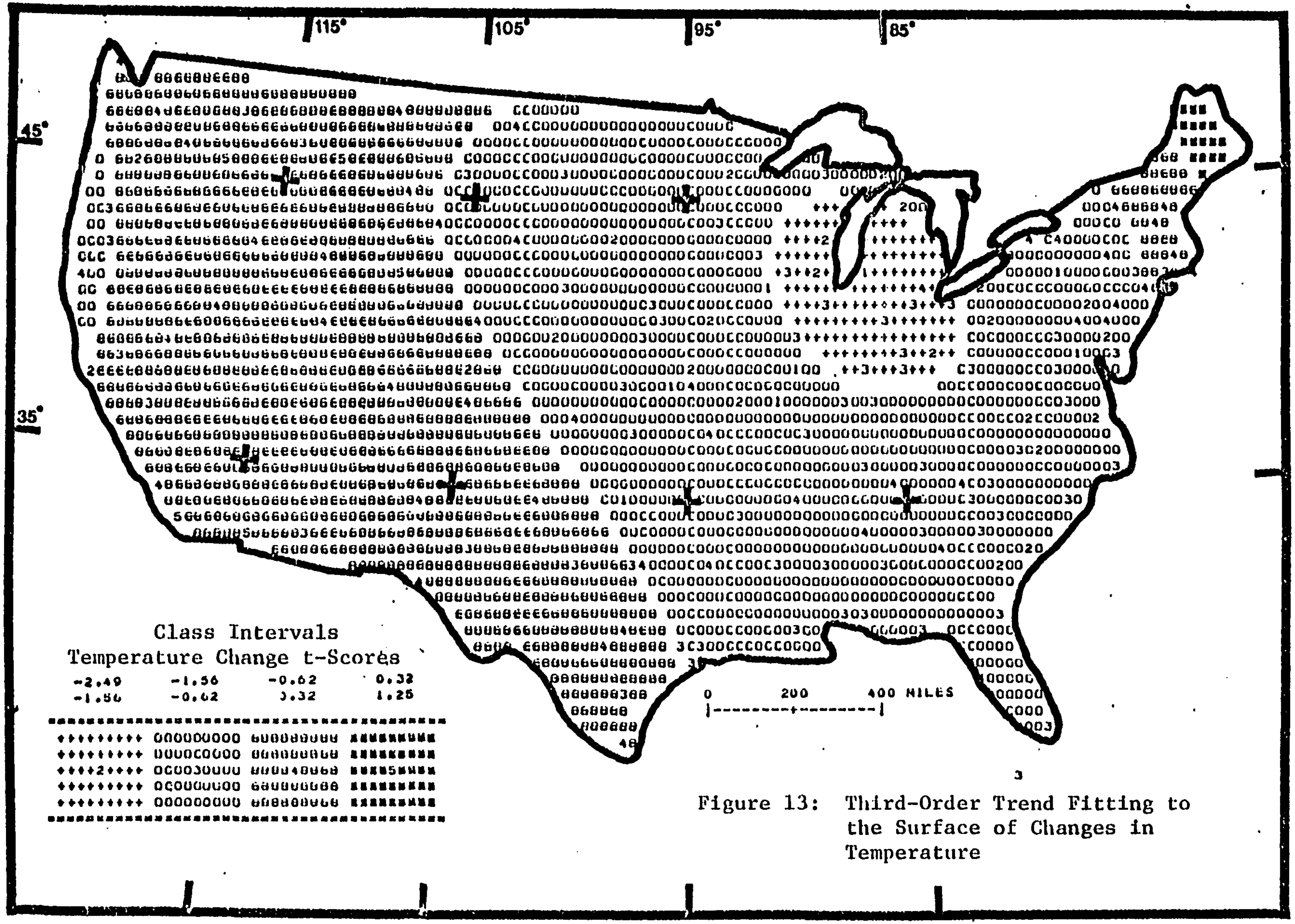


Figure 13: Third-Order Trend Fitting to the Surface of Changes in Temperature

erature, having occurred in the Western states, and lowest values determined in the East. More detail was displayed on the third-order map as more of the "signal" was uncovered. The southern Great Lakes region was a distinct "valley" indicating maximum decrease in temperature in that region. The northern California and Oregon coasts showed a decrease in temperature that did not show up with the linear fitting. Most of New England north of New York appeared to be a region of relative temperature increase; a pattern also not found in the first-order map.

A sixth-order fitting is displayed in Figure 14. The equation needed to produce this surface was similar in form to those presented for the other two trend-surface maps, but this equation had twenty-eight terms and is not presented here. The surface formed by the equation had a correlation coefficient of 0.70 with the original surface, and explained forty-nine per cent of the total variation. The Rocky Mountain states were dominated by a temperature increase, most of the eastern half of the United States displayed a decline in temperature. Once again, the Great Lakes region showed a distinct pocket of temperature decline, representing the lowest t-values in the country. A second area of increased temperatures fell along the United States - Mexican border, another in the New England area was observed. Kalnicky (1974) reported that a semi-permanent upper level ridge over the Rockies existed during the meridional period allowing

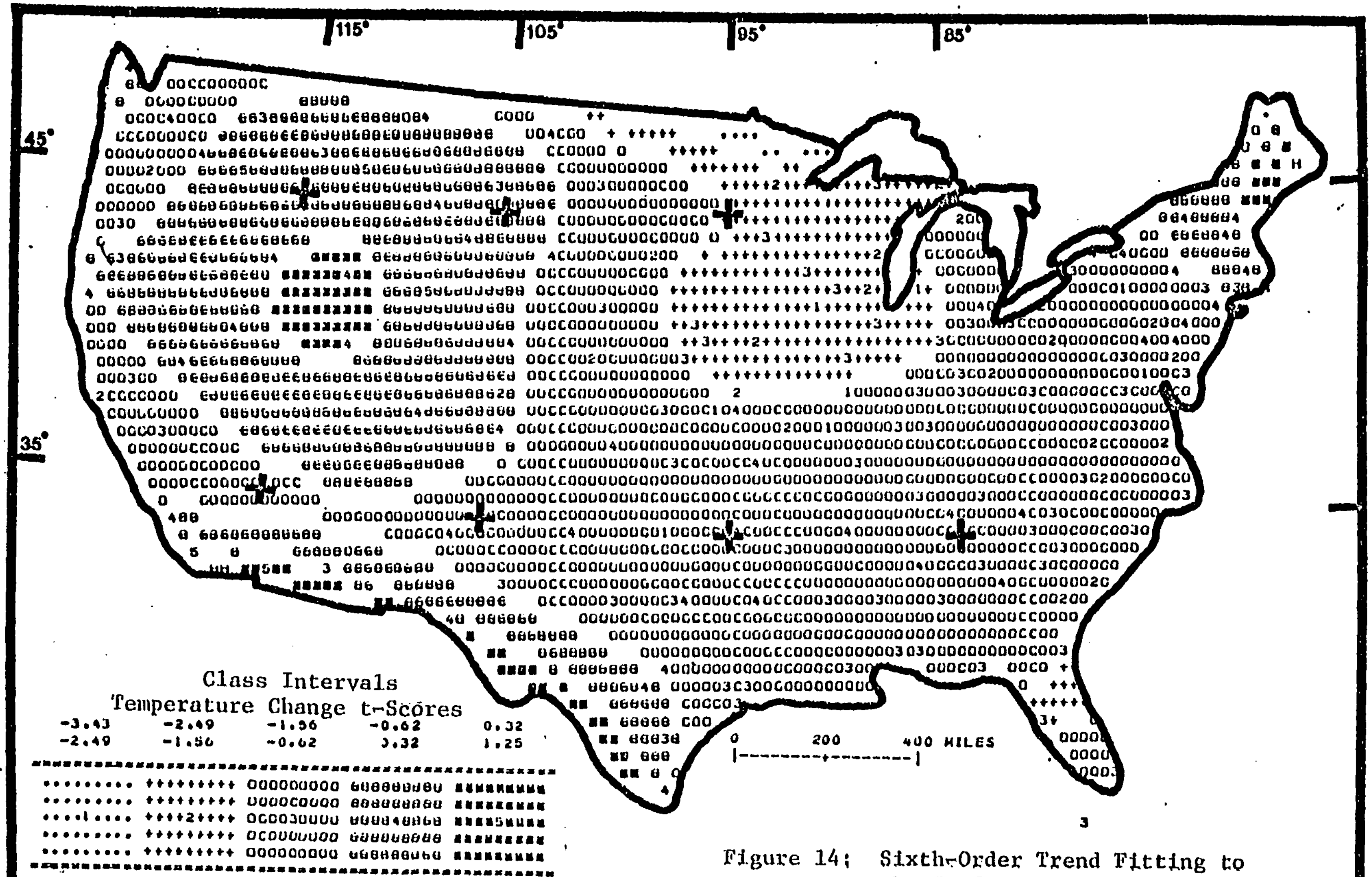


Figure 14; Sixth-Order Trend Fitting to the Surface of Change in Temperature for advection of warmer tropical air masses into the western states. A semi-permanent upper level trough in the eastern half of the continent allowed a greater frequency of polar air masses to penetrate the East, accounting for the drop in monthly temperatures. The relatively high values in New England indicated that the trough was positioned well behind, or west, of the region, allowing greater frequencies of mT air to have penetrated during the meridional period.

Obviously, maps for all eleven variables could be presented from the climatic change matrix, and each could be discussed separately (see Appendix IV for presentation of these maps). A principle-components factor analysis was used to condense the matrix, as significant interrelationships existed between many of the variables in the climatic change matrix (see Table 2). Five orthogonal factors produced eigenvalues greater than one, and these five factors accounted for seventy-one per cent of the total variance in the original change matrix. The factors were orthogonally rotated in such a way as to pass through correlation clusters in n-space, allowing for more precise interpretation of the factors. The loadings for each variable on each factor (see Table 3) displayed the correlation between the variable and the factor. Factor scores for each station were calculated from each eigenvector, and the results were mapped.

Factor 1 accounted for twenty-three per cent of the total variance in the change matrix and was clearly domi-

Table 2

Correlation Matrix of Variables in the

Climatic Change Matrix

	1	2	3	4	5	6	7	8	9	10	11
Psr	1.00	.10	.12	-.07	-.18	-.08	.01	.01	.08	.14	.10
Temp		1.00	.03	.06	-.19	-.25	.01	-.09	-.09	.01	.01
Hum			1.00	.05	.03	.10	-.07	.08	.05	-.03	-.06
Prec				1.00	.54	-.11	.01	.07	-.08	-.15	-.13
Prec D					1.00	.01	-.02	.09	-.02	-.12	-.22
Wind S						1.00	.18	.27	.59	.01	.05
Wind North							1.00	.17	.12	.07	.16
Wind West								1.00	.27	.02	.09
Res Wind S									1.00	.66	.45
Persist Y										1.00	.64
Persist M											1.00

nated by the variables associated with wind persistence. The loadings were highest on wind persistence calculated by years (0.93), wind persistence by calendar months (0.82), and resultant wind speed (0.76). Figure 15 displays the spatial pattern in the factor scores from this wind persistence component in the data. This sixth-order fitting to the original surface accounted for only twenty per cent of the variance in the original surface. The pattern showed wind persistence generally increased in the southwestern states, and decreased in an eastward direction. The general decline across the eastern one half of the United States reflected increases in frontal passages in the meridional period which

Table 3

Loadings for Five Rotated Factors

Factors	1	2	3	4	5
Psr	.17	.19	.37	-.54	.03
Temp	.00	.05	.74	-.12	.09
Hum	-.08	-.07	-.07	-.82	-.01
Prec	-.07	-.87	.18	-.03	.07
Prec D	-.09	-.86	-.21	.05	-.01
Wind S	.12	.12	-.68	-.18	.49
Wind North	.07	.05	.18	.25	.80
Wind West	.06	-.14	-.19	-.22	.63
Res Wind S	.76	.01	-.39	-.19	.28
Persist Y	.93	.05	.03	-.01	-.07
Persist M	.82	.13	.10	.09	.09
Factor Variance	23%	16%	12%	12%	8%
Cumulative Variance	23%	39%	51%	63%	71%
Eigenvalue	2.52	1.76	1.28	1.16	1.07

were associated with increased variability in wind direction. The semi-permanent ridge in the West forced these cyclonic storms poleward, which minimized the effect of these storms on the Southwest.

Factor 2 was dominated by negative loadings on total precipitation (-0.87) and precipitation days (-0.86) and was therefore labeled the precipitation change component. These first two factors combined to account for thirty-nine per cent of the total variance in the change matrix. The map of

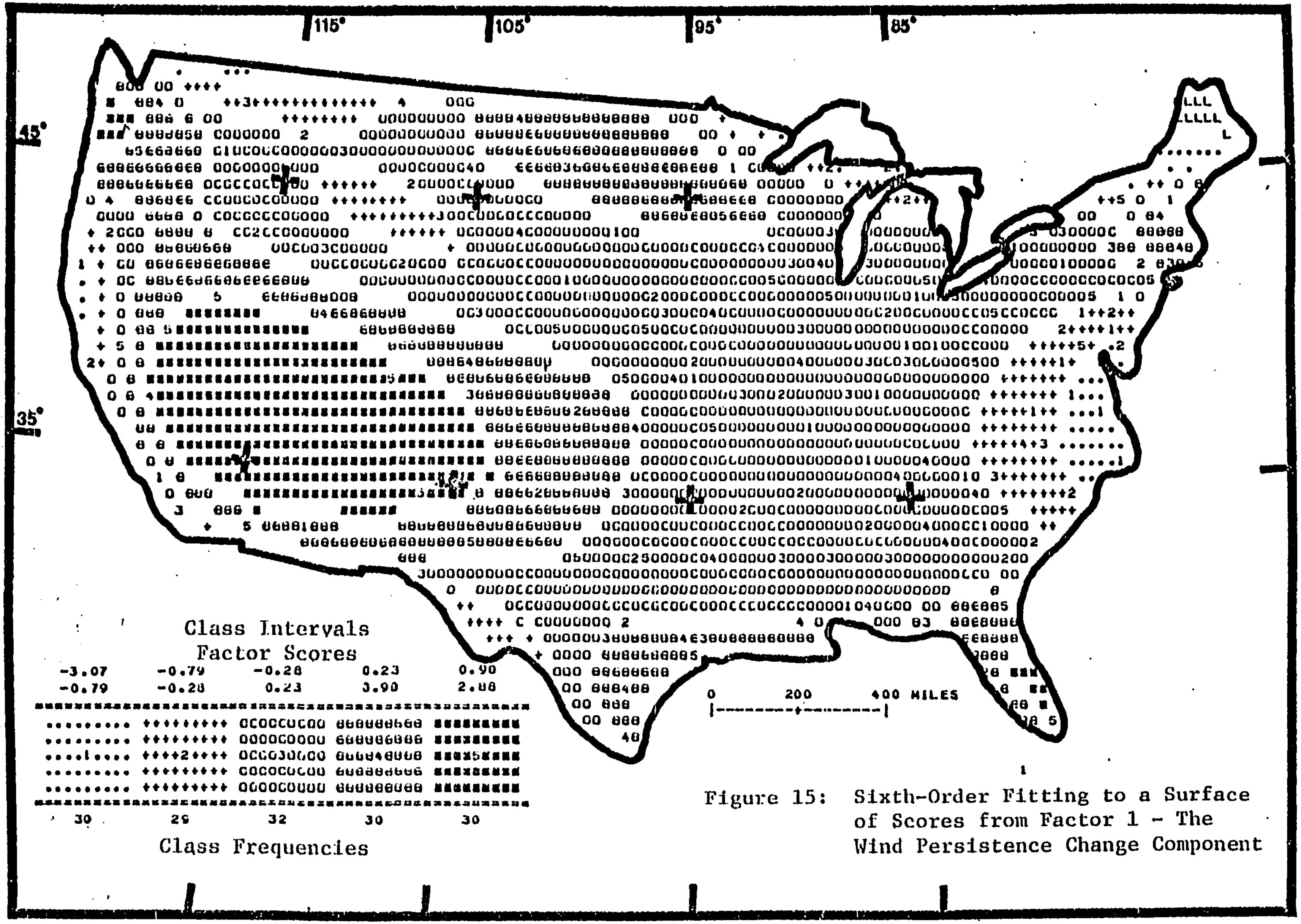


Figure 15: Sixth-Order Fitting to a Surface of Scores from Factor 1 - The Wind Persistence Change Component

the factor scores for precipitation displayed some distinctive spatial patterns (see Figure 16). The fitting explained fifty-four per cent of the variance of the original surface, and distinctly uncovered the underlying structure in the data. The northwestern states were dominated by increased precipitation, the prairie states were dominated by a major decrease in precipitation. Generally, an increase was observed in the eastern region, with exceptions along the Carolina coast and in northern New England. These findings reflected a shift in the circulation system of the atmosphere. Just ahead of the semi-permanent ridge which brought the warmer temperatures to the Rockies, convergence aloft inhibited vertical motions in the atmosphere which produce precipitation. Just ahead of the trough off the California coast and the trough centered over the central United States, divergence in the upper levels of the atmosphere supported vertical motions in the atmosphere, creating a greater potential for precipitation formation.

Factor 3 was characterized by a high loading on average monthly temperature (0.74) and also had a relatively high, but negative, loading with wind speed (-0.68). It was interpreted as the temperature change component, and when combined with factors 1 and 2, the three factors accounted for fifty-one per cent of the total variance in the change matrix. The spatial pattern shown in Figure 17 was very similar to the ones found when temperature was discussed

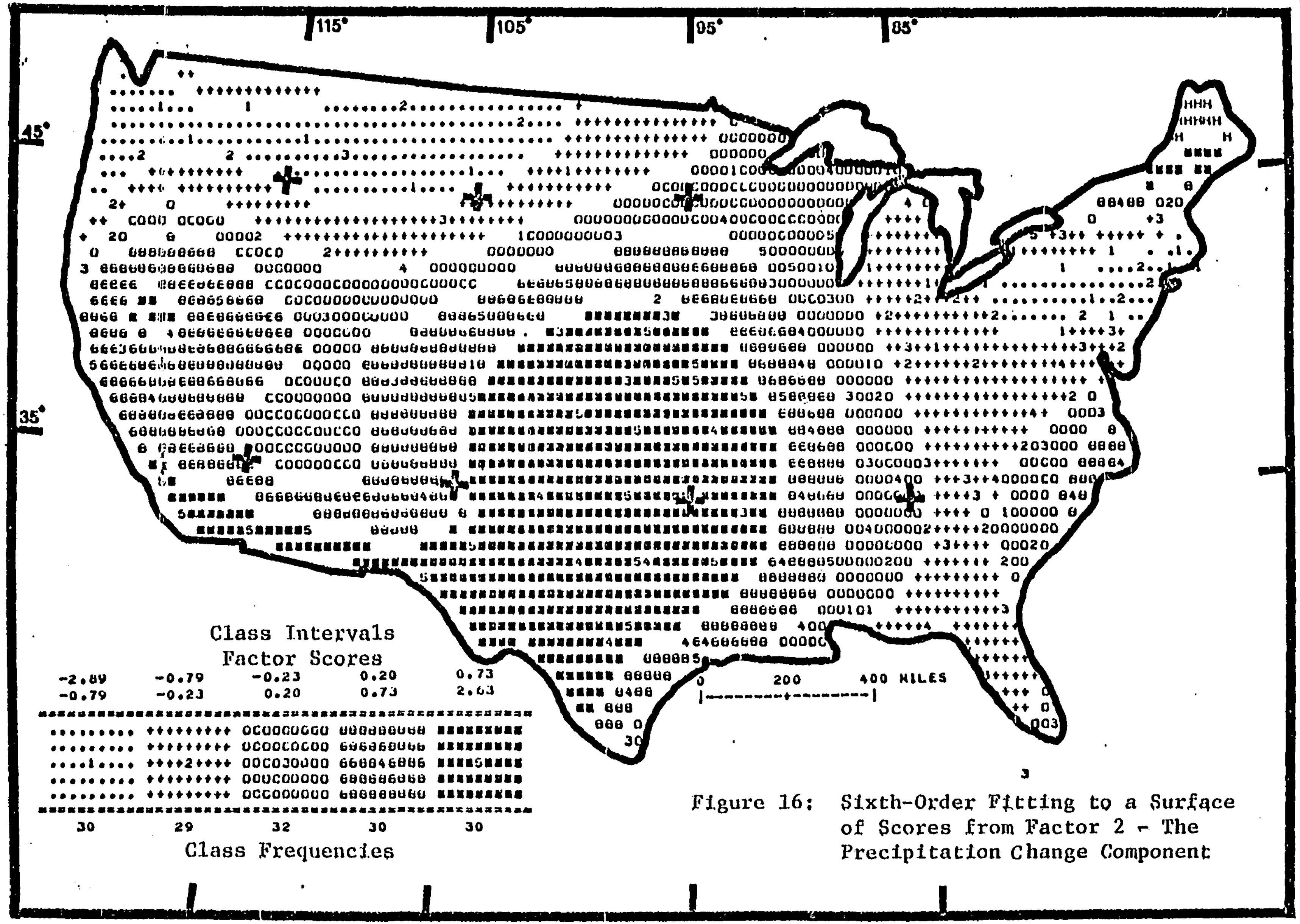


Figure 16: Sixth-Order Fitting to a Surface of Scores from Factor 2 - The Precipitation Change Component

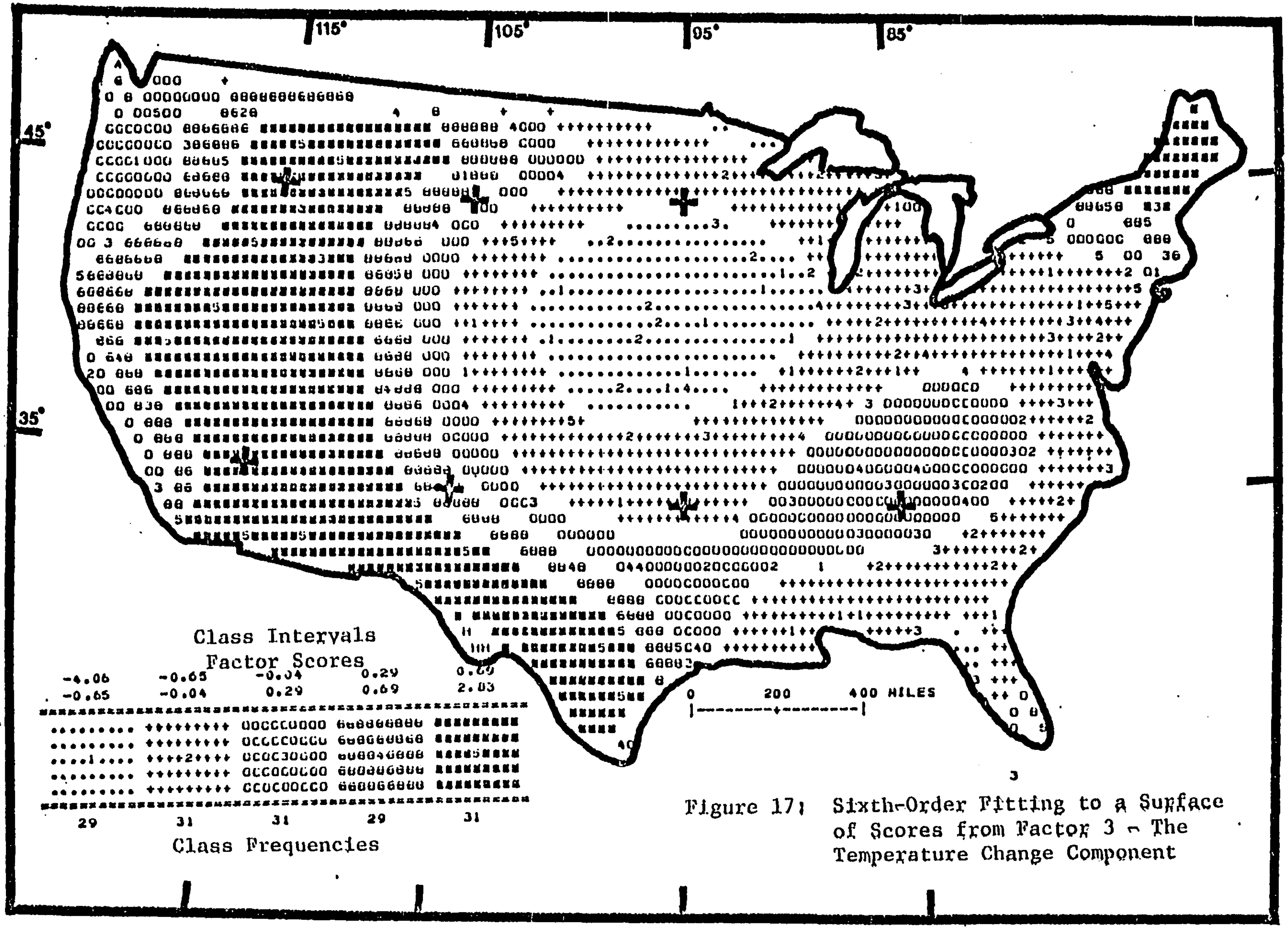


Figure 17: Sixth-Order Fitting to a Surface of Scores from Factor 3 - The Temperature Change Component

alone (see Figures 11 through 14). The Rocky Mountain states became relatively warmer, with lighter wind speeds, as the semi-permanent ridge over the region, with associated subsidence, allowed advection of tropical air masses into the region. The trough over the eastern states allowed advection of colder, polar air into the eastern region, creating the decline in average temperatures. The central plains showed up as an area of maximum convergence as the circulation shifted, with an associated cooling trend having occurred throughout the eastern half of the United States. Wind speeds generally increased throughout much of the United States, except in the Rocky Mountain area which became dominated by a ridge of high pressure.

Factor 4 was dominated by a negative loading with relative humidity (-0.82) making it a relative humidity change component. When combined with the first three components, sixty three per cent of all variance was accounted for. The spatial pattern is displayed in a trend-surface map (Figure 18) which accounted for forty-four per cent of the variance in the humidity surface. The spatial pattern was similar to the pattern for the precipitation factor. The map showed that the western states and the east coast states became more humid in the meridional period, the midwestern states became significantly drier. The trough centered over the midwest advected cold, dry air from the polar region, where the ridge over the Rockies allowed moist,

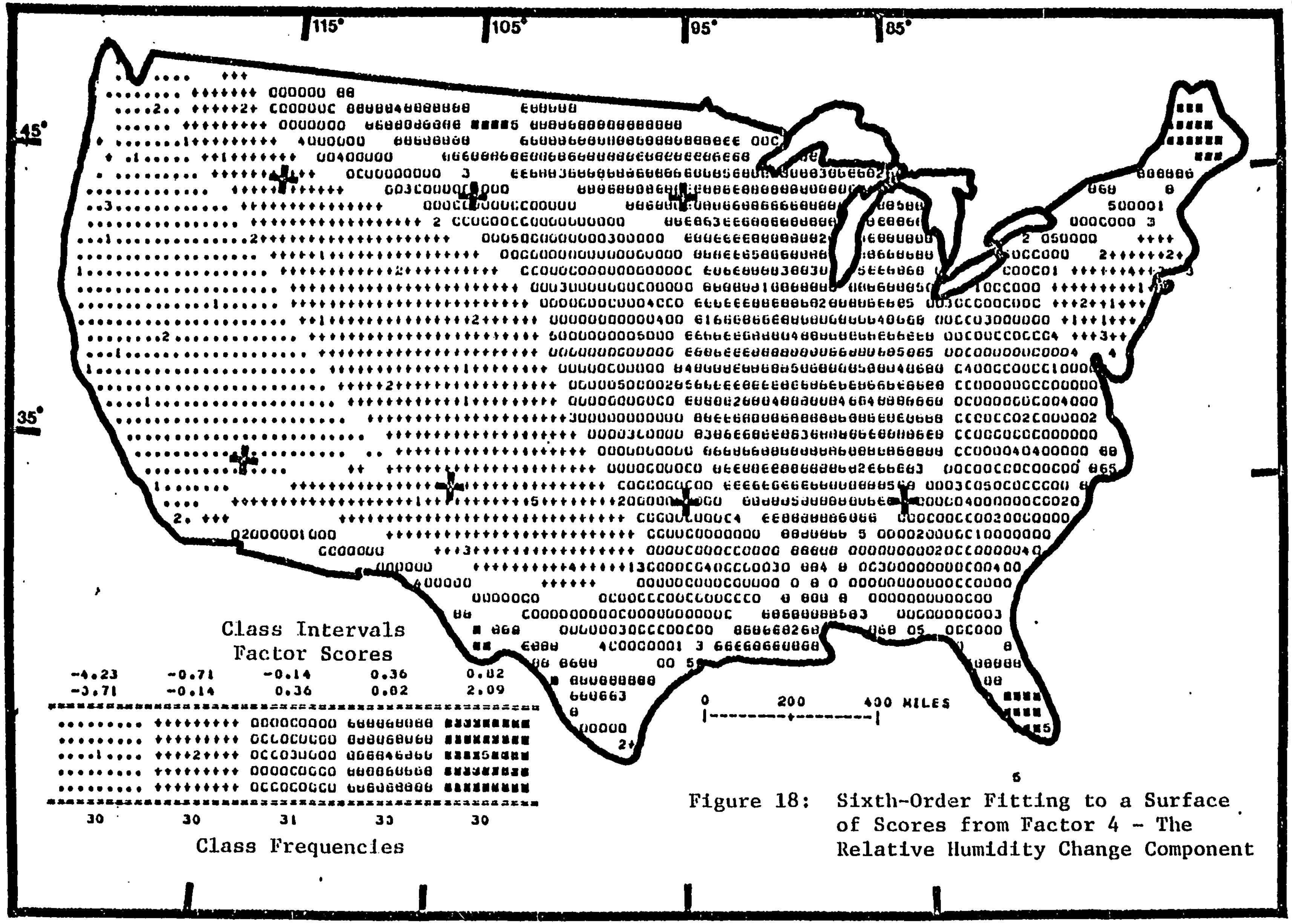


Figure 18: Sixth-Order Fitting to a Surface of Scores from Factor 4 - The Relative Humidity Change Component

tropical air to penetrate into the western states. The convergence in the upper atmosphere inhibited precipitation formation in the prairie states, keeping precipitation down despite higher relative humidities. Although the large region of the midwest had the largest decreases in relative humidity, the convergence in the upper levels of the atmosphere was not as persistent, and greater precipitation occurred when compared to the states slightly westward.

The last factor with an eigenvalue greater than one had highest loadings with the northerly wind component (0.80) and with the westerly wind component (0.63) and was therefore labeled the northwesterly wind change component. The five factors accounted for seventy-one per cent of the total variance in the climatic change matrix. The sixth-order fitting displayed in Figure 19 accounted for only twenty-two per cent of the total variance in the surface produced by the factor scores of the fifth component. The sixth-order fitting was difficult to interpret because both wind speeds and directional persistence were included in this component. Northwesterly components decreased in the West Coast states in association with southwesterly flow aloft in the meridional period. They increased downstream from the ridge axis in the western Great Plains where northwesterly flow aloft occurred. In the eastern states, northwesterly components decreased in association with southwesterly flow aloft. Decreases in the northwesterly

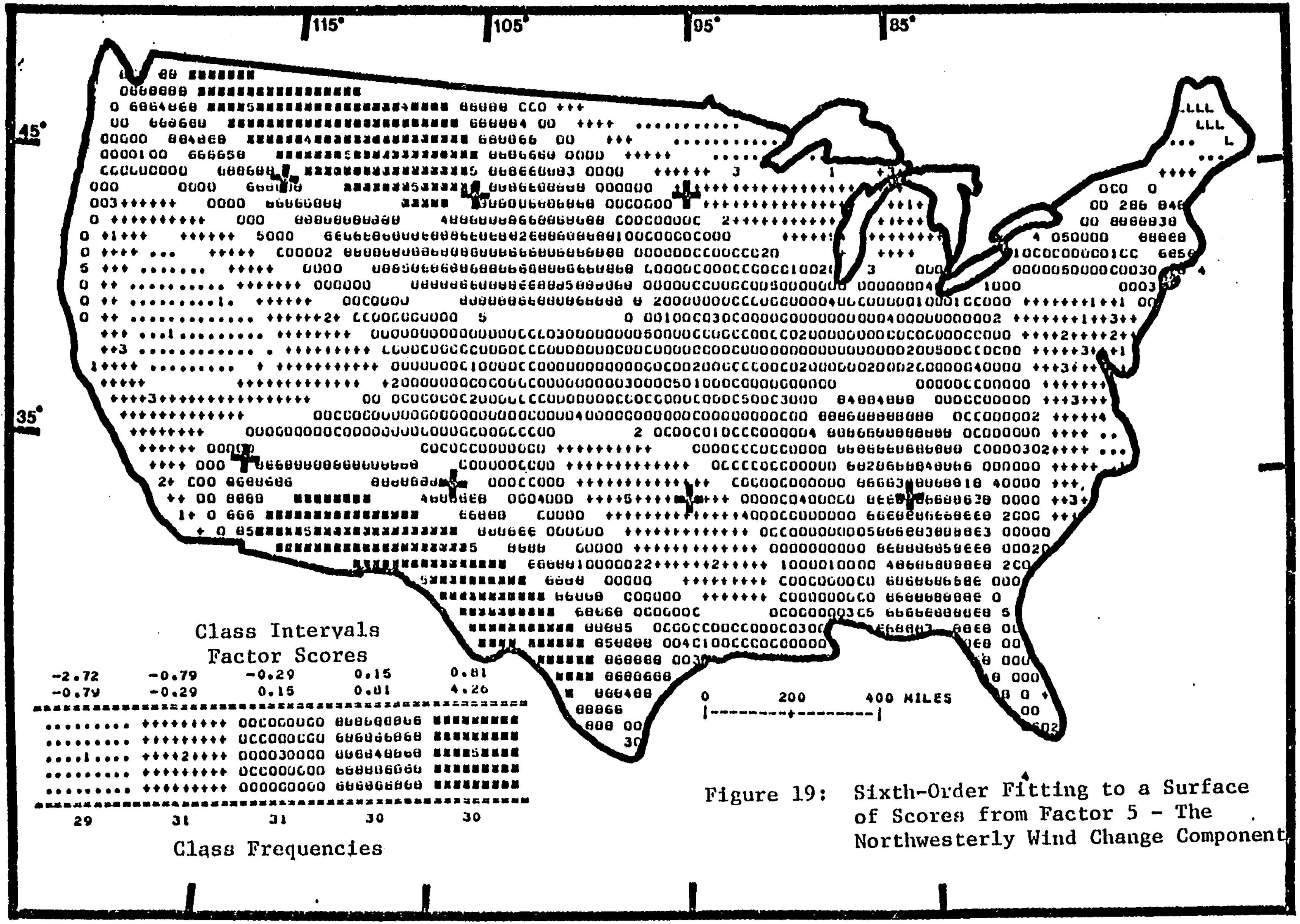


Figure 19: Sixth-Order Fitting to a Surface of Scores from Factor 5 - The Northwesterly Wind Change Component

components also occurred in the Great Lakes area and in the southern Great Plains.

Kalnicky (1974) demonstrated that a ridge was developed in the upper atmosphere over the Rockies during the meridional period. Over the eastern half of the United States, an upper level trough also became predominant in the meridional years. The effect of the change in circulation flow was noted in composite factors in this section. Two factors (1 and 5) were dominated by wind related measures. Factor 1 was a wind persistence change component which showed persistence values tended to decrease in the eastern one half of the United States where increases in frontal passages occurred in the meridional period. In the Southwest where cyclonic storms were driven northward, persistence tended to increase. Factor 5 was a northwesterly wind change component which tended to generally decrease in areas dominated by southwesterly winds aloft, and tended to increase in those regions where northwesterly flow aloft occurred in the meridional period. The spatial patterns were relatively difficult to interpret probably indicating the overwhelming affect of local conditions, particularly topography, on wind parameters. The second factor was interpreted as a precipitation change component and it showed that the lower plains became much drier as the circulation shifted from a zonal to a meridional pattern. Subsidence in the upper atmosphere was suggested as the key in restricting precipitation over that region. Factor 4 was a relative humidity change component in the data which displayed a decrease in atmospheric moisture from the northern plains through the Great Lakes, suggesting that little moisture was advected into the region during the meridional period. Moisture was advected into the Plains where precipitation levels were low. Therefore, even though sufficient moisture was available in the southern plains states, the upper level flow restricted the development of precipitation. A temperature change component, Factor 3, showed that the advection of warm air beneath the ridge in the Rockies during the meridional years brought warmer temperatures and decreased wind velocities to the region, and the advection of cooler, polar air masses into the eastern states beneath a trough lowered temperatures and increased wind velocities. In summary, the observed patterns demonstrated that a change in the upper level circulation was associated with changes in the surface climatic conditions. Most of the findings in this section were clearly explained by the shift in the circulation. The findings also strongly supported the notion that the general circulation of the atmosphere fluctuated in the early 1950's.

CHAPTER V

CHANGES IN THE CONFIGURATION OF ZONAL TO MERIDIONAL CLIMATIC REGIONS

Results and Analyses for a Combined Zonal-Meridional "Average" Period

To produce maps of climatic regions for the two time periods, the data for the climatic parameters were factor analyzed to transform the original data onto orthogonal axes. The factor scores from the computed eigenvectors became the data which were cluster analyzed based upon distances in Euclidean space. Only then were stations grouped into distinctive climatic groups based on distance levels in the computed phenogram. The results may not necessarily have produced continuous or homogeneous regions. The regions produced may possibly bear no resemblence to preconceived notions of the configuration of climatic regions in the United States.

Most climatic classifications that have gained wide acceptance in geography have been based primarily on temperature and precipitation values. A pilot study by this investigator showed that addition of too many variables created a confused spatial pattern, therefore, only the two rather commonly used variables, temperature and precipitation were employed. To develop a sense of some "average" condition, the monthly temperature and precipitation amounts were averaged for all twenty years, including both the zonal and meridional periods. This yielded one value for temperature for each month and one value of precipitation for each month for all one hundred fifty-one stations in the study. This matrix of six columns, one for each variable, and one hundred fifty-one rows, one for each station, was then factor analyzed. Two eigenvectors emerged as significant; factor 1 was clearly the temperature component and factor 2 was dominated by precipitation (see Table 4).

The factor scores for each station were then cluster analyzed, and a linkage tree was developed from the results of the distance level calculations. A cophenetic correlation was determined to be 0.88 indicating that little distortion existed between the implied distances on the phenogram (linkage tree) and the actual distances in Euclidean space. A decision was then made regarding the proper distance to be selected which divided the stations into climatic groups. If the distance level selected was too great, too few regions would have developed. Conversely, a very low distance level would have created too many groupings,

Table 4

Loadings for Two Rotated Factors based upon

Combined Zonal and Meridional Data

Variable	Factor 1	Factor 2
Temp(D)	.97	.24
Temp(J)	.96	.27
Temp(F)	.97	.22
Precip(D)	.21	.96
Precip(J)	.21	.97
Precip(F)	.30	.94
Factor Variance	73%	26%
Cumulative Variance	73%	99%
Eigenvalues	4.36	1.56

not allowing for any large homogeneous patterns to be formed. In that the calculations were used only to produce an average picture from which more specific zonal and meridional regions were compared, the decision to produce only ten climatic regions was made. To obtain the ten regions, the 0.85 phenon line divided the phenogram into eleven clusters, but as station 142, Tatoosh Island, Washington, was a single station region, it was eliminated , leaving the ten regions displayed in Figure 20. Table 5 shows the average winter temperature and precipitation values for each station

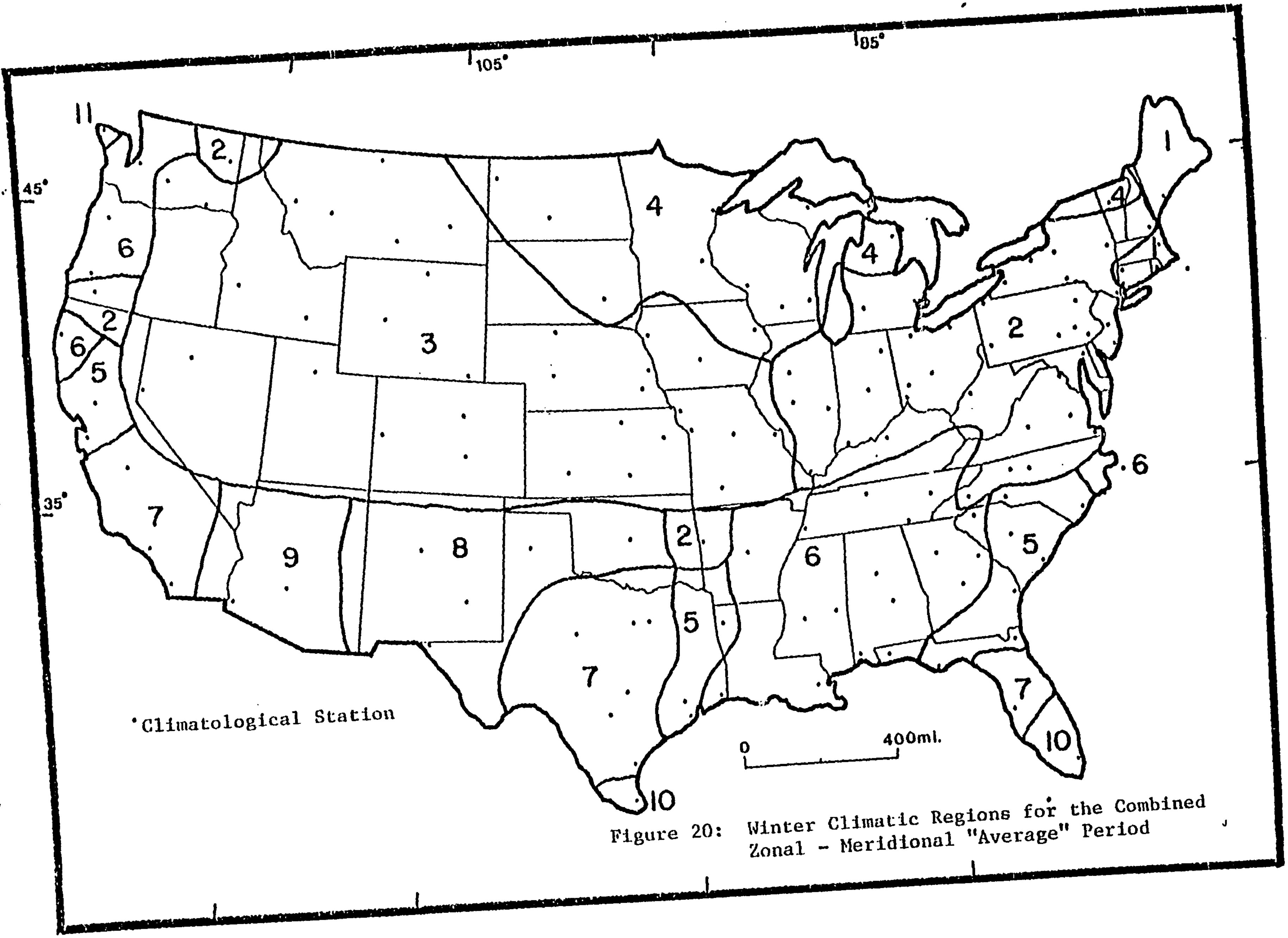


Figure 20: Winter Climatic Regions for the Combined Zonal - Meridional "Average" Period

Table 5

Combined Zonal - Meridional Temperature and

Precipitation Values by Regions

Region	Station Code	Station	Winter Temp.	Winter Precip.
1	1	Portland, ME	22.57	3.38
	7	Hartford, CT	26.69	3.35
	5	Nantucket, MA	32.43	3.94
	8	New Haven, CT	29.75	3.54
	6	Providence, RI	29.86	3.62
	4	Boston, MA	29.84	3.60
		Means (1)	28.52	3.57
2	11	New York, NY	33.10	3.23
	14	Reading, PA	32.29	3.00
	18	Baltimore, MD	35.22	3.10
	64	Louisville, KY	35.20	3.17
	65	Evansville, IN	34.03	2.95
	70	Parkersburg, WV	33.61	2.86
	67	Cincinnati, OH	33.40	2.90
	17	Trenton, NJ	32.61	2.85
	13	Philadelphia, PA	33.19	2.93
	95	Cairo, IL	37.71	3.50
	16	Atlantic City, NJ	34.76	3.57
	49	Fort Smith, AR	41.35	2.81
	21	Norfolk, VI	41.66	3.27
	27	Raleigh, NC	41.62	3.21
	20	Lynchburg, VI	37.73	2.96
	23	Asheville, NC	38.55	2.96
	25	Greensboro, NC	39.10	3.23
	143	Medford, OR	39.63	3.10
	22	Richmond, VI	38.79	3.11
	19	Washington DC	36.35	2.81
	12	Harrisburg, PA	31.10	2.65
	75	Erie, PA	28.11	2.48
	71	Pittsburgh, PA	29.43	2.48
	66	Indianapolis, IN	29.29	2.27

Region	Station Code	Station	Winter Temp.	Winter Precip.
	69	Dayton, OH	29.37	2.23
	68	Columbus, OH	30.40	2.29
	138	Spokane, WA	29.49	1.99
	76	Cleveland, OH	28.21	2.13
	78	Fort Wayne, IN	26.24	1.95
	15	Scranton, PA	27.06	2.08
	97	Springfield, IL	29.13	1.61
	84	Chicago, IL	26.29	1.55
	96	Peoria, IL	26.34	1.55
	81	Grand Rapids, MI	25.49	1.72
	79	Detroit, MI	26.71	1.76
	77	Toledo, OH	26.30	1.79
	9	Albany, NY	23.20	2.22
	73	Rochester, NY	24.93	2.28
	10	Binghamton, NY	24.27	2.33
	72	Buffalo, NY	25.66	2.84
	74	Syracuse, NY	24.37	2.86
	2	Concord, NH	22.17	2.62
		Means (2)	31.51	2.60
3	93	Des Moines, IA	23.66	1.14
	112	Missoula, MT	24.45	1.01
	110	Havre, MT	19.03	.42
	111	Helena, MT	22.32	.46
	116	Lander, WY	21.73	.56
	113	Miles City, MT	20.74	.43
	107	Sioux City, IA	21.58	.74
	106	Valentine, NB	23.66	.36
	114	Rapid City, SD	25.20	.46
	118	North Platte, NB	26.76	.46
	115	Cheyenne, WY	27.63	.49
	105	Omaha, NB	25.32	.86
	117	Sheridan, WY	24.33	.67
	109	Billing, MT	26.44	.67
	137	Pocatello, ID	26.46	1.01
	104	Lincoln, NB	27.02	1.00
	119	Denver, CO	32.28	.61
	122	Dodge City, KS	32.58	.63
	135	Grand Junction, CO	30.64	.60
	120	Pueblo, CO	31.73	.38
	101	St. Joseph, MO	29.11	1.26

Region	Station Code	Station	Winter Temp.	Winter Precip.
	136	Boise, ID	31.88	1.28
	134	Salt Lake City, UT	30.68	1.25
	103	Topeka, KS	31.04	1.25
	123	Wichita, KS	33.41	1.12
	132	Reno, NV	34.17	1.09
	140	Yakima, WA	32.02	1.11
	133	Winnemucca, NV	31.60	.96
	121	Concordia, KS	29.68	.85
	139	Walla Walla, WA	36.50	1.78
	99	Columbia, MO	31.80	1.64
	100	Kansas City, MO	31.93	1.56
	102	Springfield, MO	34.46	1.81
	98	St. Louis, MO	33.20	1.92
		Means (3)	28.38	.94
4	87	Duluth, MN	12.45	.85
	90	Minneapolis-St. Paul, MN	16.76	.68
	108	Huron, SD	16.54	.52
	89	Williston, ND	14.05	.47
	88	Bismarck, ND	13.10	.39
	80	Alpena, MI	21.10	1.50
	82	Marquette, MI	20.23	1.60
	94	Dubuque, IA	21.75	1.37
	86	Milwaukee, WI	22.66	1.40
	92	Madison, WI	20.36	1.09
	91	La Crosse, WI	18.91	.87
	85	Green Bay, WI	18.74	1.01
	83	Sault Ste. Marie, MI	16.29	1.80
	3	Burlington, VT	18.74	1.63
		Means (4)	17.98	1.09
5	28	Wilmington, NC	47.16	3.42
	30	Columbia, SC	46.75	3.44
	147	Sacramento, CA	47.58	3.47
	29	Charleston, SC	49.87	3.28
	148	San Francisco, CA	51.20	3.96
	48	Shreveport, LA	48.18	4.05
	32	Augusta, GA	47.37	3.80
	34	Jacksonville, FL	56.11	3.14
	57	Houston, TX	54.43	3.52
	56	Galveston, TX	54.86	3.41
	40	Apalachicola, FL	54.69	3.45
	33	Savannah, GA	51.47	2.92

Region	Station Code	Station	Winter Temp.	Winter Precip.
		Means (5)	50.81	3.49
6	60	Chattanooga, TN	41.14	5.35
	144	Portland, OR	41.79	5.26
	145	Roseburg, OR	42.82	5.20
	146	Eureka, CA	48.57	5.99
	41	Pensacola, FL	53.36	4.57
	58	Port Artur, TX	53.60	4.57
	47	New Orleans, LA	54.44	4.79
	43	Mobile, AL	52.35	5.08
	42	Birmingham, AL	45.33	5.13
	46	Vicksburg, MS	48.65	5.10
	45	Meridian, MS	47.46	4.95
	38	Atlanta, GA	44.17	4.45
	141	Seattle, WA	43.23	4.63
	62	Memphis, TN	41.74	4.38
	63	Nashville, TN	39.44	4.30
	61	Knoxville, TN	40.10	4.70
	26	Hatteras, NC	46.49	4.45
	44	Montgomery, AL	49.08	4.60
	39	Macon, GA	48.16	4.36
	31	Greenville, SC	43.19	4.15
	50	Little Rock, AR	42.48	3.99
	24	Charlotte, NC	42.91	3.73
		Means (6)	45.93	4.72
7	37	Tampa, FL	61.44	2.62
	150	Los Angeles, CA	57.03	2.52
	59	San Antonio, TX	52.45	1.78
	151	San Diego, CA	57.12	1.73
	53	Corpus Christi, TX	57.63	1.98
	125	Abiline, TX	45.74	1.19
	149	Fresno, CA	47.50	1.70
	54	Dallas, TX	46.74	2.50
	55	Fort Worth, TX	46.30	2.17
	51	Austin, TX	51.14	2.33
		Means (7)	52.31	2.05
8	128	El Paso, TX	46.19	.49
	126	Amarillo, TX	37.43	.72

Region	Station Code	Station	Winter Temp.	Winter Precip.
	129	Albuquerque, NM	37.17	.46
	127	Roswell, NM	40.85	.58
	124	Oklahoma City, OK	39.01	1.38
		Means (8)	40.13	.72
9	130	Phoenix, AZ	53.75	.69
	131	Yuma, AZ	57.75	.35
		Means (9)	55.75	.52
10	52	Brownsville, TX	61.56	1.62
	36	Miami, FL	67.85	2.03
	35	Key West, FL	70.69	1.74
		Means (10)	66.70	1.80
11	142	Tatoosh Island, WA	43.53	10.00

and the mean values for each of the regions. Large, homogeneous regions developed over most of the United States except in a few isolated locations, especially along the southern Pacific coast. The interplay of a wide variety of station elevations, topography, and ocean currents produced the diversity of climatic types in this region. The goal here was not to identify these winter-month climatic regions and to characterize each one, but to note the existence and configuration of the regions. Zonal and meridional regions were later developed and details regarding each follow in this chapter.

Results and Analyses for the Zonal Period

The same procedure used to create the combined zonal and meridional winter climatic regions was applied to the zonal data alone. Again, only temperature and precipitation values were used in the principle-components analysis. Two factors emerged, one temperature and the other precipitation, which accounted for ninety-eight per cent of the total variance in the data set. The loadings displayed in Table 6 showed that factor 1 was a temperature component and factor

Table 6

Loadings for Two Rotated Factors based on Zonal Data

Variable	Factor 1	Factor 2
Temp(D)	.97	.25
Temp(J)	.96	.28
Temp(F)	.97	.23
Precip(D)	.26	.95
Precip(J)	.22	.96
Precip(F)	.27	.94
Factor Variance	73%	25%
Cumulative Variance	73%	98%
Eigenvalues	4.38	1.49

2 was a precipitation component. The factor scores calculated from these two components were used as the base for

the clustering algorithm. A linkage tree (see Figure 21) was developed based on the Euclidean distance in the precipitation and temperature factor scores calculated for each station. The cophenetic correlation was found to be 0.93 indicating little distortion existed between implied and actual distances between the stations.

A phenon line of 0.773 divided the stations into eleven groupings, but as in the combined case, Tatoosh Island, Washington, stood far alone as a single station winter climatic region, and was eliminated, leaving ten climatic regions (see Figure 22). Table 7 contains a listing of the station names, by zonal climatic regions, with temperature and precipitation data. The values are the zonal winter means produced by averaging the zonal monthly means.

The largest feature in the pattern was a large climatic region (4) extending from the Rocky Mountains to stations in Pennsylvania. When compared to data for the rest of the United States (see Figure 23), it became obvious that this group was marked by cool temperatures (27.78 degree average) and below average precipitation levels (1.30 inches on average). The New England region (1), extended from New York State through Maine, was marked by similar cooler than normal average monthly temperatures (25.46 degrees) and greater than average precipitation values (2.77 inches).

A large region (2) extended from the mid-Atlantic states through the continental interior to Arkansas. It was

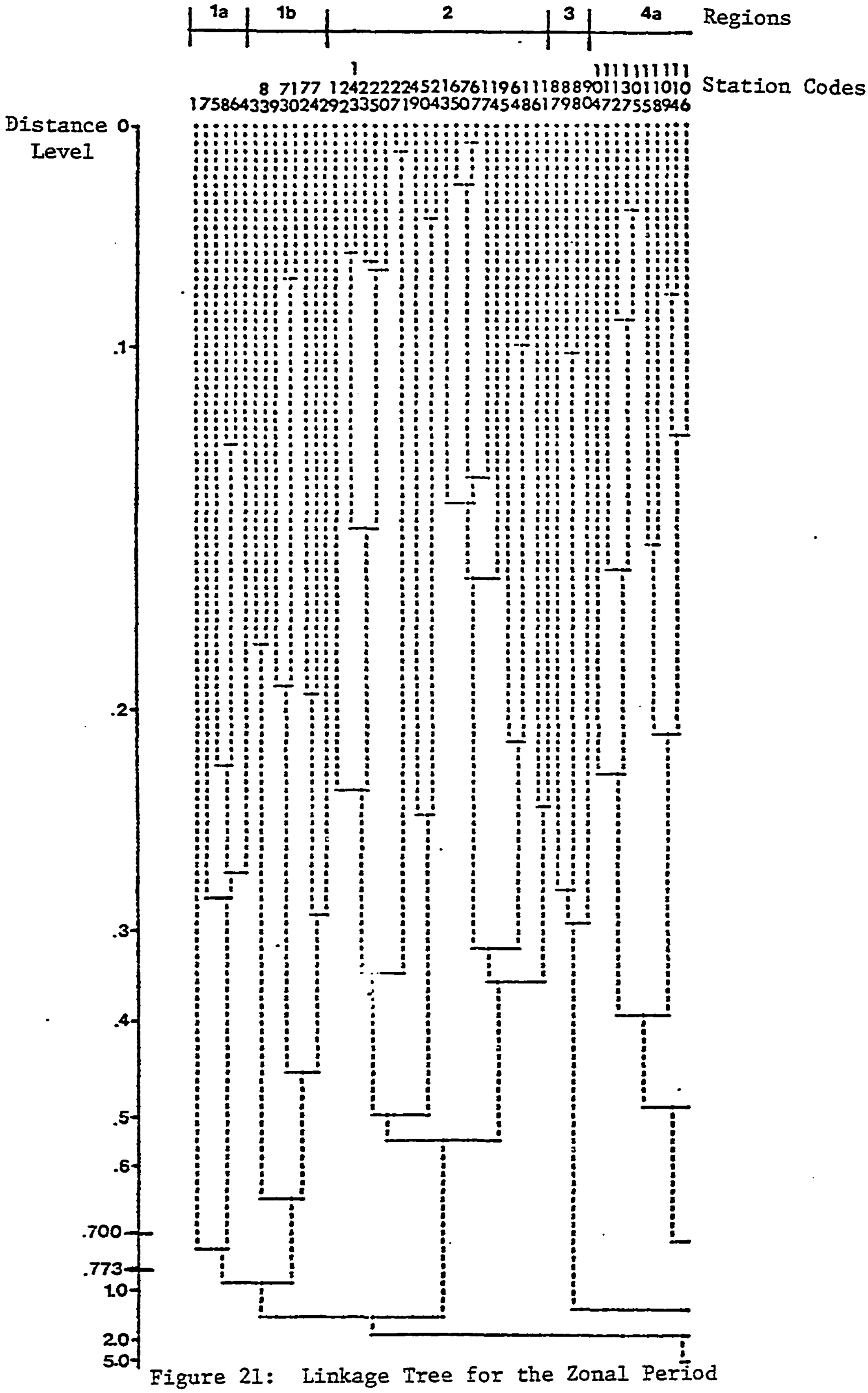


Figure 21: Linkage Tree for the Zonal Period

Figure 21: Continued

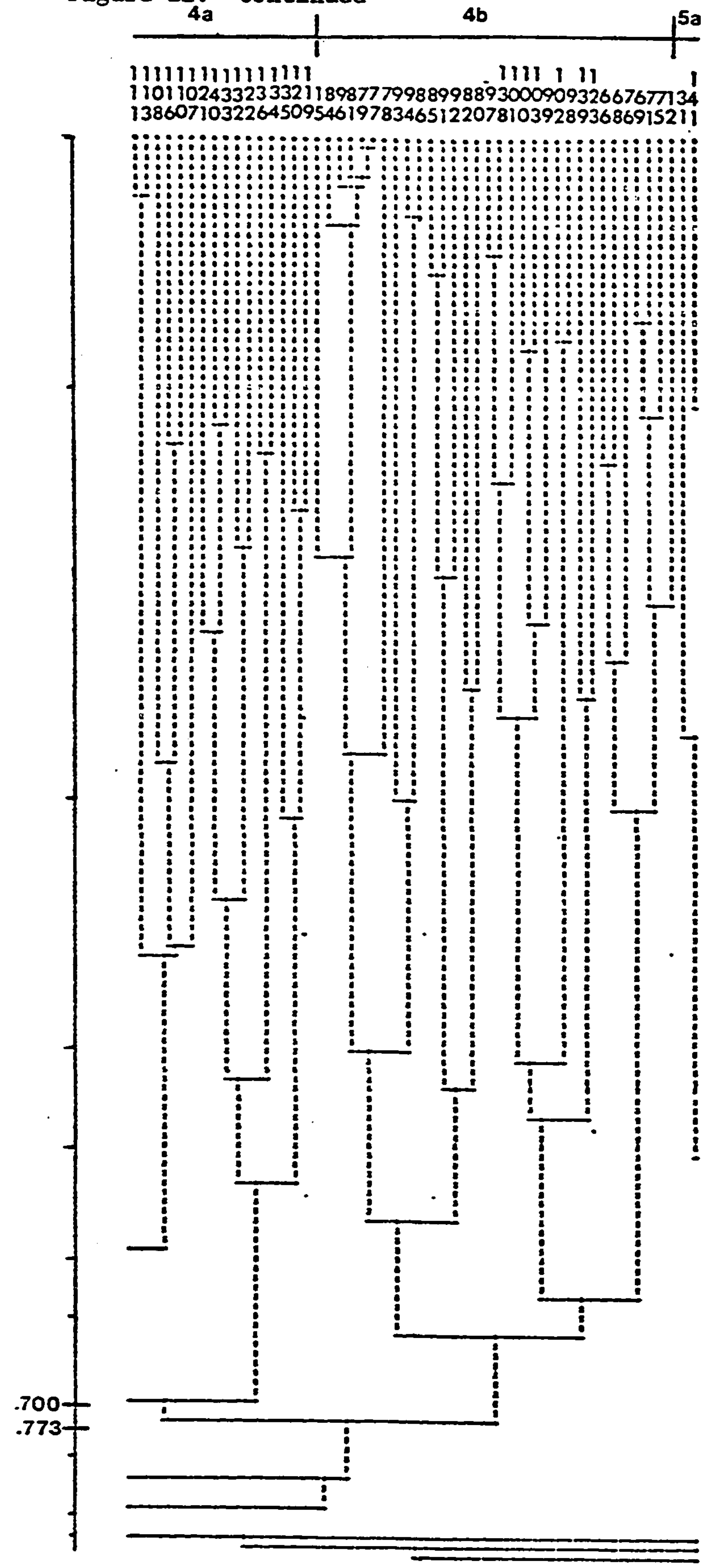
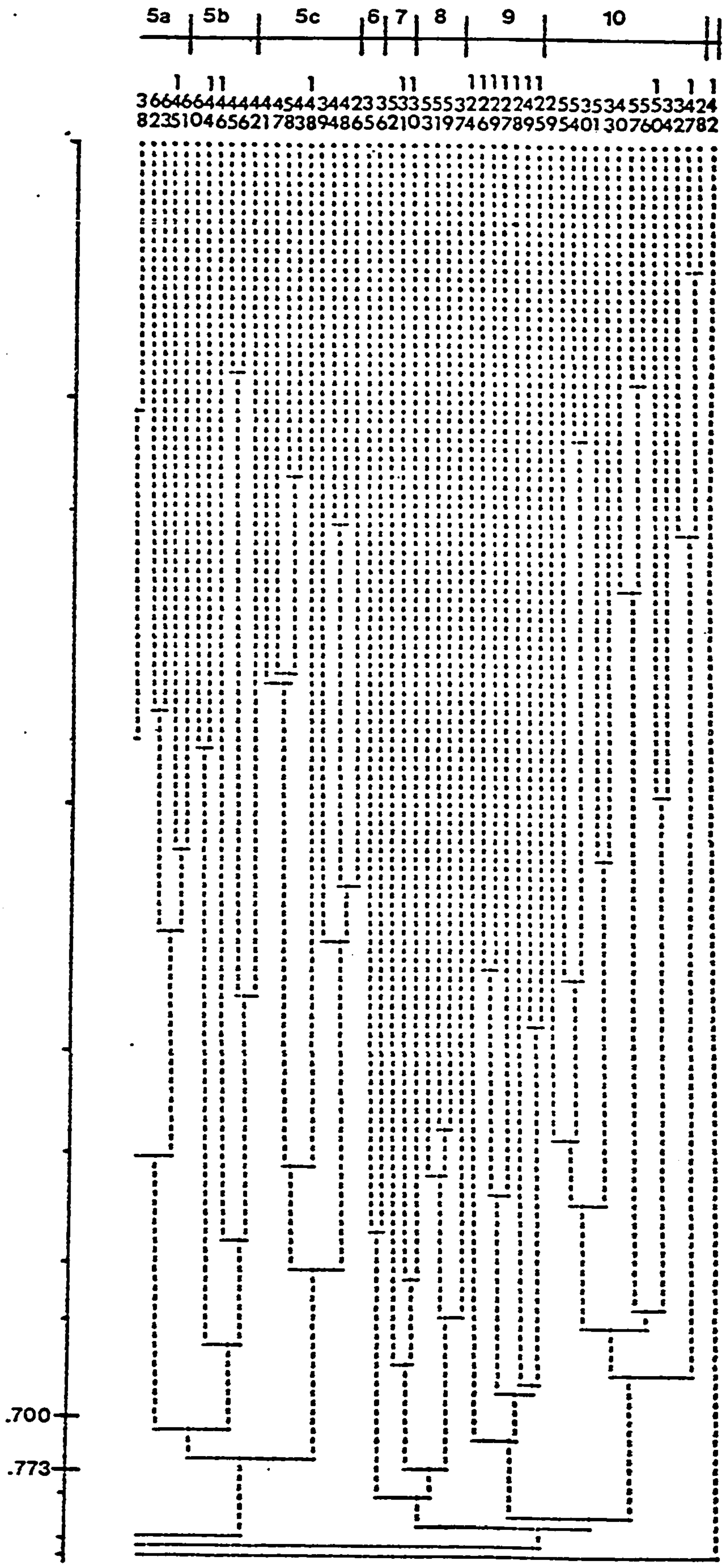


Figure 21: Continued



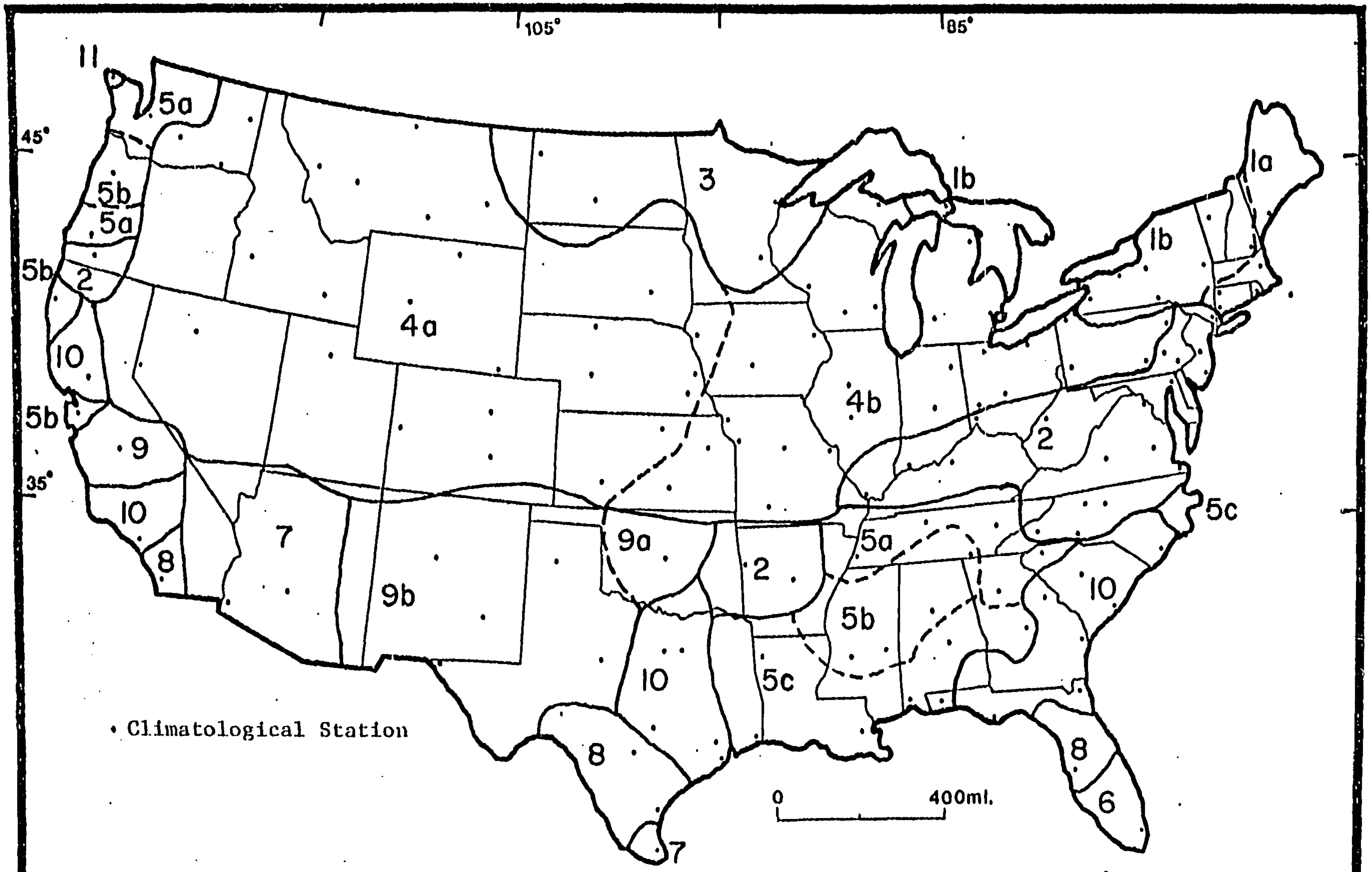


Figure 22: Winter Climatic Regions for the Zonal Period

Table 7

Listing of Temperature and Precipitation Values

By Zonal Climatic Regions

Region	Station Code	Station	Winter Temp.	Winter Precip.
1a	1	Portland, ME	22.53	3.36
	7	Hartford, CT	27.38	3.31
	5	Nantucket, MA	32.58	3.57
	8	New Haven, CT	29.84	3.60
	6	Providence, RI	30.53	3.46
	4	Boston, MA	29.78	3.16
		Means (1a)	28.77	3.41
1b	3	Burlington, VT	19.01	1.66
	83	Sault Ste. Marie, MI	17.39	1.74
	9	Albany, NY	23.35	2.11
	73	Rochester, NY	25.21	2.27
	10	Binghamton, NY	26.08	2.26
	72	Buffalo, NY	26.10	2.75
	74	Syracuse, NY	24.55	2.85
	2	Concord, NH	22.05	2.61
		Means (1b)	22.97	2.28
		Means (1)	25.46	2.77
2	19	Washington, DC	36.89	2.85
	22	Richmond, VA	39.63	2.85
	143	Medford, OR	40.02	2.85
	23	Asheville, NC	38.91	2.91
	25	Greensboro, NC	39.54	3.00
	20	Lynchburg, VA	38.76	3.00
	27	Raleigh, NC	42.63	3.06
	21	Norfolk, VA	42.73	3.04
	49	Fort Smith, AR	41.59	3.40
	50	Little Rock, AR	42.88	3.73
	24	Charlotte, NC	43.65	3.75
	13	Philadelphia, PA	34.19	2.98
	65	Evansville, IN	34.58	2.83
	70	Parkersburg, WV	34.23	2.83
	67	Cincinnati, OH	34.12	2.82
	17	Trenton, NJ	32.76	2.72

Region	Station Code	Station	Winter Temp.	Winter Precip.
	14	Reading, PA	32.50	2.91
	95	Cairo, IL	38.15	3.41
	64	Louisville, KY	35.80	3.07
	18	Baltimore, MD	36.97	3.18
	16	Atlantic City, NJ	35.62	3.48
	11	New York, NY	32.98	3.21
		Means (2)	37.69	3.08
3	87	Duluth, MN	14.30	.76
	89	Williston, ND	14.70	.47
	88	Bismarck, ND	13.80	.33
	90	Minneapolis-St. Paul, MN	17.64	.74
		Means (3)	15.11	.57
4a	104	Lincoln, NB	27.50	1.18
	117	Sheridan, WY	24.29	.71
	112	Missoula, MT	25.26	.87
	137	Pocatello, ID	26.31	1.01
	105	Omaha, NB	25.84	.96
	115	Cheyenne, WY	27.53	.62
	118	North Platte, NB	28.14	.48
	109	Billings, MT	26.19	.56
	114	Rapid City, SD	25.53	.41
	106	Valentine, NB	24.52	.47
	111	Helena, MT	21.76	.42
	113	Miles City, MT	21.51	.36
	108	Huron, SD	18.00	.47
	116	Lander, WY	20.71	.58
	110	Harve, MT	19.63	.42
	107	Sioux City, SD	22.35	.74
	121	Concordia, KS	30.24	.95
	140	Yakima, WA	32.53	1.00
	133	Winnemucca, NV	31.72	1.05
	132	Reno, NV	34.31	.98
	122	Dodge City, KS	32.71	.81
	136	Boise, ID	31.64	1.26
	134	Salt Lake City, UT	30.63	1.29
	135	Grand Junction, CO	30.86	.58
	120	Pueblo, CO	31.73	.42
	119	Denver, CO	33.34	.53
		Means (4a)	27.11	.74

Region	Station Code	Station	Winter Temp.	Winter Precip.
4b	15	Scranton, PA	28.03	1.89
	84	Chicago, IL	26.90	1.61
	96	Peoria, IL	27.28	1.69
	81	Grand Rapids, MI	27.01	1.66
	79	Detroit, MI	26.98	1.70
	77	Toledo, OH	27.17	1.70
	78	Fort Wayne, IN	26.75	1.90
	93	Des Moines, IA	25.12	1.28
	94	Dubuque, IA	23.85	1.38
	86	Milwaukee, WI	23.73	1.42
	85	Green Bay, WI	20.29	1.16
	91	La Crosse, WI	19.49	1.10
	92	Madison, WI	21.43	1.30
	82	Marquette, MI	21.08	1.70
	80	Alpena, MI	22.57	1.60
	97	Springfield, IL	30.48	1.77
	138	Spokane, WA	30.10	1.69
	101	St. Joseph, MO	30.13	1.58
	100	Kansas City, MO	32.04	1.68
	103	Topeka, KS	32.23	1.59
	99	Columbia, MO	32.60	1.86
	102	Springfield, MO	34.68	1.98
	98	St. Louis, MO	34.51	2.07
	139	Walla Walla, WA	36.04	1.72
	123	Wichita, KS	33.90	1.51
	66	Indianapolis, IN	30.17	2.03
	68	Columbus, OH	31.58	2.16
	76	Cleveland, OH	28.97	2.08
	69	Dayton, OH	29.98	2.28
	12	Harrisburg, PA	31.65	2.42
		Means (4b)	28.33	1.76
		Means (4)	27.78	1.30
5a	31	Greenville, SC	43.54	4.01
	141	Seattle, WA	43.27	4.31
	38	Atlanta, GA	44.64	4.30
	62	Memphis, TN	42.05	4.31
	63	Nashville, TN	39.91	4.20
	145	Roseburg, OR	43.16	4.71
	61	Knoxville, TN	40.61	4.57
		Means (5a)	42.46	4.34

Region	Station Code	Station	Winter Temp.	Winter Precip.
5b	60	Chattanooga, TN	41.47	5.56
	144	Portland, OR	42.73	5.55
	146	Eureka, CA	48.58	5.95
	45	Meridian, MS	48.23	5.25
	46	Vicksburg, MS	49.22	5.32
	42	Birmingham, AL	45.69	5.22
		Means (5b)	45.99	5.47
5c	41	Pensacola, FL	53.99	4.55
	47	New Orleans, LA	55.57	4.79
	58	Port Arthur, TX	54.17	4.74
	43	Mobile, AL	53.06	4.78
	148	San Francisco, CA	52.17	4.18
	39	Macon, GA	48.29	4.21
	44	Montgomery, AL	50.02	4.55
	48	Shreveport, LA	48.45	4.50
	26	Hatteras, NC	46.97	4.56
		Means (5c)	51.41	4.53
		Means (5)	47.08	4.73
6	35	Key West, FL	71.10	1.66
	36	Miami, FL	68.21	1.92
		Means (6)	69.65	1.79
7	52	Brownsville, TX	61.83	1.50
	131	Yuma, AZ	57.11	.39
	130	Phoenix, AZ	54.06	.76
		Means (7)	57.67	.88
8	53	Corpus Christi, TX	57.95	1.83
	151	San Diego, CA	56.56	2.23
	59	San Antonio, TX	52.60	1.79
	37	Tampa, FL	62.23	2.51
		Means (8)	57.33	2.09
9a	124	Oklahoma City, OK	39.85	1.65
9b	126	Amarillo, TX	37.53	.81

Region	Station Code	Station	Winter Temp.	Winter Precip.
	129	Albuquerque, NM	37.26	.48
	127	Roswell, NM	41.64	.62
	128	El Paso, TX	46.39	.55
	149	Fresno, CA	47.87	1.67
	125	Abiline, TX	45.99	1.26
		Means (9b)	42.78	.89
		Means (9)	42.36	1.01
10	29	Charleston, SC	50.88	3.11
	55	Fort Worthh, TX	46.75	2.43
	54	Dallas, TX	46.84	2.71
	30	Columbia, SC	47.63	2.87
	51	Austin, TX	51.16	2.4 7
	33	Savannah, GA	52.80	2.81
	40	Apalachiola, FL	55.23	3.73
	57	Houston, TX	54.81	3.47
	56	Galveston, TX	55.31	3.60
	150	Los Angeles, CA	57.17	2.95
	34	Jacksonville, FL	57.04	3.17
	32	Augusta, GA	48.37	3.42
	147	Sacramento, CA	47.90	3.58
	28	Wilmington, NC	47.86	3.50
		Means (10)	51.41	3.13
11	142	Tatoosh Island, WA	43.75	9.49

a region marked by above average temperatures (37.69 degrees) and above average precipitation (3.08 inches). Another large region (5) emcompassed most of the Gulf states region and was marked by still higher temperatures (47.08 degrees) and relatively high precipitation levels (4.73 inches). Another climatic type (10) flanked this "Southern" winter climatic region and was characterized by high

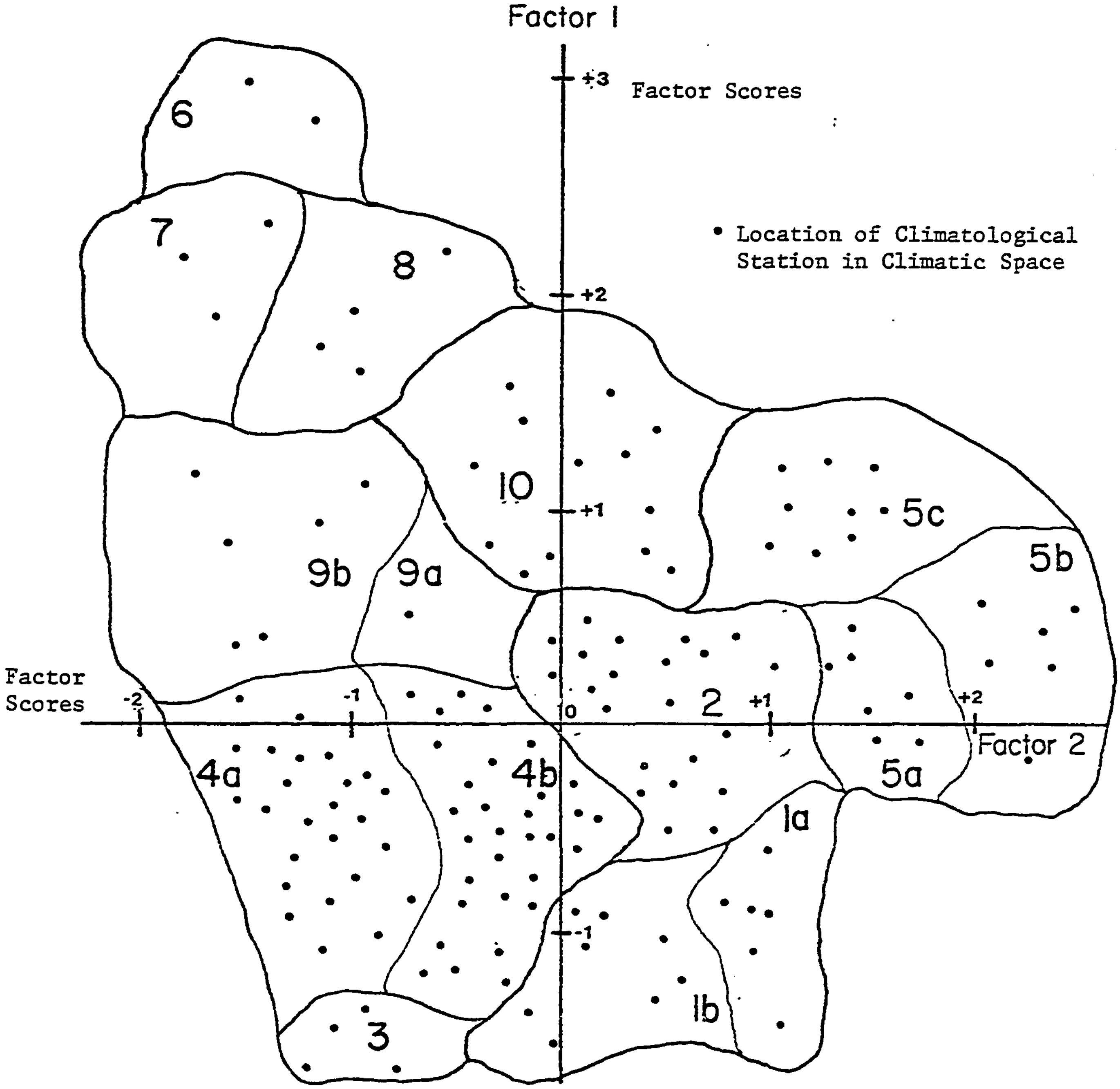


Figure 23: Scatter Diagram of Factor Scores for the Zonal Period

temperatures (51.41 degrees) and lower precipitation values (3.13 inches). Several smaller regions (6 and 8) were found equatorward of these regions and were marked by high temperatures (69.65 degrees for region 6 and 57.33 degrees for region 8) and surprisingly low precipitation amounts (1.79 inches for region 6 and 2.09 inches for region 8) due to decreased convective activity. Region 9 was the characteristic Southwest region with higher than average temperatures (42.36 degrees) and very low rainfall amounts (1.01 inches). Stations in region 7 showed even higher temperatures (57.67 degrees) and lower precipitation values (0.88 inches). Region 3 was one of extremely cold temperatures (15.11 degrees) and lower than average precipitation amounts (0.57 inches). The pattern along the west coast displayed a good amount of variation in the winter climatic types with only one large continuous region (5) being found in the Northwest. It was a region of above average temperatures and very high precipitation amounts described above.

These patterns were valid for the winter component of climate based upon temperatures and precipitation values for the years 1940 through 1949. It represented only one interpretation of the clustering where ten climatic regions were chosen. If some phenon line other than 0.773 was drawn through the phenogram, the regions were further divided creating a different pattern.

A phenon line at the 0.700 distance level divided the stations into sixteen winter climatic regions, but as two stations, Oklahoma City, Oklahoma and Tatoosh Island, Washington, formed single station regions, only fourteen regions were recognized.

The large region covering most of the interior United States in the ten region pattern was cut in half with the western section (4a) being dominated by precipitation amounts below those of the eastern one half. Generally, monthly precipitation values were below 1.25 inches in the western section. Region 1 was subdivided on the basis of precipitation with larger amounts (all above 3.00 inches) recorded on the seaward portion of the region. The region (5) that covered much of the South sudivided into three subregions. An interior region (5a) was relatively cool (42.46 degrees) and dry (4.34 inches) compared the other subdivisions, the semicoastal region (5b) was the wettest of the three (all above 5.00 inches), reflecting an increase in local relief for the area. The coastal group of stations (5c) was dominated by the highest temperatures (51.41 degrees) and surprisingly low precipitation amounts (4.53 inches).

The large Southwestern region (9) remained unchanged except that Oklahoma City, Oklahoma, was left to form a single station region. The location of Oklahoma City on the scatter diagram in Figure 23 showed it to be a relatively cool (39.85 degrees) and wet (1.65 inches) station compared to the rest in region 9. The remaining regions were all the same as those found when the 0.773 phenon line was used.

The focus of this section of the investigation was not to derive a classification of the winter component of climate, but to demonstrate that significant changes occurred in climatic regions in association with a shift in the circulation of the atmosphere.

Results and Analyses for the Meridional Period

To compare differences in the configuration of the climatic regions between the two time periods, the same procedure used to generate regions for the combined zonal and meridional periods, and those for the zonal years must be applied to the meridional time period. Again, only temperature and precipitation data for the winter months were employed. These data were condensed into two factors using principle-components factor analysis. The loadings for the factors (see Table 8) showed factor 1 to again be the temperature component and factor 2 to be the precipitation component. The two combined to account for ninety-eight per cent of the total variance in the meridional data. The factor scores from these two factors were calculated and the scores became the basis for the clustering procedure.

The results are presented in a linkage tree in Figure 24. The cophenetic correlation for this case was 0.88, indicating relatively low distortion existed between the

Table 8

Loadings for Two Rotated Factors based upon Meridional Data

Variable	Factor 1	Factor 2
Temp(D)	.97	.22
Temp(J)	.97	.24
Temp(F)	.97	.20
Precip(D)	.17	.96
Precip(J)	.20	.97
Precip(F)	.32	.92
Factor Variance	71%	27%
Cumulative Variance	71%	98%
Eigenvalues	4.24	1.63

implied distances on the phenogram and actual climatic distances between the stations. To produce only ten climatic regions to compare with the ten climatic regions in the first two cases, a phenon line with a distance level of 0.821 was required. This value was substantially higher than the 0.773 phenon line distance level needed to separate the zonal clusters into ten climatic regions. These findings demonstrated that greater distances, in climatic space, existed between in the meridional period when compared to those in the zonal period. Climates were less similar

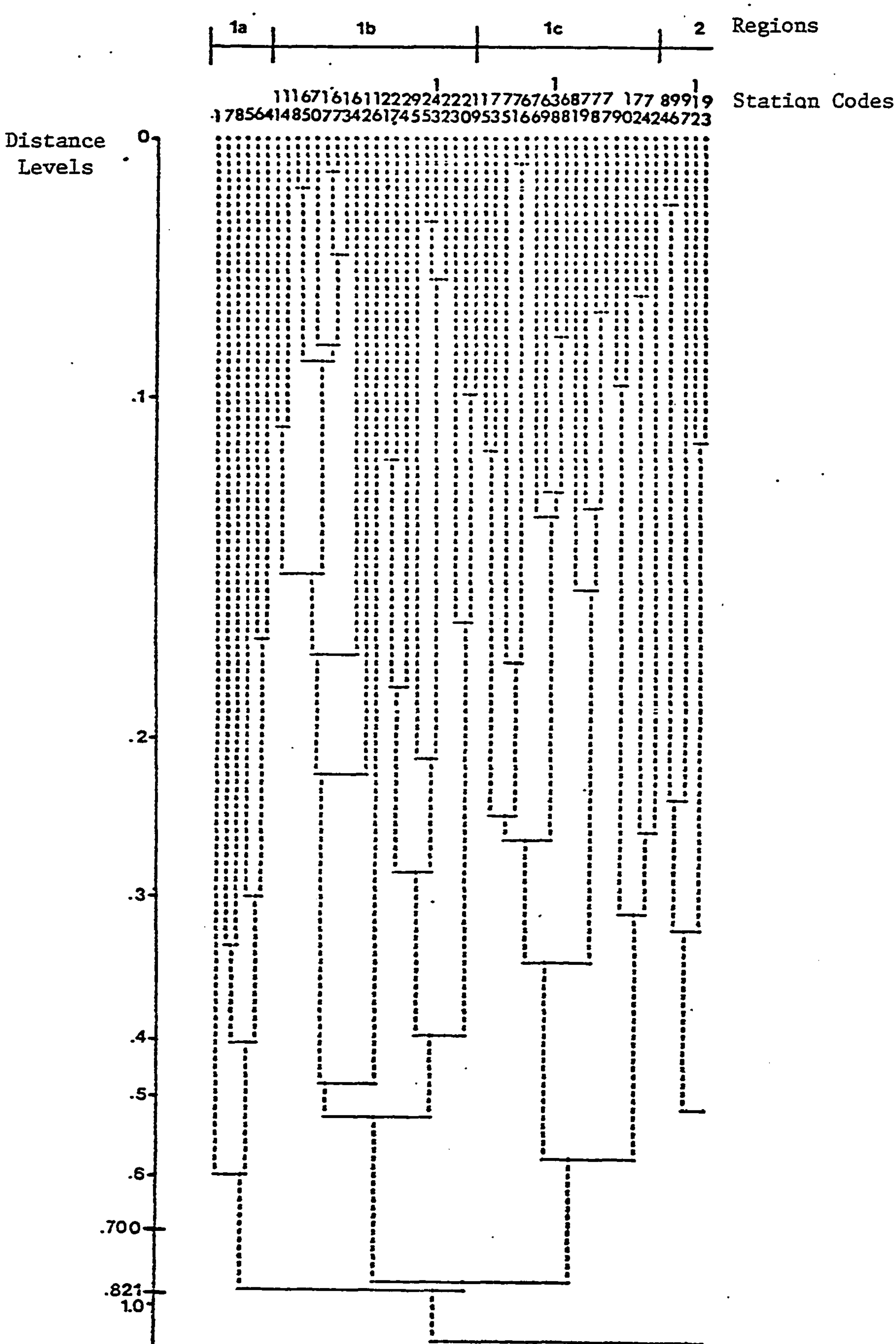


Figure 24: Linkage Tree for the Meridional Period

Figure 24: Continued

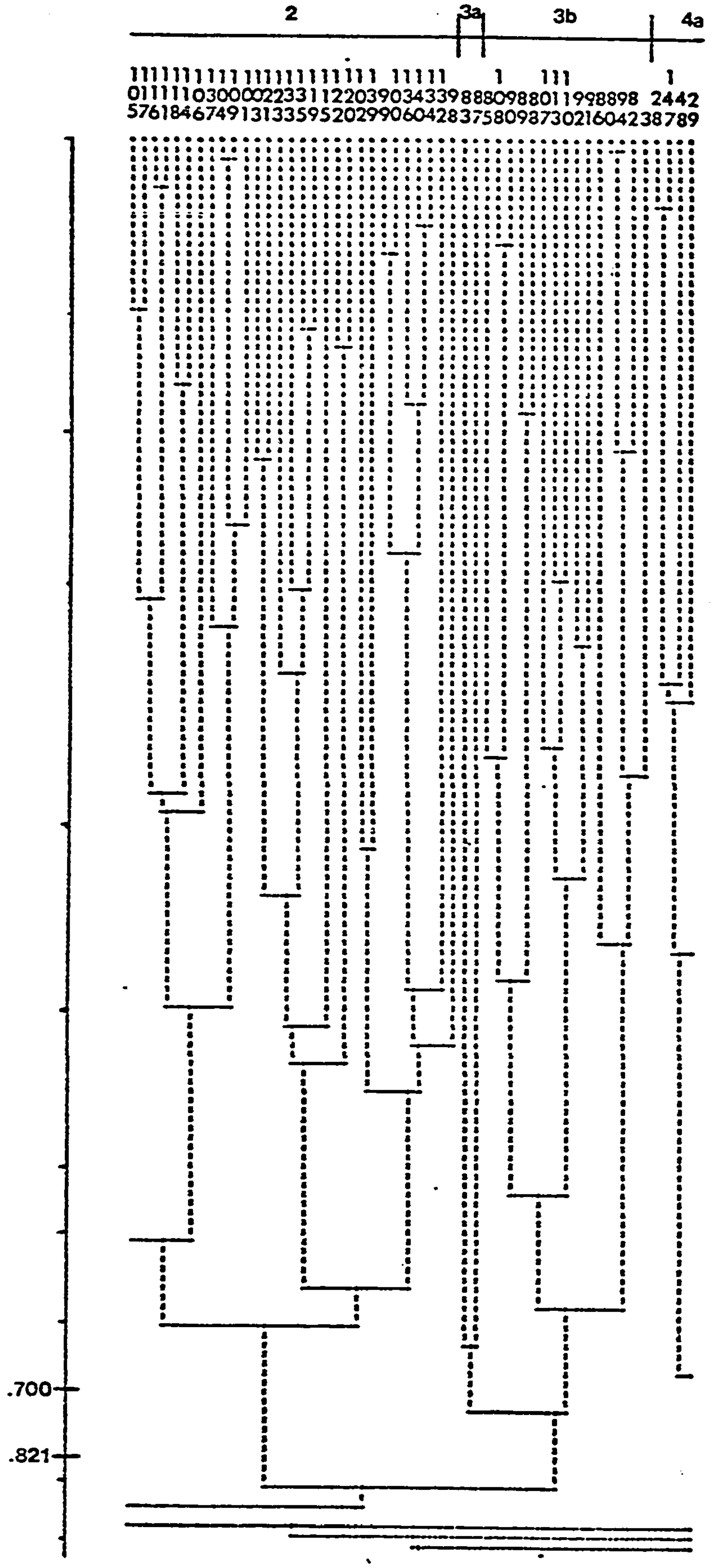
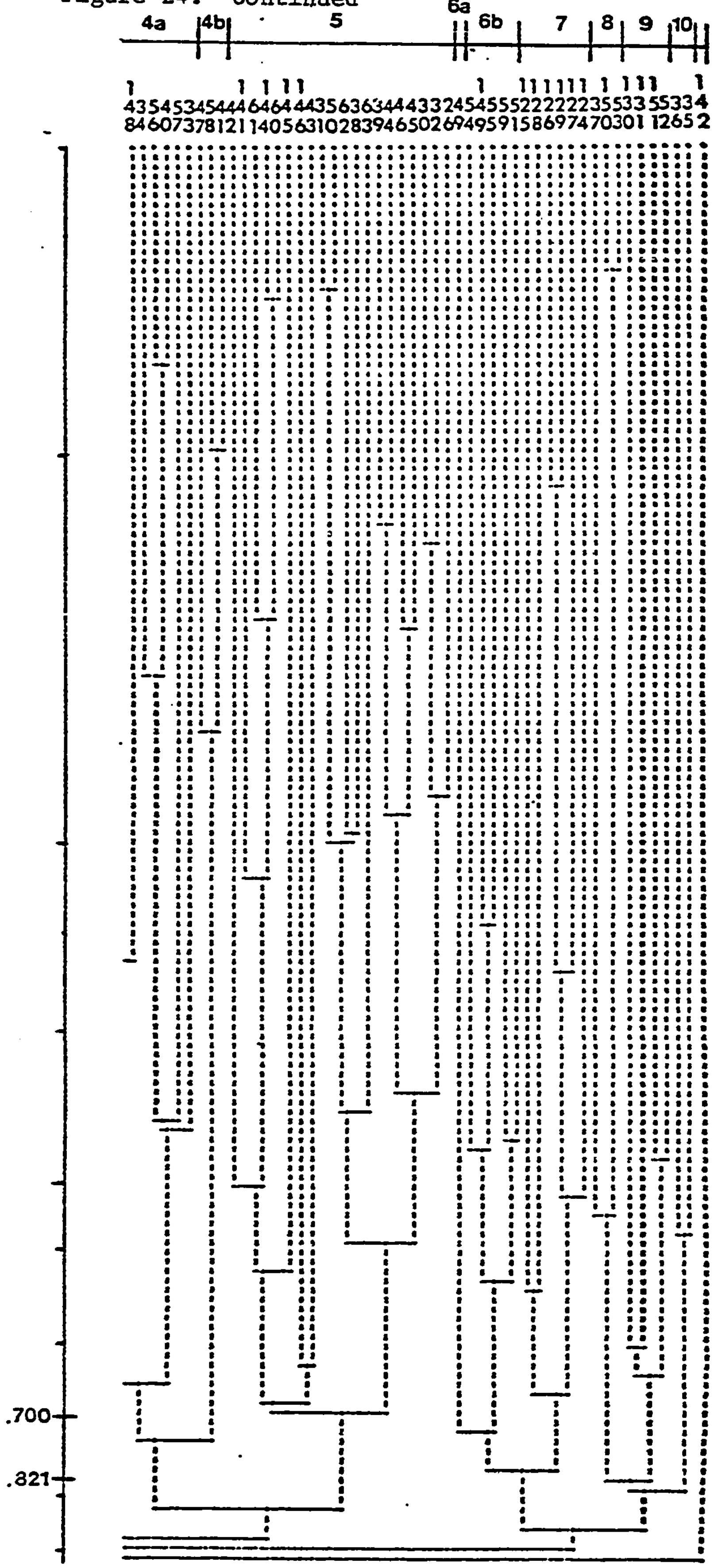


Figure 24: Continued



across the United States in the meridional years compared to the winter climates in the zonal period.

The resulting map of ten climatic regions (see Figure 25) and the scatter diagram in Figure 26 allowed for the interpretation of the spatial pattern of the climatic regions. Table 9 lists the stations in each meridional region along with temperature and precipitation data. A large region (2) from the Rockies to Illinois dominated the pattern. These stations fell in the cool (28.58 degrees for average monthly winter temperatures) and dry (0.96 inches) section of the plot on Figure 26. A large region (3) was located poleward of region 2 and was differentiated from its southern neighbor by decreased temperatures (17.37 degrees), and on a relative scale, was drier (0.96 inches) than the rest of the United States.

Another large winter climatic region (1) was found throughout the northeastern quarter of the United States. It was characterized by cooler than average temperatures (30.80 degrees) and by above average precipitation amounts (2.92 inches).

The South was broken into two distinctive regions: the first, region 5, was an interior type marked by above average temperatures (44.52 degrees) and was well above the United States' mean precipitation level (4.76 inches). The same climatic type appeared in the northwestern corner of the United States. The coastal southern region extended

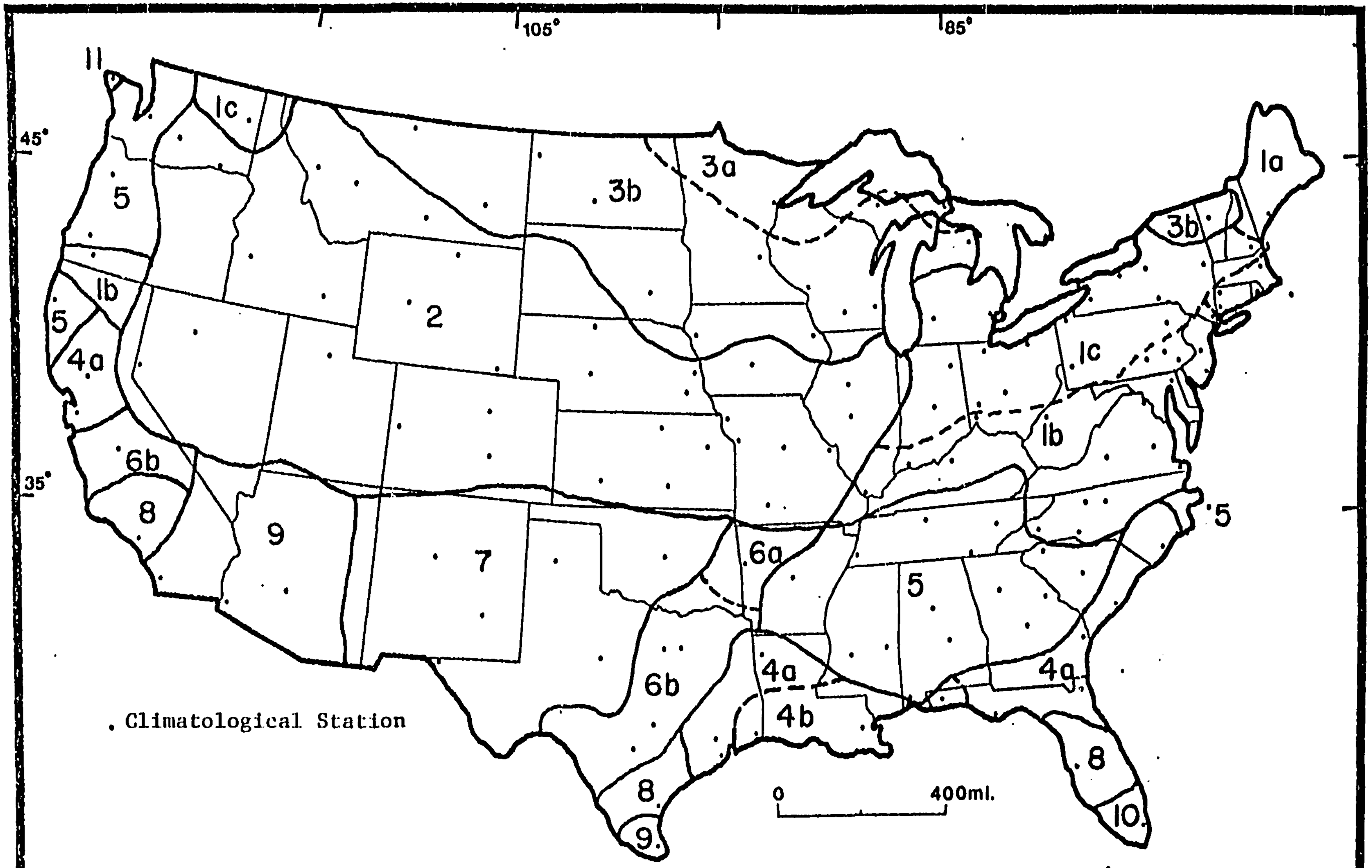


Figure 25: Winter Climatic Regions based Upon Meridional Data

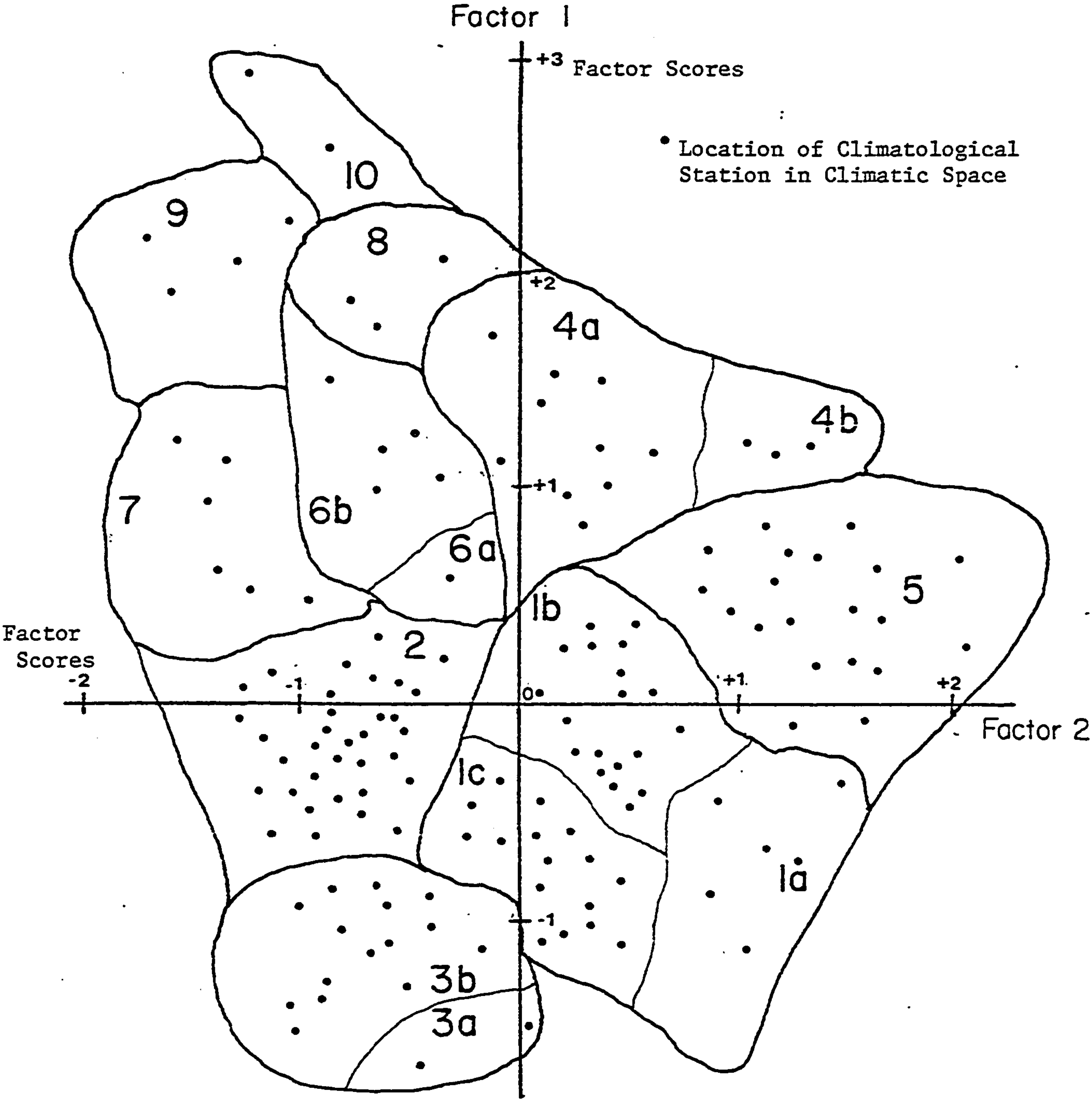


Figure 26: Scatter Diagram of Factor Scores for the Meridional Period

Table 9

Listing of Temperatures and Precipitation Values

By Meridional Regions

Region	Station Code	Station	Winter Temp.	Winter Precip.
1a	1	Portland, ME	22.62	3.39
	7	Hartford, CT	26.00	3.39
	8	New Haven, CT	29.66	3.48
	5	Nantucket, MA	32.27	4.31
	6	Providence, RI	29.20	3.79
	4	Boston, MA	29.89	4.05
		Means (1a)	28.28	3.73
1b	11	New York, NY	33.22	3.24
	14	Reading, PA	32.09	3.10
	18	Baltimore, MD	33.47	3.03
	65	Evansville, IN	33.48	3.08
	70	Parkersburg, WV	33.00	2.89
	17	Trenton, NJ	32.46	2.98
	67	Cincinnati, OH	32.67	2.97
	13	Philadelphia, PA	32.19	2.88
	64	Louisville, KY	34.60	3.28
	12	Harrisburg, PA	30.56	2.88
	16	Atlantic City, NJ	33.91	3.66
	21	Norfolk, VA	40.58	3.50
	27	Raleigh, NC	40.60	3.36
	24	Charlotte, NC	42.17	3.72
	95	Cairo, IL	37.27	3.60
	25	Greensboro, NC	38.66	3.47
	143	Medford, OR	39.25	3.36
	22	Richmond, VA	37.96	3.38
	23	Asheville, NC	38.18	3.01
	20	Lynchburg, VA	36.70	2.92
	19	Washington, DC	35.82	2.78
		Means (1b)	35.66	3.19
1c	15	Scranton, PA	26.09	2.28
	73	Rochester, NY	24.66	2.30
	75	Erie, PA	27.13	2.64
	71	Pittsburgh, PA	28.31	2.53
	66	Indianapolis, IN	28.40	2.50

Region	Station Code	Station	Winter Temp.	Winter Precip.
	76	Cleveland, OH	27.46	2.17
	69	Dayton, OH	28.77	2.19
	138	Spokane, WA	28.88	2.29
	68	Columbus, OH	29.21	2.43
	81	Grand Rapids, MI	23.98	1.78
	79	Detroit, MI	26.44	1.83
	78	Fort Wayne, IN	25.74	2.01
	77	Toledo, OH	25.43	1.87
	9	Albany, NY	23.04	2.32
	10	Binghamton, NY	22.45	2.40
	72	Buffalo, NY	25.23	2.94
	74	Syracuse, NY	24.19	2.87
	2	Concord, NH	22.29	2.64
		Means (1c)	25.98	2.33
		Means (1)	30.80	2.92
2	84	Chicago, IL	25.68	1.50
	96	Peoria, IL	25.41	1.41
	97	Springfield, IL	27.78	1.45
	112	Missoula, MT	23.65	1.14
	93	Des Moines, IA	22.19	1.00
	105	Omaha, NB	24.81	.76
	117	Sheridan, WY	24.38	.63
	116	Lander, WY	22.75	.54
	111	Helena, MT	22.88	.51
	118	North Platte, NB	25.39	.43
	114	Rapid City, SD	24.88	.50
	106	Valentine, NB	22.81	.26
	137	Pocatello, ID	26.62	1.02
	104	Lincoln, NB	26.55	.83
	109	Billings, MT	26.70	.79
	101	St. Joseph, MO	28.09	.95
	103	Topeka, KS	29.86	.91
	121	Concordia, KS	29.12	.74
	123	Wichita, KS	32.92	.74
	133	Winnemucca, NV	31.48	.87
	135	Grand Junction, CO	30.42	.61
	119	Denver, CO	31.23	.70
	115	Cheyenne, WY	27.73	.36
	122	Dodge City, KS	32.45	.46
	120	Pueblo, CO	31.74	.34
	102	Springfield, MO	34.25	1.64
	139	Walla Walla, WA	36.96	1.85
	99	Columbia, MO	31.00	1.42
	100	Kansas City, MO	31.82	1.44

Region	Station Code	Station	Winter Temp.	Winter Precip.
	136	Boise, ID	32.12	1.30
	140	Yakima, WA	31.52	1.21
	134	Salt Lake City, UT	30.73	1.21
	132	Reno, NV	34.03	1.20
	98	St. Louis, MO	31.89	1.76
		Means (2)	28.58	.96
3a	83	Sault Ste. Marie, MI	15.20	1.85
	87	Duluth, MN	10.59	.95
		Means (3a)	12.89	1.40
3b	85	Green Bay, WI	17.19	.87
	108	Huron, SD	15.09	.58
	90	Minneapolis-St. Paul, MN	15.89	.61
	89	Williston, ND	13.40	.48
	88	Bismarck, ND	12.39	.44
	107	Sioux City, IA	20.81	.73
	113	Miles City, MT	19.98	.51
	110	Havre, MT	18.43	.43
	92	Madison, WI	19.29	.89
	91	La Crosse, WI	18.34	.65
	86	Milwaukee, WI	21.59	1.38
	80	Alpena, MI	19.64	1.40
	94	Dubuque, IA	19.64	1.37
	82	Marquette, MI	19.37	1.51
	3	Burlington, VT	18.47	1.60
		Means (3b)	17.97	.90
		Means (3)	17.37	.96
4a	28	Wilmington, NC	46.47	3.35
	147	Sacramento, CA	47.27	3.37
	48	Shreveport, LA	47.91	3.60
	29	Charleston, SC	48.86	3.45
	148	San Francisco, CA	50.24	3.80
	34	Jacksonville, FL	55.18	3.12
	56	Galveston, TX	54.42	3.22
	40	Apalachicola, FL	54.15	3.18
	57	Houston, TX	54.05	3.57
	33	Savannah, GA	50.14	3.02
		Means (4a)	50.87	3.37

Region	Station Code	Station	Winter Temp.	Winter Precip.
4b	47	New Orleans, LA	53.31	4.79
	58	Port Arthur, TX	53.03	4.41
	41	Pensacola, FL	52.74	4.59
		Means (4b)	53.03	4.59
		Means (4)	51.37	3.65
5	42	Birmingham, AL	44.96	5.04
	141	Seattle, WA	43.19	4.96
	61	Knoxville, TN	39.60	4.84
	144	Portland, OR	40.86	4.97
	60	Chattanooga, TN	40.81	5.14
	145	Roseburg, OR	42.47	5.70
	146	Eureka, CA	48.56	6.03
	43	Mobile, AL	51.63	5.38
	31	Greenville, SC	42.84	4.30
	50	Little Rock, AR	42.08	4.24
	62	Memphis, TN	41.43	4.44
	38	Atlanta, GA	43.71	4.60
	63	Nashville, TN	38.98	4.41
	39	Macon, GA	48.02	4.52
	44	Montgomery, AL	48.14	4.65
	46	Vicksburg, MS	48.09	4.88
	45	Meridian, MS	46.69	4.65
	30	Columbia, SC	45.88	4.01
	32	Augusta, GA	46.38	4.19
	26	Hatteras, NC	46.01	4.33
		Means (5)	44.52	4.76
6a	49	Fort Smith, AR	41.12	2.22
6b	54	Dallas, TX	46.64	2.29
	149	Fresno, CA	47.13	1.73
	55	Fort Worth, TX	45.86	1.92
	59	San Antonio, TX	52.31	1.78
	51	Austin, TX	51.13	2.19
		Means (6b)	48.61	1.98
		Means (6)	47.36	2.02
7	125	Abilene, TX	45.49	1.12

Region	Station Code	Station	Winter Temp.	Winter Precip.
	128	El Paso, TX	45.99	.42
	126	Amarillo, TX	37.32	.62
	129	Albuquerque, NM	37.08	.45
	127	Roswell, NM	40.06	.54
	124	Oklahoma City, OK	38.18	1.11
		Means (7)	40.69	.71
8	37	Tampa, FL	60.65	2.74
	150	Los Angeles, CA	56.89	2.09
	53	Corpus Christi, TX	57.32	2.13
		Means (8)	58.29	2.32
9	130	Phoenix, AZ	53.43	.63
	131	Yuma, AZ	58.38	.31
	151	San Diego, CA	57.69	1.22
	52	Brownsville, TX	61.29	1.74
		Means (9)	57.70	.97
10	36	Miami, FL	67.50	2.14
	35	Key West, FL	70.28	1.82
		Means (10)	68.89	1.98
11	142	Tatoosh Islands, WA	43.31	10.52

from the Carolina coast through the Gulf coast of Texas. Region 4 showed higher than average winter temperatures (51.37 degrees) when compared to region 5, and was noticeably drier than its interior neighbor (3.65 inches). Increases in topography in region 5 best accounted for this finding. Warmer and drier regions (8 and 10) were found equatorward of these southern regions. Region 8 had an average monthly temperature value of 58.29 degrees and a precipitation value of 2.32 inches. Region 10 was much warmer (68.89 degrees) and was slightly drier (1.98 inches).

From the Gulf coast of Texas, a transitional region (6) fell between the wetter region to the south and the cooler, dry region to the west. It was marked by an average temperature of 47.36 degrees and an average precipitation level of 2.02 inches. Region 7 was a large climatic region in the Southwest characterized by above average temperatures (40.69 degrees) and very low precipitation totals (0.71 inches) when compared to the rest of the United States. Region 9 was similar to region 7 in precipitation amounts (0.97 inches), but temperatures were substantially higher (57.70 degrees) in this southern Arizona climatic type.

If the 0.700 phenon line was used to divide the clusters, as used in the zonal case, the same number of climatic regions emerge. Although sixteen regions appeared to be created, two single stations regions, including Tatoosh Island, Washington, and Fort Smith, Arkansas, were formed. The large region (2) that extended from the Rockies to Illinois was not broken into smaller sections. The two southwestern regions (7 and 9) were not subdivided, nor was the interior southern region 5. The far southern regions 8 and 10 were also not affected by shifting the phenon line to 0.700. However, regions 1, 2, and 4 were divided into smaller subregions in accordance with the shift in the phenon line.

The large northeastern region (1) was divided into three distinct regions. The New England subregion (1a) was distinguished by the greatest precipitation amounts (3.73 inches) for the region. The southern one half of region 1 (1b) was differentiated by warmer temperatures (35.66 degrees) when compared with all other stations in the region. The southern Great Lakes section (1c) was the cool (25.98 degrees) and dry (2.33 inches) portion of the entire region.

The Gulf coast region (4) was separated into two subregions. Region 4a represented most of the stations in the coastal group and was characterized by temperatures in the upper 40's and low 50's and precipitation from 3.00 to 3.80 inches. The three stations of 4b were distinguished from the rest by substantial increases in precipitation (4.59 inches).

The northern Plains region (3) was divided into two subregions as well. Only two stations formed region 3a which was marked by extremely cold temperatures (12.89 degrees). Subregion 3b made up most of the area and most of the stations in region 3, and was characterized by very cold wintertime temperatures (17.97 degrees) and relatively dry conditions (0.90 inches).

The findings from this section suggested that large, regionally homogeneous wintertime climatic regions could be developed for most of the United States given ten year climatic averages. Only along the West coast did these large regions fail to develop. When twenty year means were used to form the combined zonal - meridional climatic regions, a similar pattern developed. However, in this investigation, the focus of this section was not to demonstrate that wintertime-component climatic regions could be developed, but was to show how climatic regions changed their configuration as the general circulation of the atmosphere shifted from a zonal to a meridional pattern.

Comparison of Zonal to Meridional Climatic Regions

By comparing the results of the zonal groupings to those for the meridional period in a general way, a number of interesting patterns developed. Looking at the ten regions for each time period (see Figures 22 and 25), the most striking difference was that the large interior region (4) in the zonal period did not extend as far eastward in the meridional period. The entire southern Great Lakes region was covered by this climatic type only in the zonal period. Precipitation values in the two comparative regions, zonal region 4 and meridional region 2, showed the meridional region to be drier. The meridional region was also slightly drier that the zonal region 4. These findings supported Borchert's (1971) report that the "prairie wedge" extended farther eastward during the zonal period.

The very cold continental interior region (3 in both cases) was not as extensively developed in the zonal years as in the meridional period, when large sections of the Great Lakes region were encompassed by this type. A discussion in Chapter IV showed this to be an area where temperature fell sharply between the two time periods, causing this climatic region to expand significantly during the meridional years. Zonal region 3 was slightly drier, by approximately one inch, than the comparative meridional region 3a.

The cool, relatively moist New England region (1 in the zonal period) was shown to greatly expand in the meridional period, reflecting an increase in precipitation for the area in the meridional years. Much of the area around the Great Lakes, where during the zonal years dry conditions existed, was dominated by the northeastern climatic type in the meridional years.

A region separating the northeastern from southeastern climates in the zonal period (2) disappeared in the meridional years, indicating a decreased north-south gradient in climatic elements in the meridional years in this region. Some remnant of the zonal region 2 existed in the form of meridional region 1b.

The large region (5) covering most of the South in the zonal years appeared in the meridional period with a smaller areal extension. Similar patterns on the maps could be found for most of the other regions around the country. Panhandle Florida had two types of climate that were similar in both periods. Southern Texas displayed climates that were similar to those of Florida in both periods, and the entire Southwest displayed nearly identical boundaries for both sets of years. A transitional climatic type (6) appeared in the meridional period that did not exist earlier. For both time periods, the entire California coast showed a great deal of spatial variation in the types of climate represented, but with the same general patterns for each period. The diversity of climatic types along the Pacific coast was found in most of the commonly used classifications used in climatology.

By overlaying the meridional and zonal maps (Figures 22 and 25) along with the mean set of climatic regions (Figure 20), the regions in the United States that appeared to fluctuate in their clustering with other stations became apparent. A wedge extending from the southern shores of Lake Michigan southward to the Ohio River and eastward into western Pennsylvania was an area that during the zonal years was connected to the large continental winter climatic type. In the meridional period, and during the combined period, this same wedge aligned with a Northeastern type of winter climate. The very cold climatic region of the Northern Plains appeared to contract on the average of about one hundred miles along its southern margins during the zonal period.

Climatic regions in the Texas, Oklahoma, Arkansas, and Louisiana regions produced different orientations between the periods. In the zonal period, the major axis of the regions was in the northwest-southeast direction, indicating a climatic gradient along the prevailing southwest-northeast wind-flow pattern. The axis of the alignment shifted to a southwest-northeast direction in the meridional period, reflecting a shift in the prevailing wind direction of the flow aloft.

A large region extended from the mid-Atlantic states westward through Kentucky divided into a separate climatic region in the zonal period, indicating a stronger north-south gradient in the climate configuration of this region during periods of zonal circulation. This region became part of the large Northeastern winter climatic region during the meridional and average periods.

Results and Analyses from Shape Tests

To quantitatively analyze changes in the resulting climatic regions, a shape measurement representing a ratio between the north-south and west-east major axes was obtained for each region, and for each subregion (Table 10). These measurements were made to test the hypothesis that climatic regions were more elongated in a west to east direction during periods of zonal flow. In association with a shift to a meridional pattern, the climatic regions were expected to become less elongated along west to east axes. To avoid the extremely variable pattern of the Pacific coast and to allow all regions to change shape without the interference of the Rockies, only the regions that extended eastward of the Rockies were used in the shape measurements. Using the ten region configuration as a base, the average ratio in the zonal period was 0.84 and the mean shape in the meridional period was 0.83. Although the differnce was not significant ($t = -0.03$), the decline in the average ratio value was opposite of what was expected. The hypothesis tested stated that shapes of the regions would be more elongated in the west-east direction during the zonal period. A significant increase in the shape measures was expected to confirm this hypothesis, and with simple averages using ten regions, this was certainly not found. However, if the shapes were weighted according to the area of each region, an increase from 0.31 to 0.35 was observed in the average shape values. A t-score representing the difference in these means was calculated to be 0.27, well below the 2.10 value needed to be significant at the 0.05 confidence level.

When the fourteen region scheme was used, the unweighted mean shape value increased from 0.77 to 0.85 with a t-score of 0.43. Again, this value was not statistically significant. A weighted test produced a slight decrease in the means with a t-score of -0.07.

Table 10

Shape and Area Measurements for All Regions

Zonal Regions	Shape	Area	Weighted Shape	Meridional Regions	Shape	Area	Weighted Shape
1	.50	.30	.15	1	.80	.94	.75
2	.43	.50	.22	2	.50	1.74	.87
3	.56	.40	.22	3	.29	.83	.24
4	.37	2.41	.89	4	.70	.36	.25
5	.65	.55	.36	5	.66	.48	.32
6	2.00	.04	.08	6	1.43	.25	.36
7	.83	.21	.17	7	.68	.56	.38
8	1.00	.18	.18	8	.60	.07	.04
9	.68	.56	.38	9	.65	.24	.16
10	1.35	.36	.49	10	2.00	.04	.08
Mean	.84		.31		.83		.34
Std. Dev.	.25		.06		.25		.07
1a	.50	.12	.06	1a	2.00	.13	.26
1b	.29	.18	.05	1b	.57	.44	.25
2	.43	.50	.22	1c	.61	.37	.23
3	.56	.40	.22	2	.50	1.74	.87
4a	.64	1.46	.93	3a	.51	.16	.08
4b	.58	.95	.55	3b	.33	.67	.22
5a	.75	.17	.13	4a	1.17	.27	.32
5b	.63	.15	.09	4b	.25	.09	.02
5c	.57	.23	.13	5	.66	.48	.32
6	2.00	.04	.08	6	1.43	.25	.36
7	.83	.21	.17	7	.68	.56	.38
8	1.00	.18	.18	8	.60	.07	.04
9	.68	.56	.38	9	.65	.24	.16
10	1.35	.36	.49	10	2.00	.04	.08
Mean	.79		.26		.85		.26
Std. Dev.	.19		.06		.43		.04

For this entire chapter where the changes in climatic regions between two selected time periods were examined, the following could be concluded. Firstly, the results showed that homogeneous winter climatic regions could be produced for both time periods. Analyses demonstrated that greater distances existed, in climatic space, between the climatic groupings in the meridional period when compared to the distances for the zonal years. Examination of the maps of zonal and meridional regions showed that many stations were grouped differently in the two time periods. Evidence of the extension of the "prairie wedge" was found in the zonal period as stations as far eastward as Pennsylvania were clustered with stations in the Rockies. A very cold climate region located in the northern Plains expanded substantially as the circulation shifted to a meridional pattern. A large mid-Atlantic climatic region appeared in the zonal period, but was part of the larger Northeastern region in the meridional period. The orientation of the climatic regions in the southern Plains appeared to shift with a change in the general circulation.

In general, many of the changes in climatic regions followed logically from the changes found in the climatic elements analyzed in Chapter IV. The changes that were found in the climatic regions could be explained in terms of a shift in the pattern of flow for the general circulation of the atmosphere. Measurements of shape could not demonstrate that a significant changed occurred between the two time periods in the elongation of the regions in the west-east direction.

CHAPTER VI

THE DEVELOPMENT OF REGIONS BASED UPON CHANGES IN CLIMATIC ELEMENTS

Introduction

In this final section of the investigation, statistical techniques were used to produce homogeneous regions based on the changes in selected climatic elements. These regions could be developed only if changes in the circulation of the atmosphere produced relatively consistent fluctuations in the climatic configuration in an area. It was hypothesized that distinctive types of changes would occur in specific, identifiable regions across the United States in association with a shift in the general circulation of the atmosphere. Each "type" of climatic change could then be characterized, and the resulting regions could then be analyzed.

Results and Analyses from Preliminary Attempts to Produce "Change" Regions

The first attempt to produce regions based on changes in the configuration of climate for the United States utilized the entire climatic change matrix data set. Using principle-components factor analysis, the entire matrix was condensed into five components (these were presented in Chapter IV). The factor scores from these five components provided the data base upon which the clustering algorithm was performed.

At any distance level chosen, the results of the clustering were unsatisfactory. For example, when the phenon line was selected that separated the clustering into eleven groups, one hundred twenty-seven stations formed one large group, the remaining twenty-four formed the other ten groups. Of these, five formed single station regions, and the remaining five groupings did not produce homogeneous regions. Some clusters included such odd combinations as Birmingham, Alabama and Seattle, Washington, Havre, Montana and Roseburg, Oregon, or New Orleans, Louisiana and Portland, Oregon. Consistently throughout this study, if too many variables entered the clustering procedure, the results were often confused. In this case, several problems accounted for the unacceptable clustering. Of the five factors utilized, two represented changes in wind measures which in Chapter IV were shown to produce a pattern of little to no spatial homogeneity. These wind measures represented forty per cent of the variable mix, so the confused clustering pattern was expected. Also, although all variables were standardized, a small decrease in precipitation in an arid area produced exactly the same data value as a moderate decrease in a humid region. Similarly, a small rise in temperature in a cold climatic region produced the same value as an increase in temperature in a warm climatic region. Examples could be extended for all factors, but the essential problem was the same: this type of clustering did not take into account the type of climate existing prior to the time of the climatic fluctuation.

To eliminate the first problem, one of too many different variables confusing the pattern, only temperature and precipitation components were used in the clustering. The results were, in many ways, similar to those obtained when all five components were clustered. Once again, phenon lines continued to separate the clusters into one large group and many very small groups. For example, when eleven clusters were created, well over half of the stations (84) fell into one group. Four stations formed single station regions and for the first time in the entire study, Tatoosh Island, Washington, was grouped into a cluster of stations. Figure 27 displays the spatial pattern of the results. The one large grouping (1) appeared across the entire map, the remaining groups showed no propensity towards spatial homo-

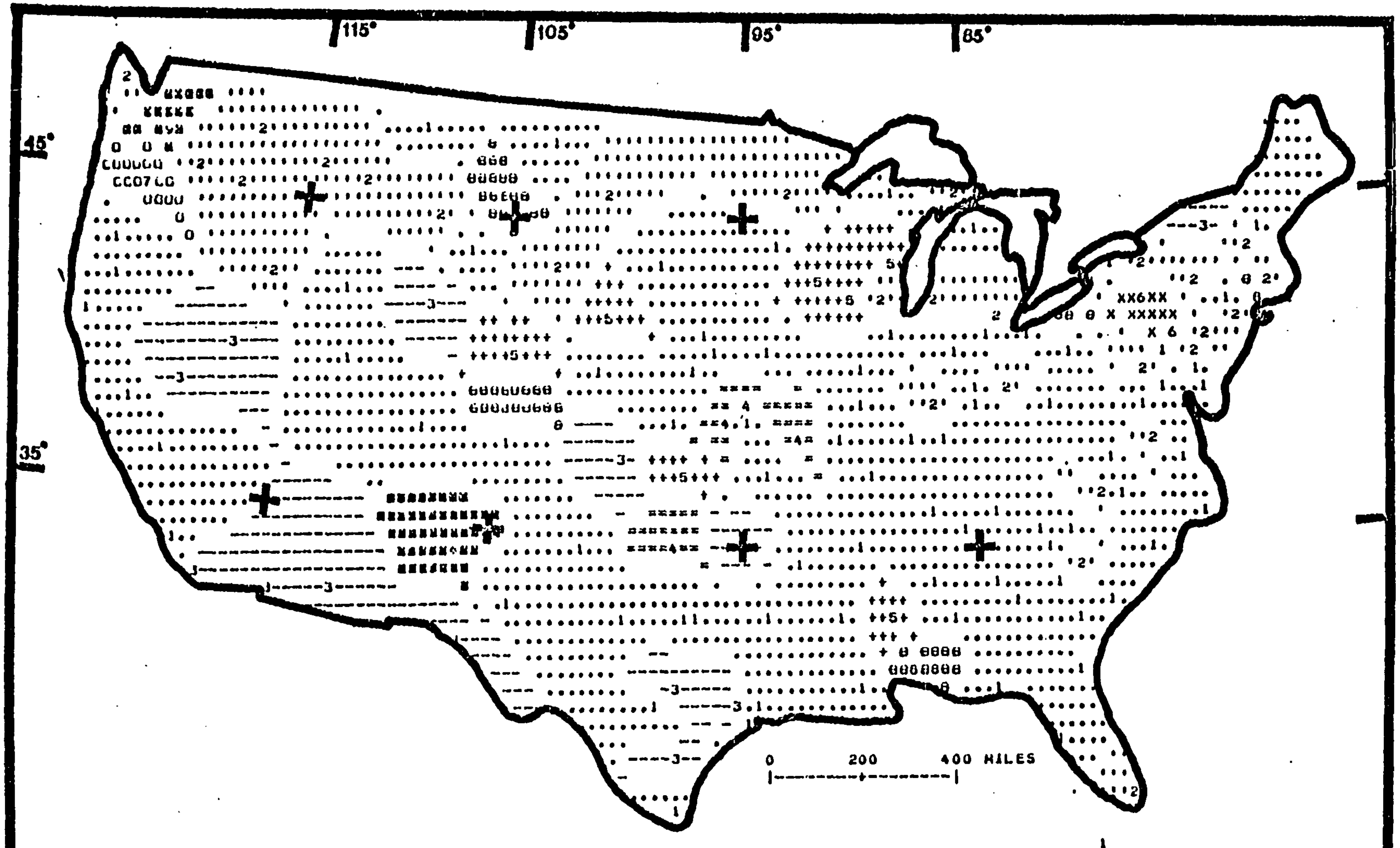


Figure 27: Climatic Change Regions based upon Temerature Change and Precipitation Change Components

geneity. The pattern contained a great deal of "noise" which may have contributed to these poor results. To alleviate this problem, the data values calculated by sixth-order trend fittings to these factors were clustered and the results were mapped.

Figure 28 displays the results of this procedure, and in general, the problems of Figure 27 remained. Eighty-two stations fell into one large group, several single station regions developed, and the spatial pattern showed little spatial homogeneity. Stations from the largest cluster (1) could be found across the map along with stations from the next largest grouping (2). These findings strongly suggested that the climatic configuration existing before the fluctuation must be considered to obtain any interpretable groupings of stations. In practice, any climatic year or other time period could be used, just as long as some weight was given in the clustering to stations which had similar "base" climates.

The Resulting Climatic Change Regions

To obtain a base of climatic similarity, a number of procedures could be utilized. For example, stations with the same Koppen or Thornthwaite classification type could be assigned identical values, giving some weight to stations that were climatically similar. Mean temperature and precipitation values from any time period could also be used.

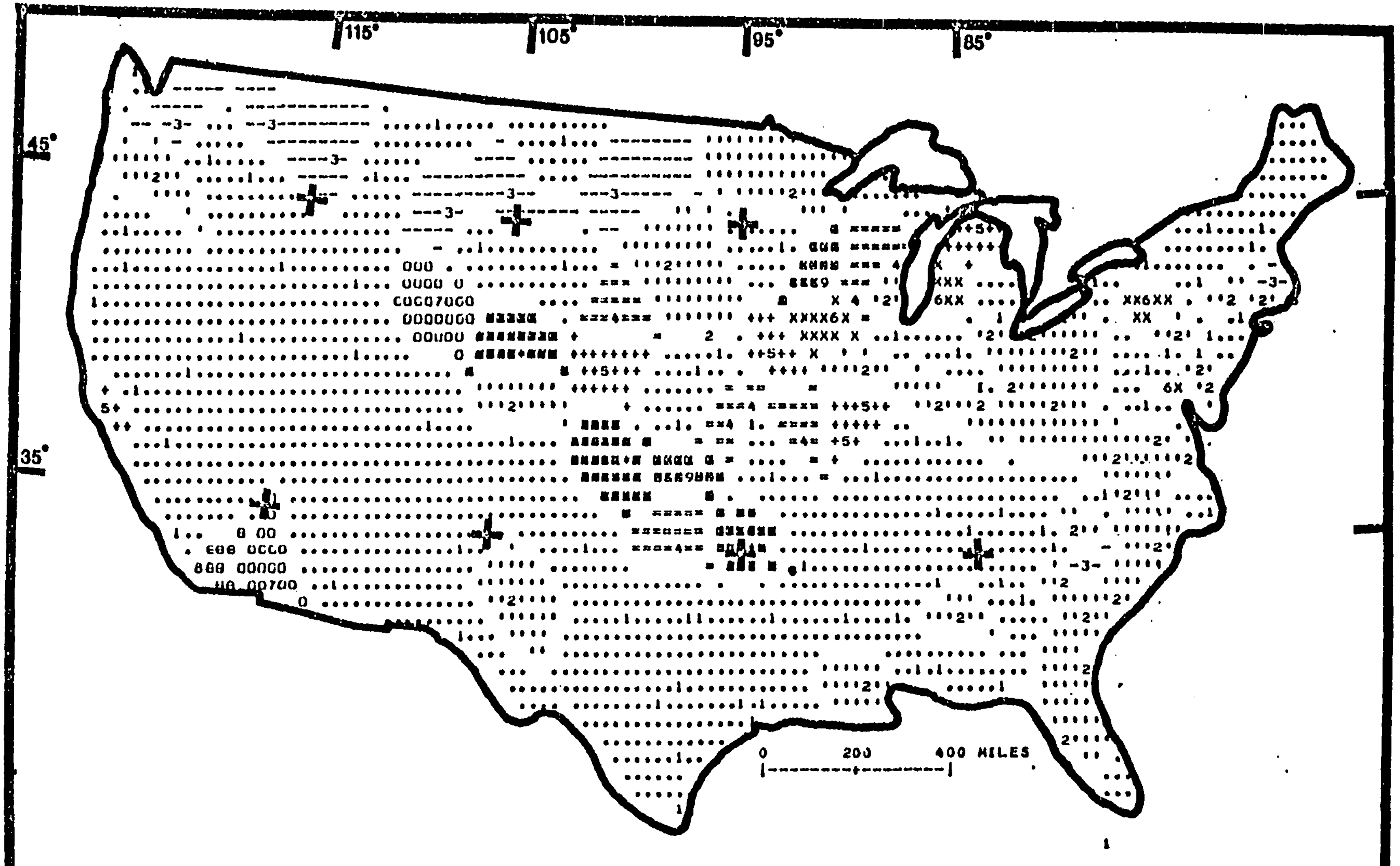


Figure 28: Climatic Change Regions based upon Trend Fittings to Temperature Change and Precipitation Change Components

However, in this study only winter data were used, limiting the choices. Therefore, the principle-component factor scores for temperature and precipitation data from the zonal period were included in the matrix of values of temperature and precipitation change from the change matrix. This matrix showed the change in the most commonly used elements in climate and contained elements which have already been shown (in Chapter V) to produce a spatially homogeneous pattern.

Before the four variables could be clustered using the Euclidean distance algorithm, insignificant correlations between the elements must be demonstrated. The correlation

Table 11

Correlation Matrix of Zonal Factor Scores and Precipitation and Temperature Change Values

	1	2	3	4
1. Factor 1 (Temp)	1.00	0.00	.13	-.05
2. Factor 2 (Precip)		1.00	-.05	.17
3. Temperature Change			1.00	.06
4. Precipitation Change				1.00

matrix in Table 11 displays the results. With one hundred forty-nine degrees of freedom, any absolute value greater than 0.16 in the correlation matrix was statistically significant at the 0.05 confidence level. At this level, only one correlation value (0.17) between Factor 2 and Precipitation Change was significant. However, a correlation coefficient of 0.21 was required to be significant a the 0.01 confidence level. In that the 0.17 correlation value was barely significant at the 0.05 level and was not significant at the 0.01 level, the correlation was not regarded significant. Such a small correlation would produce little effect on the clustering results.

Once orthogonality of the axes was confirmed, the clustering algortihm was applied to the data. The clustering was the same as those used previously where distances in Euclidean space provided the basis for the groupings. The centroids of the groups became the points in n-space for which ungrouped stations or other groups were compared. Figure 29 is the linkage tree that resulted from the clustering. The cophenetic correlation was 0.89, demonstrating that little distortion existed between real distances and implied distances on the tree. Any number of phenon lines may have been selected to divide the clusters. An attempt was made to produce between ten and twenty groupings as one hundred fifty-one stations were used in all, and an attempt was made to break the clustering at some discontinuity in the size of the distance levels. Such a discontinuity, or jump, occurred between the 1.43 and 1.55 distance level; therefore, the 1.50 phenon line was selected. It appeared

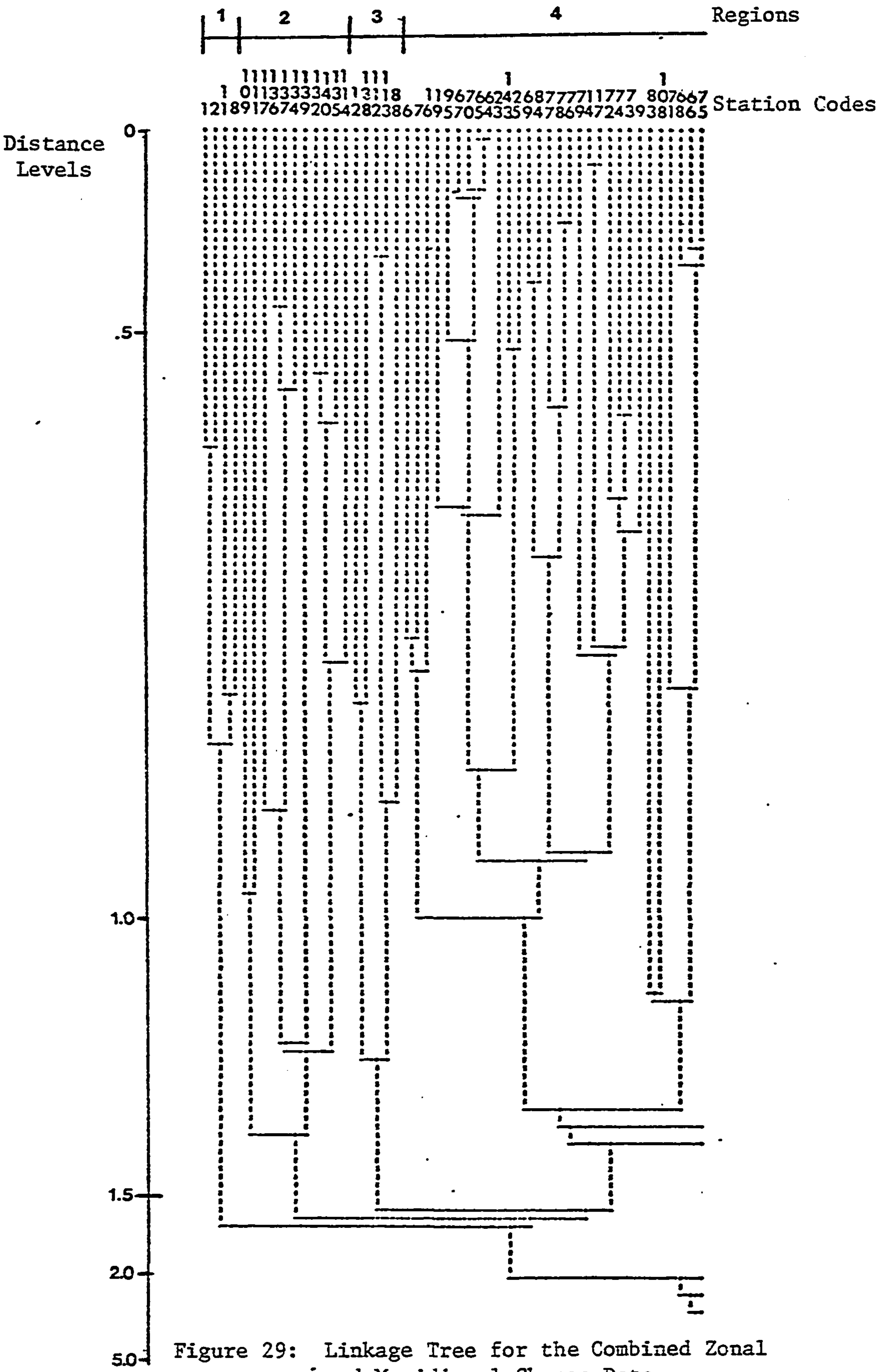


Figure 29: Linkage Tree for the Combined Zonal and Meridional Change Data

Figure 29: Continued

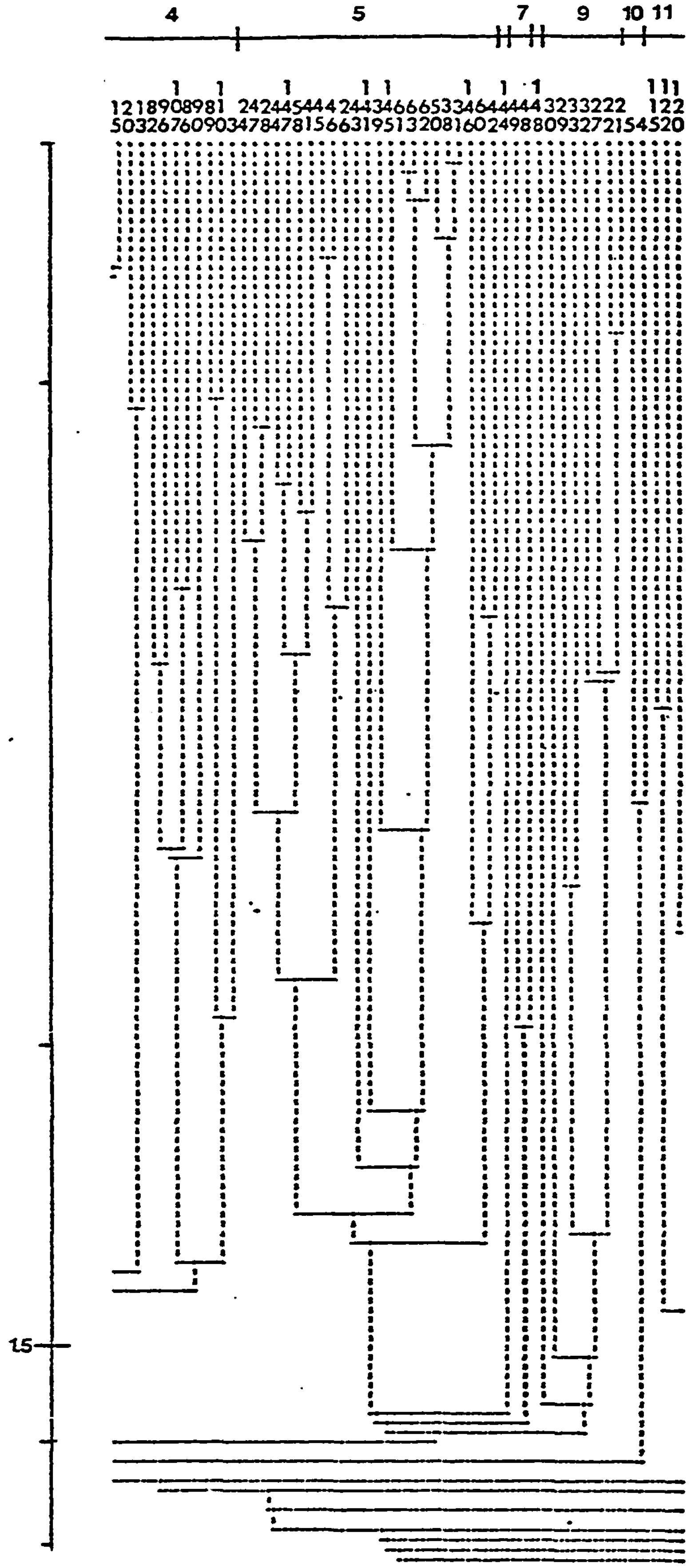
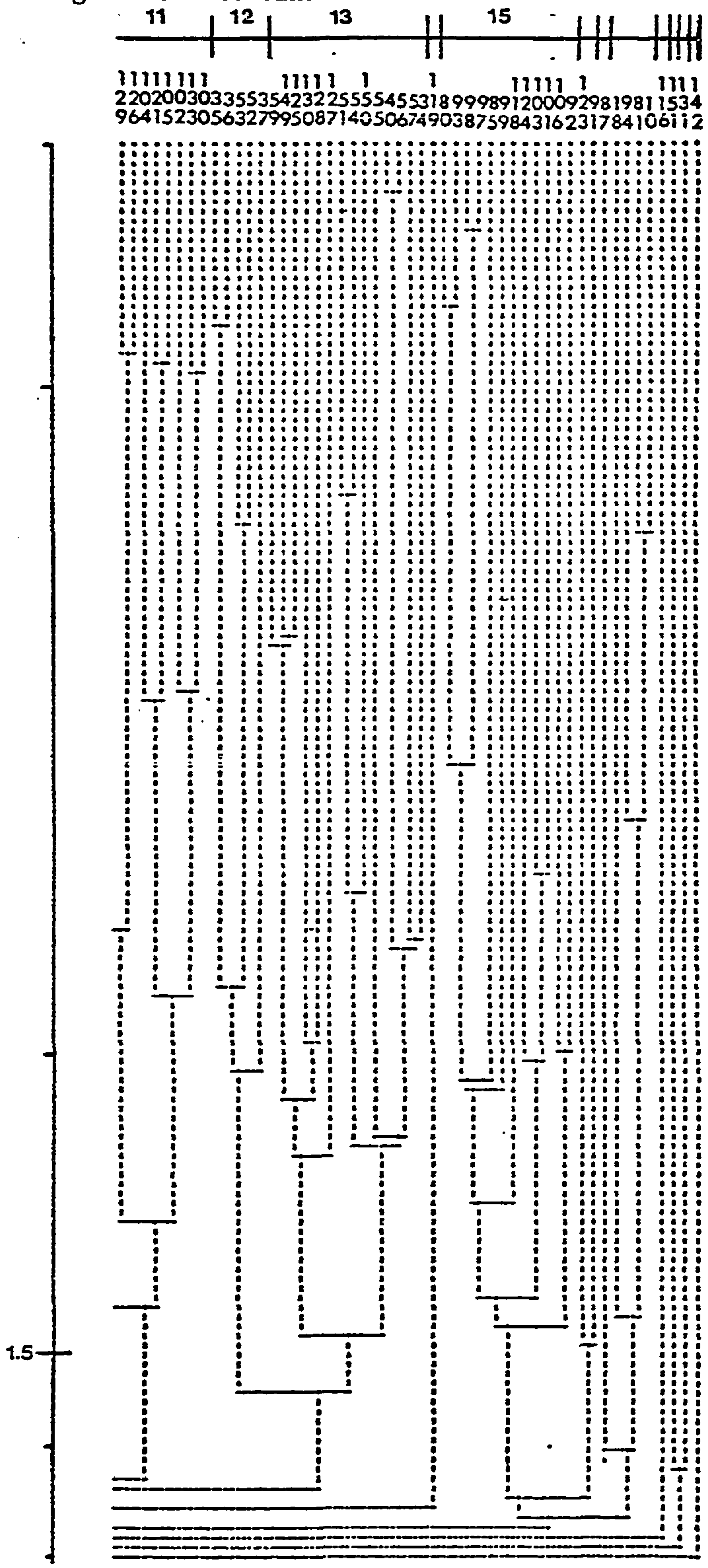


Figure 29: Continued



that this line divided the linkage tree into twenty-two distinctive clusters or groups, however, in eight cases, single station regions occurred. These include Portland, Oregon, San Francisco, California, Denver, Colorado, Duluth, Minnesota, Lander, Wyoming, San Diego, California, Yuma, Arizona, and Tatoosh Island, Washington. This left fourteen regions formed not only on the basis of climatic similarity, but also upon similarity in the type of climatic fluctuation that occurred in association with a change in the flow pattern of the upper atmosphere.

Once the clusters were plotted onto a map to produce regions based on change, it became obvious that much more regional homogeneity was present when compared to previous attempts where the zonal climate components were not utilized. Of the fourteen clusters of more than one station found on the linkage tree, two (16 and 18) did not produce homogeneous regions, leaving twelve regions in all for further analyses (see Figure 30). The single station regions were eliminated as the validity of any interpretation in these cases was questionable. Table 12 contains a listing of the stations that fell into each region along with the temperature and precipitation t-scores and mean monthly absolute change values.

To aid in the characterization each of these twelve regions, the centroids for each were computed and displayed in Table 13. The scatter diagrams used in Chapter V were

Table 12

Listing of Temperature and Precipitation t-scores and Change Values by Change Regions

Reg	Station Code	Station	Temp t	Temp Diff	Precip t	Precip Diff
1	1	Portland, MA	.09	.08	.06	.03
	2	Concord, NH	.19	.24	.06	.02
	11	New York, NY	.23	.24	.00	.03
	8	New Haven, CT	-0.19	-0.17	-0.32	-0.11
		Means (1)	.18	.10	-0.05	-0.01
2	109	Billings, MT	.26	.51	1.86	.23
	111	Helena, MT	.50	1.11	.98	.09
	117	Sheridan, WY	.03	.09	-0.79	-0.08
	136	Boise, ID	.27	.48	.25	.04
	137	Pocatello, ID	.18	.30	.08	.01
	134	Salt Lake City, UT	.04	.10	-0.35	-0.08
	139	Walla Walla, WA	.62	.92	.55	.14
	132	Reno, NV	-0.19	-0.28	.71	.22
	140	Yakima, WA	-0.58	-1.01	.88	.21
	135	Grand Junction, CO	-0.31	-0.44	.28	.03
	114	Rapid City, SD	-0.49	-0.64	1.02	.09
		Means (2)	.03	.10	.50	.08
3	12	Harrisburg, PA	-0.98	-1.10	1.35	.46
	138	Spokane, WA	-0.70	-1.22	1.85	.59
	112	Missoula, MT	-0.85	-1.60	1.73	.27
	113	Miles City, MT	-0.70	-1.54	1.79	.15
	88	Bismarck, ND	-0.69	-1.41	1.90	.11
		Means (3)	-0.79	-1.37	1.72	.32
4	6	Providence, RI	-1.30	-1.32	.81	.33
	7	Hartford, CT	-1.15	-1.38	.13	.08
	16	Atlantic City, NJ	-1.51	-1.71	.29	.18
	19	Washington, DC	-0.98	-1.08	-0.32	-0.07
	95	Cairo, IL	-0.80	-0.88	.25	.19
	67	Cincinnati, OH	-1.25	-1.45	.33	.15
	70	Parkersburg, WV	-1.00	-1.23	.13	.07
	65	Evansville, IN	-0.96	-1.10	.49	.25
	64	Louisville, KY	-0.93	-1.20	.50	.21

Reg	Station Code	Station	Temp t	Temp Diff	Precip t	Precip Diff
	23	Asheville, NC	-0.57	-0.73	.26	.10
	143	Medford, OR	-0.75	-0.78	.76	.51
	25	Greensboro, NC	-0.75	-0.88	1.27	.48
	69	Dayton, OH	-0.97	-1.21	-0.26	-0.09
	84	Chicago, IL	-0.97	-1.22	-0.40	-0.11
	77	Toledo, OH	-1.32	-1.75	.56	.17
	78	Fort Wayne, IN	-0.81	-1.01	.26	.11
	76	Cleveland, OH	-1.08	-1.51	.32	.09
	79	Detroit, MI	-0.48	-0.54	.48	.13
	14	Reading, PA	-0.39	-0.41	.42	.19
	17	Trenton, NJ	-0.31	-0.30	.67	.27
	72	Buffalo, NY	-0.76	-0.87	.57	.20
	74	Syracuse, NY	-0.33	-0.35	.01	.02
	73	Rochester, NY	-0.55	-0.55	.09	.04
	9	Albany, NY	-0.25	-0.31	.68	.21
	83	Sault Ste. Marie, MI	-1.80	-2.19	.58	.11
	108	Huron, SD	-1.63	-2.90	.90	.10
	71	Pittsburgh, PA	-1.66	-2.26	.29	.11
	68	Columbus, OH	-1.74	-2.37	.78	.27
	66	Indianapolis, IN	-1.42	-1.77	1.18	.47
	75	Erie, PA	-1.67	-1.95	1.07	.30
	15	Scranton, PA	-1.76	-1.94	1.34	.39
	20	Lynchburg, VA	-1.87	-2.06	-0.36	-0.08
	13	Philadelphia, PA	-1.64	-2.00	-0.32	-0.10
	82	Marquette, MI	-1.37	-1.71	-1.05	-0.18
	96	Peoria, IL	-1.55	-1.87	-0.77	-0.29
	107	Sioux City, IA	-1.30	-1.54	-0.15	-0.01
	86	Milwaukee, WI	-1.66	-2.14	-0.15	-0.04
	90	Minneapolis, MN	-1.10	-1.75	-0.93	-0.13
	89	Williston, ND	-0.59	-1.30	.10	.01
	110	Havre, MT	-0.49	-1.20	.06	.00
	3	Burlington, VT	-0.45	-0.54	-0.28	-0.07
		Means (4)	-1.07	-1.35	.26	.11
5	24	Charlotte, NC	-1.16	-1.48	-0.12	-0.03
	47	New Orleans, LA	-1.47	-2.27	-0.08	-0.00
	28	Wilmington, NC	-1.17	-1.40	-0.38	-0.15
	44	Montgomery, AL	-1.29	-1.88	.14	.10
	147	Sacramento, CA	-0.75	-0.63	-0.26	-0.21
	58	Port Arthur, TX	-0.93	-1.14	-0.62	-0.34
	41	Pensacola, FL	-0.87	-1.25	0.00	0.03
	45	Meridian, MS	-1.05	-1.54	-1.04	-0.60
	46	Vicksburg, MS	-0.96	-1.13	-0.64	-0.43
	26	Hatteras, NC	-0.87	-0.96	-0.46	-0.23
	43	Mobile, AL	-0.98	-1.43	1.18	.60
	141	Seattle, WA	-0.09	-0.08	1.39	.66

Reg	Station Code	Station	Temp t	Temp Diff	Precip t	Precip Diff
	39	Macon, GA	-0.23	-0.27	.49	.32
	145	Roseburg, OR	-0.74	-0.69	.98	.99
	61	Knoxville, TN	-0.75	-1.01	.33	.27
	63	Nashville, TN	-0.72	-0.94	.24	.20
	62	Memphis, TN	-0.57	-0.62	.18	.13
	50	Little Rock, AR	-0.81	-0.80	.65	.51
	38	Atlanta, GA	-0.65	-0.94	.56	.30
	31	Greenville, SC	-0.63	-0.71	.48	.29
	146	Eureka, CA	-0.03	-0.02	.07	.08
	60	Chattanooga, TN	-0.50	-0.66	-0.56	-0.43
	42	Birmingham, AL	-0.56	-0.73	-0.25	-0.18
		Means (5)	-0.77	-0.98	.10	.08
6	144	Portland, OR	-1.80	-1.87	-0.74	-0.58
7	49	Fort Smith, AR	-0.43	-0.46	-2.06	-1.19
	48	Shreveport, LA	-0.55	-0.54	-1.48	-0.90
		Means (7)	-0.49	-0.50	-1.77	-1.04
8	148	San Francisco, CA	-2.20	-1.92	-0.41	-0.33
9	30	Columbia, SC	-1.32	-1.75	2.38	1.44
	29	Charleston, SC	-1.61	-2.02	.49	.34
	33	Savannah, GA	-2.23	-2.66	.32	.21
	32	Augusta, GA	-1.47	-1.99	1.14	.78
	27	Raleigh, NC	-1.81	-2.03	.72	.30
	22	Richmond, VA	-1.55	-1.67	1.41	.53
	21	Norfolk, VA	-1.88	-2.15	1.48	.46
		Means (9)	-1.70	-2.04	1.13	.54
10	5	Nantucket, MA	-0.37	-0.31	2.25	.74
	4	Boston, MA	.12	.11	1.82	.89
		Means (10)	-0.10	-0.10	2.03	.81
11	115	Cheyenne, WY	.16	.20	-2.36	-0.26
	122	Dodge City, KS	-0.27	-0.27	-2.44	-0.35
	120	Pueblo, CO	.02	.01	-1.33	-0.09
	129	Albuquerque, NM	-0.15	-0.19	-0.35	-0.04
	126	Amarillo, TX	-0.19	-0.21	-0.81	-0.19
	104	Lincoln, NB	-0.82	-0.95	-1.71	-0.35
	121	Concordia, KS	-1.09	-1.12	-1.16	-0.21
	105	Omaha, NB	-0.98	-1.03	-0.94	-0.20
	102	Springfield, MO	-0.55	-0.43	-1.35	-0.34

Reg	Station Code	Station	Temp t	Temp Diff	Precip t	Precip Diff
	133	Winnemucca, NV	-0.13	-0.24	-0.93	-0.17
	100	Kansas City, MO	-0.22	-0.22	-1.05	-0.24
		Means (10)	-0.38	-0.40	-1.31	-0.22
12	35	Key West, FL	-0.81	-0.81	.32	.16
	36	Miami, FL	-0.73	-0.71	.46	.22
	53	Corpus Christi, TX	-0.64	-0.63	.54	.31
	52	Brownsville, TX	-0.53	-0.54	.39	.24
	37	Tampa, FL	-1.22	-1.58	.38	.23
		Means (12)	-0.79	-0.85	.42	.23
13	59	San Antonio, TX	-0.35	-0.29	-0.09	-0.01
	149	Fresno, CA	-0.83	-0.74	.12	.06
	125	Abilene, TX	-0.63	-0.49	-0.49	-0.14
	130	Phoenix, AZ	-0.66	-0.63	-0.56	-0.13
	128	El Paso, TX	-0.35	-0.40	-1.24	-0.13
	127	Roswell, NM	-1.26	-1.59	-0.59	-0.08
	51	Austin, TX	-0.07	-0.03	-0.70	-0.29
	54	Dallas, TX	-0.28	-0.20	-0.68	-0.42
	150	Los Angeles, CA	-0.28	-0.27	-1.20	-0.86
	55	Fort Worth, TX	-1.24	-0.89	-1.04	-0.51
	40	Apalachicola, FL	-0.80	-1.08	-1.04	-0.55
	56	Galveston, TX	-0.80	-0.88	-0.73	-0.39
	57	Houston, TX	-0.72	-0.76	.12	.11
	34	Jacksonville, FL	-1.33	-1.86	-0.17	-0.05
		Means (13)	-0.69	-0.72	-0.59	-0.24
14	119	Denver, CO	-1.68	-2.11	1.61	.18
15	80	Alpena, MI	-2.40	-2.93	-0.95	-0.20
	93	Des Moines, IA	-2.40	-2.93	-1.16	-0.28
	98	St. Louis, MO	-2.56	-2.62	-1.07	-0.31
	97	Springfield, IL	-2.50	-2.70	-1.22	-0.33
	85	Green Bay, WI	-2.24	-3.10	-1.92	-0.28
	99	Columbia, MO	-1.75	-1.61	-1.69	-0.44
	118	North Platte, NB	-2.38	-2.75	-0.56	-0.05
	124	Oklahoma City, OK	-2.52	-1.67	-2.09	-0.54
	103	Topeka, KS	-2.70	-2.38	-2.71	-0.68
	101	St. Joseph, MO	-2.03	-2.04	-2.78	-0.63
	106	Valentine, NB	-1.49	-1.71	-2.11	-0.21
	92	Madison, WI	-1.56	-2.14	-2.69	-0.41
		Means (15)	-2.21	-2.38	-1.75	-0.36

Reg	Station Code	Station	Temp t	Temp Diff	Precip t	Precip Diff
16	123	Wichita, KS	-1.26	-0.98	-3.58	-0.76
	91	La Crosse, WI	-0.71	-1.15	-3.48	-0.44
		Means (16)	-0.99	-1.07	-3.53	-0.60
17	87	Duluth, MN	-2.49	-3.71	1.41	.19
18	18	Baltimore, MD	-3.10	-3.50	-0.50	-0.14
	94	Dubuque, IA	-3.43	-4.21	-0.03	-0.01
	81	Grand Rapids, MI	-2.88	-3.02	.50	.12
	10	Binghamton, NY	-3.16	-3.63	.43	.14
		Means (18)	-3.14	-3.59	.10	.03
19	116	Lander, WY	1.13	2.04	-0.29	-0.03
20	151	San Diego, CA	1.24	1.13	-2.22	-1.01
21	131	Yuma, AZ	1.26	1.27	-0.63	-0.08
22	142	Tatoosh Island, WA	-0.38	-0.45	1.13	1.03

inappropriate here as these clusters were produced in a four dimensional model. The means for centroids presented in Table 13 came from standardized variables. Table 14 presents the means and standard deviations of each variable in the clustering algorithm, and aided in the intrepretation of the results. Temperature and precipitation values were averages, through space, for the ten year zonal means from each station for each winter month. Factors 1 and 2 were derived from these measures. The temperature change and precipitation change values were the averages, through space, of the t-scores calculated for each of these varia-

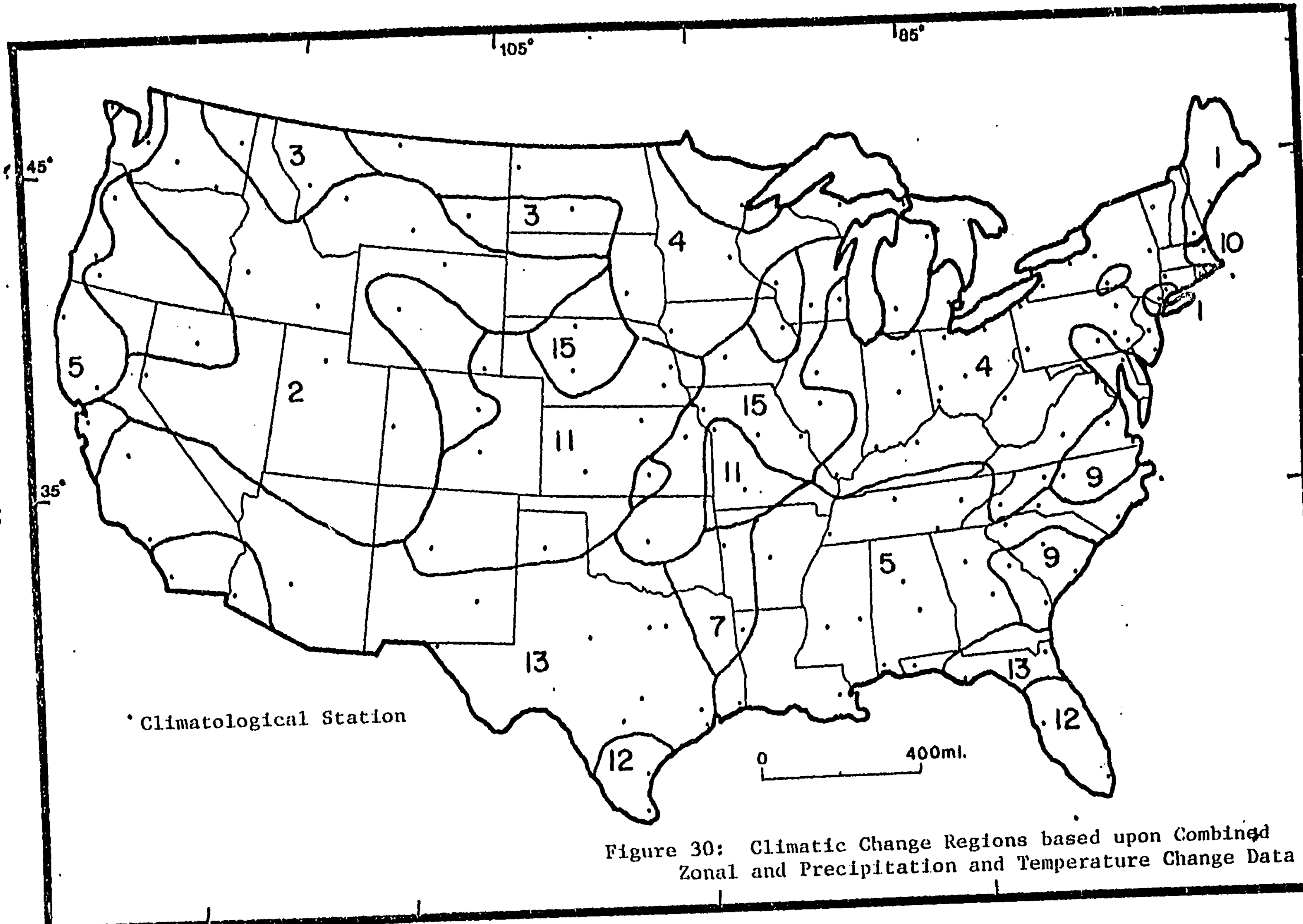


Figure 30: Climatic Change Regions based upon Combined Zonal and Precipitation and Temperature Change Data

Table 13

Centroids for Clusters of the

Twelve Change Regions

Region	Factor 1 (Temp)	Factor 2 (Precip)	Temp Change	Precip Change
1	-1.04	.82	1.22	.03
2	-0.38	-0.94	1.16	.53
3	-0.85	-0.66	.18	1.63
4	-0.67	.06	-0.16	.31
5	.54	1.34	.20	.17
7	.50	.94	.54	-1.52
9	.80	.21	-0.91	1.10
10	-0.68	.86	.97	1.91
11	-0.16	-0.94	.66	-1.11
12	2.68	-1.07	.18	.46
13	1.38	-0.49	.30	-0.46
15	-0.53	-0.56	-1.52	-1.50

bles at each station.

The northern New England region (1) was characterized by temperatures around 25 degrees, which were a full standard deviation below the national mean. Precipitation values were generally above 3.00 inches, which were well above the national averages. The most significant feature in this region was that temperature on average, showed an absolute increase of 0.10 degrees between the time periods. Precipitation values remained essentially unaltered (a decline of 0.01 inches for an average). The stations in this grouping were located in New England, all near the

Table 14

Means and Standard Deviations of Variables Used

As Input in the Clustering Algorithm

Variable	Mean	Std. Dev.
Temp(D,Z)	38.03	11.41
Temp(J,Z)	33.96	12.32
Temp(F,Z)	37.17	12.46
Precip(D,Z)	2.59	1.68
Precip(J,Z)	2.35	1.43
Precip(F,Z)	2.27	1.46
Temp. Change	-0.94	.84
Precip. Change	-0.09	1.11

coast. The type of change observed here was the kind that would be expected as the circulation changed. During the zonal period, fewer tropical air masses were able to penetrate to this northerly location. With an upper level trough located over the midwest in the meridional period, New England would often be located ahead of the trough, allowing the advection of warmer air masses. The region fell along the exit path of most cyclonic storms in the United States, and as result, a good amount of precipitation could be expected under most circulation types.

Region 10 represented a more severe case when compared to the stations in region 1. Both stations that formed this type, Boston and Nantucket, Massachusetts, were more oceanic than the stations of region 1. The oceanic effect moderated the temperatures as seen in the factor 1 value of only -0.68, and during the zonal period, precipitation values were comparable to those for region 1. The temperature change was similar to the New England case (a small decrease of 0.10 degrees was the average), but what differentiates these stations was the large increase in precipitation of 0.81 inches as the circulation shifted from a zonal to a meridional pattern. Since this region was normally well ahead of the midwestern trough, divergence aloft encouraged vertical motion in the atmosphere. These two stations were close to the sea where a good amount of moisture was readily available to the atmosphere. The upper air support triggered more precipitation, explaining the large increase in precipitation which distinquished this region.

Falling beneath the trough that developed more frequently in the midwest in the meridional period was a large region (4) that was broken into two sections. The eastern section extended from the southern shores of Lake Superior southward to the Ohio River and extended eastward to the Atlantic coast. The type of change associated with this region was a drop in temperature of 1.35 degrees on average which was over one standard deviation, and an increase of 0.11 inches in precipitation. The decreased temperatures could be explained by the advection of polar air masses beneath the upper level trough. The increase in precipitation was attributed to greater efficiency of the precipitation forming processes. These stations fell along the storm tracks of the meridional period and would receive greater numbers of cyclonic storms as result. The same explanation could be extended to include the western section of this climatic change region.

A distinctive climatic change grouping (15) was found between the two sections of region 4. The zonal temperatures were very similar to those found in region 4, but conditions were substantially drier in region 15 compared to surrounding regions. The changes that occurred in climate markedly separated these two adjacent regions. For region 15, temperatures fell an average of 2.38 degrees and the average t-score was -2.21. The zonal configuration apparently allowed greater frequencies of warm, mT air masses to penetrate into this region. The advection of cooler air masses into this region accounted for the large decline in temperature. Along with the large decline in temperature, precipitation decreased an average of 0.36 inches. For all stations in this region, two factors contributed to this finding: (1) these stations were located just ahead of the upper level ridge over the Rockies where convergence in the flow inhibited vertical motions and precipitation formation, and (2) the tremendous decline in temperature limited the amount of moisture the air masses contained.

Adjacent to this region was cluster 11 where temperatures declined on the average of 0.40 degrees, and a decline in precipitation of 0.22 inches was observed. The average station in this region showed a drop in precipitation between the two time periods of over one standard deviation. Temperatures on average fell about one half of one standard deviation. The large decline in precipitation could be explained by the location of the region relative to the semi-permanent upper level ridge over the Rockies during the meridional period. Region 11, just as region 15 (see Figure 30), was located ahead of the ridge where convergence aloft inhibited precipitation forming processes. One of the more striking features of this region was its proximity to regions 4 and 15 on its eastern side. Region 4 displayed much greater temperature decreases and a slight increase in precipitation; region 15 showed an enormous decrease in temperature and precipitation. By comparing the characteristics of change for these three regions, it became apparent that this area of the country contained a steep gradient in a climatic change surface. Within only a few hundred miles, very different "types" of climatic changes could be observed.

Continuing the survey of regions across the northern one half of the United States, the next region encountered (2) was one dominated by an absolute increase of 0.10 degrees in temperature associated with a shift in the circulation pattern. Warm air advection beneath the ridge over the Rockies was responsible for the increase in temperature. These stations did, however, lie on the western margin of the upper level ridge where divergence aloft was supporting precipitation forming processes, explaining the increase of 0.80 inches determined for precipitation values.

To the north of this region was a small, broken region (3) dominated by a large increase in precipitation of 0.30 inches. The high pressure ridge over the Rockies forced cyclonic storms from the Pacific to pass over this northerly location during the meridional period, accounting for the increase in precipitation determined for this region. Temperatures in this region fell an average of 1.37 degrees.

The next region encountered (5) was one found in the Northwest and throughout the American South. Both of these areas showed above average temperatures and precipitation levels for the zonal period. Averages for the change measures demonstrated that temperatures generally decreased approximately one degree which represented about three fourths of one standard deviation for each station. A higher frequency of cold air influx into the South explained this decrease in temperatures. Warm sea surface temperatures in the North Pacific produced a deep trough over the Pacific allowing for cold air advection in the Northwest (Namias, 1970). The greater frequency of polar air masses explained the drop in temperature over the Northwest. The increase in precipitation for the stations in group 5 was small (0.08 inches on average), indicating little change between the two periods in this element. The Northwest received sufficient moisture in most types of circulation; the South received a greater number of cyclonic storms in the merdional period, counteracting any decreases in precipitation that arose from a loss in convective activity associated with a decrease in temperature.

Flanking both sides of the coast in Region 5 in the South were the stations from cluster 9. It was a change region marked by very large drops in temperature of over 2.00 degrees and substantial increases in precipitation of 0.54 inches. The changes observed in the more southerly region 5 were greatly accentuated throughout this region. This was a region that fell just ahead of the semi-permanent trough of the midwest, in a location where maximum divergence occurred in the upper levels of the troposphere. It is well-known by synoptic meteorologists that low pressure systems at the surface are often positioned ahead of the center of the low pressure system in the upper levels (Petterssen, 1958:160-163). This region (9) would frequently be found in this position during the meridional period. The cyclonic systems passing through region 9 carried with them the cooler air masses, causing the decreases in temperature, and greater amounts of precipitation. The precipitation increase was particularly high in this region due to increased moisture availability associated with its coastal location.

Region 12 covered all of southern Florida and the southern coastal section of Texas. It was a climatic type dominated by extremely high temperatures when compared to the rest of the United States, and relatively low precipitation amounts. During the winter months, cyclonic storms generally passed northward of these areas, and convective activity was at an annual minimum. Combined, these two factors kept winter precipitation levels low in these southerly locations. The changes that occurred in these regions were relatively mild compared to most of the United States. Temperature values showed a decrease of 0.85 inches, which was not of the same magnitude of most of the eastern United States. Precipitation values increased 0.23 inches, which was almost one half of one standard deviation, indicating the passage of more cyclonic storms during the meridional period.

Region (13) developed throughout the southern section of the Southwest, yet some stations in this cluster were also found in northern Florida. Warm temperatures and low precipitation amounts characterized this region during the zonal period. With the shift in circulation came an average decrease in temperature of 0.72 degrees. This represented a temperature decrease that was less than the values found for most of the United States. This decrease in temperature did not reflect any substantial shift in air mass dominance, but simply reflected the generally cooling trend across the United States. The decrease in precipitation of approximately one fourth of one inch in the Southwest was associated with a stronger, more persistent upper level high pressure ridge in the meridional flow. The drier readings in northern Florida were, in all probability, associated with decreased convective activity that was coupled with the decrease in temperatures.

The last cluster (7) to be discussed here was one whose stations were found in northern Louisiana and Arkansas. It was a transitional region between the Southern and the Southwestern regions (5 and 13). Zonal temperature and precipitation values were similar to those in region 5. Temperatures in this region generally decreased one half of one inch on average. What distinguished region 7 was the large decline in precipitation of 1.04 inches which represented over one and three fourths standard deviations. The precipitation change t-score value was nearly identical to the one for adjacent region 15. Convergence aloft associated with the position of the stations relative to the high pressure western ridge was the explanation for the decrease in precipitation in both regions (7 and 15).

The following concluding statements could be made from the analyses of this section. The clustering of zonal components along with climatic change data could result in the determination of large homogeneous regions whose stations appeared to change climatically in unison in association with a shift in the circulation of the atmosphere. Twenty-two clusters were identified from the one hundred fifty-one stations entering the cluster analysis, and of these, twelve groupings produced regions marked by at least two contiguous stations. The centroids of these clusters were analyzed in conjunction with an appraisal of the location of the resulting regions in the United States. In each case, the type of change appeared to be appropriate, or expected, as the circulation shifted from a zonal to a meridional pattern. Stations beneath the ridge over the Rockies that existed in the meridional period generally became relatively warmer and drier compared to the rest of the United States. Those ahead of the ridge where convergence aloft occurred with subsidence near the surface displayed extreme decreases in precipitation. Stations beneath the meridional upper level trough in the midwest generally became much cooler and wetter. Stations ahead of this trough where divergence aloft occurred showed substantial increases in precipitation. These findings strongly suggested that fluctuations in the circulation of the atmosphere produced regionally homogeneous changes in the configuration of surface climatic elements.

CHAPTER VII

SUMMARY, CONCLUSIONS, POTENTIAL APPLICATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

Summary

The primary focus of this investigation was to analyze how changes in the general circulation of the atmosphere were manifested regionally in the surface climatic elements. The major questions raised by such a focus were addressed in three distinct sections. First, emphasis was placed on displaying changes in a number of selected climatic elements. Secondly, the changes that occurred in climatic regions between periods dominated by different types of circulation were explored. Finally, an effort was made to produce regions based upon the type of climatic adjustments made between circulation regimes.

Work by many investigators aided in the temporal considerations in this study. The ten-year time period from December, 1939 through February, 1949 was defined as a time when the circulation of the atmosphere was predominantly zonal. Ten years extending from December, 1955 through Febraury, 1965 represented a period dominated by a meridional flow pattern. Only winter data were used as the circulation was much stronger, and more well defined during the low-sun months.

For one hundred fifty-one stations across the coterminous United States, climatic elements from three atmospheric components, circulation, heat energy, and moisture were included. Tests of homogeneity demonstrated that differential trends in the data did not exist in either the zonal or the meridional period.

The first of the actual hypotheses were tested in Chapter IV where discriminant analyses were used to test the notion that surface climates were distinctly different in the two time periods. Seventy-eight per cent of the discriminant models were able to correctly reclassify all but one year, or better, into the zonal or meridional categories. Large distinctive, homogeneous spatial patterns in the accuracy of the models did not appear in the results. One of the many features of the calculations was the identification of the most discriminating variable. In most cases (fifty-six per cent), moisture components proved to be the best discriminators, and in forty-three per cent of the cases, circulation components were selected first. Data from the extremely meridional winter of 1976-1977 were entered into selected discriminant functions and in ninety-five per cent of the trials, the winters were classified as meridional.

For each station and for each climatic element, a standardized t-score was calculated indicating the amount of change that occurred in each element between the two time periods. The climatic change matrix that resulted was factor analyzed to condense the matrix. This procedure avoided overlap in the analysis of the spatial patterns in the climatic fluctuation.

The first factor that emerged was a wind persistence change component in the data structure. Approximately sixty per cent of the stations across the United States displayed the expected decrease in wind persistence between the circulation types. The spatial patterns for the factor scores of this component appeared to show a decrease in wind persistence in a west to east direction. The Southwest displayed increases in wind persistence in association with the ridge that developed over the Rockies. Generally, the rest of the United States displayed a decrease in the wind persistence values.

A second factor was interpretated as a precipitation change component. About one half of the stations (fifty-two per cent) displayed an increase in precipitation, while the other stations showed a precipitation decrease. However, distinctive spatial patterns developed in these data. A precipitation increase was observed in much of the West and along the eastern coast, and the Plains and midwestern states were dominated by substantial decreases.

Factor three was characterized as a temperature change component in the climatic change data, with high positive loadings on temperature and negative loadings with wind speed. At only eleven per cent of the stations did temperatures increase, in the remaining cases, temperatures decreased as the circulation shifted from a zonal to a meridional pattern. Wind speeds increased in sixty-six per cent of the stations. A high pressure ridge, with higher temperatures and lower wind speeds, developed in the Rocky Mountain states and in northern New England. Most of the eastern two thirds of the United States became dominated by an upper level trough, with lower temperatures and higher wind speeds as the circulation shifted from a zonal to a meridional pattern.

The relative humidity change factor (4) showed that the atmosphere of the midwestern states became significantly drier in the meridional period, and for the western and eastern coastal states, the moisture content of the atmosphere increased. In ninety per cent of the cases, relative humidity decreased between wthe time periods.

The last significant factor (5) was a northwesterly wind change component in the data. Stations located in regions dominated by northwesterly flow aloft in the meridional period tended to show an increase in the northwesterly wind component. Conversely, the stations located in regions where upper level flow was from the southwest in the meridional pattern displayed decreases in this measure.

In a second section (presented in Chapter V), winter climatic regions were developed for the zonal and meridional periods, along with an average, combined twenty year set of regions. To keep the patterns relatively simple, only the commonly used elements, temperature and precipitation were employed. All data were factor analyzed to transform these data onto orthogonal axes. The transformed data were then clustered based on a Euclidean distance model. Phenon lines which divided the clusters were selected, and resulting regions were mapped.

Within the zonal period, ten regions were identified, with one very large region extending from the Rockies eastward through Pennsylvania. Except along the southern Pacific coast, large spatially homogeneous winter climatic regions developed. Shifting the phenon line to a point where a break occurred in the distance level produced fourteen regions, forcing some of the original ten regions to be subdivided. A scatter diagram of the data allowed for the characterization of each region.

The same procedure was applied to the meridional data and ten and fourteen region schemes were presented. A much higher distance level was needed to separate the clusters into ten regions, indicating a greater distance, in climatic space, existed between the stations in the meridional period. The clusters were mapped, and as in the zonal case, large regions developed for most of the United States.

When the zonal and meridional maps were compared, along with the combined results, a number of differences were apparent. The large interior zonal region (4) did not extend as far eastward in the meridional period. A cold continental interior region in the northern Plains was more extensively developed in the meridional years. The cool and moist New England type was also greatly expanded in the meridional period. The large Southern region shrank considerably as the circulation shifted its basic flow pattern. Throughout some sections of the country, the climatic regions remained relatively constant between the two time periods, suggesting that circulation change did not affect climatic regionalization in all parts of the country.

Comparisons of the zonal, meridional, and average climatic regions showed that the "prairie wedge" extended into Pennsylvania in the zonal period. A very cold winter climatic regions in the northern Plains shifted northward in the zonal years. Climatic regions in Texas, Oklahoma, Arkansas, and Louisiana displayed differing alignments between the periods of different flow. A large mid-Atlantic region extending from the coast through Kentucky was part of a larger Northeastern region in the meridional flow, but was a separate climatic cluster in the zonal years. This indicated that a stronger north-south gradient in climatic parameters was present when the west to east zonal flow was dominant.

Shape measurements were used on the regions to test for significant changes in the elongation of the regions along a west-east axis. Some findings suggested that the regions became less elongated, as expected, but the results were not statistically significant.

In the final section of this investigation (Chapter VI), attempts were made to generate regions based on the type of change that occurred in the surface climatic elements. Preliminary attempts where the entire change matrix was used, or where only temperature and precipitation change data were used, proved unsuccessful. However, if two zonal components were added to temperature and precipitation change data, giving some weight to climatic similarity, results were more promising. This led to the conclusion that stations in different regions in the United States displayed similar types of climatic change, such as increased temperatures and decreased precipitation levels, but to show spatial homogeneity in the pattern, some base of climatic similarity must be included.

Before clustering on the combined zonal and change variables could be performed, the data were shown to be orthogonal. The clustering algorithm produced twelve spatially homogeneous climatic change regions. The centroids for each cluster were computed and analyzed in conjunction with the discussion of the location of the resulting regions. The characteristics of each of the twelve regions appeared to support the notion that homogeneous changes occurred in association with a change in the upper level circulation. The characteristics of each region could be explained through the development of a strong ridge in the west, and an upper level trough through the midwest during the meridional period.

Conclusions

Inevitably in an investigation of this type, the mass of data and all the analyses led to some set of conclusions that went beyond summarizing all the results. These conclusions represented the most concise answers to the major questions examined in this study. The following eight statements were the key points for this research effort.

1. Changes in the predominant circulation pattern of the atmosphere appeared to significantly and persistently be associated with changes in the surface climatic elements. Discriminant models showed that for most stations in the United States, carefully selected zonal and meridional time periods could be accurately discriminated based upon surface climatic data.

2. In nearly all cases, circulation and moisture

components of the atmosphere were most significantly affected by circulation change. Rarely did temperature, a heat energy component, prove to be the variable most affected.

3. An index on zonality and meridionality could be created based upon surface climatic conditions. Data from the extremely meridional winter of 1976-1977 were entered into discriminant models, and a zonal-meridional continuum was formed. The winter was classified as meridional in ninety-five per cent of the cases.

4. Generally for the United States, as the circulation shifted into the meridional pattern, the atmosphere cooled, held less moisture, and wind speeds increased.

5. Distinctive spatial patterns existed in the changes observed in many of the climatic elements. These changes appeared to be associated with the development of an upper level ridge over the Rockies and a trough in the midwest during the meridional period.

6. Large spatially homogeneous winter climatic regions could be developed for each time period based on factor and cluster analyses.

7. The configuration of climatic regions appeared to change substantially between the zonal and meridional time periods. Statistically significant changes

in the west-east elongation of the resulting climatic regions could not be verified.

8. Large spatially homogeneous regions could be developed across the United States based upon the type of change that occurred in the surface climatic elements between the two time periods dominated by distinctively different circulation regimes. Each region could be explained based on known changes in the atmospheric circulation system.

Potential Applications and Suggestions for Future Research

For general climatological studies, the findings of this investigation are useful in a variety of ways. This study clearly demonstrated that significant changes occurred in climate in association with a circulation change. These findings demand that the presentation of any climatological research must include specific temporal information. Maps of climatic regions or of the distribution in the value of climatic elements must include the time period for which the data are representative, for through time, climate certainly does not remain constant. The findings presented here pointed to the need to extend the so called "normal" periods to include all types of atmsopheric circulation. These "normal" periods could be dominated by one type of circulation and could be extremely abnormal under another circulation regime.

The development of seasonal climatic regions for the United States or for the globe is a relatively unexplored field in climatology. Production of such maps may have practical applications in a variety of physical, social, or economic systems, or to students in climatology interested in changes in seasonal climatic regions.

The findings of this study may prove useful in forecasting surface conditions at the monthly time scale, or in the interpretation of past climatic histories. In a recent article, Harman and Harrington (1978) examined surface and upper level patterns for two different Augusts, 1975 and 1976. These two months were well outside the time range of this investigation both in the years included and in the season examined. Yet, the findings of their study were close to what would have been predicted based upon the findings presented here. August, 1975 was dominated by a zonal flow pattern, August, 1976 was a meridional month with considerably lower precipitation totals for the eastern two thirds of the United States. Ahead of the upper level ridge in the meridional month, conditions were extremely dry, leaving the plains in drought conditions. Ahead of the upper level low, precipitation amounts in New England were substantially increased. Moisture content in the atmosphere was generally much lower in the meridional month. All of these findings were similar to those developed here for winter averages in the 1939 through 1965 time period. Unfortunately, Harman and Harrington only analyzed moisture components, not allowing for comparisons in other climatic elements.

Another finding that may be useful to long range forecasters was the identification of the relative persistence in the surface climatic conditions that appeared to exist during a period of a particular flow type. Results from the discriminant tests showed that more variation in climate existed between periods of differing circulation rather than within a period with one dominant circulation pattern. Determining the nature of this persistence of climatic conditions from one year to the next appears to be an area of promising research.

The findings of this study may be extended to a variety of areas outside of climatology. The recent United States Climate Program Plan (Interdepartmental Committee for Atmospheric Sciences, 1977) had as a central focus the evaluation of climate variability on national activities including agriculture, forestry, fishing industries, management of land and water resources, energy consumption and distribution, transportation, and communications. The first "element" of the United States Climate Program Plan was the:

> Evaluation of relationships between climate variability and national activities, particularly climatic impacts on food, fiber, and water, as well as climate impacts on and from energy and transportation.

The findings of this study may prove useful in each of these areas.

For example, statistical models reviewed by McQuigg (1975) dealing with agriculture, forestry, energy, and commerce use a variety of climatic inputs to calculate expected crop yields. The data from this study may be directly applied to these models to determine the effect on yields of changes in climatic elements. By defining regions where climatic fluctuations were most severe, indices of risk to crop yields could be formulated in various areas across the United States. Similar models have been developed for forest productivity, including growth rate variables and fire risk, and results from this study may prove helpful in this area. Although oceanic regions were not included here, future similar research efforts using data from the seas may be useful to the fishing industry. Most of the research needed in these areas is in the development of better statistical and physical models to improve current predictions in yields, for only then will climatic variability and climatic change data produce accurate estimates of impacts. For now, this study's main contribution in this type of applied climatology is in defining regions in the United States where climatic fluctuations, and resultant changes in crop and forest productivity, are likely to be most pronounced.

Changes in climatic elements clearly affect the land and water resources of the United States. Risks from floods are obviously climate related, and as this study has shown, the changes in the circulation produced substantial changes in the precipitation amounts throughout the United States. Precipitation change information may be useful to hydrologists working on ground water supplies, soil moisture, or flood hazards. Other natural hazards including mudflows, erosion by wind, water, or even ice are all closely linked to the climatic conditions. Determining the exact changes in climate for various regions, and the precise nature of the relationship of climate to the problems of land and water management will prove invaluable in the future.

Perhaps the most pressing problem in the United States today is in the area of energy demand. Statistical models can be produced at various spatial scales, ranging from individual rooms to the entire United States, where energy use is viewed as a function of climatic variables. Determining the precise types of climatic changes and the location of these changes could be used to calculate a new set of demands on the energy supply. Demand regions for energy, such as those developed by Spurlock (1972) may change along with the changes in climatic regions demonstrated in this study. Information on changes in some variables such as cloudiness or total incoming radiation will be useful in calculating potential energy supplies from alternative sources.

Increased precipitation in winter months presents obvious problems to the nation's transportation systems. Aviation routes are clearly affected by significant changes in climate, and to a lesser extent, ground transportation routes are substantially affected by increased snowfall, or by heavy rains with related flooding or mass wasting of slopes. Ice packs on the Great Lakes or in interior waterways have severe economic consequences and are certainly climate related. Over both the short and long terms, communication systems including landline and radio are affected by the state of the climate. Ice storms and high winds can severely damage communication lines, increases in lightning affect all types of radio communications.

The list of activities that are linked to climate could be extended on and on. Many investigators are working to discover the statistical and physical relationships between climate and a wide range of natural phenomena and human activities. Few would argue that climate determines the observed results, but the role climate plays is often quite substantial. Once these relationships are precisely known, climatic change information, including the findings of this study, will prove invaluable in forecasting future supplies, demands, and needs of the population. Future studies should be extended to include the entire globe, both for the land and sea surfaces, to determine the magnitude of climatic changes for the world, for problems that arise from climatic changes are certain to be global in scope, and not confined to the borders of the coterminous United States.

BIBLIOGRAPHY

Books

Andrews, F. M., J. N. Morgan, J. A. Sonquist, and L. Klein.
1973 _Multiple Classification Analysis_. Ann Arbor: University of Michigan.

Bryson, R. A. and T. J. Murray.
1977 _Climates of Hunger_. Madison: University of Wisconsin Press.

Haggett, P. and R. J. Chorley.
1969 _Network Analysis in Geography_. New York: St. Martin's Press.

Hoel, P. G.
1960 _Elementary Statistics_. New York: John Wiley and Sons, Inc.

King, L. J.
1969 _Statistical Analysis in Geography_. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Mather, J. R.
1974 _Climatology: Fundementals and Applications_. New York: McGraw-Hill Book Company.

Oliver, J. E.
1973 _Climate and Man's Environment_. New York: John Wiley and Sons, Inc.

Panofsky, H. A. and G. W. Brier.
1958 _Some Applications of Statistics to Meteorology_. Unversity Park, Pennsylvania: Pennsylvania State University.

Pettersen, S.
1958 _Introduction to Meteorology_. New York: McGraw-Hill Book Company, Inc.

Rummell, R. J.
1970 _Applied Factor Analysis_. Evanston: Northwestern University Press.

Smith, K.
1975 _Principles of Applied Climatology_. New York: John Wiley and Sons, Inc.

Sneath, P. H. A. and R. R. Sokal.
1973 _Numerical Taxonomy_. San Francisco: W. H. Freeman and Company.

Stringer, E. T.
1972 _Foundations of Climatology_. San Francisco: W. H. Freeman and Company.

Yeates, M.
1974 _An Introduction to Quantitative Analysis in Human Geography_. New York: McGraw-Hill Book Company.

Articles

Barrett, E. C.
1970 Rethinking Climatology. Chapter 4 in _Progress in Geography_, Vol. 2. edited by C. Board, R. J. Chorley, P. Haggett, and D. R. Stoddart. London: Edward Arnold. pp. 154-205.

Beckinsale, R. P.
1973 Climatic Change: A Critique of Modern Theories. in _Climate in Review_. edited by G. McBoyle. Boston: Houghton Mifflin Company. pp. 132-151.

Borchert, J. R.
1971 The Dust Bowl in the 1970's. _Annals_ of the Association of American Geographers 61:1-22.

Brooks, C. E. P.
1951 Geological and Historical Aspects of Climatic Change. in _Compendium of Meteorology_. edited by T. F. Malone. Boston: American Meteorological Society. pp. 1004-1019.

Coffin, H. C.
1964 Wind Analysis by Vector Summation. _The Professional Geographer_ 16:13-14.

Crisp, D. J.
1959 The Influence of Climatic Changes on Animals and Plants. Geographical Journal 125:1-16.

Curry, L.
1962 Climatic Change as a Random Series. Annals of the Association of American Geographers 52:21-31.

Davitaya, F. F.
1969 Atmospheric Dust Content as a Factor Affecting Glaciation and Climatic Change. Annals of the Association of American Geographers 59:552-560.

Dickson, R. R.
1977 Weather and Circulation of February 1977. Monthly Weather Review 105:684-689.

Donovan, H., editor-in-chief.
1977 The Great Western Drought of 1977. Time (7 March 1977), pp. 76-81.

Dzerdzeevskii, B. L.
1969 Climatic Epochs in the Twentieth Century and Some Comments on the Analysis of Past Climates. in Quaternary Geology and Climate. edited by H. E. Wright. Washington: National Academy of Sciences. pp. 49-60.

Grove, A. T.
1969 Landforms and Climatic Change in the Kalahari and Ngamiland. The Geographical Journal 135:191-212.

Haggett, P. and R. J. Chorley.
1968 Trend-Surface Mapping in Geographical Research. in Spatial Analysis. edited by B. J. L. Berry and D. F. Marble. Englewood Cliffs, New Jersey: Prentice Hall, Inc. pp. 195-217.

Hare, F. K.
1951 Climatic Classification. in London Essays in Geography. edited by L. D. Stamp and S. W. Wooldridge. Cambridge, Mass.: Harvard University Press. pp. 111-134.

1966 The Concept of Climate. Geography 51:99-110.

Harman, J. R. and J. A. Harrington.
1978 Contrasting Rainfall Patterns in the Upper Middle West. Annals of the Association of American Geographers 68:402-413.

Jones, S. B.
1950 What Does Geography Need From Climatology? The Professional Geographer 2:41-44.

Kalnicky, R. A.
1974 Climatic Change Since 1950. Annals of the Association of American Geographers 64:100-112.

King, L. J.
1968 A Quantitative Expression of the Pattern of Urban Settlements in Selected Areas of the United States. in Spatial Analysis. edited by B. J. L. Berry and D. F. Marble. Englewood Cliffs, New Jersey: Prentice Hall, Inc. pp. 159-167.

Kukla, G. J. and H. A. Kukla.
1974 Increased Surface Albedo in the Northern Hemisphere. Science 183:709-714.

Lamb, H. H.
1966 Climate in the 1960's:World's Wind Circulation Reflected in the Prevailing Temperatures, Rainfall Patterns, and the Levels of African Lakes. Geographical Journal 132:183-212.

1969 Climatic Fluctuations. in World Survey of Climatology. edited by H. Flohn. New York: Elsevier. pp. 173-249.

Landsberg, H. E.
1970 Man-Made Climatic Changes. Science 170:1265-1274.

1975 The Definition and Determination of Climatic Changes, Fluctuations, and Outlooks. in Atmospheric Quality and Climatic Change. edited by R. J. Kopec. Chapel Hill: The University of North Carolina, Department of Geography, Studies in Geography, No. 9. pp. 52-64.

McBoyle, G. R.
1971 Climatic Classification of Australia by Computer. Australian Geographical Studies 9:1-14.

Magnuson, E.
1977 The Big Freeze. Time (31 January 1977), pp. 22-28.

Manabe, S.
1969 Climate and the Ocean Circulation. Monthly Weather Review 97:739-774.

Markham, C. G.
1975 Twenty-Six Year Cyclical Distribution of Drought and Flood in Ceara, Brazil. The Professional Geographer 27:454-456.

Milankovitch, M.
1930 Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen. in Koppen-Geiger, Handbuch der Klimatologie, Vol. 1, Pt. A, Gebruder Borntrager, Berlin.

Namias, J.
1970 Climatic Anomaly Over the United States during the 1960's. Science 170:174-743.

Peterson, J. T.
1971 The Climate of Cities: A Survey of Recent Literature. in Climate in Review. edited by G. McBoyle. Boston: Houghton Mifflin Company. pp. 264-285.

Pitts, F. R.
1956 What One Geographer Wants from Climatology. The Professional Geographer 8:8-10.

Plass, G. N.
1956 The Carbon Dioxide Theory of Climatic Change. Tellus 8:140-154.

Schneider, S. H. and C. Mass.
1975 Volcanic Dust, Sunspots, and Temperature Trends. Science 190:741-746.

Smagorinsky, J.
1971 Large-Scale Atmospheric Circulation. in Man's Impact on the Climate. edited by Matthews, Kellogg, and Robinson. Cambridge: MIT Press. pp. 200-204.

Taubensee, R. E.
1977 Weather and Circulation of December 1976. Monthly Weather Review 105:368-373.

Terjung, W. H.
1976 Climatology for Geographers. Annals of the Association of American Geographers 66:199-222.

Thornthwaite, C. W.
1943 Problems in the Classification of Climates. The Geographical Review 33:233-255.

1948 An Approach Toward a Rational Classification of Climate. The Geographical Review 38:55-94.

Trewartha, G.
1957 A Reply to "What One Geographer Wants from Climatology". The Professional Geographer 9:8-9.

Wahl, E. W. and T. L. Lawson.
1970 The Climate of the Midnineteenth Century United States Compared to the Current Normals. Monthly Weather Review 98:259-265.

Wagner, A. J.
1977 Weather and Circulation of January 1977. Monthly Weather Review 105:553-560.

Wendland, W. M. and R. A. Bryson.
1974 Dating Climatic Episodes of the Holocene. Quaternary Research 4:9-24.

Wexler, H.
1952 Volcanoes and World Climate. Scientific American 186:74-80.

Wilcock, A. A.
1968 Koppen after Fifty Years. Annals of the Association of American Geographers 58:12-28.

Willett, H. C.
1951 Extropolation of the Sunspot-Climate Relationships. Journal of Meteorology 8:1-6.

Miscellaneous

Climatological Data: National Summary.
United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, Asheville, North Carolina.

Dougenik, J. A. and D. E. Sheehan.
1975 SYMAP User's Reference Manuel. Bedford, Massachusetts: Camera Stat.

Harman, J. R.
1971 Tropospheric Waves, Jet Streams, and the United States Weather Patterns. Commission on College Resource Paper, Number 11. Washington: Association of American Geographers.

Interdepartmental Committee for Atmospheric Sciences.
1977 A United States Climate Program Plan. Washington: National Science Foundation.

McQuigg, J.
1975 Economic Impacts of Weather Variability. Columbia, Missouri: Atmospheric Sciences Department, University of Missouri (NSF Grant No. GI37218X, ESR73-07752-A01).

Mitchell, J. M., chief editor.
1971 Climatic Change. Geneva: World Meteorological Organization, Technical Note No. 79.

Spurlock, C. W.
1972 Predictive Marketing Regions for Liquified Petroleum Gas: A Conceptual Relationship of Heating Degree Days and Demand. Unpublished Ph.D. Thesis. University of Oklahoma.

APPENDICES

APPENDIX I

LISTING OF FIRST-ORDER CLIMATOLOGICAL STATIONS USED IN

ANALYSES AND REGIONAL CLASSIFICATIONS

Station Code	Station	Zonal Region	Merid. Region	Change Region
1	Portland, ME	1a	1a	1
2	Concord, NH	1b	1c	1
3	Burlington, VT	1b	3b	4
4	Boston, MA	1a	1a	10
5	Nantucket, MA	1a	1a	10
6	Providence, RI	1a	1a	4
7	Hartford, CT	1a	1a	4
8	New Haven, CT	1a	1a	1
9	Albany, NY	1b	1c	4
10	Binghamton, NY	1b	1c	18
11	New York, NY	2	1b	1
12	Harrisburg, PA	4b	1b	3
13	Philadelphia, PA	2	1b	4
14	Reading, PA	2	1b	4
15	Scranton, PA	4b	1c	4
16	Atlantic City, NJ	2	1b	4
17	Trenton, NJ	2	1b	4
18	Baltimore, MD	2	1b	18
19	Washington DC	2	1b	4
20	Lynchburg, VA	2	1b	4
21	Norfolk, VA	2	1b	9
22	Richmond, VA	2	1b	9
23	Asheville, NC	2	1b	4
24	Charlotte, NC	2	1b	5
25	Greensboro, NC	2	1b	4

Station Code	Station	Zonal Region	Merid. Region	Change Region
26	Hatteras, NC	5c	5	5
27	Raleigh, NC	2	1b	9
28	Wilmington, NC	10	4a	5
29	Charleston, SC	10	4a	9
30	Columbia, SC	10	5	9
31	Greenville, SC	5a	5	5
32	Augusta, GA	10	5	9
33	Savannah, GA	10	4a	9
34	Jacksonville, FL	10	4a	13
35	Key West, FL	6	10	12
36	Miami, FL	6	10	12
37	Tampa, FL	8	8	12
38	Atlanta, GA	5a	5	5
39	Macon, GA	5c	5	5
40	Apalachicola, FL	10	4a	13
41	Pensacola, FL	5c	4b	5
42	Birmingham, AL	5b	5	5
43	Mobile, AL	5c	5	5
44	Montgomery, AL	5c	5	5
45	Meridian, MS	5b	5	5
46	Vicksburg, MS	5b	5	5
47	New Orleans, LA	5c	4b	5
48	Shreveport, LA	5c	4a	7
49	Fort Smith, AR	2	6a	7
50	Little Rock, AR	2	5	5
51	Austin, TX	10	6b	13
52	Brownsville, TX	7	9	12
53	Corpus Christi, TX	8	8	12
54	Dallas, TX	10	6b	13
55	Fort Worth, TX	10	6b	13
56	Galveston, TX	10	4a	13
57	Houston, TX	10	4a	13
58	Port Arthur, TX	5c	4b	5
59	San Antonio, TX	8	6b	13
60	Chattanooga, TN	5b	5	5
61	Knoxville, TN	5a	5	5
62	Memphis, TN	5a	5	5
63	Nashville, TN	5a	5	5
64	Louisville, KY	2	1b	4
65	Evansville, IN	2	1b	4

Station Code	Station	Zonal Region	Merid. Region	Change Region
66	Indianapolis, IN	4b	1c	4
67	Cincinnati, OH	2	1b	4
68	Columbus, OH	4b	1c	4
69	Dayton, OH	4b	1c	4
70	Parkersburg, WV	2	1b	4
71	Pittsburgh, PA	4b	1c	4
72	Buffalo, NY	1b	1c	4
73	Rochester, NY	1b	1c	4
74	Syracuse, NY	1b	1c	4
75	Erie, PA	4b	1c	4
76	Cleveland, OH	4b	1c	4
77	Toledo, OH	4b	1c	4
78	Fort Wayne, IN	4b	1c	4
79	Detroit, MI	4b	1c	4
80	Alpena, MI	4b	3b	15
81	Grand Rapids, MI	4b	1c	18
82	Marquette, MI	4b	3b	4
83	Sault Ste. Marie, MI	1b	3a	4
84	Chicago, IL	4b	2	4
85	Green Bay, WI	4b	3b	15
86	Milwaukee, WI	4b	3b	4
87	Duluth, MN	3	3a	17
88	Bismarck, ND	3	3b	3
89	Williston, ND	3	3b	4
90	Minneapolis - St. Paul, MN	3	3b	4
91	La Crosse, WI	4b	3b	16
92	Madison, WI	4b	3b	15
93	Des Moines, IA	4b	2	15
94	Dubuque, IA	4b	3b	18
95	Cairo, IL	2	1b	4
96	Peoria, IL	4b	2	4
97	Springfield, IL	4b	2	15
98	St. Louis, MO	4b	2	15
99	Columbia, MO	4b	2	15
100	Kansas City, MO	4b	2	11
101	St. Joseph, MO	4b	2	15
102	Springfield, MO	4b	2	11
103	Topeka, KS	4b	2	15
104	Lincoln, NB	4a	2	11
105	Omaha, NB	4a	2	11

Station Code	Station	Zonal Region	Merid. Region	Change Region
106	Valetine, NB	4a	2	15
107	Sioux City, IA	4a	3b	4
108	Huron, SD	4a	3b	4
109	Billings, MT	4a	2	2
110	Havre, MT	4a	3b	4
111	Helena, MT	4a	2	2
112	Missoula, MT	4a	2	3
113	Miles City, MT	4a	3b	3
114	Rapid City, SD	4a	2	2
115	Cheyenne, WY	4a	2	11
116	Lander, WY	4a	2	19
117	Sheridan, WY	4a	2	2
118	North Platte, NB	4a	2	15
119	Denver, CO	4a	2	14
120	Pueblo, CO	4a	2	11
121	Concordia, KS	4a	2	11
122	Dodge City, KS	4a	2	11
123	Wichita, KS	4b	2	16
124	Oklahoma City, OK	9a	7	15
125	Abilene, TX	9b	7	13
126	Amarillo, TX	9b	7	11
127	Roswell, NM	9b	7	13
128	El Paso, TX	9b	7	13
129	Albuquerque, NM	9b	7	11
130	Phoenix, AZ	7	9	13
131	Yuma, AZ	7	9	21
132	Reno, NV	4a	2	2
133	Winnemucca, NV	4a	2	11
134	Salt Lake City, UT	4a	2	2
135	Grand Junction, CO	4a	2	2
136	Boise, ID	4a	2	2
137	Pocatello, ID	4a	2	2
138	Spokane, WA	4b	1c	3
139	Walla Walla, WA	4b	2	2
140	Yakima, WA	4a	2	2
141	Seattle, WA	5a	5	5
142	Tatoosh Island, WA	11	11	22
143	Medford, OR	2	1b	4
144	Portland, OR	5b	5	6
145	Roseburg, OR	5a	5	5

Station Code	Station	Zonal Region	Merid. Region	Change Region
146	Eureka, CA	5b	5	5
147	Sacramento, CA	10	4a	5
148	San Francisco, CA	5c	4a	8
149	Fresno, CA	9b	6b	13
150	Los Angeles, CA	10	8	13
151	San Diego, CA	8	9	20

APPENDIX II

Description of Computer Maps Used In this Investigation

Throughout this investigation, a large number of maps were presented that were produced using the SYMAP package. Basically, in every case, the x and y coordinates for all 151 stations were entered into the program along with a data value for each station. A separate set of coordinates was entered which defined the boundary of the coterminous United States.

Three different types of maps were used, including (1) proximal maps, (2) contour maps, and (3) trend-surface maps. The proximal map construction did not assume that a continuous surface existed in the data. Every location in an area was assigned the data value of the station nearest that location. The contour map interpolated a continuous surface based on all given values for the station locations. A trend-surface map fit a polynomial equation, of varying orders, to the array of data values.

Figure 20 in Chapter V displays climatic regions for a combined zonal-meridional time period. Following a separate clustering algorithm, each station was assigned a value from one to ten identifying the cluster in which it was grouped. All points on the map were assigned the value of the nearest station. Each cluster was assigned a map pattern from a continuous gray-tone series. For example, clusters labeled one and two were represented by much lighter shades than clusters nine and ten. At each station location, the actual data value was printed.

Figure 11 in Chapter IV shows the continuous surface of temperature change values across the United States, and is an example of a contour or isopleth map. Temperature change values were entered for each x and y station location. The SYMAP package then interpolated a continuous surface from the given data values. The interpolation procedure utilized both the data values and the distances to the nearby station location to produce the surface. The actual contour lines on this map are the white lines separating the regions that display different shading. The procedure of shading sections of a surface with heights in some range of a data is widely used in hypsometric maps showing landform height. The original data were grouped into five classes formed using an approximately equal range in the data values for each class. The key in the lower left corner displays the data range for each class. Stations with values following on the border between two groups (directly on one of the contour lines) were grouped into the higher class. For example, a station with a value of -2.49 was grouped into the second class in Figure 11. The frequency, or number of stations in each class, is shown directly beneath the display of symbols used for each class. Eight stations were in class 1, twenty-three in class 2, and sc on. At each station location on the map, the value printed was the value of the class for that station.

Figure 15 in Chapter IV is an example of a trend-surface map prepared from the factor scores of the Wind Persistence component in the climatic change matrix. Using a regression technique described in the text, a polynomial equation was fitted to the surface formed by the given data. The effect of this technique was to smooth, or filter, patterns that contain large amounts of "noise". The class intervals are printed just above the display of symbols in use. The intervals were determined by breaking the data into quintiles where five fairly equal classes, in terms of the number of stations in each class, were created. Again, values on the class borders were assigned to the higher quintile. The frequency of the stations in the groupings was given beneath the symbols. All of this information was determined before a polynomial was fitted to the data.

Once the polynomial was calculated, the resulting surface was presented using the same class intervals. The map that resulted was essentially a contour map of the surface described by the calculated polynomial. The values printed at each station location were the class symbols (1 to 5) of the original data. A wide range of numbers could, therefore, appear in an area where the polynomial surface was at some constant class height. Occassionally, "H" or "L" appeared across some region instead of one of the given map symbols. If the surface formed by the polynomial fell below the data values printed in the key, the symbol "L" was printed. These symbols can be found in northern Maine on Figure 15. Conversely, if the height of the trend-surface exceeded the highest value in the data range, the region was represented by the symbol "H". These appear in northern Maine on Figure 16.

APPENDIX III

MODIFIED DISCRIMINANT FUNCTIONS AND RESULTING INDICES USED IN THE EVALUATION OF THE 1976-1977 WINTER

Index	Code	Station	Function
1.15	12	Harrisburg, PA	Y=6.8-.1(RH)+.1(PD) RH=58,PD=7.3
1.56	22	Richmond, VA	Y=7.3-.1(T)-.1(RH)+.2(PD) T=37.4,RH=62.3,PD=8
1.28	25	Greensboro, NC	Y=6.4-.1(RH)+.2(P) RH=62.7,P=2.6
1.18	27	Raleigh, NC	Y=5.0-.1(RH)+.2(P) RH=62.7,P=3.0
.66	31	Greenville, SC	Y=4.8+.1(T)-.1(RH)+.1(PD) T=37.7,RH=58.7,PD=8
1.66	43	Mobile, AL	Y=5.5+.1(T)-.1(RH) T=47.0,RH=64
2.07	50	Little Rock, AR	Y=6.9-.1(RH)+.1(PD) RH=55,PD=5.7
1.03	59	San Antonio, TX	Y=6.3-.1(RH)+.1(PD) RH=66,PD=9.3
1.07	61	Knoxville, TN	Y=9.6-.1(RH)+.1(PD) RH=64.7,PD=9.3
.86	67	Cincinnati, OH	Y=8.7-.1(RH)+.1(PD) RH=72.7,PD=8.7
.90	87	Duluth, MN	Y=-38.2+.1(PS)-.1(RH)+.4(P) PS=961,RH=66,P=.4

.30	89	Williston, ND	Y=5.3-.1(RH)+.8(P) RH=78.3,P=.6
1.38	91	LaCrosse, WI	Y=6.2-.1(RH) RH=69
2.71	92	Madison, WI	Y=86.7-.1(PS)-.1(T)-.1(RH) PS=983,T=13.1,RH=70.1
1.43	96	Peoria, IL	Y=6.31-.1(RH)-.2(P)+.1(PD) RH=67.3,P=.8,PD=8.7
.93	105	Omaha, NB	Y=5.16-.1(RH)+.1(PD) RH=71.7,PD=5.7
1.18	109	Billings, MT	Y=2.3+.1(T)-.1(RH)+1.1(P) T=29,RH=51.7,P=.6
.53	121	Concordia, KS	Y=5.8-.1(RH)+.2(PD) RH=66.3,PD=4
2.15	125	Abiline, TX	Y=-107.8+.1(PS)-.1(RH)+.1(PD) PS=955.5,RH=57.3,PD=3.7
1.63	148	San Francisco, CA	Y=-141.3+.1(PS)+.1(P) PS=1019.9,P=1.98

where Y = Continuum Index
PS = Pressure
RH = Relative Humidity
P = Precipitation
PD = Precipitation Days

The variables in use were chosen from stepwise discriminant models. The models here represented results from regression analyses where the dependent varaible was assigned 0 for zonal years and 1 for meridional years.

APPENDIX IV

SIXTH-ORDER TREND FITTINGS FOR CHANGE SURFACES IN ELEVEN CLIMATIC ELEMENTS

Figure	Element	Coefficient of Correlation	Coefficient of Determination
A	Pressure	.49	.24
B	Temperature	.70	.49
C	Relative Humidity	.65	.43
D	Precipitation	.71	.51
E	Precipitation Days	.74	.54
F	Wind Velocity	.37	.14
G	Northerly Wind Comp.	.52	.57
H	Westerly Wind Comp.	.32	.10
I	Resultant Wind Sp.	.47	.23
J	Yearly Wind Pers.	.41	.17
K	Monthly Wind Pers.	.53	.28

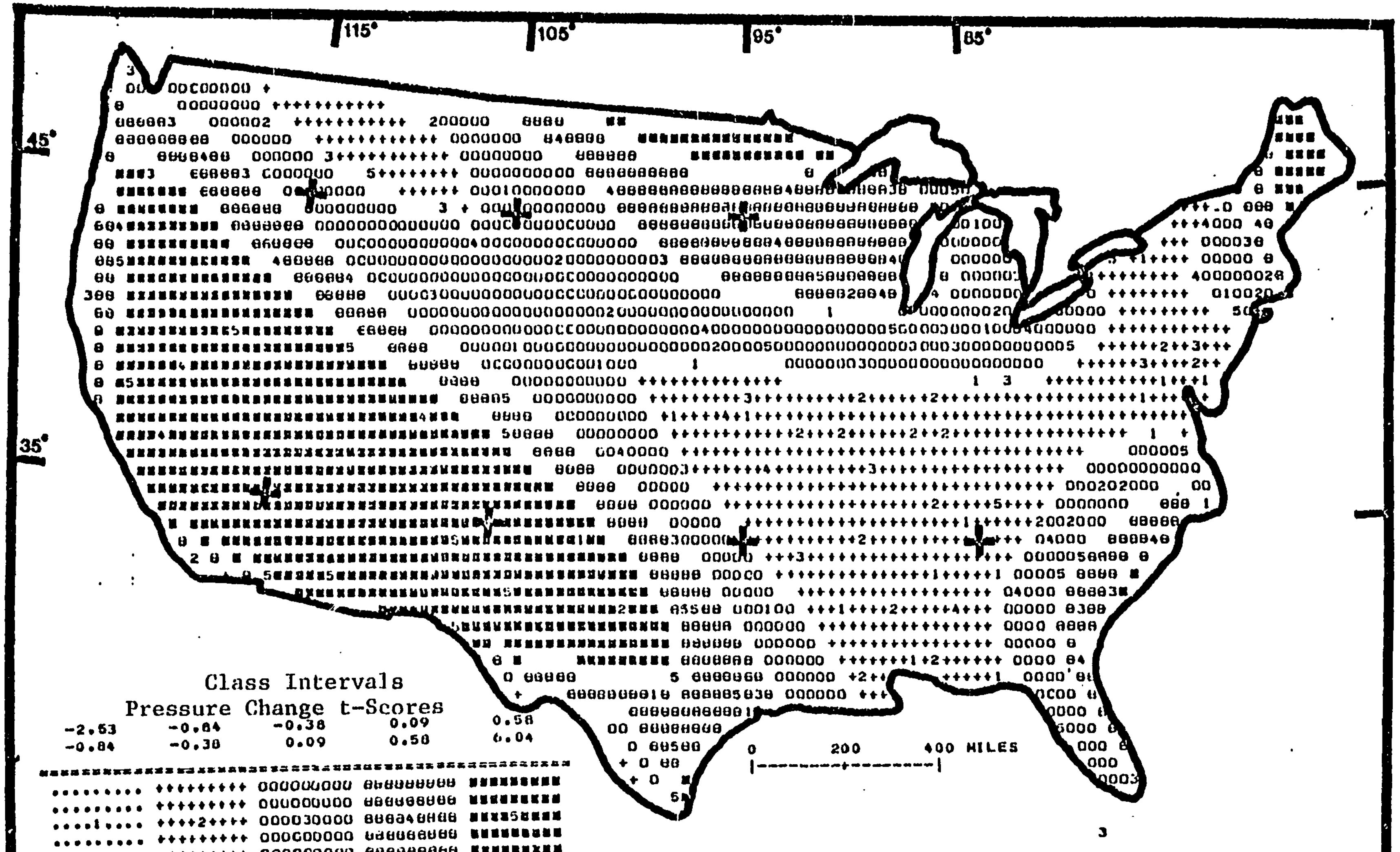


Figure A: Sixth-Order Trend Fitting to a Surface of Pressure Changes

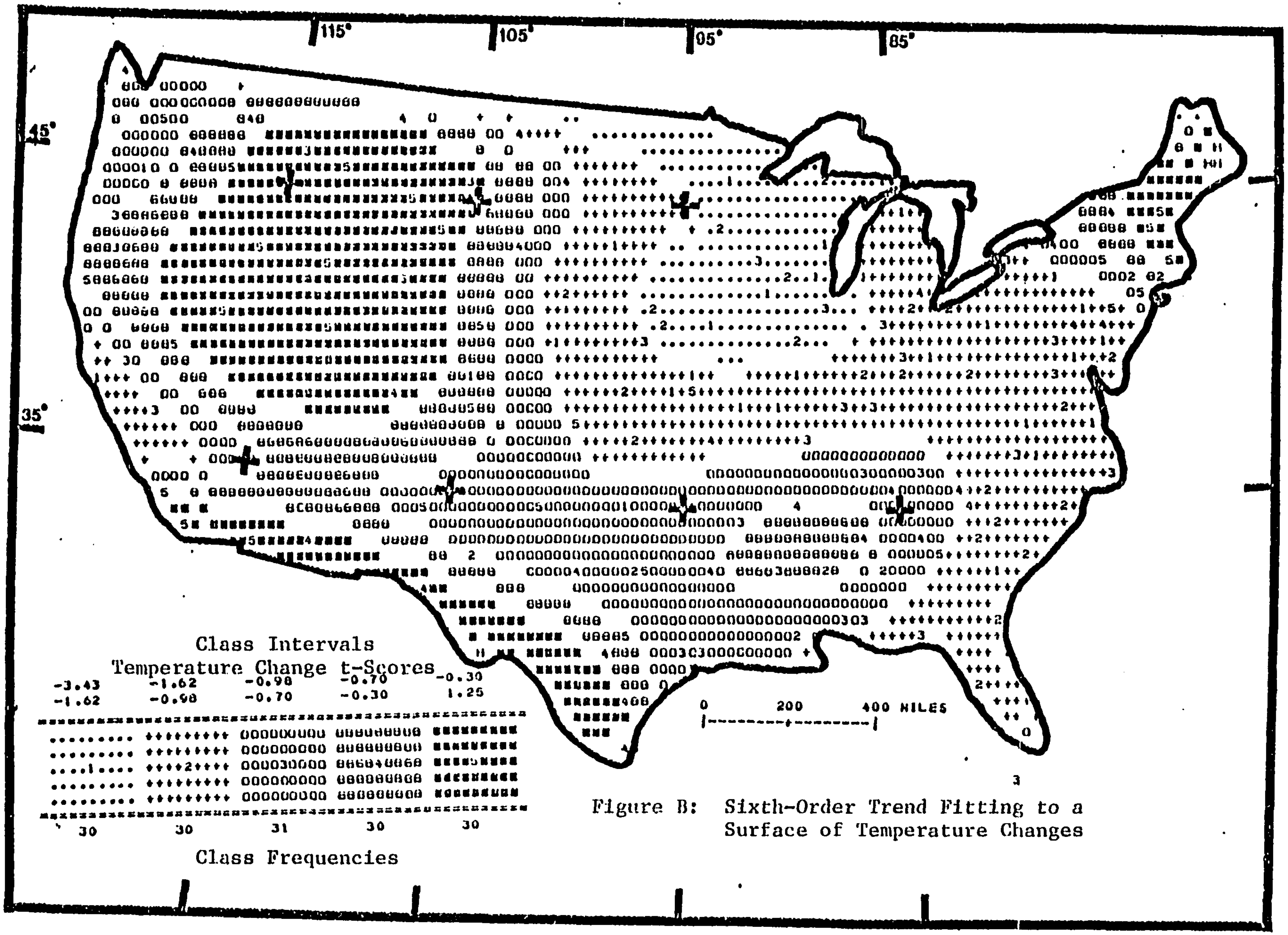


Figure B: Sixth-Order Trend Fitting to a Surface of Temperature Changes

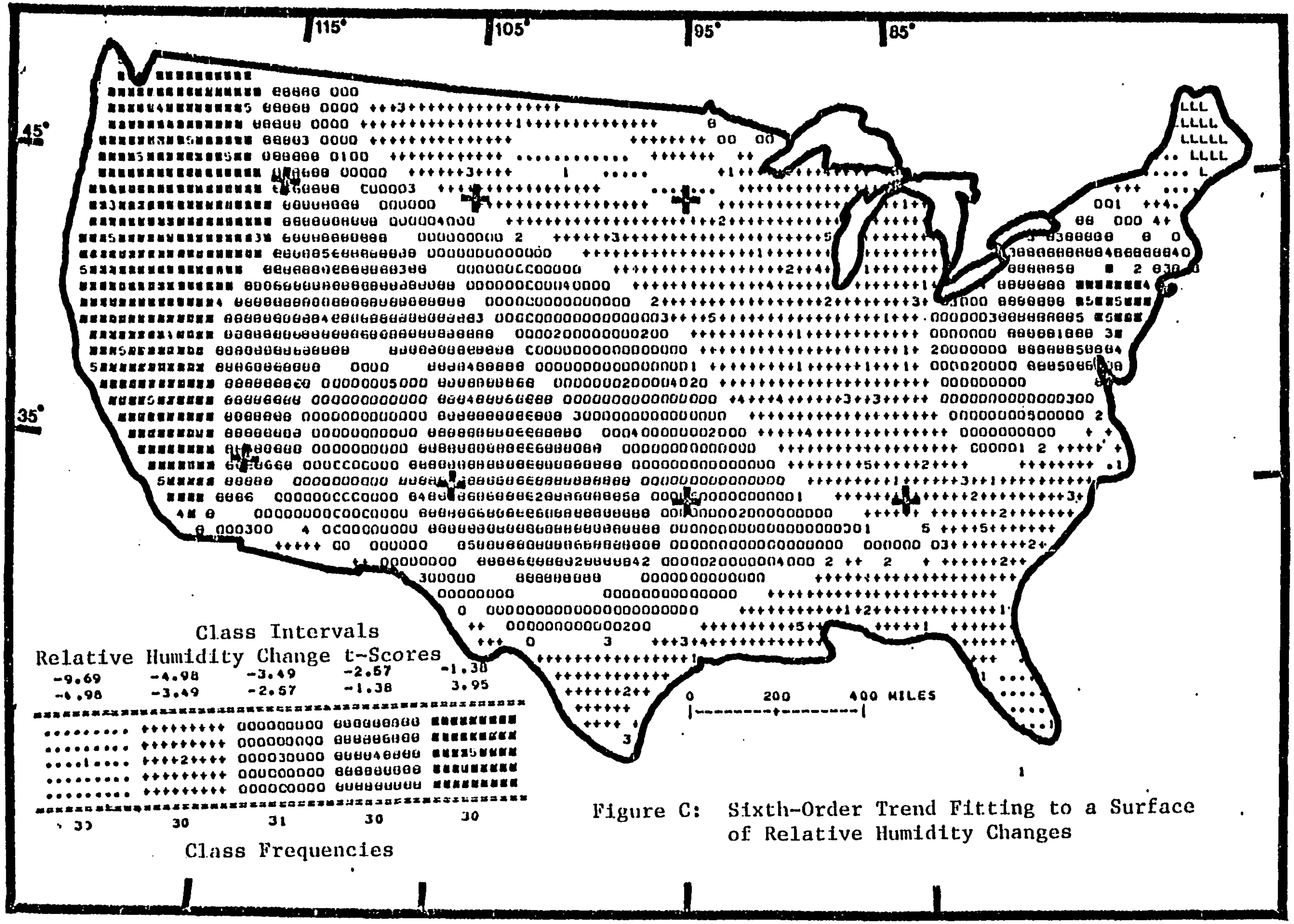


Figure C: Sixth-Order Trend Fitting to a Surface of Relative Humidity Changes

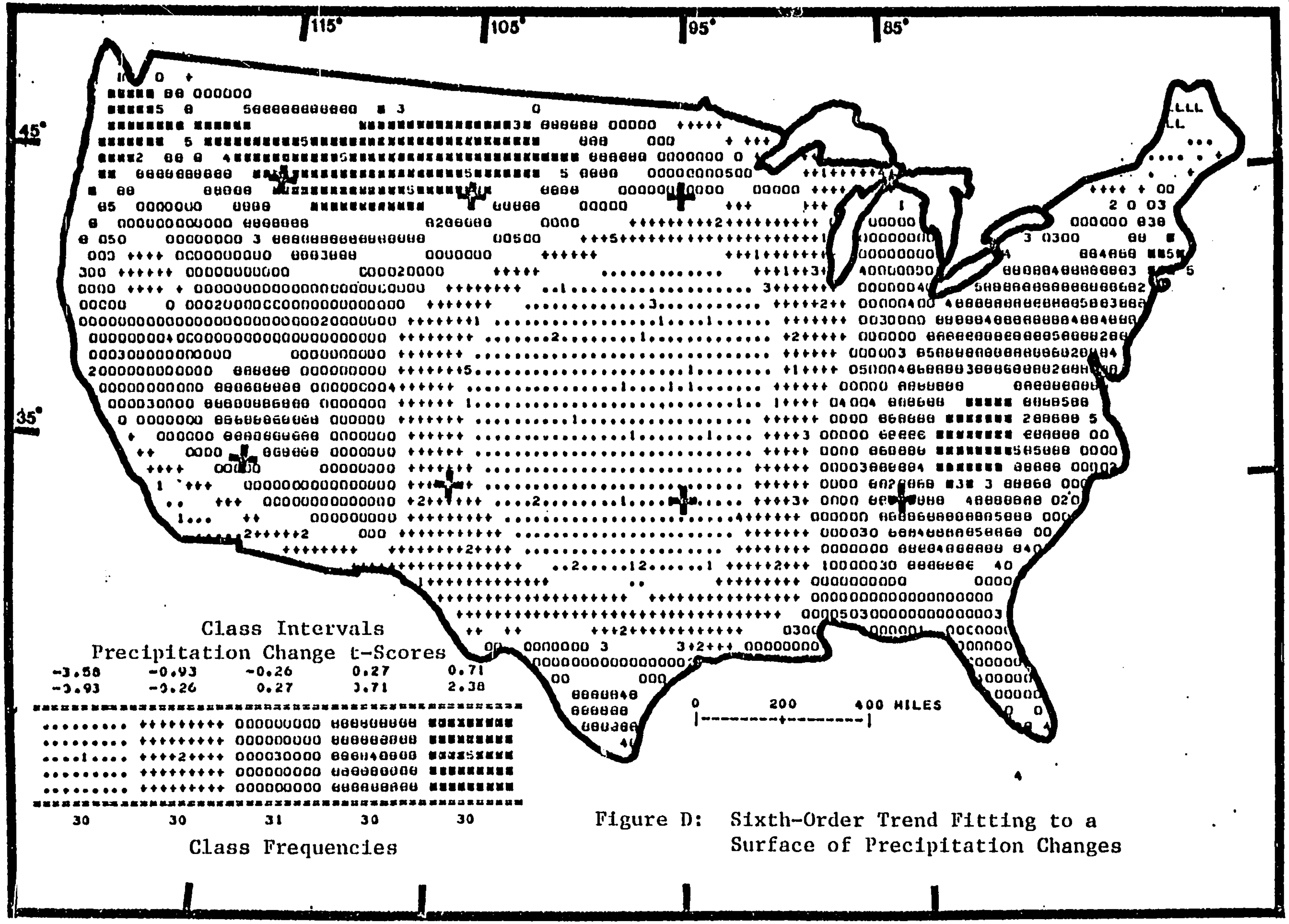


Figure D: Sixth-Order Trend Fitting to a Surface of Precipitation Changes

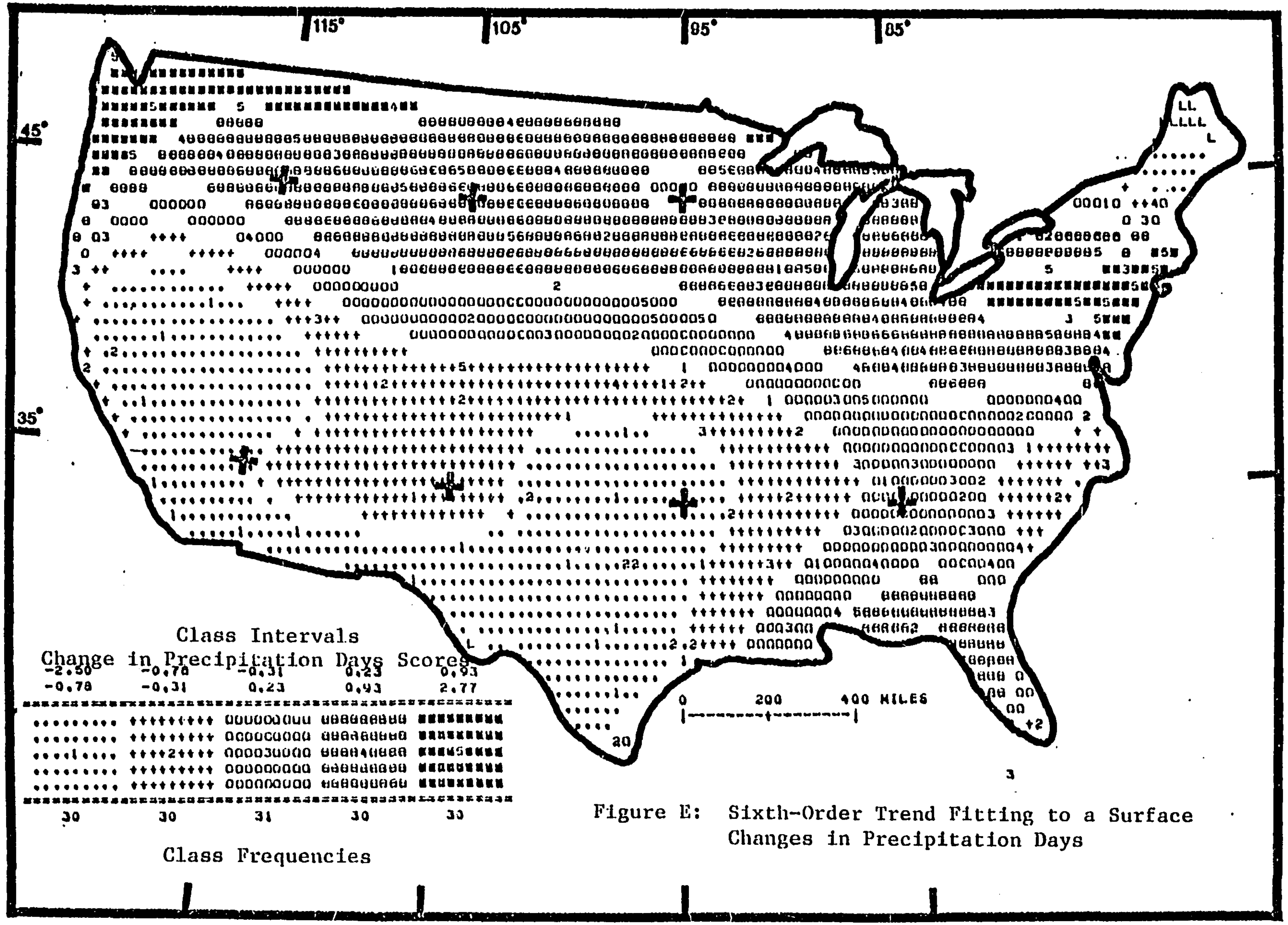


Figure E: Sixth-Order Trend Fitting to a Surface Changes in Precipitation Days

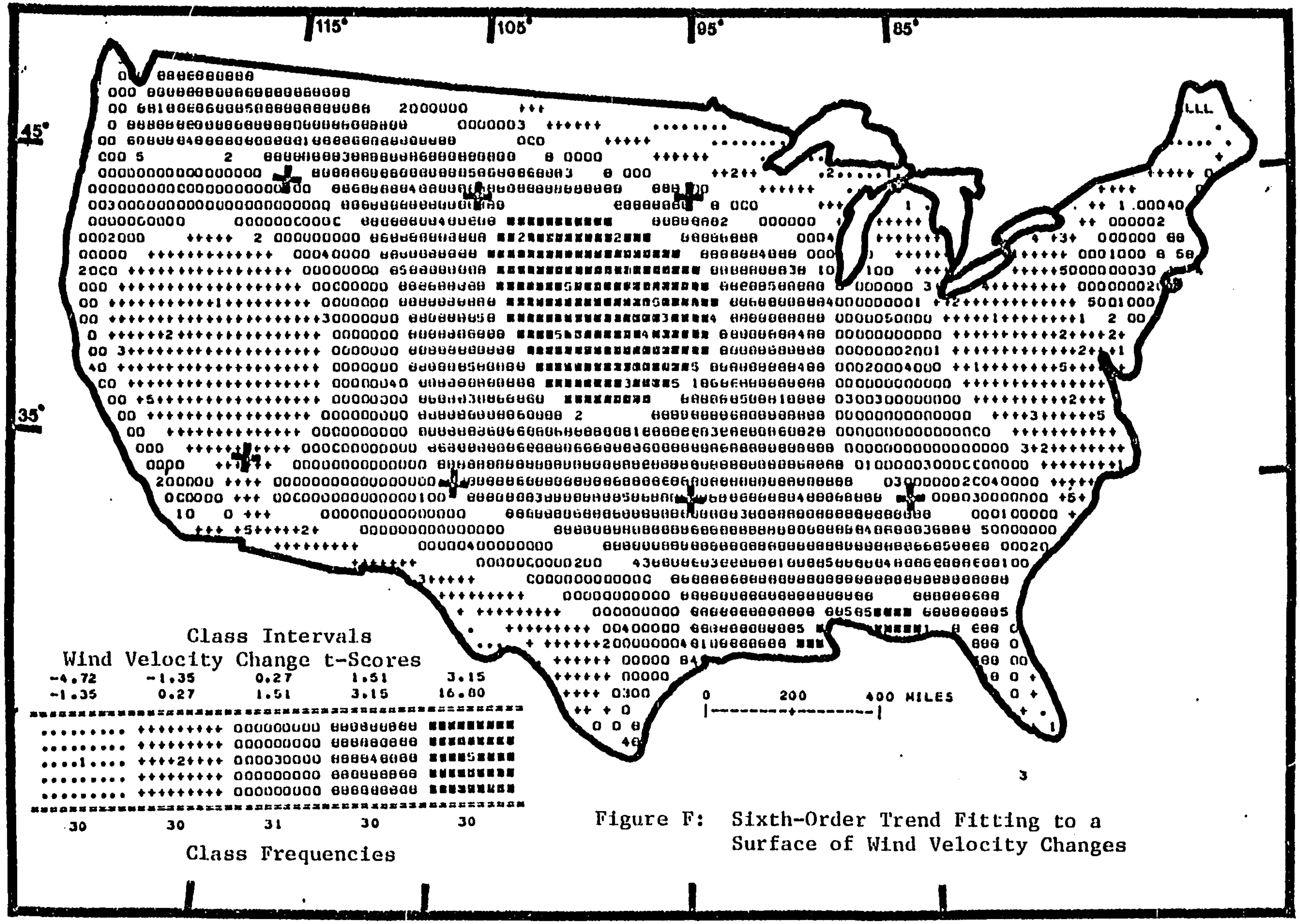
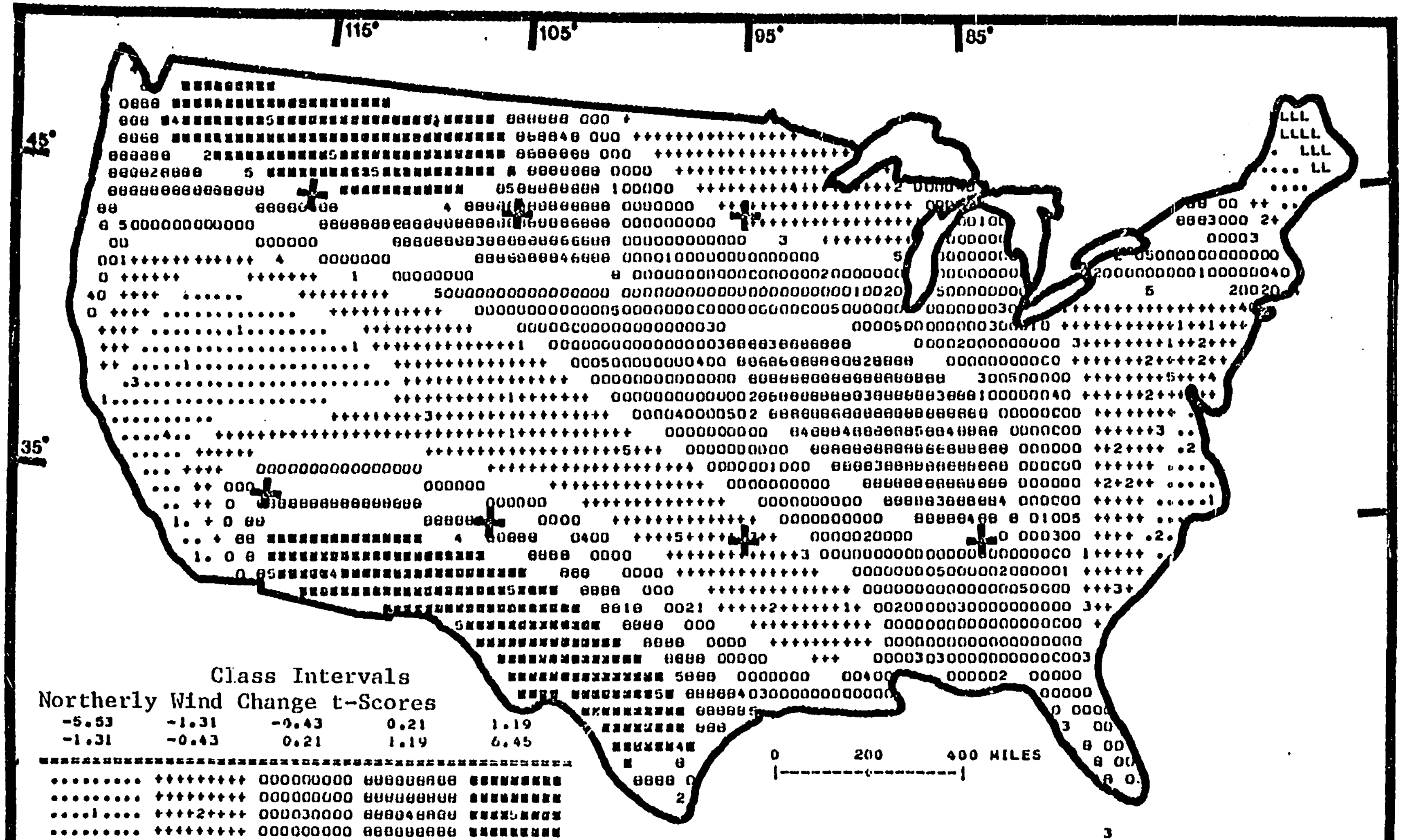


Figure F: Sixth-Order Trend Fitting to a Surface of Wind Velocity Changes



Class Intervals
Northerly Wind Change t-Scores

-5.53 to -1.31	-1.31 to -0.43	-0.43 to 0.21	0.21 to 1.19	1.19 to 6.45
....	+++++++++	000000000	888888888	■■■■■■■■■
30	30	31	30	30

Class Frequencies

Figure G: Sixth-Order Trend Fitting to a Surface of Northerly Wind Velocity Changes

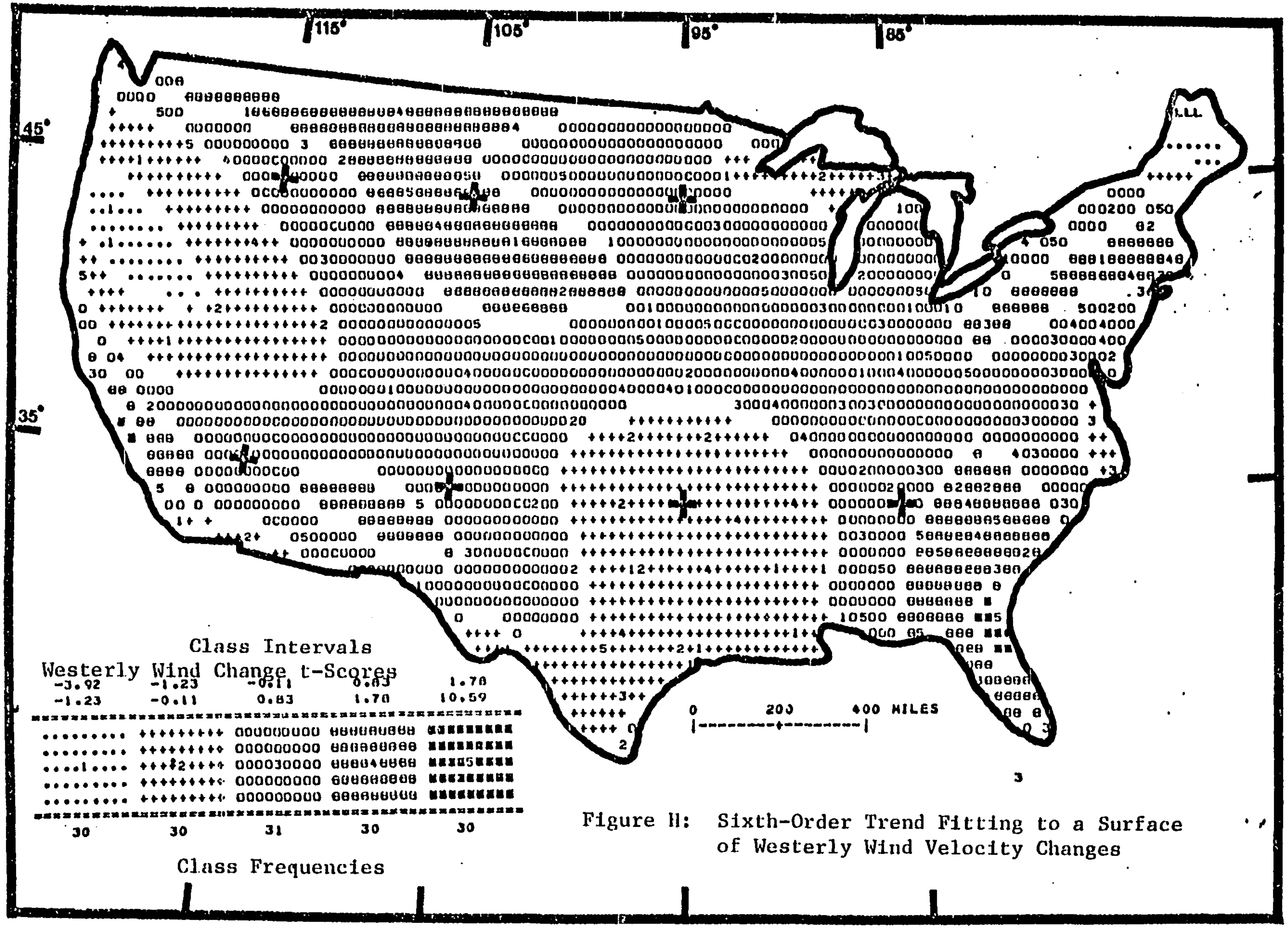


Figure 11: Sixth-Order Trend Fitting to a Surface of Westerly Wind Velocity Changes

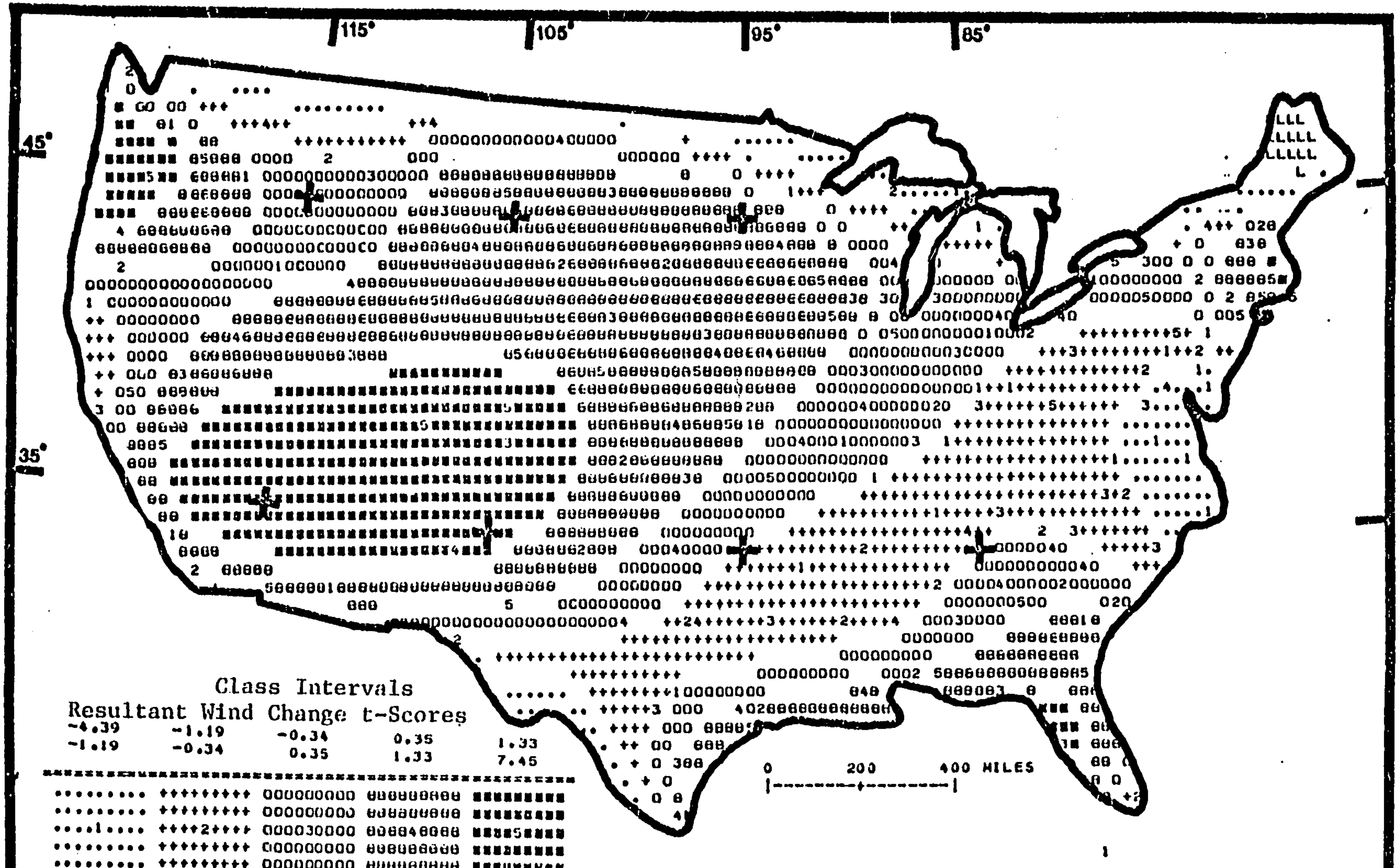


Figure I: Sixth-Order Trend Fitting to a Surface of Resultant Wind Speed Changes

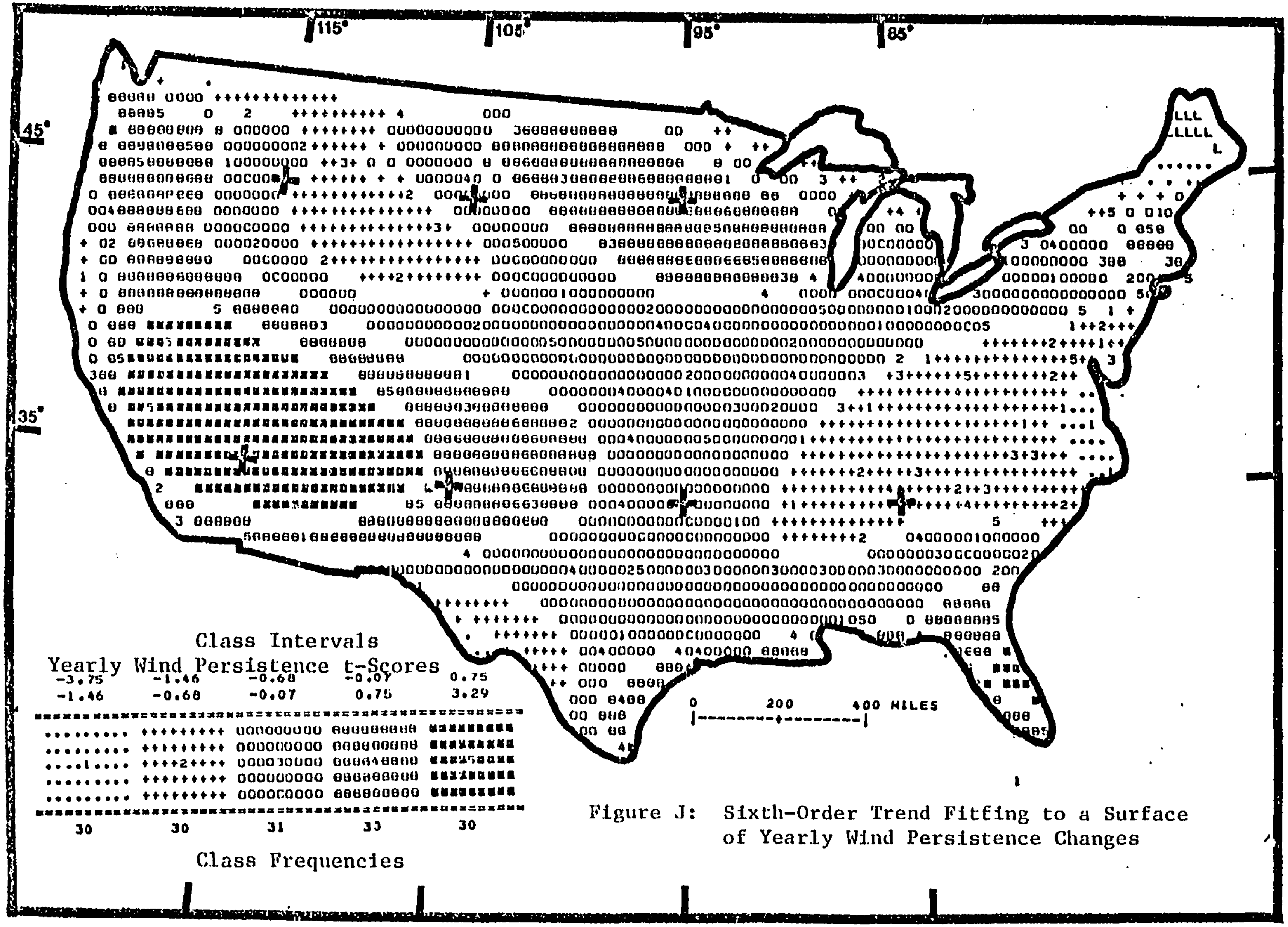
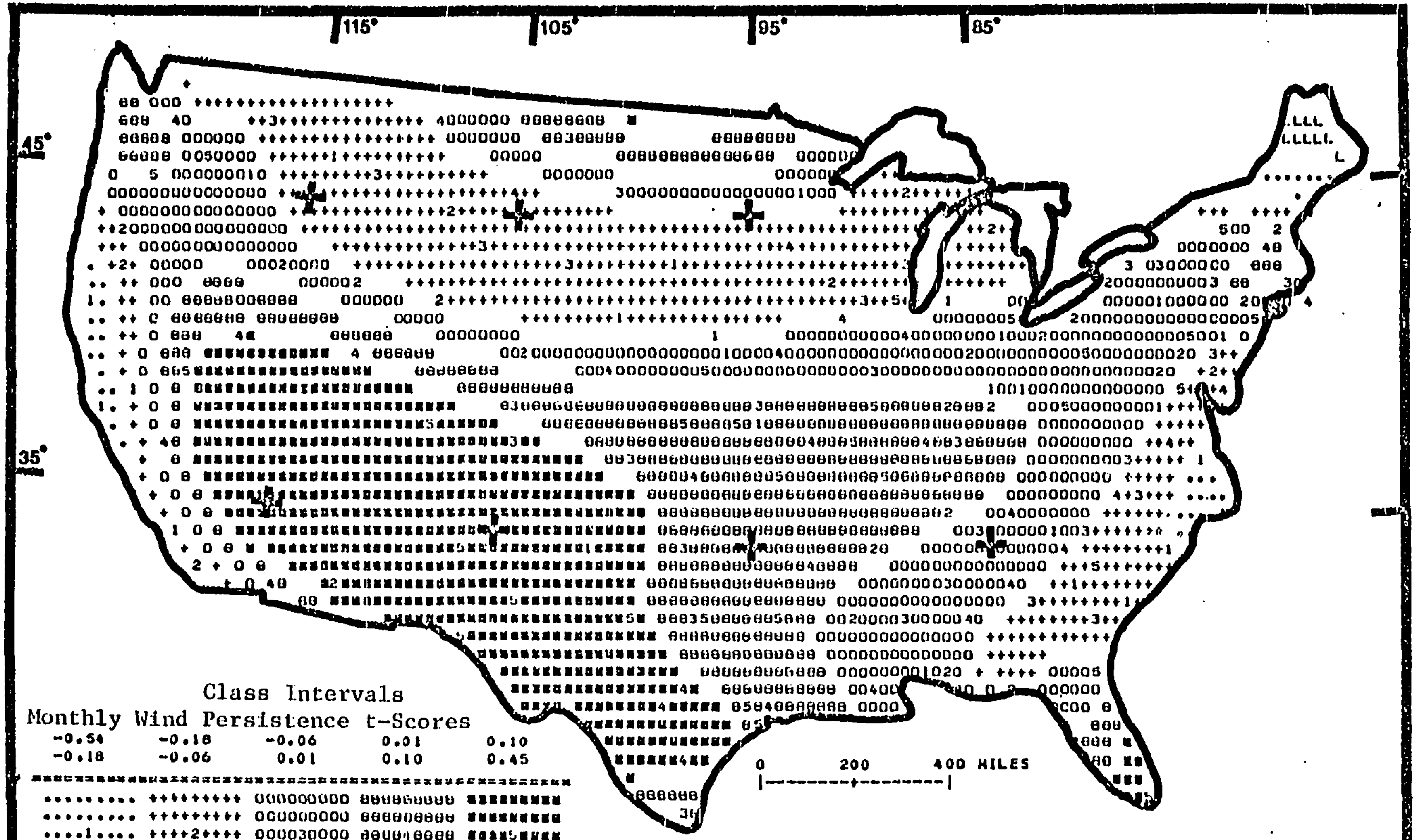


Figure J: Sixth-Order Trend Fitting to a Surface of Yearly Wind Persistence Changes



Class Intervals
Monthly Wind Persistence t-Scores

-0.54	-0.18	-0.06	0.01	0.10
-0.18	-0.06	0.01	0.10	0.45
30	30	31	30	30

Class Frequencies

Figure K: Sixth-Order Trend Fitting to a Surface of Monthly Wind Persistence Changes