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CONTINENTALITY VARIABILITY IN THE UNITED STATES, 1934-1973

by

John L. Kerr

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
December 1975

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ACKNOWLEDGEMENTS

During the initial researching of this topic and throughout the consequential compilation of the manuscript, I have benefited from the gracious assistance of several people. First and foremost, Dr. Val Eichenlaub, who has served as my advisor throughout this undertaking. Not only has Dr. Eichenlaub fulfilled the traditional role of an advisor by offering sage advice and criticism when the situation warranted and by suggesting which path to follow or which technique to employ, he has also gone out of his way to ensure that the most recent information available on certain topics was at my disposal. I am particularly grateful to Dr. Eichenlaub for allowing me complete freedom in formulating the initial research design, in pursuing the many unanswered questions which arose during the research process, and in the compilation and construction of the final study. As a direct result of this distinct lack of constraint, I feel that I have benefited much more from the thesis-producing process than I would have had I been confined or restrained in any way. I express a heart-felt "thanks" to Dr. Eichenlaub for these reasons.

In addition to Dr. Eichenlaub, I wish to acknowledge the contributions of the following people: Dr. Rainer Erhart, who has served as the second reader of the original manuscript, and in so doing has offered several suggestions and criticism which have unquestionably enhanced the quality of the final manuscript; Dr. Charles

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Heller, who has patiently provided answers to innumerable questions concerning the style and format of the final manuscript; Tim Kendall, who has provided the cartographic services necessary in producing the final copies of the maps and graphs contained herein; and my wife, Carol, who has steadfastly typed not only the final manuscript, but also the original manuscript, as well as the numerous rewrites which were necessary.

Finally, I wish to thank the entire faculty and staff of the Geography Department at Western Michigan University for creating and maintaining an environment conducive not only to academic and intellectual pursuits, but also to the growth and development of the individual. Their warm and personal friendship is unquestionably the greatest single benefit from my two years of residency at Western Michigan University. In offering not only their guidance and assistance in a professional capacity, but also their friendship on a more personal basis, the faculty and staff of the Geography Department have made my graduate work at Western Michigan University a truly enjoyable and fulfilling experience.

John L. Kerr

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KERR, John L.
CONTINENTALITY VARIABILITY IN THE UNITED STATES, 1934-1973.

Western Michigan University, M.A., 1975
Physical Geography

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CHAPTER I

INTRODUCTION

This study is concerned with the effect of recent global circulation changes on the character of certain climatic variables in the conterminous United States. The focal point of this investigation is the temporal variability of annual monthly temperature extremes over the period 1934-1973. However, instead of directly examining the character of the aforementioned climatic variables, the subsequent investigation focuses on a third climatic variable--continentality--which is itself an expression of the other two. This study thus becomes an indirect investigation of climatic change since it examines the variability of continentality as an expression of the variation of annual monthly temperature extremes. In this way, continentality may be seen as both an indicator and a product of climatic change. Structuring the study in this method allows for the integration of two climatological concepts which have long held a certain mystique for members of the climatological professions: climatic change and continentality.

Climatic Change

The concept of climatic change has received a great deal of attention in scientific circles during recent years. The flood of literature published of late attests to its new found popularity. By and large this growing interest stems from the recent realiza-

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tion that "climate", by definition, does not contain an aura of permanence as was long believed. As recently as the turn of the century, the belief was common that climatic changes of a significant nature were encountered only over the geological time scale. Only with the occurrence of the dramatic climatic changes of the last 75 years has such antiquated thinking been outmoded. The climatic changes which have characterized the 20th century are far too prominent to be dismissed as merely minor oscillations on the scale of geologic time. Such changes have already clearly affected not only man and his activities, but also many of the other inhabitants of the earth (Lamb, 1966a). The fact that climatic change is one of the most active fields of climatological research indicates the importance of this subject for the future of mankind.

Continentality

Continentality is perhaps one of the most abstract concepts within the field of climatology. As such, it is certainly one of the most illusive climatic variables to define. A brief survey of available literature indicates a distinct lack of agreement concerning a clear, concise, concrete definition of this term. Even such usually reliable reference works as the <u>Encyclopedia of Atmospheric Sciences and Astrogeology</u> and the <u>Meteorological Glossary</u> yield results which lack both precision and clarity.

While an acceptable definition of continentality is noticeably lacking, it is possible to identify certain climatic variables

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as being intricately linked to continentality. Changes in the relative magnitude of continentality produce corresponding changes in the character of these climatic variables. By monitoring the behavior of these climatic variables--which are actually manifestations of continentality--the character of continentality may in turn be monitored.

Thankfully then, for the sake of this study, while continentality is not easily defined, it is readily measurable. The rather wide range of climatological manifestations which are associated with continentality make it possible to measure this abstract entity through a variety of different mediums. Since this study is concerned with annual temperature variations, a method of measuring continentality based on temperature characteristics will be employed. However, before choosing a method of measurement appropriate to this study, it is first necessary to understand exactly what continentality is and upon what principles it is founded. This information is contained in Chapter 2.

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CHAPTER II

THE CONCEPT OF CONTINENTALITY

Differential Heating and Cooling of Land and Water Surfaces

The concept of continentality is based on the fundamental principle of physics which states that if the same amount of solar radiation is incident on both a land and a water surface, the land surface will heat more rapidly and to a higher temperature than will the water surface. Conversely, the land surface will cool more rapidly and to a lower temperature than will the water surface. At first it appears as though the immediate cause for this thermal differential may be the difference in albedo values of the two respective surfaces.

Climatologists have long recognized that the reflective ability of a particular surface--hence, its albedo--is directly related to the ability of that surface to radiate heat. In turn, the albedo of a specific surface is dependent upon not only the type of surface involved, but also the condition and color of the surface, as well as the angle of incidence. These physical characteristics determine to a large extent whether incoming solar radiation will be absorbed or reflected once it reaches the earth's surface. If the solar radiation is absorbed, then the temperature of the surface rises and a heat flux is established between the surface and the overlying atmosphere. If, on the other hand, the

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solar radiation is reflected by the surface, there is no net gain of energy, and hence, no change in surface temperature (Crowe, 1971). The ability of a specific type of surface to absorb solar radiation and to transmit heat energy to the overlying atmosphere is thus indirectly proportional to its albedo value.

At this point, it is logical to assume that since land surfaces heat more rapidly and to a greater degree than do water surfaces, the former must have lower albedo values. Table 1 shows some of the common types of land surfaces and their respective albedo values as measured by Fritz (1948), Johnson (1954), and Sellers (1965).

Table 1

Albedo Values of Different Types of Land Surfaces

Type of Surface	Albedo
Black Top Road	5-10%
Green Meadow	10-15%
Concrete	15-30%
Sandy Soil	30-45%
Snow (several days old)	40-70%
Snow (fresh fallen)	75-95%

It is at once apparent that the albedo of a land surface is controlled preponderantly by the specific type of surface involved--soil, grass, concrete, etc.--as well as the color of that surface.

Are the values in Table 1 indeed lower than corresponding values for water surfaces? This question is difficult to answer,

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for no equivalent list may be compiled for water surfaces. The physical condition of a water surface may vary only slightly--liquid water, solid ice, or snow covered--and the color of water even less. Hence, it is not surprising to discover that the albedo of a water surface is controlled largely by the angle of incidence. Of somewhat less importance is the smoothness or roughness of the water. Table 2 displays the relationship between the angle of incidence and the corresponding albedo values over a water surface.

Table 2

Reflectivity Over Water as Related
to Sun's Zenith Angle

Zenith	0°	20°	40°	50°	60°	70°	80°	85°	90°
Albedo	2.0	2.1	2.5	3.4	6.0	13.4	34.8	58.5	100

Source: Encyclopedia of Atmospheric Sciences and Astrogeology, p. 12.

In order to draw a valid comparison between the albedoes of land and water surfaces it becomes necessary to further refine the data in Tables 1 and 2. This may be accomplished by averaging the respective values in each table. It then becomes possible to speak of the "average albedo" of a land surface vs. that of a water surface. Surprisingly enough, when these computations are concluded, it is discovered that the two average values are nearly identical. Since the average albedo values of land and water surfaces are approximately the same, the average absorption capacity of these two surfaces must also be nearly identical. It must then be concluded

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that the marked contrast in the heating and cooling characteristics of land and water surfaces exists principally because the two surfaces respond quite differently to the solar radiation which is absorbed--not reflected.

The discovery of this latter fact makes it clear that differences in albedo values do not account for the aforementioned differences in the heating and cooling characteristics of land and water surfaces. Instead, the reason for the previously described differences in both the rate and magnitude of surface temperature changes resides in the fact that the process of heat redistribution within each of these two substances is entirely different. Within a water body, heat energy is redistributed mainly through turbulence and convectional overturning. Waves, tides, drifts, and currents all act to disseminate the solar radiation received at the surface and disperse it throughout the water body. When the surface water begins to cool, density differences established by the temperature contrast between the cold surface water and the warmer water at lower depths create convectional currents. In this way, the cooler surface water sinks and is replaced by the warmer subsurface water. Consequently, a large portion of the water body must be either heated or cooled before the water surface will show an appreciable temperature change. Observations reveal that diurnal temperature variations in water bodies are felt at least 20 feet below the surface, while annual variations have been recorded at depths of 2000 feet (Trewartha, 1968).

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Obviously, no such mixing can occur with land masses. The solar radiation incident on land surfaces is redistributed through the process of molecular heat conduction. In this way, heat is transferred from particle to particle. Since the earth is such a poor conductor, this is a much less efficient means of heat redistribution than is convectional overturning and turbulence. The heat flux downward from a land surface is so slow that diurnal temperature variations are only felt in the upper 2-3 feet of the soil, while annual variations penetrate only to a depth of 47 feet (Trewartha, 1968). The heating of a land mass via solar radiation is, thus, confined to a relatively thin layer at the surface.

There appear to be other significant contrasts between the properties of land and water masses which contribute to the differential heating and cooling of their respective surfaces; however, a closer examination reveals that such factors are much less important as compared to the method of heat redistribution. One such apparent contrast has been previously dealt with and dismissed. This is the variation in albedo values. While there can be significant differences between the albedo values of land and water surfaces in specific situations, at the macroscale level the average value for each of these two diverse surface types is the same. As such, the differences which exist at the microscale level are insignificant, and their contribution to the total explanation for such a marked variation in the thermal properties of land and water surfaces is only of minor importance.

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Three other differences in the properties of land and water masses play minor roles in creating and maintaining the contrast in the heating and cooling characteristics of these two surface types. The first such difference is related to the principle of specific heat. This is the amount of heat required to raise the temperature of a particular unit mass by 1° Kelvin (McIntosh, 1972). Calculations reveal that the specific heat of a unit mass of water is almost three times that of soil (Blair & Fite, 1965). Closely related to this idea of specific heat is the concept of heat capacity. The heat capacity of a substance is equal to the density of the substance times its specific heat. The heat capacity of water is calculated to be about five times greater than that of soil. By these calculations, it will require five times more energy to heat a volume of water to the same temperature as a similar volume of soil (Mather, 1974). Thus, if the same amount of solar radiation is received by both a soil and a water surface, the soil surface will heat appreciably more than will the water surface.

Differential evaporation is another of the minor factors responsible for creating temperature differences between land and water surfaces. Evaporation is always at a maximum over water surfaces, while in continental regions, effective evaporation is exceeded by potential evaporation. Since evaporation is, by nature, a cooling process, the heating of water surfaces will be retarded. In addition, approximately 30 percent of the total solar radiation incident on a water surface is used in the evaporation process and is, therefore, not available for heating purposes (Blair & Fite,

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1965).

The final contrast contributing to the differential heating capabilities of land and water surfaces is what might be termed the "transparency-opaqueness" factor. It would seem as though the obvious transparency of a water mass would allow solar energy to penetrate to a much greater depth than would be the case with an opaque land surface, hence, creating a more equitable heat distribution. Crowe (1971) estimates that solar radiation incident on a water surface may penetrate to a depth approaching 200 meters. Consequently, this factor should be one of the major reasons why a land surface heats more rapidly and more intensely than does a water surface. Such is not the case, however, for the longer waves of the solar spectrum do not penetrate far beyond the surface. As a result, the transparency differential between land and water surfaces, while not totally insignificant, is far less important than might be assumed (Trewartha, 1968).

The Origin and Definition of "Continentality"

From previous discussion it may be concluded that differences in the properties of land and water masses are responsible for creating differential rates of heating and cooling with respect to the two surface types. The most important difference between the properties of land and water masses has been identified as the process of heat redistribution inherent to each. While this difference is the primary factor accounting for the marked thermal contrast between land and water surfaces, such differences as those

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exhibited with regard to (1) evaporation rates, (2) specific heat values, (3) the degree of transparency, and (4) albedo values while of but minor importance, are not entirely inconsequential. The ultimate effect of this thermal differential between land and water surfaces is to create two distinctly different types of climatic regimes: continental and marine.

It has already been noted that if the same amount of solar radiation is received by both a land and a water surface, the land surface will heat more rapidly and to a higher temperature than will the water surface. This principle holds true regardless of the time factor involved. Thus, the temporal limitation placed on this principle may be delineated in order to suit a specific purpose. By defining the length of time as one year, the climatic repercussions of this principle may be closely identified.

During the summer, solar radiation incident upon a water surface will slowly heat a rather large volume of water to a moderate temperature. In winter, this same water surface will cool slowly since it draws upon heat reserves accumulated throughout a large volume. As a result, the temperature regimes of locations found near large water bodies--particularly on the windward shore--will be significantly modified by the marine influences as described above. These ocean-controlled or marine climates will be characterized by (1) small diurnal and seasonal temperature variations, and (2) a more pronounced lag in time between the periods of maximum and minimum solar radiation and the times of maximum and min-

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imum air temperature (Trewartha, 1968).

In contrast, solar radiation received by a land surface during the summer will rapidly heat a shallow layer of ground to a high temperature. Since the land mass is heated to only a shallow depth, it quickly depletes its heat reserves and cools rapidly to a low temperature during the winter. The temperature regimes of regions located far from large water bodies toward the interior of continents will reflect these thermal properties of land surfaces to a marked degree. These land-controlled or continental climates are characterized by (1) large diurnal and seasonal temperature variations, with (2) the times of maximum and minimum surface temperatures closely following the periods of maximum and minimum solar radiation (Trewartha, 1968).

In light of the aforementioned differences between land-controlled or continental climates and ocean-controlled or marine climates, it is possible to construct a climatic continuum ranging from a climate which is entirely dominated by marine controls (hence, a complete lack of continental influence) to a climate characterized solely by continental controls. In between these two extremes are found climates which reflect varying degrees of marine or continental influence. Somewhere in the center of the spectrum is the demarcation point which separates those climates whose character is determined by marine influences from those regions in which character of the climate is conditioned by continental controls. In describing the relative degree of continental control which a given climate exhibits, the term "continentality" is employed, while a

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similar account of the marine influence displayed by a specific climate will use the term "oceanicity". Thus, the terms continentality and oceanicity refer to the same concept: they are measures of the extent to which the climate of a particular location is subject to land (continental) or marine (oceanic) influences, respectively (McIntosh, 1972).

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CHAPTER III

DERIVATION AND EVOLUTION OF METHODS FOR MEASURING CONTINENTALITY

The Basis for Measuring Continentality

Any attempt to measure the degree of continental or marine influence which the climate of a given location displays can be undertaken only with the understanding that the values yielded by any index created towards this end may be taken only as a rough approximation of the magnitude of the relationship (Conrad, 1946). In part, this is due to the rather fluid definition of the terms "continental climate" and "marine climate". Such terms do not refer to any specific set of conditions, and as such, they represent highly abstract climatic concepts. According to the Encyclopedia of Atmospheric Sciences and Astrogeology, the term "continental climate" refers in a general way to the characteristics found in areas where the climatic conditions typical of oceanic regions are minimal. In a similarly ambiguous fashion, a "marine climate" is recognized as one which is dominated by its propinquity to the sea (Encyclopedia).

The relative degree of continentality/oceanicity inherent to the climate of a given location is manifested in the deviation of certain climatic variables from the anticipated norm (as measured with regard to the latitude of the location). To cite an example, coastal Norway is much warmer during the winter than would other-

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wise be expected at this latitude. These deviant or anomalous temperature characteristics are attributable to the pronounced marine influence in this general area (Hoffman, 1967). Hence, positive temperature anomalies during the winter are associated with higher oceanicity values and lower continentality values.

Some of the climatic manifestations indicative of the degree of continentality/oceanicity of a region are seasonal in character. During one season, the values of certain climatic variables clearly reflect the relative degree of continentality/oceanicity of a given region, while the next season, these same variables will yield spurious results. An example of a situation in which a climatic variable indicates the relative degree of continentality/oceanicity of an area only seasonally is the absolute humidity of continental climates. In summer, the absolute humidity of continental air hardly differs from that of marine air, while during the winter, the former is significantly lower. This seasonal fluctuation of the absolute humidity is directly attributable to the pronounced annual temperature range, and as such, it is a manifestation of the relative degree of continentality which the climate exemplifies. Climatic variables such as cloudiness, relative humidity, and precipitation may return similar ambiguous results when employed on a seasonal basis.

Some climatic variables yield values which are annually, rather than seasonally, different from the norm. These climatic variables are better indicators of the relative degree of continentality/oceanicity exhibited by a given climate. By examining such

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values, it is possible to identify in general terms the relative importance of a large land or water mass on the climate of a region. This difference may then be measured quantitatively by first defining the method in which the variable has been modified by the land or water mass, and then by measuring the magnitude of the modification. Subsequently, a formula may be derived to express the direction and the degree of modification in more precise terms. It then becomes possible not only to measure continentality/oceanicity in more concise terms, but also to compare the continentality/oceanicity of two locations using precise numerical language, rather than the relative terms "higher" and "lower".

Thus, by (1) identifying the climatic characteristics which differentiate continental climates from marine climates, and (2) examining certain climatic variables which give personality to these climatic characteristics and whose annual variation in values are known indicators of the degree of continental or marine influence innate to a region, it is possible to measure continentality/oceanicity in a realistic, meaningful method.

Measuring Continentality Via the Annual Thermal Amplitude

The most conspicuous climatic characteristic differentiating regions with continentally-controlled climates from those with marine climates is the annual range of temperature (Kopec, 1965). Continental or interior regions experience hot summers and cold winters, while in coastal or marine provinces, the summers are cool

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and the winters mild. As such, a coastal region on the windward shore will experience a smaller annual range of temperature and a greater degree of marine influence than will an area found well toward the interior of the continent along the same parallel. The annual thermal amplitude may thus be taken as a measure of the degree of marine or continental influence which the climate of a specified location exhibits.

It is not appropriate, however, to measure continentality/oceanicity solely by the annual range of temperature, for a general correlation exists not only between the annual range of temperature and the degree of continental/marine influence, but also between the annual range of temperature and latitude. As a rule, the annual range of temperature increases with a corresponding increase in latitude (Haurwitz & Austin, 1944). This relationship is attributable to the increasing seasonal variation of solar radiation receipts, which is in turn a function of latitude. Seasonal changes and, hence, seasonal extremes, become more accentuated as latitude increases (Landsberg, 1962). If the average annual range of temperature is to be used as a basis for computing an index for measuring the continentality of a region, this inherent fluctuation of the annual thermal amplitude with latitudinal variation must be compensated for.

One of the earliest attempts to define a quantitative method of measuring continentality was that of Zenker (1888) who based his computations on the recognized relationship between the annual range of temperature and the degree of continental/marine influence.

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He proposed the simple formula $K=100(A/\theta)$, in which K is the coefficient of continentality, A is the annual range of temperature in degrees Celsius, and θ is the latitude of the specific location. K then represents the degree to which the temperature regime of a given location is modified by a large water body, or lack of the same. This figure is expressed as a percent with higher values indicating a greater degree of continental control, and lower values revealing a more pronounced marine influence (Kopec, 1965).

Under certain circumstances, Zenker's early formula has the unfortunate shortcoming of producing values in excess of the theoretical limits of 0 and 100 percent (Conrad, 1946). In an attempt to correct this fault, Zenker modified his original formula by introducing arbitrary constants and correcting factors. The revised formula became $K=(1.2A/\theta)-20$ (Conrad, 1946).

In 1920, Gorczyniski, building on the fundamental principles of Zenker, further modified the formula by substituting $\sin\theta$ in place of θ. This modification is theoretically preferable (Conrad, 1946). In addition, Gorczyniski altered the constants and the correcting factors so that the formula then became $K=(1.7A/\sin\theta)-20.4$ (Gorczyniski, 1920).

A decade later, Johansson (1931) further modified the pioneering work of Zenker and Gorczyniski by recomputing the correcting factors and constants using empirically derived bilateral limits. The two locations chosen to be representative of these limits are Verkhoyansk in the Soviet Union (67° 30'N, 133° 24'E) where A $61.6^{\circ}C$, and Thorshaven in the Faroe Islands ($62^{\circ}N$, 6° 48'E) where

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A equals 7.6°C. The former is thought to represent a location in which continental influence reaches a maximum (K=100%), and the latter a location which is entirely void of continental influence (K=0%). Johansson's formula is expressed as $K=(1.6A/\sin \theta)-14$ (Johansson, 1931).

The work of Johansson represents considerable progress on one hand, but introduces certain difficulties on the other. Johansson's formula is derived from temperature data gathered from a very limited latitudinal region. The application of this formula to other regions is an extrapolation (Conrad, 1946). Investigations conducted by Conrad (1936) reveal that the formula loses its validity when θ approaches zero. A location such as Kisangani, Zaire (1°N), which exhibits an annual temperature range of 2.2°C, shows a coefficient of continentality of almost 450 percent. Such a location would supposedly be characterized by a continental influence nearly $4\frac{1}{2}$ times as great as that found at Verkhoyansk. In equatorial regions the effect of latitude is so strong that it overwhelms all other factors. Thus, the K values obtained within 15° of the equator, using Johansson's formula, are not representative of the actual degree of continental influence found in these locations (Conrad, 1946).

Recognizing the validity limitations inherent in Johansson's work, Conrad (1946) sought to modify the formula so as to obtain realistic results for the lower latitudes. This was accomplished by substituting $\sin(\theta + 10^\circ)$ in place of $\sin \theta$. By initiating this change, the absurd values which the Johansson formula yields for

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equatorial regions are eliminated (Conrad, 1950). The resulting formula, as expounded by Conrad, is $K = 1.7/\sin(\theta + 10^{\circ}) - 14$. By dividing the annual range of temperature (A) by $\sin(\theta + 10^{\circ})$ Conrad has not only reduced the annual range of temperature to equality for all latitudes, but he has also solved the aforementioned problem with respect to equatorial regions. The reason for multiplying the average annual range of temperature by 1.7, as well as the reason for subtracting 14 from $1.7A/\sin(\theta + 10^{\circ})$, is to ensure that K values obtained for the two locations chosen to be representative of the bilateral limits of the formula will equal 100% and 0% (Conrad, 1950). Essentially, the Conrad formula appears accurate since it yields a coefficient of continentality for Verkhoyansk of 99.2% and for Thorshaven of -.4% (Kerr, 1973).

The major drawback of Conrad's work is that the formula breaks down if θ exceeds 80° (Conrad, 1946). Since $\sin(90^{\circ})$ equals one, then for any location over 80° (the formula necessitates that 10° be added to the latitude, thus $\sin 80^{\circ} + 10^{\circ} = 1$) the sin of the angle of latitude for that location must be greater than one. According to the law of sines, this is an impossibility. This flaw is only of minor significance, however, since very few weather stations exist in latitudes greater than 80° north or south.

Alternative Indices for Measuring Continentality

Other indices for measuring the degree of continental or marine influence on a region have been developed which vary considerably in character from those previously mentioned. All are

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based on one or more of the established differences existing between the climatic conditions characteristic of continental regions, and those characteristic of coastal or marine provinces. Perhaps the most complicated formula is that proposed by Ivanov (1959) in which the coefficient of continentality (K) equals $100(A_y + A_D + .25D/.36\theta + 14)$. A_y is the annual thermal amplitude and A_D is the diurnal thermal amplitude. Both are expressed in degrees Celsius. D is the saturation deficit, or the inverse of the relative humidity, while θ is the latitude. The resulting index ranges from a minimum value of 37, which Ivanov designates as "extremely oceanic", to a maximum value of 262 considered to be "extremely continental". Those locations characterized by values of 100 or less are considered to be oceanic climates, while those displaying values of 101 or greater are designated as continental climates (Ivanov, 1959).

Table 3

Stages of Continentality (After Ivanov)

Extremely Oceanic	47
Oceanic	48-56
Moderately Oceanic	57-68
Marine	69-82
Weakly Marine	83-100
Weakly Continental	101-121
Moderately Continental	122-146
Continental	147-177
Strongly Continental	178-214
Extremely Continental	214

Two entirely different approaches to the problem of measuring the degree of continental or marine control which the climate of a

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specific location exhibits are those offered by Berg (1944) and Kerner (1905). The former proposes an index of continentality based on the frequency of continental air masses which transverse a given region. The relatively simple formula offered by Berg is $K=c/c+m$, where c represents continental air and m represents maritime air. The major drawback in the use of this formula lies in the data gathering procedure which is both tedious and time consuming (Berg, 1944).

Kerner proposes a "thermoisodromic ratio" which is actually designed to measure marine influence rather than continental influence. The formula is expressed as $O=100(T_a-T_o/A)$ where O represents "oceanicity" or the degree of marine influence, T_o and T_a represent the average October and April temperatures respectively, and A is the mean annual thermal amplitude. All temperatures are expressed in degrees Celsius. Kerner's work is based on the existence of a thermal lag between the times of maximum and minimum solar radiation receipt and the periods of maximum and minimum surface temperatures. The magnitude of this retardation in the response to incident solar radiation is more pronounced in relation to water surfaces than land surfaces. While Kerner's thermoisodromic ratio is a measure of marine influence rather than continental influence, an index of continentality based on the thermal lag may be expressed as the reciprocal of Kerner's O (Encyclopedia). The new formula thus becomes $K=100-(100)\ (T_o-T_a/A)$, or K=100-"O".

A comparison of the results obtained from Kerner's formula with

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those derived from Conrad's formula is given in Table 4. Since the empirically established bilateral limits of the two formulas are different--Conrad ranging from 0 to 100 and Kerner ranging from -4 to 49--the results need to be standardized before any valid comparisons can be drawn. This has been accomplished by transforming Kerner's values into percentages.

Table 4

A Comparison of Values Derived from Conrad and Kerner

Location	O	O(%)	K(O)	K
Huron, South Dakota	6.2	19.2	80.8	56.5
Omaha, Nebraska	6.5	19.8	80.2	51.3
Detroit, Michigan	11.3	28.9	71.1	42.3
New York, New York	14.7	35.3	64.7	39.5
Greensboro, North Carolina	1.5	10.4	89.6	36.0
Flagstaff, Arizona	12.9	31.9	68.1	35.7
Athens, Georgia	2.2	11.7	88.3	34.0
Galveston, Texas	15.2	36.2	63.8	29.5
Pensacola, Florida	6.6	20.0	80.0	28.7
Salem, Oregon	12.2	30.5	69.5	17.8
Oakland, California	33.5	70.7	29.3	6.0

Note: O is oceanicity according to Kerner (raw scores), O(%) is oceanicity expressed as a percent, K(O) is the reciprocal of O(%)--continentality, and K is continentality according to Conrad. All data are based on current normals: 1941-70.

The data depicted above indicate that the two formulas yield significantly different results. In theory, Kerner's formula appears to be a more realistic appraisal of the relative importance of continental and marine influences on the climate of a region since it considers not only the average annual thermal amplitude,

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but also the magnitude of the seasonal thermal lag. It should be noted, however, that Kerner has failed to take into consideration the natural relationship between the average annual range of temperature and latitude. In addition, a recent investigation by Kendall (1974) reveals that the Kerner formula is unduly sensitive to the slightest variation in the October-April temperature differential. Evidence of this fact is exhibited here in Table 4. It appears as though the spurious values obtained for both Greensboro, North Carolina, and Athens, Georgia, originate from this portion of the formula. In light of such evidence, Kendall concludes that Kerner's formula does not accurately portray the relative importance of continental and/or marine influences as well as does the Conrad formula (Kendall, 1974).

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CHAPTER IV

EXPANDING THE USE AND DEFINITION OF CONTINENTALITY

Continentality and Regional Climatic Classification

Although widely recognized as a significant, if somewhat abstract, climatic variable and defined in quantitative terms by several authors, continentality continues to be used rather sparingly as a criterion for regional climatic classification. Only the classification of Miller (1931) employs the distinct dichotomy of continental-oceanic regional delineations. With respect to tropical and equatorial areas, this lack of application is explainable since continentality does not assume the paramount importance it does in the higher latitudes. Low latitude climates which are warm throughout the year are delineated on the basis of a moisture-deficit and moisture-surplus characteristic. They are classified further according to precipitation seasonality. Extratropical climates, however, can only partially be defined by moisture balance, seasonal temperature, and precipitation criteria. The real essence of extratropical climates lies in the degree to which they are conditioned by land masses or water bodies (Currey, 1974). In addition, a continentality index applicable to all regions regardless of latitude has been an extremely illusive concept to define in quantitative language. Many formulas, as have previously been noted, tend to yield ambiguous results for tropical areas.

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The significance of the concept of continentality in the classification of extratropical climates is evidenced by the frequent use of continentally-related criteria in existing schemes to distinguish between closely related climatic regions (Currey, 1974). Köppen, for example, differentiates a continental or interior Mediterranean climate (Csa) with hot summers from a coastal Mediterranean climate (Csb) with cool summers. Trewartha acknowledges a difference between a mid-latitude continental climate with cold winters (Dc) and a mid-latitude oceanic climate with mild winters (Do) (Trewartha, 1968). Neither classification, however, distinguishes continentality across the entire spectrum of extratropical climates. Moreover, each author employs continentality standards which change abruptly from one region to the next (Currey, 1974).

Recently, Currey (1974) has undertaken the task of developing a method of relating the dimension of continentality to existing systems of regional climatic classification on a basis that employs the same standards throughout the entire realm of extratropical climates. Currey calculated the average annual range of temperature for all latitudes by using the formula $A_\theta = 1 + \theta/3$, in which A_θ is the annual thermal amplitude in degrees Celsius for any specific latitude, and θ is the specified latitude. By comparing the annual thermal amplitude of the climate of a given location with the average annual thermal amplitude of the latitude of that location, Currey was able to develop a simple basis for dividing the continentality continuum into continental and oceanic regions. Those locations displaying a less-than-average annual thermal amplitude

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are classified as oceanic climates, while those with a greater-than-average annual thermal amplitude are categorized as continental climates. Since average annual temperature ranges are biased toward the small side by the predominance of the oceans, the boundary between oceanic and continental climates is best drawn where the annual temperature range (A) equals $1.1(A_\theta)$ (Currey, 1974). Further modification of this dichotomy produced five subdivisions of oceanic and continental climates, all defined in terms of A_θ. These divisions are shown in Table 5.

Table 5

Continental and Oceanic Subdivisions
of Climate (After Currey)

Ultraoceanic	A $.55(A_\theta)$
Oceanic	$.55(A_\theta)$ A $1.1(A_\theta)$
Subcontinental	$1.1(A_\theta)$ A $1.65(A_\theta)$
Continental	$1.65(A_\theta)$ A $2.2(A_\theta)$
Ultracontinental	A $2.2(A_\theta)$

Superimposing these subdivisions over a classification scheme such as Trewartha's allows for comprehensive modification of the original work. Allowance is made for the recognition of numerous regional climatic sub-types which were previously lumped together under one heading. An example is the humid subtropical climate (Cfa) of Trewartha. By employing Currey's method of regional delineation, this climate may be broken down into oceanic humid sub-

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tropical (Cfo) and continental humid subtropical (Cfc). Since continentality is one of the most important dimensions of extratropical climates, such an application as this allows for more accurate description and discrimination of regional climatic types.

In recent years continentality has found wider expression as a dimension of climate due in a large part to the advent of high speed electronic computers. This innovation has made it possible to apply high-powered quantitative statistical techniques to the intriguing problem of regional climatic classification. Such application has not only reinforced the idea that continentality is an important component of extratropical climates, but it has also helped to define the concept of continentality in more concrete, viable terms. Two such studies by Steiner (1965) and Dickason and Micklin (1974) approached the problem of regional climatic classification through the use of multivariate (factor) analysis. In each case, the concept of continentality was clearly identified.

Steiner performed a principal components factor analysis involving 16 climatic variables for 67 locations across the conterminous United States in an attempt to discern climatic regions. The results yielded four factors which account for 88.6% of the variance. Factor III, which accounts for 19.8% of the variance, is identified by Steiner as "continentality". It is positively associated with factor loadings for average annual temperature range and the July/January precipitation ratio and negatively associated with factor loadings for January temperature, January precipitation, and mean annual temperature. The annual thermal amplitude, however,

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plays the dominating role, yielding a rotated factor matrix loading of .931 (Steiner, 1965).

In a similar study, Dickason and Micklin (1974) applied Steiner's method of climatic factor analysis to the Soviet Union. However, they somewhat altered their approach in an attempt to improve on Steiner's technique. Instead of mapping the factor scores as Steiner did, Dickason and Micklin fitted a gamma function to each of the factor score distributions and then mapped the resulting probabilities using the trend surface technique.

Although Dickason and Micklin employed the same 16 climatic variables and analyzed them using the same technique (principal components analysis), their results differ somewhat from those of Steiner. As was the case with Steiner's work, four factors were identified. These factors accounted for nearly 85% of the variance. Steiner, however, identified continentality as his third most significant factor, whereas Dickason and Micklin found the equivalent--labeled the "maritimity-continentality continuum"--to be of secondary importance. This factor accounted for nearly one-fourth of the variance. It is positively associated with factor loadings for mean annual temperature, mean annual precipitation, January temperature, and January precipitation; and it is negatively associated with the July/January precipitation ratio and the average annual range of temperature. In spite of the fact that the direction of the association of the factor loadings is reversed in some cases, with the exception of the annual precipitation total, both Steiner's study and Dickason and Micklin's work identified the same climatic

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variables as being significant in defining the concept of continentality. Thus, through the use of computers the concept of continentality is being transformed from the illusive, abstract entity which Zenker wrestled with nearly a century ago, to a more concrete, definitive climatic variable capable of providing valuable information concerning the climatic character of a region.

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CHAPTER V

TECHNIQUE AND METHODOLOGY

Selecting a Technique for Measuring Continentality

Previous discussion acknowledges the fact that there are numerous formulas and indices for measuring the relative degree of continental or marine influence which the climate of a given region exhibits. Each method or technique is based upon an analysis of a different climatic variable or combination of variables. The techniques range in difficulty from Zenker's relatively simple formula $K=A/\theta$ to the more complex methodology of factor analysis employed by Dickason and Micklin. As such, the choice of technique or methodology to be employed in a particular study is predicated not only upon the established validity of the formula or index, but also upon the application of the technique with respect to the nature of the study to be undertaken.

Since the purpose of this study is to investigate the variability of annual monthly temperature extremes via an examination of continentality values, an index which measures continentality by employing seasonal temperature characteristics is required. Previous discussion suggests the Conrad formula which has been proven effective as a device for measuring continentality in a number of regional studies (Fobes, 1954; D'Ooge, 1955; Trewartha, 1961; Kopec, 1965; Kerr, 1973; and Kendall, 1974). This index expresses continen-

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tality as a function of the annual range of temperature. Any change in the annual range of temperature produces a corresponding change in continentality of proportionately equal magnitude. Since the annual range of temperature is in turn derived from the difference between the mean temperature of the warmest month and the mean temperature of the coldest month, continentality is directly dependent upon annual monthly temperature extremes. As such, any variation in continentality may be explained as the result of (1) a change in the mean temperature of the warmest month, (2) a change in the mean temperature of the coldest month, or (3) a disproportionate change in both of these climatic variables. Hence, by employing Conrad's formula for measuring continentality, changes in continentality may be seen as evidence of the variability of annual monthly temperature extremes.

Statement of Purpose or Intent

This study is an investigation of the affect(s) which recent climatic changes (see Chapter VIII) have had upon seasonal temperature extremes--hence, upon continentality. The period of study is from 1934 to 1973. Since this study focuses on continentality variability rather than upon temperature variation, it is possible not only to indirectly examine the variability of annual monthly temperature extremes, but also to observe the resulting impact of such thermal variations on the character of continentality. In this way, the variability of continentality may be looked upon as both an indicator and a product of climatic change.

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In examining the continentality of the United States, this study is concerned not only with the present patterns and values, but also with the variability which these patterns and values exhibit through time. Indeed, the temporal and spatial variation of continentality in the United States is the focal point of this study. Has the pattern of continentality in the study area remained a concrete, non-deviant entity during these years, or has this pattern experienced some measure of variation? If, as is suspected, the latter is the case, then answers need to be sought to several obvious questions: (1) What is the relative direction of change--increase or decrease? (2) What is the magnitude of change? (3) Are such changes uniform across the study region? or (4) Do distinct regional trends exist? Furthermore, the more pertinent questions such as (1) what type of temperature change accounts for these changes? and (2) what may be the immediate cause of such temperature changes?, need to be examined.

The remaining portions of this study attempt to answer these and other noteworthy questions. Chapter VI examines the mean pattern of continentality characteristic of the conterminous United States over the period 1934-1973. In so doing, analysis is offered to explain the observed patterns, with specific regard to spatial differences in magnitude. Also examined in this chapter is the temporal variability of this pattern. How has this pattern changed through time? What spatial changes have occurred in this pattern as the result of temporal changes? Examination of both the spatial and temporal aspects of continentality variability provides informa-

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tion which may be used to perform a type of regional synthesis. In this way, the study area is divided into several independent regions, each of which is homogeneous in terms of its spatial and temporal character of continentality variability. The temporal trend of continentality in each of the resulting regions is then carefully scrutinized, and the question asked, "what type of temperature change could account for this trend?" Chapter VII presents a general discussion of the recent climatic changes of the last 100 years, and the affect which they have had on mean annual temperatures in the United States. Finally, in Chapter VIII, a spatial relationship is uncovered between (1) the regions in which the temporal character of continentality is homogeneous, and (2) the areas in which the temporal variation of temperatures is uniform throughout. The regional temperature trends are then used to explain the annual variability of continentality within each of the different regions, with particular emphasis upon the role which recent climatic changes have played in producing the observed temporal trends of continentality.

Establishment of a Climatological Network

The subsequent step in this study--following the selection of an index for measuring continentality--is the establishment of a network of climatological stations across the conterminous United States. Such a system of climatological observations must provide the most uniform coverage possible, while at the same time maintaining a high level of credibility with respect to the data. It is acknowledged that these requirements--particularly the latter--may

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best be fulfilled by employing so-called "bench-mark" stations. These are climatological observation posts whose records are recognized by the National Weather Service as being characterized by a high degree of homogeneity for accessing long-term climatic fluctuations. The primary prerequisite of such stations, in addition to high quality records, is permanence. Stations selected for the Bench-Mark Network are those whose location, elevation, and instrument exposure have not, and most likely will not, change (Swartz, 1956). Current information, however, indicates that the Bench-Mark Network is in a state of flux. Stations are being both added and deleted. As a consequence, the Bench-Mark Network is not a complete entity. In addition, available information denotes only 19 such stations in the study region (Eichenlaub, 1975). This number is insufficient to obtain the degree of detail required of this study.

As the initial step toward the establishment of a climatological network, the locations of some 260 first order stations were plotted on a map of the study area. First order stations--as defined by the National Weather Service--are those staffed in whole or part by National Weather Service personnel (Leopard, 1975). The records of these stations were then investigated through an examination of the publication, Local Climatological Data: Annual Summary With Comparative Data, in an attempt to derive some measure of the degree of homogeneity exhibited by the individual stations. Those stations characterized by frequent site changes or pronounced shifts in location over the time period involved (1934-73) were omitted. Stations revealing a break in the data were also eliminated. A

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visual analysis of the spatial distribution of the remaining stations was then undertaken in an attempt to ascertain the relative degree of uniformity which the pattern exemplifies. Where clustering or grouping appeared, the intensity of the pattern was lessened by removing stations. Through this procedure optimal spatial uniformity was achieved while still retaining a marked degree of reliability with respect to the climatological records. The result is a network of 120 first order climatological stations across the 48 states (see Figure 1).

Following the establishment of a climatological network, temperature data were extracted from the publication, Local Climatological Data: Annual Summary With Comparative Data. Taking the difference between the mean temperature of the warmest month and the mean temperature of the coldest month for each year from 1934 through 1973 yielded 40 annual ranges of temperature for each of the 120 stations in Figure 1. This rather laborious and time-consuming approach to the analysis of the data allows for easy division of the study period into increments of variable duration so that comparative analyses of different periods may be undertaken later in the study with a minimum degree of effort.

The first part of this study is concerned with an examination of the average pattern of continentality characteristic of the United States during the study period. To obtain such a pattern, the 40 annual temperature ranges for each year from 1934 to 1973 were averaged for each of the 120 stations. The result was a number which represents the average annual range of temperature at each

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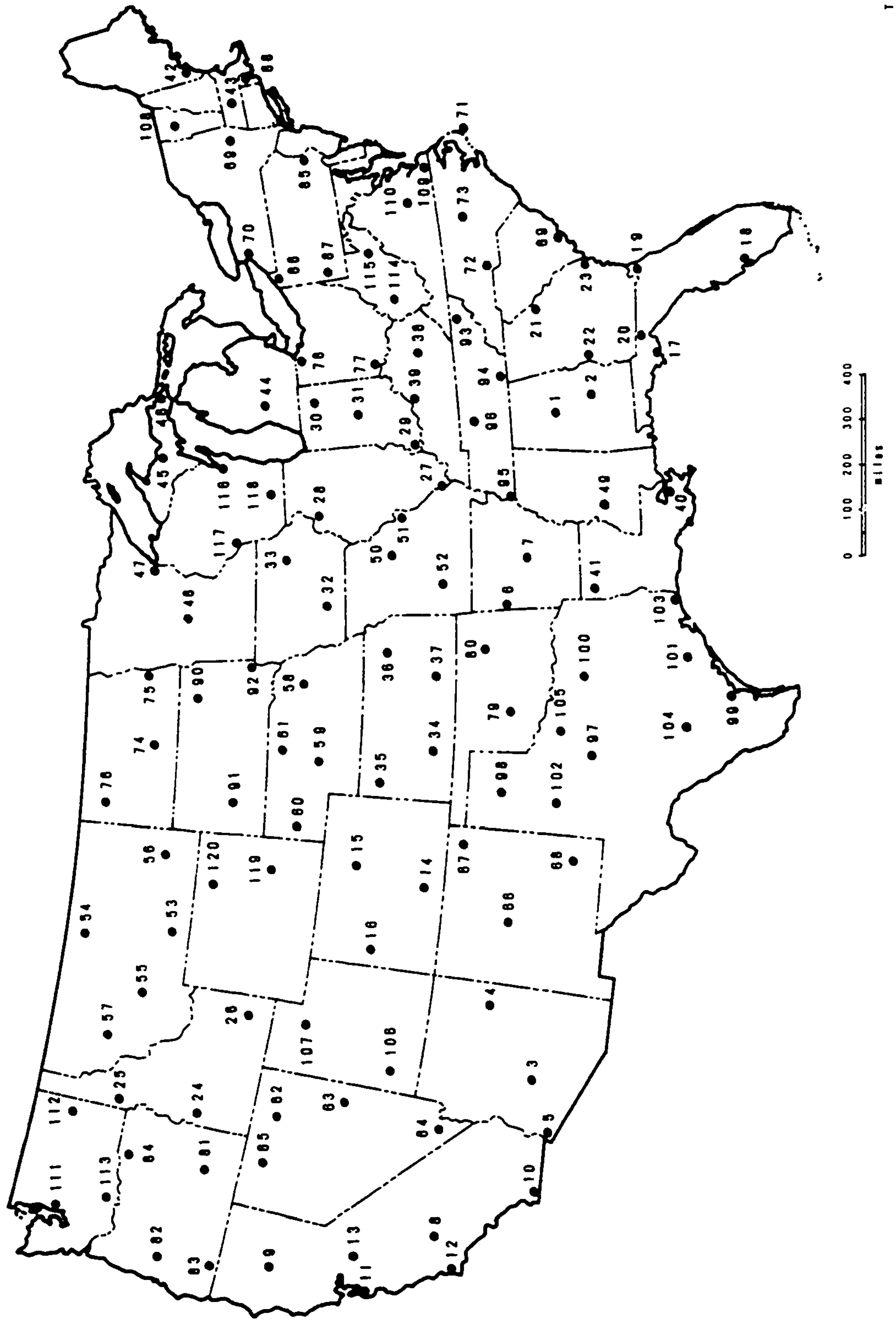
Figure 1 Network of 120 Climatological Stations



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individual station for the period 1934-73. The latitude of each location was then extracted from the previously mentioned publication. These two numbers--the average annual temperature range and the latitude--were then plugged into Conrad's formula, $K = 1.7A/\sin(\theta + 10^{\circ}) - 14$, to determine the average coefficient of continentality (K) for each station for the study period. The subsequent values were plotted on a map of the region, and through the process of linear interpolation, isolines were drawn at an interval of 5%. The resulting map (Figure 2) is an isoplethic representation of the patterns and values of continentality characteristic of the United States during the study period. An analysis of this arrangement follows in Chapter VI.

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CHAPTER VI

CONTINENTALITY IN THE CONTERMINOUS UNITED STATES: 1934-1973

Mean Spatial Pattern for the 40-Year Period

The general pattern of the isolines in Figure 2 bears an exceedingly close resemblance to the findings of Trewartha (1961). This is not surprising, though, since both studies employ the same formula for measuring continentality. However, the marked degree of similarity with the work of Steiner (1966) and Currey (1974) is rather startling. The fact that these studies arrive at similar results by employing divergent techniques lends credence to the idea that this general arrangement of the isolines is an accurate representation of the pattern of continentality in the conterminous United States.

Visual analysis of the isoplethic pattern in Figure 2 reveals several noteworthy characteristics. A core area of maximum continentality--delineated by the isoline of 60 percent--is situated over portions of the northern Great Plains states of Montana, Minnesota, and the two Dakotas. From this core area concentric isolines loop southward over the south-central United States. The symmetry of the isoplethic arrangement is distorted, however, for the axis of the loops exhibits a northwest-southeast alignment instead of the anticipated north-south orientation. This departure from the expected norm is attributable to the existence of two deviant isoplethic

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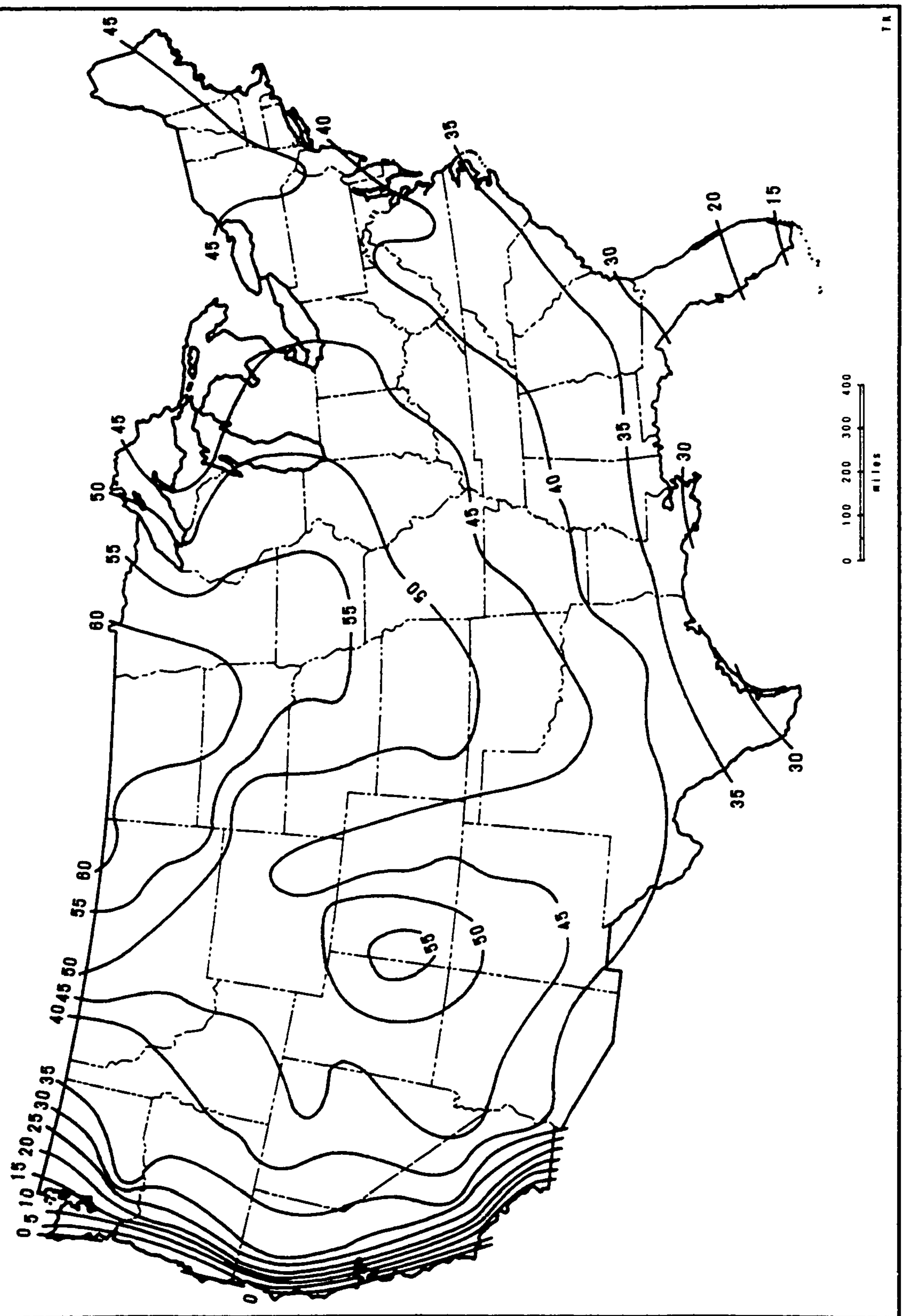

Figure 2 Continentality in the U. S.: 1934-1973

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features in the southwest quadrant of the map.

One such feature is a major trough of reduced continentality positioned immediately to the east of the continental divide. It appears as a finger-like inundation extending poleward from eastern New Mexico and western Texas, through eastern Colorado, and pentrating as far north as central Wyoming. The previous investigations of both D'Ooge (1955) and Trewartha (1961) acknowledge the existence of this feature, although the only clue to an explanation for its presence is offered in passing by D'Ooge, who notes its position with respect to the traditional line of frontogenesis in synoptic analysis (D'Ooge, 1955). It is quite feasible that this feature may owe its existence to the preponderance of Chinook winds during the winter. Such a phenomenon would have the effect of decreasing the annual temperature range by raising winter temperatures.

The second deviate feature characteristic of this area is an island of higher continentality lying just to the west of the aforementioned trough. It appears that this feature may be a southwestward extension of the main region of similar continentality values lying to the northeast of this island over the north-central states which has been disembodied by the intervening valley of lower continentality. This explanation fails to account, however, for the anomalous interior area of this island bounded by the isoline of 55%. The delimitations of this secondary feature coincide closely with the lower elevations of the Colorado Plateau. Landsberg (1962) notes that concave topography (valleys and depressions) will have the effect of increasing the annual thermal amplitude by lowering

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the annual minima. Since continentality (as measured by Conrad's formula) is directly proportional to the annual range of temperature, this explanation may well account for the higher continentality values exhibited in this region as compared to the surrounding territory. In addition, this region is noted for pronounced radiational cooling during the winter due to the influence of stagnate anticyclones. The result is a lowering of the winter minima; hence, an increase in the annual thermal amplitude.

A note of caution should be interjected concerning the actual reality of this island of increased continentality, for its presence is based on data derived from only one station: Grand Junction, Colorado. However, both D'Ooge (1955) and Trewartha (1961) recognize this region as a secondary core area of maximum continentality. Even though the size of this feature, as well as the relative values of the isolines, vary significantly among the three studies (current work included), the mere fact that this feature is identified by each author attests to its reality.

A further examination of Figure 2 discloses several additional significant features. Obvious at once is the close proximity of the isolines along the western margins of the United States. This is attributable not only to the more pronounced marine influence on this windward coast, but also to the fact that the mountain ranges paralleling the shoreline operate to rapidly weaken the marine influence inland from the coast (Trewartha, 1961). This close spacing of the isolines is indicative of an extremely steep continentality gradient in which the value of continentality increases rapidly with

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a corresponding increase in the distance inland from the shoreline. It is estimated that the magnitude of the gradient in this region varies from 20% to 30% per 100 miles. Neither the Gulf Coast nor the Atlantic seaboard display an analogous characteristic. Along the Gulf Coast from Brownsville, Texas, to Apalachee Bay on the Florida underbelly, the gradient is rather uniform. Values vary from approximately 5% per 100 miles in the vicinity of Galveston, Texas, to roughly 3% per 100 miles near Mobile, Alabama. The Florida peninsula is omitted from this discussion by virtue of the fact that the isolines run perpendicular to the coastline when depicted at this macroscale. Description and measurement of the continentality gradient in this region is thus impossible. A similar problem is encountered along the Atlantic Coast. The pattern of the isolines make it difficult to accurately gauge the strength of the continentality gradient in this area. Evidence subsequently presented, however, will indicate that the gradient along the Atlantic coastal fringe is smaller than either the Pacific or the Gulf Coast.

Additional variability among these coastal regions is evidenced by the differentiation of values characteristic of each area. Continentality is weakest along the Pacific littoral. In fact, from Eureka, California (40° 48'N), northward continental influence is deemed non-existent by the presence of the 0% isoline which coincides closely with the delineation of the coastline. South of this city the continentality of the coastal margins increases, reaching a maximum of 8.9% at San Diego, California (32° 44'N). Across the con-

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tinent along the Atlantic seaboard a marked contrast exists. Here continentality is much more variable with values ranging from 15.2% at Miami, Florida, to almost 45% along the coast of northern Maine. The characteristic paralleling of the shoreline by the isolines, so predominant along the Pacific littoral, is not as pronounced along its Atlantic counterpart. Along the Gulf Coast the values of continentality show a similar deviation to those along the Atlantic Coast. Values range from 12.5% at Key West, Florida, to 32.8% in Mobile, Alabama. This pronounced variability is due to the arc-like configuration of the coastline created by the presence of the Florida peninsula. If this latter geographical entity is omitted from inclusion within the confines of the Gulf Coast, then a value of 30% to 35% may be said to be characteristic of this region since these two isolines straddle the shoreline in a parallel fashion with the exception of the Florida promontory. The Gulf Coast is thus more continental than the Pacific littoral but somewhat less continental than the Atlantic seaboard. Currey's (1974) designation of the west coast as "ultraoceanic" and the Gulf and Atlantic Coasts as "subcontinental" acknowledges the aforementioned variability among these regions.

Although the discrepancy in continentality values among these three coastal areas is quite explicit, variation in the arrangement of the isolines characteristic of each region yields additional information concerning the relative magnitude of marine influence in each coastal region. Where the isolines parallel the shoreline, marine influence is most pronounced; and where the isolines run per-

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pendicular to the shoreline, marine influence is least pronounced (Kopec, 1965). The isolines along both the Pacific littoral and the Gulf Coast exhibit a marked degree of parallelism, more so in the case of the former. Along the Atlantic margins of the United States this characteristic is noticeably absent. The isolines terminate rather abruptly in the ocean. In part, this may be due to the configuration of the coastline. An example may be found in the area of North Carolina where the 35% isoline intersects the coast. Visual evidence appears to indicate that the isolines parallel the shoreline just off-shore. An investigation of the continentality of the oceans by Hela (1953), however, reveals that the isolines off the east coast of the United States actually trend perpendicular to the shoreline. Further out at sea the isolines do demonstrate a limited degree of parallelism (Hela, 1953). The relative standing of these three coastal regions, with respect to the degree of continentality characteristic of each, remains intact when examined with regard to the parallelism or perpendicularity exhibited by the isolines in each area.

One final feature of note on this map is the distortion of the general pattern of the isolines in the vicinity of the Great Lakes. The increased marine influence derived from these water bodies cause the isolines to deviate from their southwest-northeast alignment. The result is the creation of a major inundation in the eastern margins of the wedge of maximum continentality orientated northwest-southeast across the central United States. Were it not for the presence of the Great Lakes, the breadth of this latter feature

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would be much greater (Trewartha, 1961). By straightening the isolines it can be estimated that the modifying influence of the Great Lakes reduces the continentality of this region by 10% to 15%. The Great Lakes region thus projects as an outlier of reduced continentality into an area that would undoubtedly represent the center of continentality for North America in the absence of these water bodies (Kopec, 1965).

Temporal and Spatial Variability Among Decennial Periods

Is continentality in the United States in a state of flux as Landsberg (1967) suggests? A rough approximation of the variation in continentality experienced in the 48 states over the period 1934-73 can be ascertained by examining the decennial variability of the pattern in Figure 2. By first computing the average annual range of temperature for the four 10-year periods 1934-43, 1944-53, 1954-63, and 1964-73 for each of the 120 stations in the climatological network, and then plugging the resultant values into Conrad's formula, the coefficient of continentality is derived for each decennial period. These values are then plotted on four separate maps. The product is a graphic representation of continentality in the conterminous United States for each of these four 10-year intervals. These maps may then be examined to investigate the interperiodic variability of continentality over this 40-year span.

Dividing the period of study into four 10-year increments makes it possible to investigate the temporal variation of continentality

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through two means. First, a simple visual analysis is made of the four maps representing the pattern of continentality during each of these decades. An initial indication of the interdecennial variability of continentality is easily attained by comparing and contrasting the patterns and values of subsequent decades. Such phenomena as the variation of values and the migration of isolines from one period to the next are both evidence of interdecennial changes. These variations of fluctuations can then be clarified by constructing a second set of maps representing the net difference in continentality from one 10-year interval to the next. This second set of maps will depict more concisely the exact manner in which the pattern of continentality changes from one decade to the next. Whereas the first method cites general areas in which changes have occurred and gives a rough approximation of the direction of the change--increase or decrease--the second method not only delineates clearly the areal extent of the change, it also provides an accurate estimate of the magnitude of such change.

A comparison of the period 1934-43 with the decade 1944-53

A comparison of the map depicting continentality for the period 1934-43 (Figure 3) with the map of the subsequent decade (Figure 4) reveals several significant variations. Apparent at once is the disappearance of the 60% and 65% isolines from the core area of maximum continentality situated over the northern Great Plains states. Consequent with this phenomenon is a general shrinkage of the wedge of maximum continentality manifested by the inward migra-

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Figure 3 Average Pattern of Continentality, 1934-1943

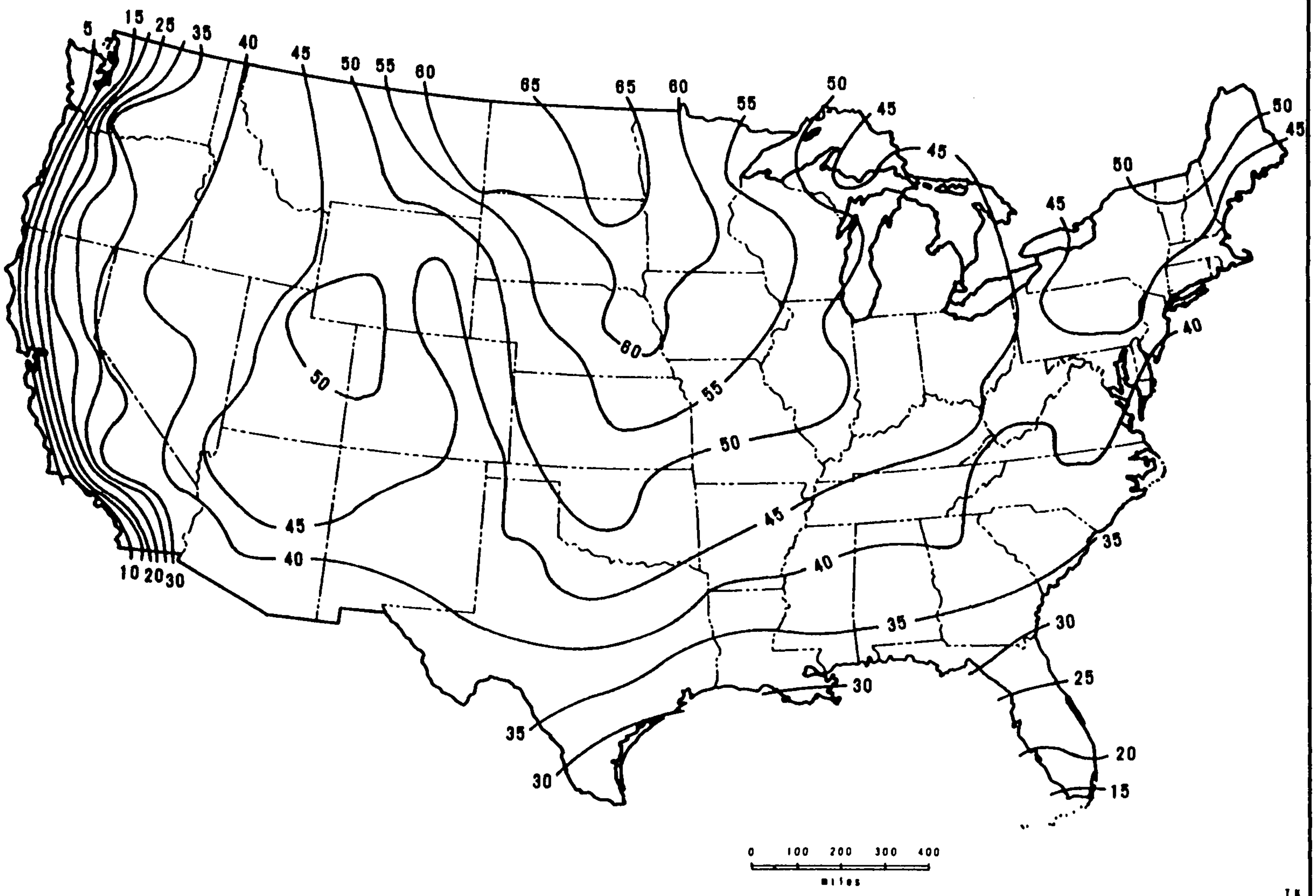

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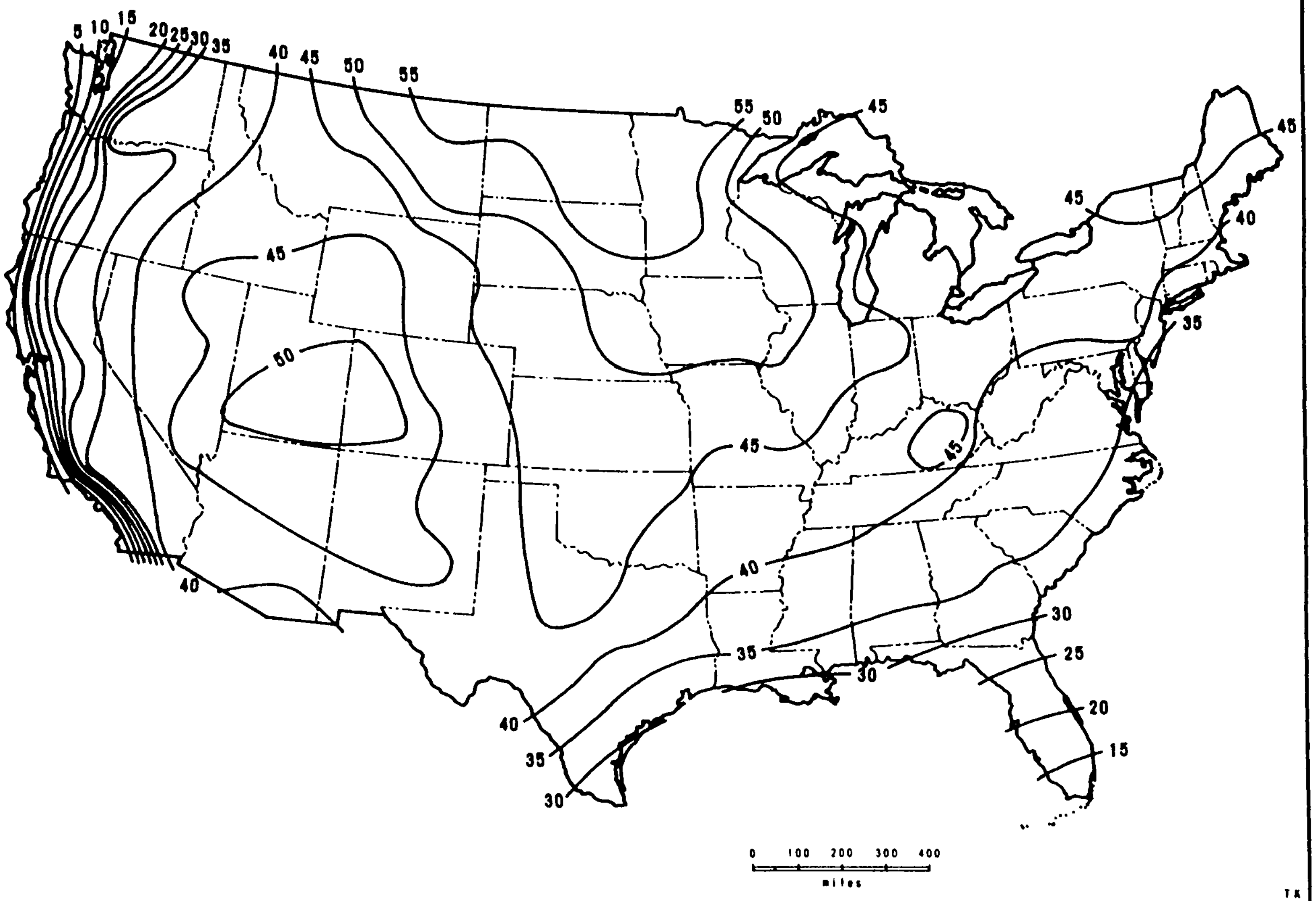
Figure 4 Average Pattern of Continentality, 1944-1953



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tion of the isolines over the eastern half of the United States. The result is a widespread decrease of continentality in this region apparently most pronounced over the interior plains states.

The pattern of change in the western portion of the United States is not as readily discernible as is that in the east; however, two distinct differences can be noted. First, the southwestward bulge of the 45% isoline over Utah, Colorado, northern Arizona, and northern New Mexico has been pinched off over Wyoming. Consequently, the trough of reduced continentality lying to the east of the continental divide has expanded creating a corridor of lower continentality stretching from the Canadian border to south-central Texas. Second, the secondary core area of maximum continentality centered on the junction of Wyoming, Utah, and Colorado has shifted equatorward to a position over southern Utah and eastern Colorado. Such a movement indicates a general increase in continentality in this region.

Indeed, while the eastern portion of the country experienced a widespread decrease in continentality from the decade 1934-43 to the period 1944-53, a large portion of the western half of the United States witnessed an increase in continentality. The seaward movement of the 5% isoline in the vicinity of San Francisco is evidence of this fact, as is the westward displacement of the 35% isoline in Oregon and northern California.

An examination of Figure 5, representing the net difference in continentality between these two 10-year periods, substantiates the previous conclusions. The 0% isoline, indicative of no change be-

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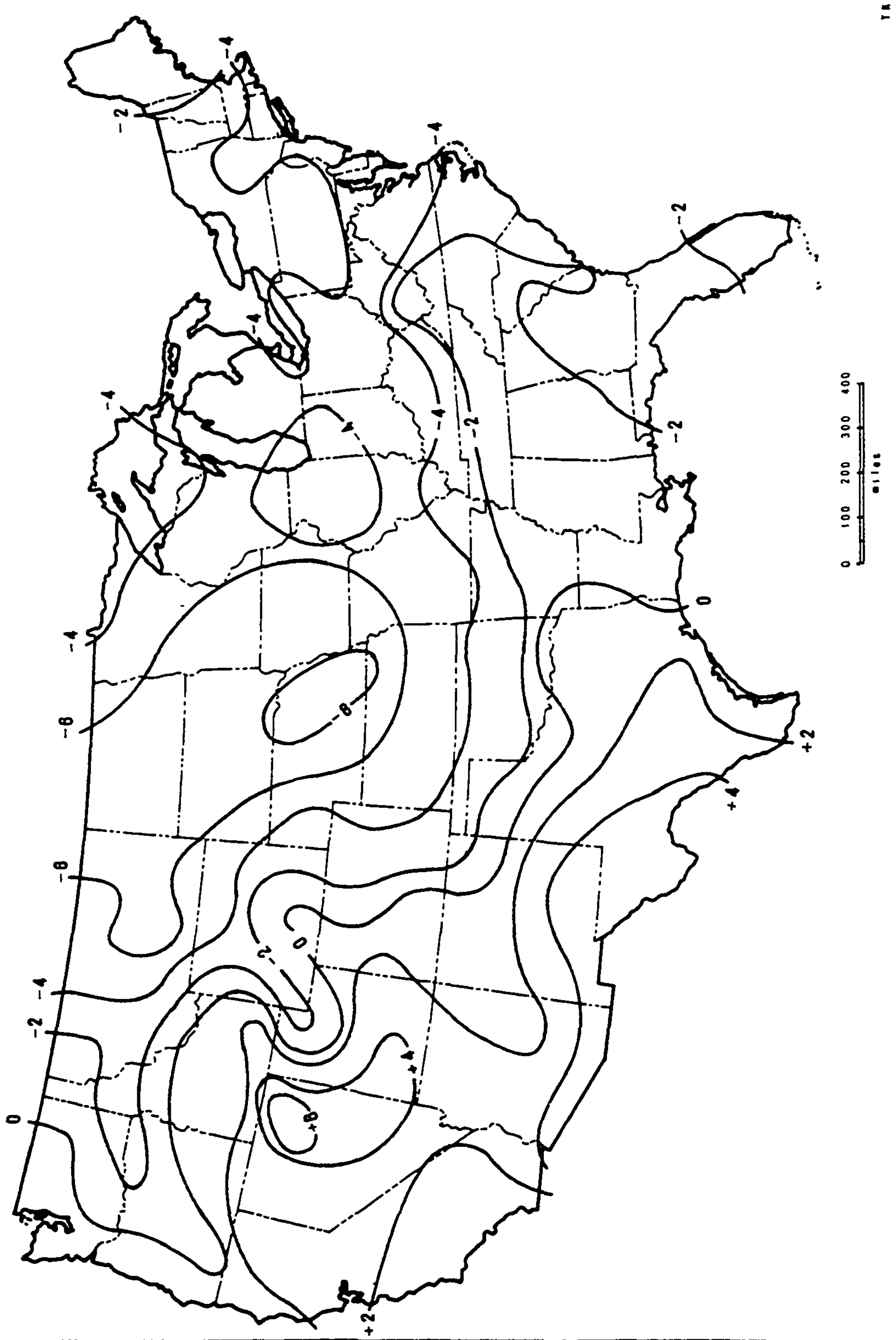

Figure 5 Change in Continentality From 1934-43 to 1944-53

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tween 1934-43 and 1944-53, trends northwest to southeast across the western half of the country. Southwest of this line continentality has increased from the earliest decade to the subsequent one. The two areas of greatest change--delineated by the +4% isoline--are (1) in eastern Nevada-southwestern Utah, and (2) along the southern borders of Arizona, New Mexico, and Texas. East of the 0% isoline over the remainder of the nation, continentality has decreased. In the southern half of this region the magnitude of the change is on the order of 2% to 4%, while in the northern portions, values range from averages of 2% to 4% in New England, to over 8% in eastern Nebraska.

<u>A comparison of the period 1944-53 with the decade 1954-63</u>

A collation of the map covering the years 1944-53 (Figure 4) with the map of the ensuing decade (Figure 6) yields results markedly divergent from those attained through the previous comparison. Whereas the earlier comparison disclosed a distinct regional dichotomy of continentality variation--an increase in the west and a decrease in the east--an analysis of the change from 1944-53 to 1954-63 reveals no such clear-cut pattern. Instead, it appears as though almost the entire area of study has experienced an increase in continentality. The only regions of the nation where even a slight hint of a decrease is evident are in the vicinity of the California-Nevada border where both the 35% and 40% isolines have moved inland and in southern Arizona where the 40% isoline exhibits much the same tendency. The remainder of the study area appears to have experienced a widespread

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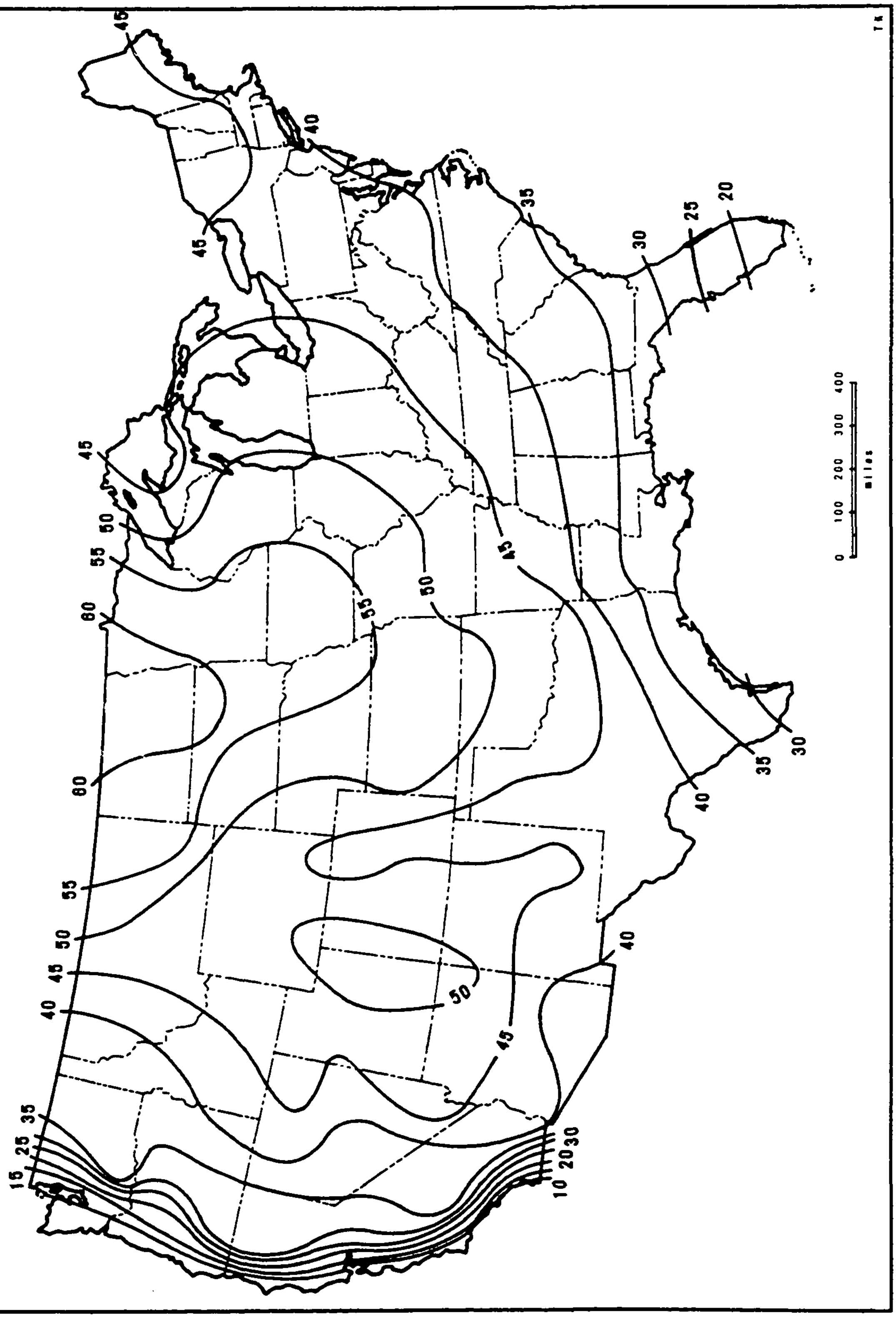
Figure 6 Average Pattern of Continentality, 1954-1963



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increase in continentality from 1944-53 to 1954-63. This increase is evidenced by the appearance of the 60% isoline over the northern Great Plains and the subsequent outward displacement of the isolines from the core area. This expansion of the isolines is most apparent (1) in southern Florida where the 15% isoline has vanished, (2) along the California coast where the 5% isoline has also vanished, and (3) along the Atlantic coast where the embarkation points of the 35% and 40% isolines from the continent have shifted far to the south.

Investigation of Figure 7, which displays the difference in continentality between these two 10-year periods, sustains the initial impression attained via a visual comparison of the two maps representing these respective decades. Two regions of increased continentality are separated from each other by a trough of reduced continentality oriented along a northwest-southeast axis. The entire pattern is displaced far to the west of the geographic center of the nation. Within this latter region, values average less than -2%. In the eastern three-fourths of the nation the increase in continentality is on the order of 2% to 4%. Values less than 2% seem to be found on the periphery of this region, while maximum values exceeding 8% characterize the interior.

<u>A comparison of the period 1954-63 with the decade 1964-73</u>

A comparison of the map covering the years 1954-63 (Figure 6) with the map of the most recent decade (Figure 8) returns results which are quite diverse from those obtained through the two previous comparisons. There is neither a distinct regional dichotomy, as is

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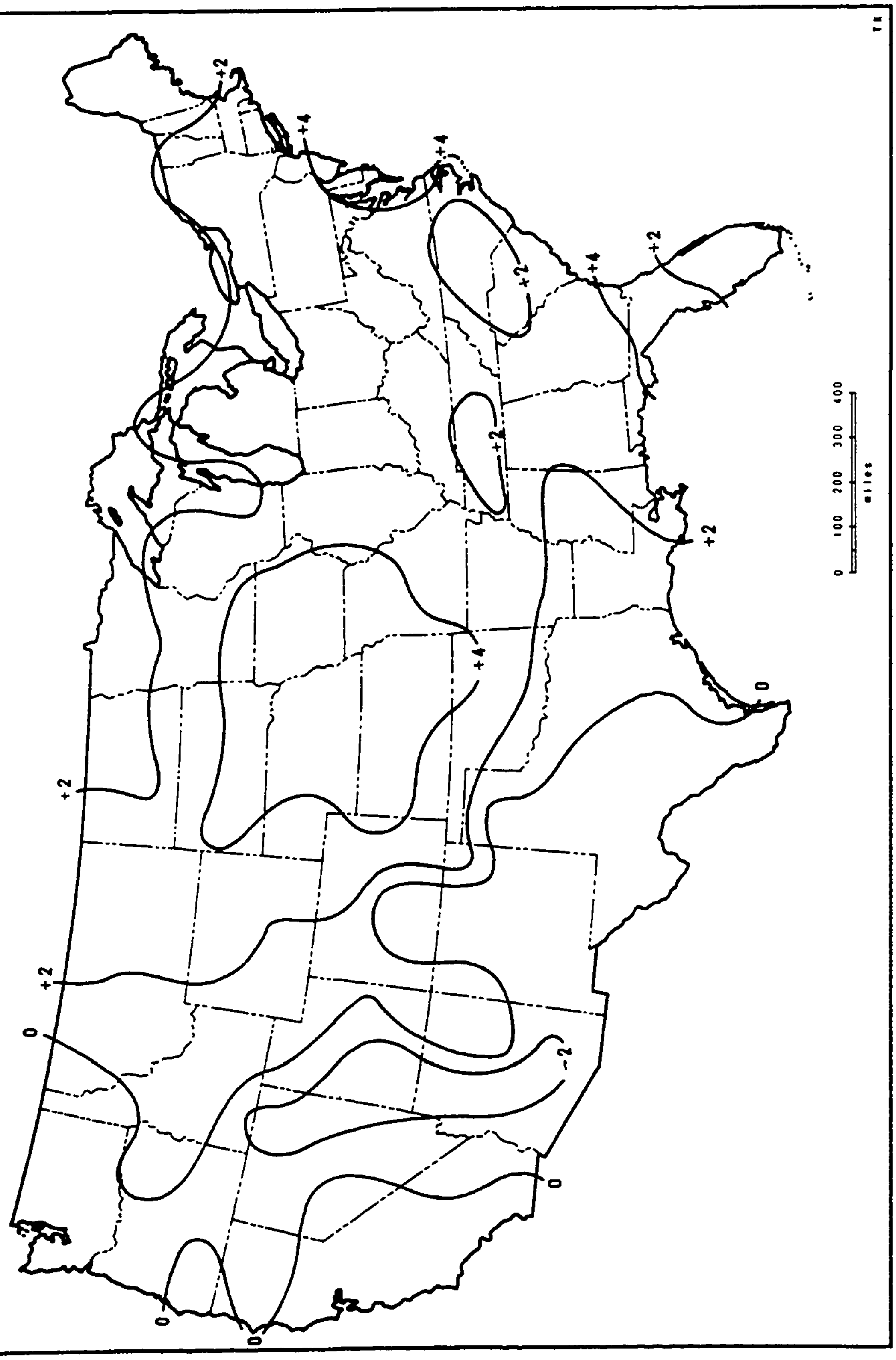

Figure 7 Change in Continentality From 1944-53 to 1954-63

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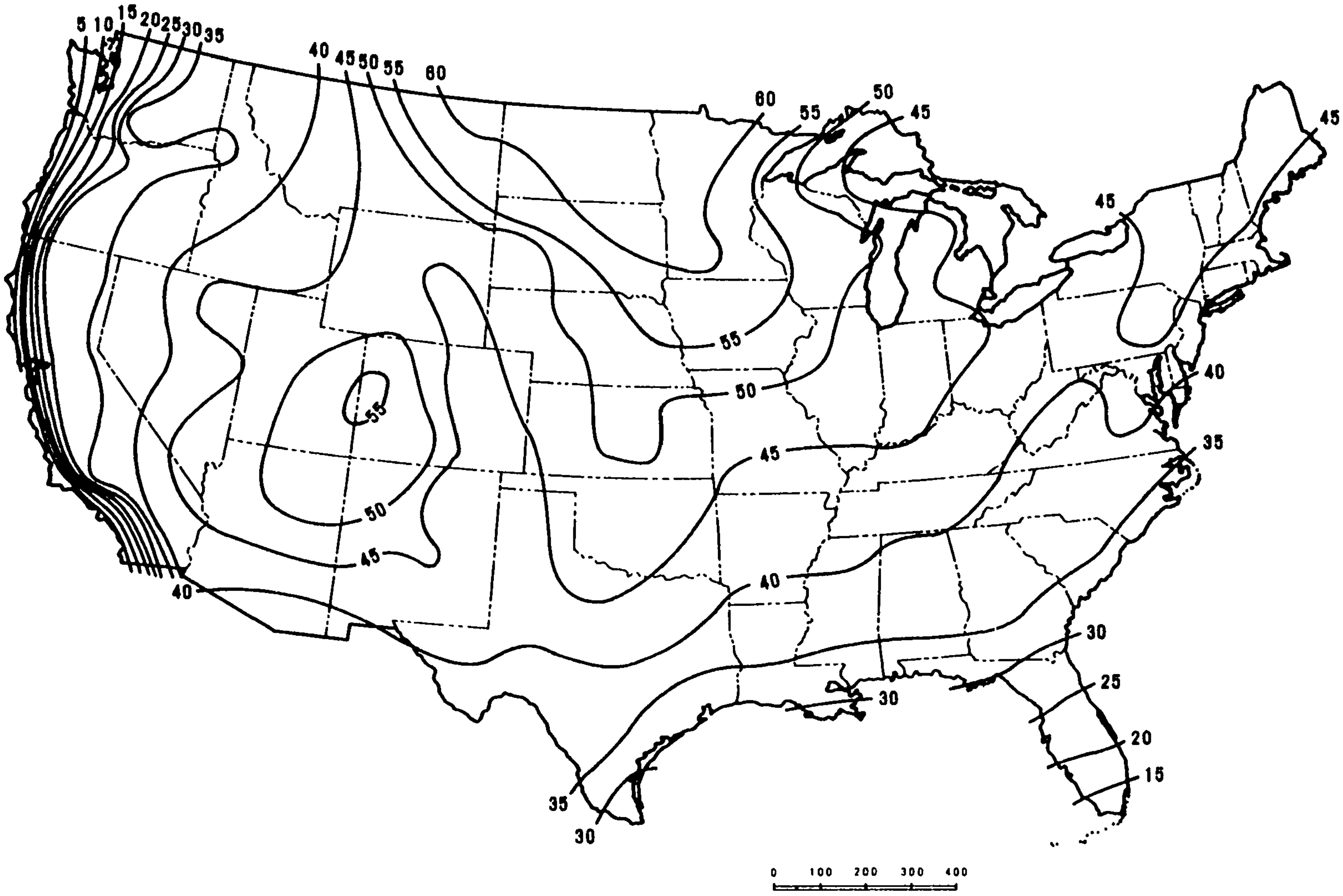
Figure 8 Average Pattern of Continentality, 1964-1973



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the case in the first comparison, nor is there a tendency toward the tripartite pattern of Figure 7 in which a region of uniform values is bifurcated by an area of dissimilar change. Instead, a far more complicated and confused pattern seems to emerge. The core area of maximum continentality has expanded to take in portions of eastern Montana and western Minnesota. It would appear logical that the remaining isolines comprising the core area, such as the 50% and 55% isolines, would also experience this enlargement; however, such is not the case. In fact, just the opposite is true. A close comparison of these two maps reveals that in the eastern two-thirds of the country the isolines have migrated toward the interior of the continent. The appearance of the 15% isoline in southern Florida and the northward displacement of the 35% isoline along the Carolina coast may be cited as the most easily distinguishable evidence of this phenomenon. Such displacement is indicative of a general decrease in continentality over the eastern two-thirds of the United States. There is, however, a conspicuous exception to this regional trend: the northeastern portion of the nation where a ridge of higher values has descended over New York and Pennsylvania.

The western portion of the nation is characterized by a similarly complex pattern of change. The secondary core area of maximum continentality in eastern Utah and western Colorado has expanded southward over the northern portions of Arizona and New Mexico. During this transition the 55% isoline has evolved in eastern Colorado. Continentality appears to have also increased

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further westward where the coastward movement of the 35% isoline over northern California can be noted. While the southwestern quadrant of the country seems to have experienced an increase in continentality from 1954-63 to 1964-73, the northwestern region displays a contradictory characteristic of change. Values have decreased in this area, as is most apparent by the inundation of the 35% isoline into west-central Idaho.

The map depicting the net change in continentality between these two decades (Figure 9) upholds the results attained through the earlier visual comparison. A majority of the country experienced a decrease in continentality from 1954-63 to 1964-73. For the most part, this change is less than 2%. Two somewhat smaller regions experienced increases in continentality. One such region encompasses the entire west coast of the United States. The line separating this region of positive values from the area of negative values lying to the east appears as a step-like configuration running from north-central Washington to southwestern New Mexico. Values west of this delineation are generally less than 2%. A second region of positive values lies over the northern portion of the country east of the continental divide. Values north of this 0% isoline are also generally less than 2%.

Each of the three previous comparisons--1934-43 with 1944-53, 1944-53 with 1954-63, and 1954-63 with 1964-73--has uncovered a unique spatial pattern of interdecennial change in continentality within the study area. A comparison of the first decade with the

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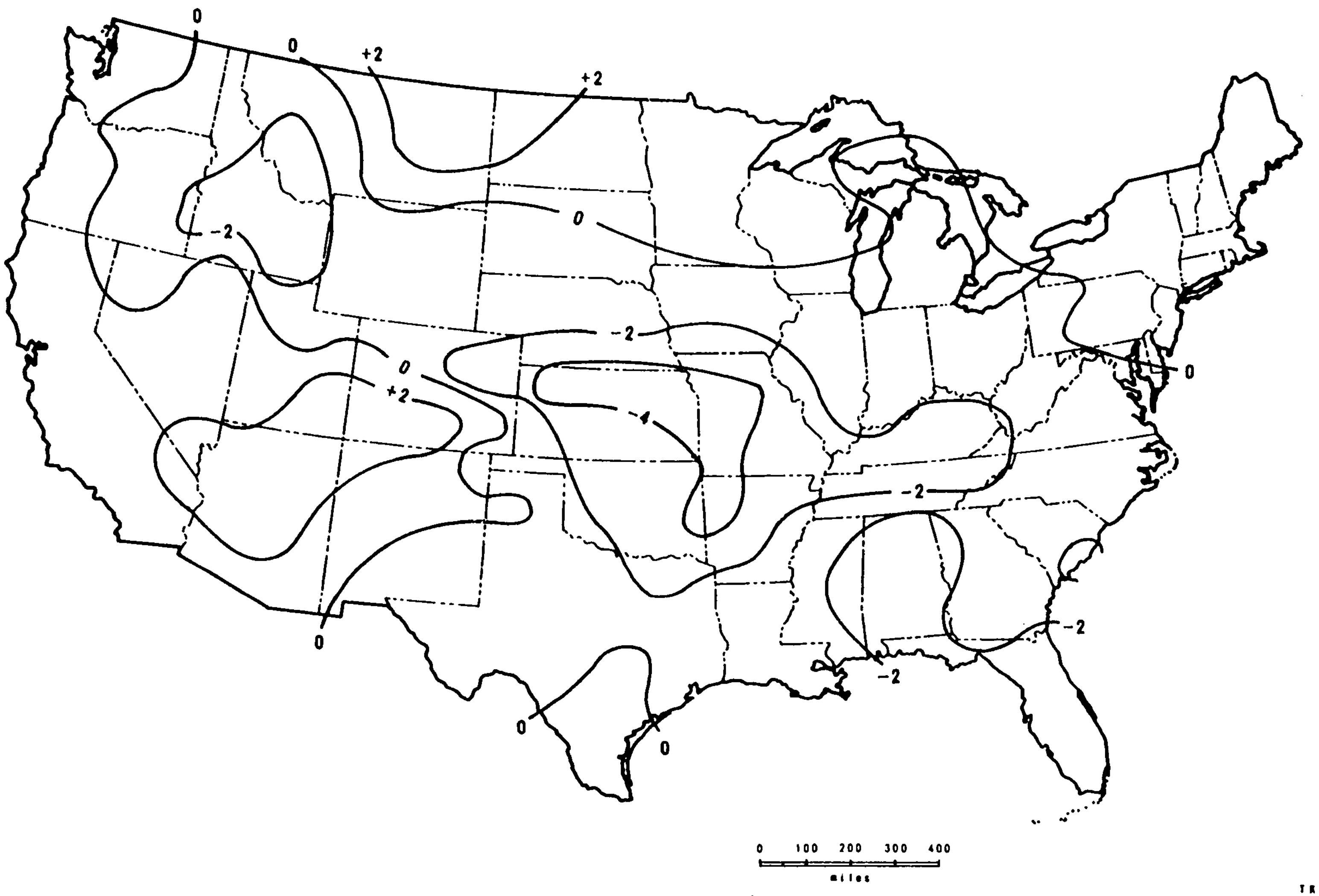
Figure 9 Change in Continentality From 1954-63 to 1964-73



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second revealed that continentality increased in the western portion of the United States and decreased in the east. The second comparison disclosed that continentality increased in both the east and west, but decreased in an intervening region running northwest-southeast from Washington to Texas. Finally, a comparison of the decade 1954-63 with the most recent 10-year period showed that continentality increased in the west, the northern midwest, and the northeast, and decreased throughout the remainder of the nation.

Spatial Synthesis: Development of Continentality Regions

The results of the previous investigation indicate that continentality in the contiguous United States has varied both temporally and spatially over the last 40 years. By carefully scrutinizing these results, individual stations may be grouped together based on the temporal character of continentality change characteristic of each. In this fashion, a temporally derived regional synthesis is undertaken. Consequently, the conterminous United States may be broken down into five such regions. These areas are delineated in Figure 10. Also evident on this map are two additional areas indicated by the use of diagonal lines. Within these areas no clear character of continentality change emerges. As such, these two areas may best be thought of as transition zones between the more clearly defined regions.

In the remaining portion of this chapter, the five regions of continentality change are identified and their respective character-

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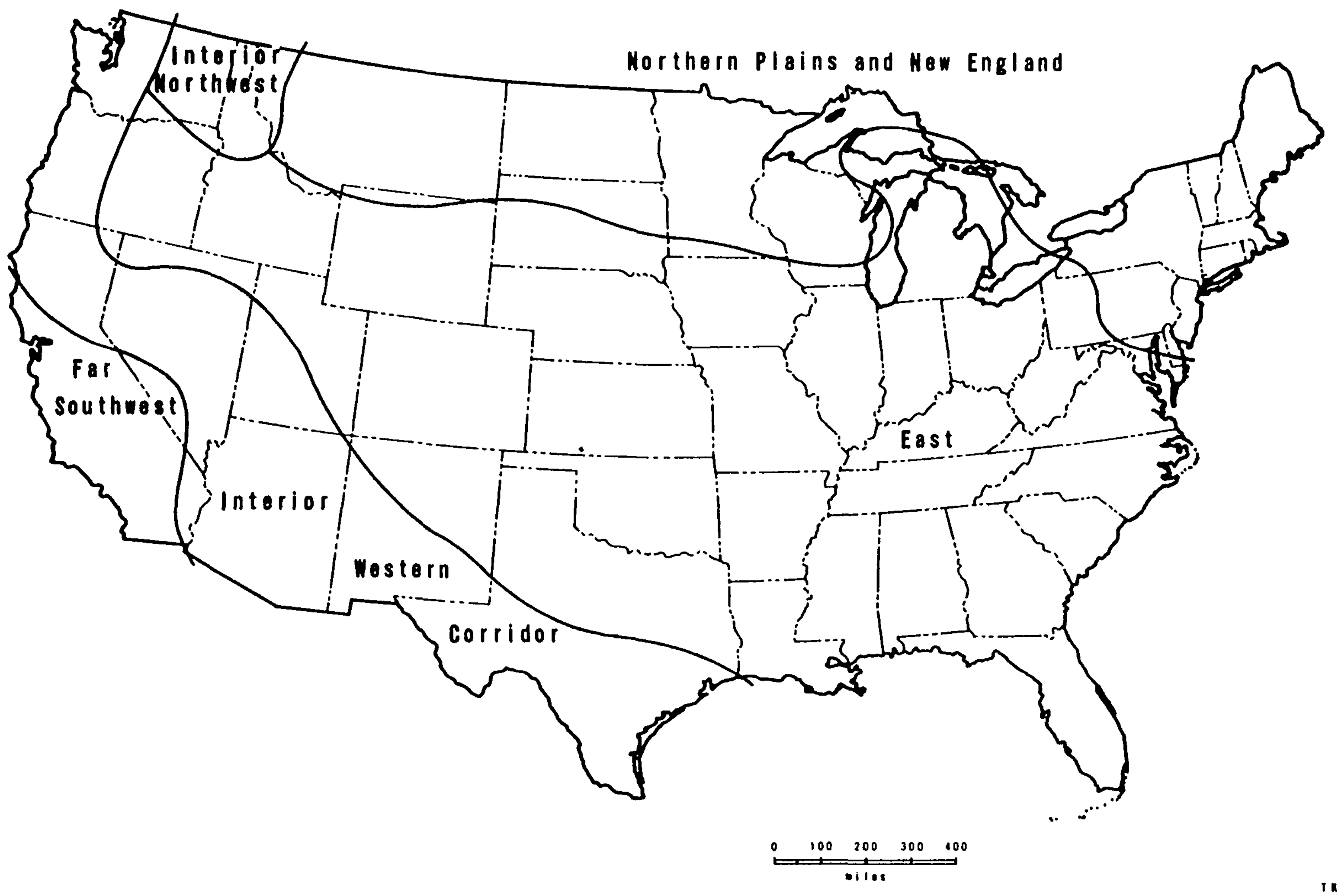
Figure 10 Quinquepartite Regional Division of the U. S.



istics of interdecennial change examined. The annual variability of continentality in each region is then investigated by examining data from a sample station selected from each region. Finally, the temporal pattern of continentality at each of the sample stations is subjected to a statistical test to determine whether or not the pattern represents an overall trend.

The Far Southwest

The first of these five regions--termed the "Far Southwest"--covers the southern two-thirds of California and the extreme southwestern portion of adjacent Nevada. The results of the previous investigations concerning the interdecennial variability of continentality reveal that this region has experienced increases from 1934-43 to 1944-53, from 1944-53 to 1954-63, and also from 1954-63 to 1964-73. This fact suggests that continentality in the Far Southwest has experienced a more or less continual rise since 1934. In order to verify the validity of this claim, a second method is employed. Figure 11 is a graph which displays the year to year variability of continentality at San Francisco, California, from 1934 to 1973. This city is chosen at random from the group of five climatological stations within this region. Because of the aforementioned regional grouping procedure, the data derived from the climatological records of this city and depicted in Figure 11 are assumed to be representative of the general pattern of continentality variation found throughout the Far Southwest.

On this graph, as well as on the entire group of graphs which

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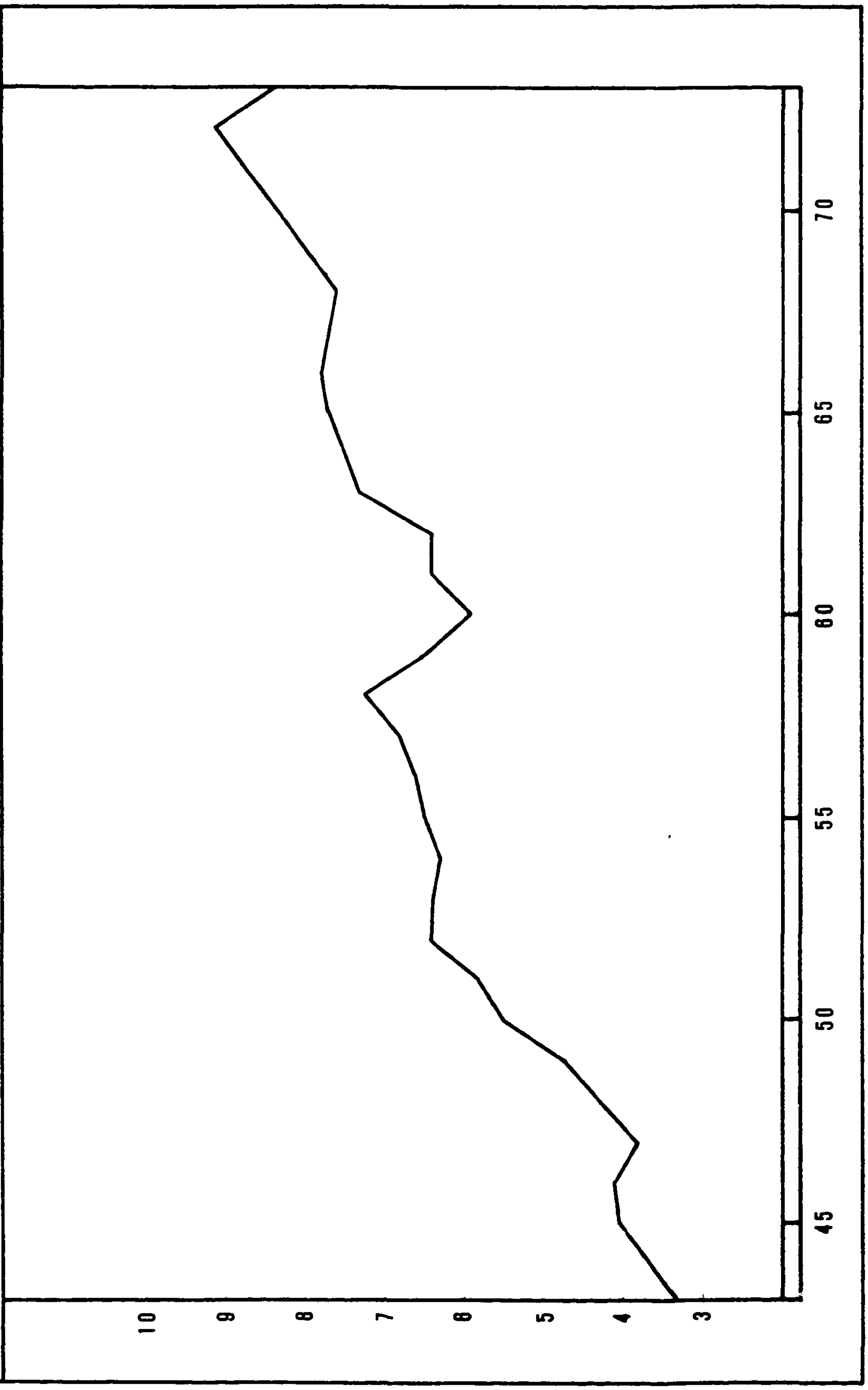
Figure 11 Continentality at San Francisco, California



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appear subsequently, values are plotted by employing a 10-year moving mean. This method is necessary in order to "smooth" the raw data, thus rendering the linear representation more readily recognizable. In this method, the years prior to a particular date on the graph are averaged to determine a value for that particular year. As an example, the years 1964-73 are averaged to obtain a value of 8.4% which represents the continentality for the year 1973.

If the San Francisco data can be assumed to accurately portray the variability of continentality throughout the Far Southwest, then a visual inspection of this graph (Figure 11) supports the idea that continentality is, and has been, steadily increasing in this region since the beginning of the study period. The line of the 10-year moving mean is quite smooth and clearly depicts the rising trend. From the earliest years to the more recent, there is nearly a 5% ascent in continentality. This averages out to more than a 1% rise per decade.

Spatially related to this region of the Far Southwest is a smaller area lying just to the east over the junction of Utah, Colorado, Arizona, and New Mexico. Within the confines of this region, the pattern of continentality change is identical in every way with that of the Far Southwest. As such, this "Four Corners" area is designated as an exclave of the Far Southwest rather than as an independent regional delineation.

The Interior Western Corridor

The second region to be identified is the "Interior Western

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Corridor". Grouped together into this twisting, turning avenue which separates the Far Southwest from the remainder of the nation are those stations which are characterized by (1) increases in continentality from 1934-43 to 1944-53 and from 1954-63 to 1964-73, and (2) an intervening decrease from 1944-53 to 1954-63.

As a check on the accuracy of these findings a graph is prepared (Figure 12) which depicts the trend of continentality since 1934 at Phoenix, Arizona. The raw data are again smoothed by employing a 10-year moving mean. The disclosure of this graph supports the contention that continentality in the Interior Western Corridor first experienced an early increase followed by a symmetrical decline, and more recently, a steady rise. Examination of the line of the 10-year moving mean reveals that values oscillate from 40.7% up to 42.8%, then down to 39.7%, and finally up again to 43.9%. The net change in continentality over this 40-year span is approximately +3.2% or roughly an increase of .8% per decade. Since the mid-1950's, the rate of increase is greater than 2% each decade. Both the Far Southwest and the Interior Western Corridor have thus experienced a net rise in continentality since 1934.

<u>The Interior Northwest</u>

The third region is identified as the "Interior Northwest". It is comprised of the extreme western portion of Montana, the northern third of Idaho, and the eastern half of Washington. The boundaries of this rather compact area are determined from data derived from only three climatological stations, and as such, this is

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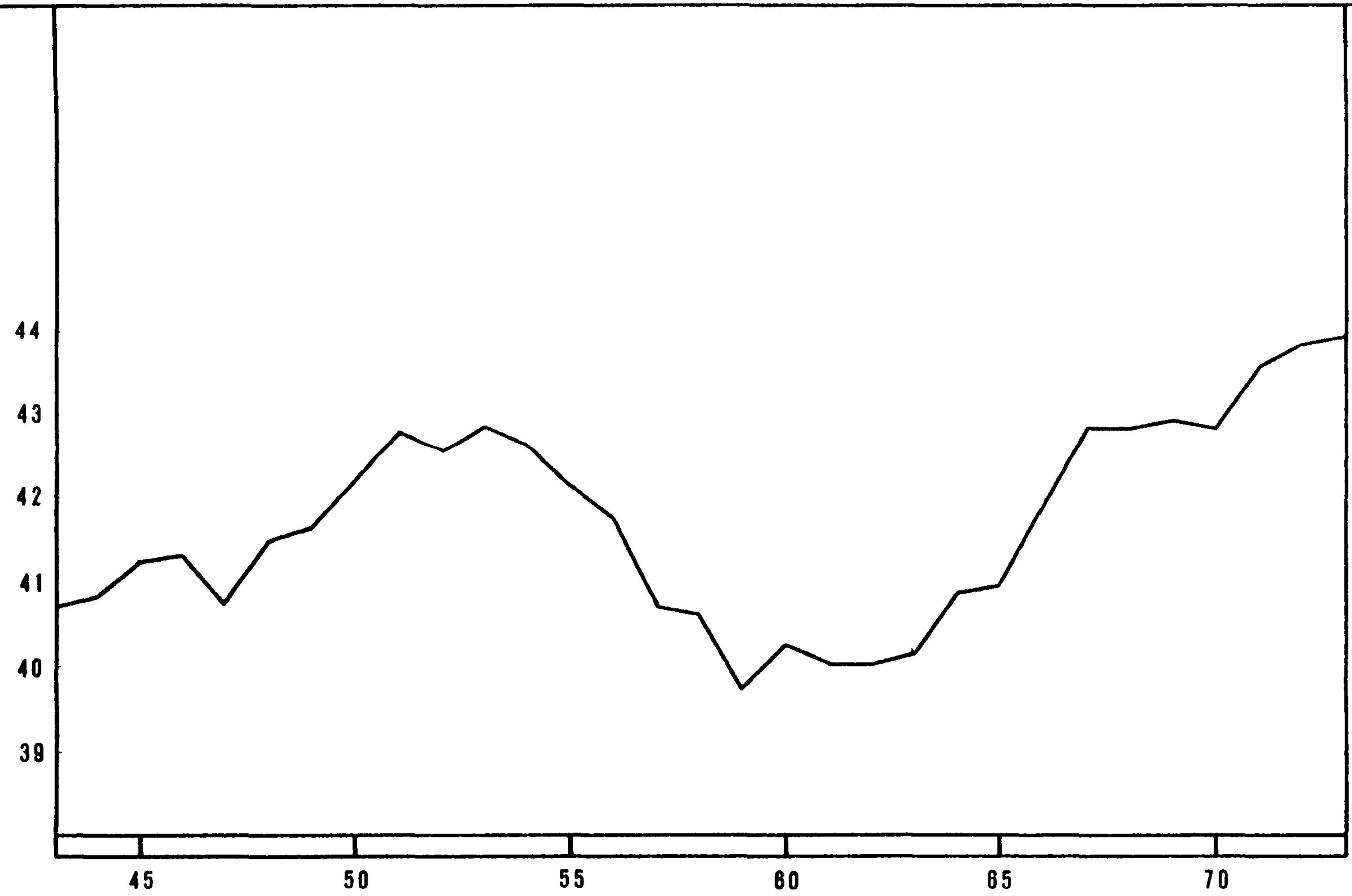
Figure 12 Continentality at Phoenix, Arizona



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the smallest of the five major regions. The minute size of this region does not, however, in any way diminish the significance of the region as a distinct entity in the macroscale pattern of continentality change, for the general trend of variability is just as pronounced in this region as in the other four.

Stations within the Interior Northwest are grouped together by virtue of the fact that they have each experienced a three-phase decline from the earliest decade to the most recent. Such a character of change suggests that continentality has steadily decreased in this region since 1934. To verify these preliminary conclusions, a graph is constructed (Figure 13) representing the long-term trend of annual continentality variability at Lewiston, Idaho. The downward linear trend depicted by the 10-year moving mean is at once recognizable. Over the period 1934-73 there is a prominent decline in continentality averaging approximately 1.5% per decade. This drop is particularly pronounced over the last ten years during which time continentality dropped 2.2%. The Interior Northwest--in opposition to the trend characteristic of both the Far Southwest and the Interior Western Corridor--thus experienced a continual, if somewhat erratic decline in continentality since 1934.

The Northern Plains and New England

The fourth region to be distinguished and delineated is designated as the "Northern Plains and New England". This region actually appears to be two separate areas partitioned by the presence of Michigan's lower peninsula (see Figure 10). The western

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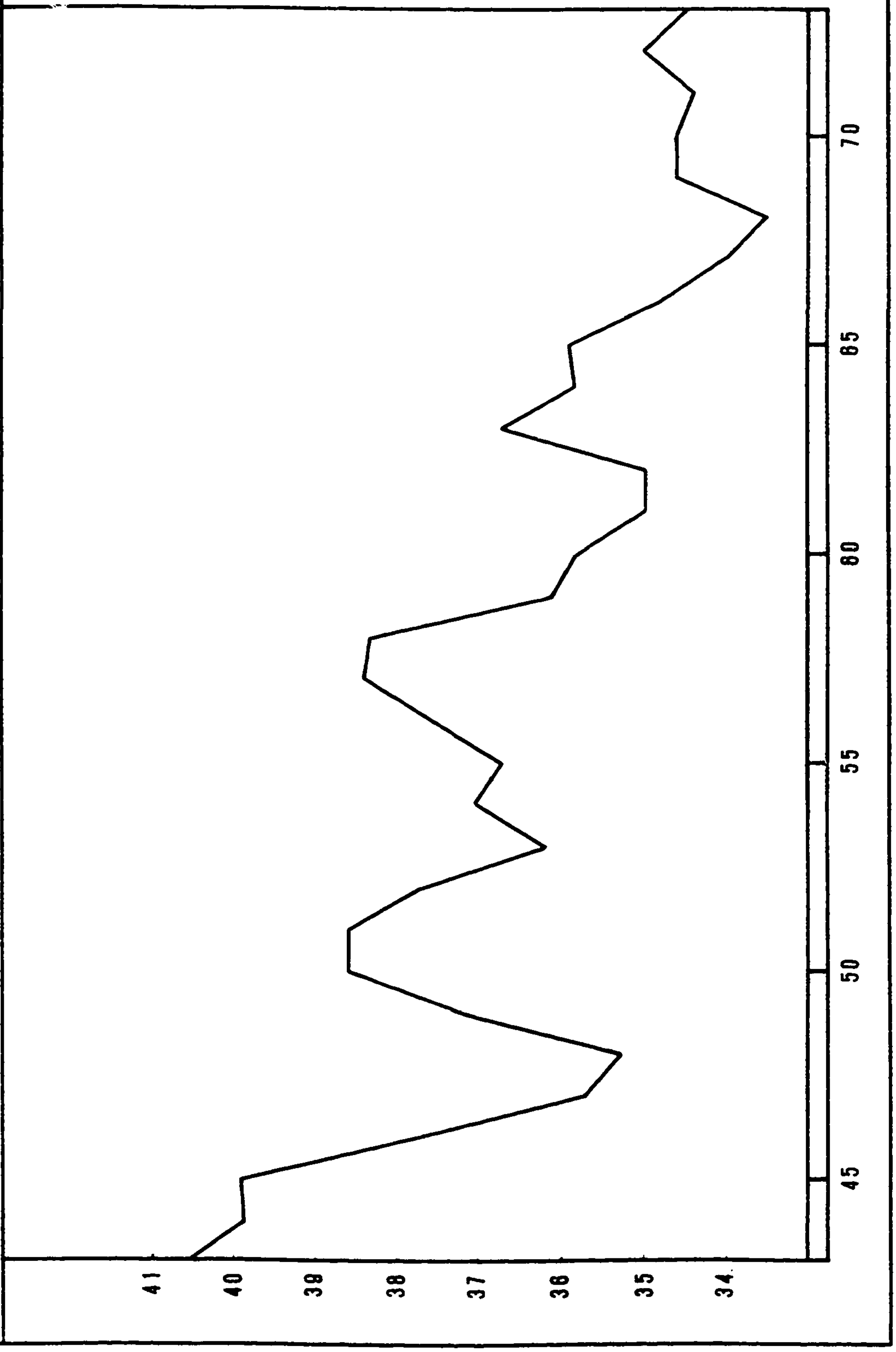
Figure 13 Continentality at Lewiston, Idaho



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portion of this region stretches from central Montana to Lake Michigan, while the eastern area covers not only the New England states, but also extends southward into the Chesapeake Bay region. The entire province is grouped together under the heading the "Northern Plains and New England" due to the homogeneous character of continentality change throughout the territory.

The results of the previous investigation into the interdecennial variability of continentality indicates that the long-term pattern of change may be divided into two distinct phases of disproportionate duration. From 1934-43 to 1944-53 continentality experienced a sharp decline in this region. Values as large as -6% are commonplace. Then from 1944-53 to 1954-63 and again from 1954-63 to 1964-73 continentality shows a modest, but significant, rise across the Northern Plains and New England. Despite the fact that the duration of the increase appears to be twice that of the initial decrease, the magnitude of the recent rise does not approach that of the earlier decline.

To substantiate the validity of this long-term trend, a graph showing the annual variation of continentality for Billings, Montana is presented (Figure 14). The aforementioned trend is distinctly evident. The early decrease up to about 1947 is on the magnitude of 7.8%, while the subsequent rise is only 5.2%. (It should be noted that because of the phase-shifting which accompanies the use of a 10-year moving mean, it is not correct to designate a certain trend as beginning or ending as a specific date; hence, the use of the terms "about" and/or "approximately" in this context.) Over the

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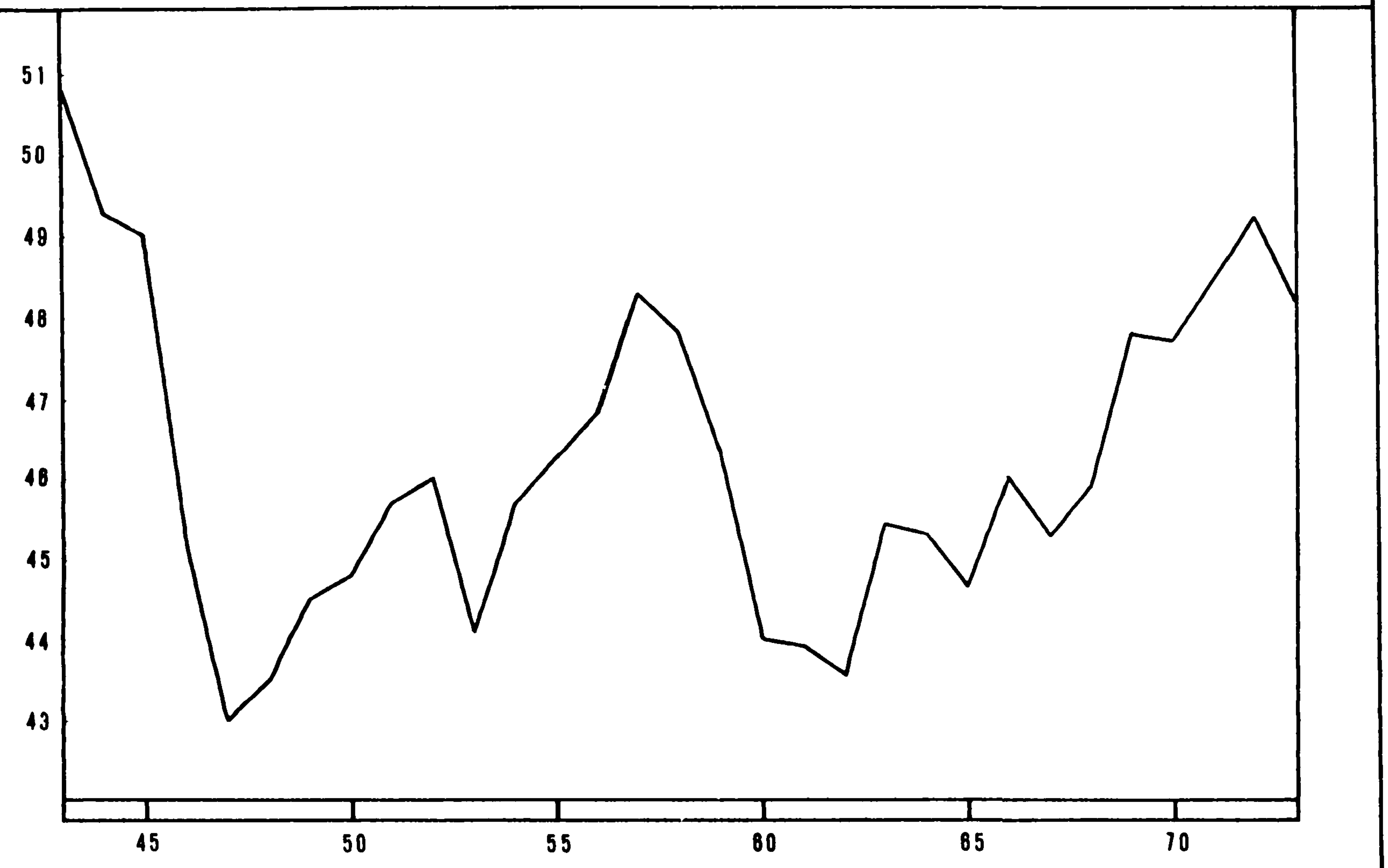
Figure 14 Continentality at Billings, Montana



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last 20 years or so continentality has risen sharply by 4.6%. In spite of this fact, the long-term net change in continentality in the Northern Plains and New England is still downward since 1934.

The East

The fifth and final region is the "East". This region is comprised of the remaining portion of the conterminous United States not previously allotted to the other four regions (see Figure 10). As such, it is by far the largest of the five regional delineations. Grouped together within this region are those stations which experienced a decrease in continentality from 1934-43 to 1944-53, then an increase from 1944-53 to 1954-63, and finally a decrease from 1954-63 to 1964-73.

Figure 15 represents the annual variability of continentality in Norfolk, Virginia, for the years 1934-73. The long-term tendency of continentality, as described previously, is distinctly discernible. During the earlier years of this 40-year period, continentality experienced a more or less steady decline until approximately 1954. This is a decrease of approximately 3.8% over a period of 21 years. Over the next decade continentality increased 4.3%. During more recent years the trend is gradually downward. Like the Interior Northwest and the Northern Plains and New England, the overall net change in continentality in the East since 1934 is downward.

Statistical Evaluation of Regional Trends

It now becomes desirable to determine whether or not these

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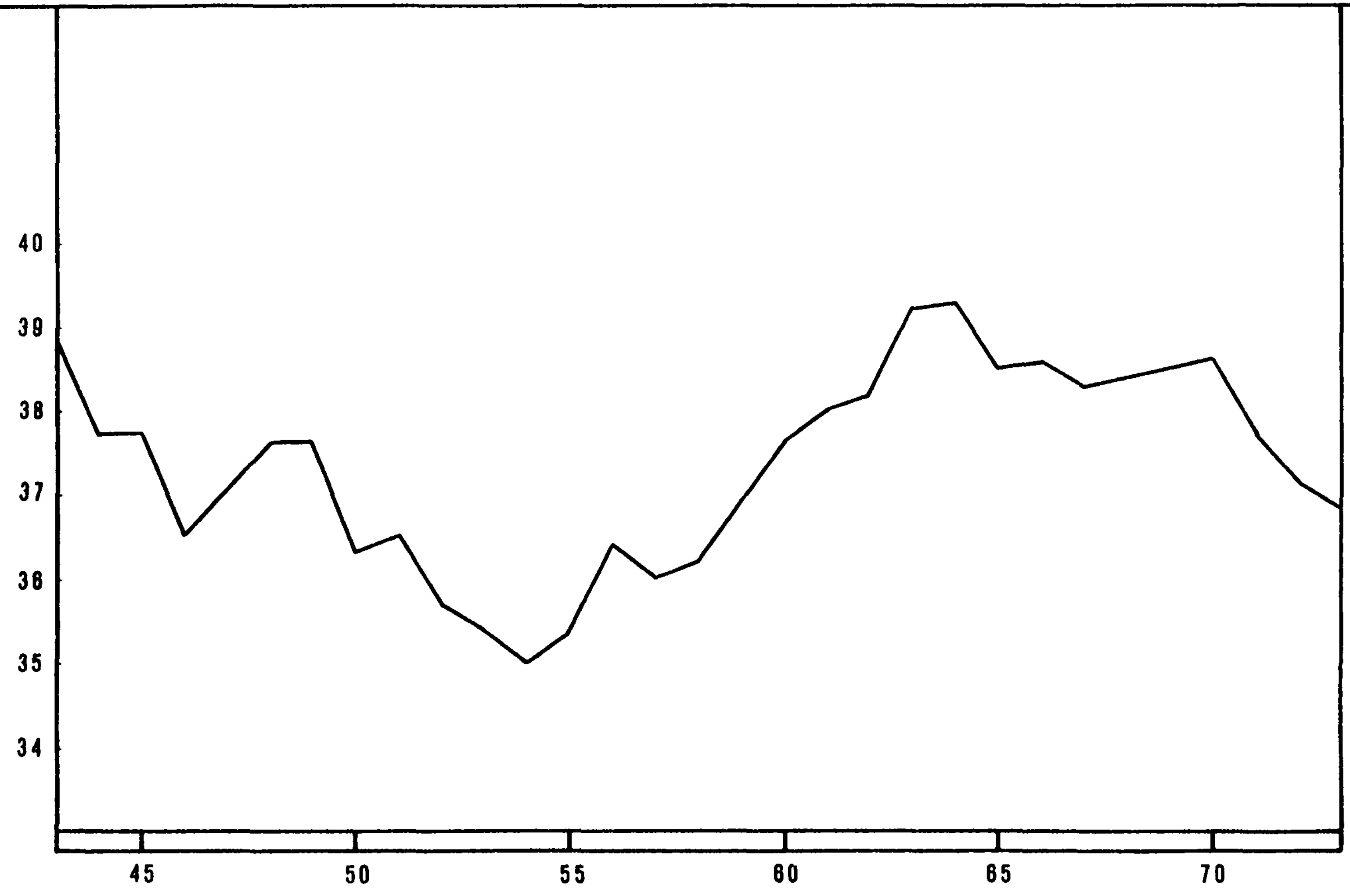
Figure 15 Continentality at Norfolk, Virginia



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temporal patterns of continentality variability exhibit a statistically significant unidirectional tendency. By depicting the annual variability of continentality in each region through implementation of the 10-year moving mean, the temporal pattern of change is somewhat simplified. This procedure tones down the amplitude of the oscillations which are inherent in any temporal pattern of temperature values. The so-called "noise" is minimized, and the directional tendency displayed by the data begins to emerge from beneath the random element. Although this procedure of employing a moving mean to "filter" out the noise is one frequently used in climatological studies, it is not an altogether efficient process. The remaining "smoothed" series data may frequently display what appears to be a distinct trend; however, before attaching any climatological significance to such findings, it must be determined whether or not such trends are statistically significant--hence, unidirectional--or whether they may have resulted merely from random data. This can be accomplished by estimating the random element in the original data set.

Quite some time ago, J. M. Craddock (1957) devised a procedure for determining whether a suspected climatic trend may be simply chance occurrence--random--or whether there is an actual unidirectional change taking place. By applying two independent filters to a time-series data set, two independent estimates of the variance of the original data set may be determined. These may then be compared using Snedecor's F-Test. If the estimates are comparable, it may be concluded that the pattern depicted by the original data

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set is not statistically significant and, therefore, does not depict an overall trend. If, however, one estimate is significantly larger than the other, then the trend is thought to represent a true climatic change (Craddock, 1957).

In this study the relationship between these two variances is termed the "variance ratio" (VR) and is expressed as $60V_{10}/V_3$. The variance of the original data set after it has been smoothed by a 10-year moving mean is V_{10}, while V_3 represents a three-year filter variance. This latter value is obtained by employing the formula $V_3 = -X_{n-1} + 2X_n - X_{n+1}$. Once the variance ratio is derived, it is compared with the appropriate F-statistic to determine whether or not the results are significant at a certain level. If so, then the original data is thought to depict a statistically valid unidirectional trend.

By following this prescribed procedure, the temporal pattern of continentality characteristic of each of the five regional divisions of the United States may be tested. In order to be significant at the .05 level, the variance ratio (VR) must exceed an F-value of 3.50. If the VR value is less than 3.50, then the belief that the pattern of continentality variability represents a unidirectional tendency of change is rejected, and it is concluded that no overall trend exists. Table 6 summarizes the results of this investigation (see page 75).

From the data displayed in Table 6 it must be concluded that there is no unidirectional tendency or overall trend depicted by the annual variability of continentality in any of the five regions.

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Table 6

Testing the Regional Trends of Continentality

City	V_{10}	V_3	VR	Conclusion
San Francisco	2.54	48.83	3.1160	rejected
Phoenix	1.43	104.66	.8198	rejected
Lewiston	3.49	285.12	.7338	rejected
Billings	3.94	418.36	.5648	rejected
Norfolk	1.40	149.79	.5592	rejected

Only in the Far Southwest--at San Francisco--does the temporal pattern of change approach the level of significance. This conclusion corroborates the initial impression obtained via a simple visual examination of Figures 11 through 15. This is not to say, however, that the patterns of continentality variability depicted in Figures 11 through 15 represent merely random patterns of change. Significant non-random fluctuations such as periodicities and cycles may well occur. To separate the random elements from the non-random elements is, however, beyond the scope of this study.

Although previous statistical analysis has determined that the temporal patterns of continentality in these five regions do not represent overall trends, there nevertheless exists specific patterns of change which are unique to each region. The explanation for these unique patterns of change resides in the character of warm month and cold month temperatures within each individual region. How have changes in annual monthly temperature extremes created the temporal patterns of continentality which characterize these five regions?

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CHAPTER VII

RECENT CLIMATIC CHANGES AND THEIR EFFECT ON TEMPERATURE TRENDS IN THE UNITED STATES

Measuring Climatic Change: A Word of Warning

The question of whether or not our climate is changing is one that has long intrigued climatologists as well as laymen. The recent increase in the number of studies and articles written concerning this phenomenon attest to its unflagging--if not mounting--interest. However, before a general discussion of the character of climatic change in the twentieth century is undertaken, certain limitations concerning the validity of such findings should be acknowledged.

There is a significant degree of difficulty involved in assessing the nature and magnitude of any climatic change, for unfortunately many other factors may affect weather records (see especially Mitchell, 1953). As such, it is extremely difficult to verify whether a climatic change or trend--particularly a small or gradual one--is climatologically real or whether it is the result of observational difficulties and/or artificial modification of the local environment. The first step toward solving this dilemma is to recognize and identify the observational and local-environmental factors capable of producing temperature changes which are not climatologically real.

A major problem affecting the reliability of weather records to accurately divulge patterns of climatic variation involves loca-

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tion and site changes as well as corresponding changes of exposure. The locations of temperature instruments change from the rooftops of downtown buildings to ground level exposures in parks and on lawns and possibly back to the tops of skyscrapers before ultimately moving to airport sites several miles away (Von Eschen, 1958). These latter changes have been particularly prominent in the years following the culmination of World War II as instruments were relocated from urban areas to, in many cases, a more rural environment (Callendar, 1961). Often accompanying such changes is a distortion in the continuity of the original weather record (Landsberg, 1960). Equally important is the frequent relocation of equipment when one observer can no longer serve and a new cooperator must be found (Von Eschen, 1958). Each shift in site or location reduces the reliability of the record to accurately portray climatic trends and, thus, renders the resulting temperature record less desirable for studying long-term climatic changes.

A second factor hindering the identification of climatologically real and significant changes is the affect of the urban environment. Most of the readily accessible climatic data covering a period of many years are for urban stations (Wanl, 1968). The feasibility of employing such data in an attempt to discern climatological trends is greatly reduced by virtue of the fact that urban areas tend to develop their own climate which may be radically different from that of the surrounding rural region (see especially Landsberg, 1970). Generally, an urban location has higher temperatures--both seasonally and annually--than does a rural station in

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the same region (Mitchell, 1961b). This differential is due largely to the many heat-producing activities characteristic of modern industrial cities (Landsberg, 1958). As urban areas grow larger, this temperature differential between the city and the surrounding rural region increases. Mitchell (1953) has discovered that temperature increases in urban areas are directly proportional to the square root of the population increase. Thus, if the temperature trend is believed to be downward, data from an urban area may not reveal the change. On the other hand, if the trend is upward, it will be difficult to apportion what part of the rise is natural and what part is artificially induced by examining the weather records of an urban location. The problem remains one of determining what part of a given temperature trend is climatically real and what part is the result of other factors.

Documentation of the Warming Trend, Circa 1880-1940

A downward temperature trend--referred to by Baerreis and Bryson (1965) as the "Neoboreal" and by Brooks (1951) as the "Little Ice Age"--apparently began in the middle of the sixteenth century (Wahl, 1968). During this era glacial advances were noted in both Europe and North America (Lamb, 1966a). This distinctly cooler climate continued well into the nineteenth century (Wahl, 1968). The mean annual temperature trends of the eastern and midwestern United States--the former represented by Washington, D. C., and Philadelphia, Pennsylvania, and the latter by St. Louis, Missouri, and

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Minneapolis, Minnesota--reveal marked recessional tendencies from about 1845 until 1875 (Kincer, 1946).

Toward the end of the nineteenth century a reversal of the previous cooling trend occurred. Wahl (1968) suggests that the time of the transition was 1880, while Kalnicky (1974) and Kraus (1956) both designate 1895 as the beginning of the recent warming trend. Nevertheless, a somewhat irregular, but very definite, increase in mean annual temperatures began in the last years of the nineteenth century and continued well into the present century (Lysgaard, 1949). Although this rising trend proved statistically significant from the Arctic to latitude 45°S (Callendar, 1961), there were pronounced spatial differences concerning the temporal rate of increase. In the United States the period 1931-55 experienced a greater increase than did the earlier years, 1906-30 (Landsberg, 1960). In the remaining areas of the world where this rising trend was significant, the net increase in mean annual temperatures was especially rapid during the first decades of the twentieth century (Willett, 1950). Considering both the spatial and temporal aspects of this trend, the documented rise in temperatures was most pronounced in the middle and high latitudes of the northern hemisphere (Kincer, 1946).

In the United States this rising trend was particularly pronounced. The upward swing of temperatures in the eastern and midwestern portions of the nation was nearly uninterrupted from the late nineteenth century until the early 1930's. Even then there was no indication of a reversal or a leveling off (Kincer, 1933). This same trend was also found in the New England region by both Conover

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(1951) and Landsberg (1967). The latter discovered the upward tendency predominant throughout the first four decades of this century, while the former found that the rising trend continued until the midpoint of the twentieth century. Elsewhere in the United States temperature trends exhibit this same tendency. Climatic stations in Minnesota show increases in average annual temperatures as well as in mean summer and winter temperatures from 1900 to 1958 (Baker, 1960), while data from New Mexico displays this identical pattern (Von Eschen, 1958).

It has been suggested by some (for example, Mitchell 1953) that the warming trend characteristic of the early twentieth century may have been more apparent than real since it occurred during a time of rapid urban development when many climatological outposts were located in downtown sites. In such an environment, thermometers may be unduly affected by artificial influences native to the urban surroundings. As a test of the reliability of the urban weather records, Kincer (1933) compared data from nearby rural cooperative climatological stations with city records. He found the upward trend to be even more pronounced in the rural regions and, as such, he concluded that the rising trend indicated by urban data was indeed real (Kincer, 1933, 1946). However, it is probably more accurate to state that the warming trend of the early portion of the twentieth century was the result of both (1) a climatologically real rise in temperatures, and (2) the coincidental growth of urban areas (Mitchell, 1953).

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Documentation of the Subsequent Cooling Trend, Circa 1940-1975

Sometime in the 1940's or early 1950's the warming trend of the first portion of the twentieth century began to diminish. Kalnicky (1974) suggests that 1950 was the turning point. Results of an investigation by Mitchell (1961a) reveal that as early as 1940 the rising temperature trend had leveled off, and shortly thereafter began to reverse itself. These findings agree with the conclusion of Lamb (1966b) that the height of the warming has passed and that the climate is now reverting to the cooler climate characteristic of the mid-nineteenth century. This recent decline of temperatures is of a magnitude that has occurred only three or four times since 1700. It may well be the most sustained downturn in all that time (Lamb, 1966b).

The first hint of an approaching temperature recession was uncovered by Kincer (1946) while examining data for climatological stations across the United States for the period 1933-45. Data from this 13-year interval not only indicated that the previous warming trend was waning, it furthermore contained a veiled suggestion of an impending decline. In addition, the subsequent recession was foreshadowed in a number of regional studies. In the far southwest, annual temperatures--as well as summer and winter temperatures--have revealed a marked leveling in the early 1950's (Von Eschen, 1958). Data from Minnesota discloses that the rising trend of earlier years terminated abruptly in the mid-1950's (Baker, 1960). At Blue Hill Observatory near Boston (designated as a "bench-mark station" by the

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U.S. Weather Bureau), winter temperatures remained more or less constant in the late 1940's. This led Conover (1951) to conclude that the earlier warming trend had indeed reached its peak.

The actual downward trend in temperatures since 1940-50 was perhaps first recorded in studies of Arctic data from the Scandinavian sector by Wallen and Ahlmann (1955) and Hesselberg and Johannessen (1958). Since the middle and late 1950's, a large number of studies have further documented this cooling trend. Landsberg (1967) has found that temperatures in the circum-Atlantic region have been headed downward since the decade 1940-50. This concurs with the conclusion of Conover (1967) that the mean annual temperature in southern New England has declined since the mid-1950's. In this same region, Spar and Mayer (1973) have shown that winter temperatures in New York City have declined sharply since about 1954. Further evidence of this cooling trend has been uncovered in the Great Lakes region. Examination of temperature data for Eau Claire, Michigan, has indicated pronounced summer cooling since the 1930's and rapid winter cooling since the late 1940's and early 1950's (Eichenlaub, 1971). This corroborates the conclusions of Kerr (1973) who discovered a significant decrease in both summer and winter temperatures from 1931-55 to 1940-69 which was widespread throughout the Great Lakes region. The most recent documentation of this downswing in temperatures is that of Kalnicky (1974) who maintains that this recessional tendency exists in most portions of the Northern Hemisphere. In light of this recent downward temperature trend, it

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appears as though the "Little Ice Age" or "Neoboreal" did not terminate near the end of the nineteenth century, as previously thought, but instead was only interrupted by a temporary warm spell of some 60 to 70 odd years (Wahl and Lawson, 1970).

Causal Theories of Climatic Change

What is the cause of this pronounced oscillation of temperatures during the last 100 years? Many different theories have been postulated and propounded in an attempt to account for this thermal variation--some based on terrestrial effects and others based on extraterrestrial phenomenon--however, as of yet, there is no universal agreement as to the cause for these recent climatic fluctuations. Since the literature in this field is so immense, no attempt will be made to summarize all the previous findings. Nor would such a monsterous work retain its relevancy long, for new facts and ideas are continually being added to this realm of knowledge. In view of the aforementioned statements, only three or more widely accepted theories of climatic change will subsequently be discussed. They are by no means meant to stand as the final word on this subject.

One of the most popular theories advocated is based on a variation in the output of solar energy. Mironovitch (1960) has studied the long-term temporal aspects of a solar index derived by Baur (1949) which measures the difference between areas of faculae (intensified radiation emission) and areas of dark spots (weakened emission) on the sun's surface. The cumulative anomalies of this index over the

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period 1874-1958 correlate rather closely with the character of global temperature variation during this same period. In addition, by measuring the light reflected by Neptune and Uranus, Johnson and Iriarte (1959) have shown evidence of a 2% increase in the solar constant in the years immediately preceding 1959. Schell (1961) believes that the warming trend of the first portion of the twentieth century was caused by this increase in the output of solar energy. It appears as though a major portion of the observed variation in mean annual temperatures could be accounted for by a corresponding change in the solar constant (Mitchell, 1961a).

Shapley (1953), on the other hand, has concluded that satisfactory proof of a direct link between the variability of the solar constant and terrestrial variation in temperature trends is still lacking. If the rising temperature trend of the early twentieth century were caused by an increase in the solar constant, one would expect the trend to be most pronounced in the sunny subtropical arid and semi-arid regions of the globe. This is not the case, however, for the subtropical regions--particularly Australia and the Lake Balkhash-Caspian Sea area of central Asia--are notable for their distinct lack of any temperature trend since the turn of the century (Callendar, 1961). Theories of climatic change which suggest that temperature trends are a function of a corresponding variation of solar energy output are not reasonable, since there is no general agreement as to the type of temperature change which would follow a given variation in the sun's energy level (Tullett, 1970). An

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increase in the solar constant would not necessarily lead to a resulting increase in terrestrial temperatures. As an example, Simpson (1934) suggests that glacial periods are brought on by an initial increase in the solar energy received by the earth. Such an increase would enhance evaporation which would in turn give rise to increased cloudiness and precipitation in the middle and high latitudes. It is unlikely, however, that a small variation in the energy output of the sun (such as that recorded by Johnson and Iriarte) would result in the large-scale adjustment of the global circulation (yet to be discussed) which has been documented in recent years (Sawyer, 1966). As such, a variation in the output of solar energy is probably not a reasonable explanation for the recent thermal oscillation (Callendar, 1961; Tullett, 1970).

A second theory advocated to explain the recent thermal fluctuations relates to the variable character of atmospheric carbon dioxide. The importance of this gas resides in its ability to absorb longwave terrestrial radiation. This heat-energy is then re-radiated back to the earth as counter-radiation. In this fashion both the atmosphere and the earth are heated. Variations in the amount of carbon dioxide found in the atmosphere can cause corresponding changes in the amount of counter-radiation returned to the earth. This may result in terrestrial temperature changes sufficiently large enough to modify the climate (Plass, 1956).

Since 1900, the amount of carbon dioxide present in the atmosphere has risen substantially (Callendar, 1958). While precise

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comparisons are not possible, available data suggests that the increase has been of the magnitude of approximately 10% (Plass, 1956). This increase may be reasonably attributed to the ever-mounting combustion of fossil fuels (Bolin and Eriksson, 1959). Callendar (1938, 1949) suggests that the rising temperature trend of the early decades of the twentieth century was due to increased counter-radiation from the extra carbon dioxide in the atmosphere. Kaplan (1960), Mitchell (1961a), Pales and Keeling (1965), and Plass (1956) agree with this conclusion.

There is, however, one obvious flaw in the application of the carbon dioxide theory. In contrast to the other theories of climatic change, the carbon dioxide theory predicts a rising temperature trend which will continue for centuries, or as long as fossil fuels are burned in significant quantities (Plass, 1956). Due to the probable continued consumption of fossil fuels, Plass (1956) forecasts a 30% increase in the amount of atmospheric carbon dioxide by the year 2000. Such an increase should bring about a coincidental rise in global temperatures. This predicted thermal increase has not materialized, however, as has been previously noted. The marked cooling trend of recent years has, thus, greatly diminished the credibility of the carbon dioxide theory.

Another of the more widely accepted theories of climatic change involves particulate matter (dust) in the atmosphere. One of the largest contributors to the increasing turbidity of the atmosphere (see Peterson and Bryson, 1968) has been volcanic eruptions.

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These events, at least those of catastrophic magnitude, have long been suspected of influencing large-scale climatic changes in the realm of temperatures (see Humphreys, 1920; Wexler, 1952). Wexler (1953) has suggested that the rising temperature trend of the first few decades could have been due to increased atmospheric transparency, owing to a reduced number of dust-producing volcanic eruptions during these years. In a similar fashion, the recent reversal of this rising trend has been attributed to an increase in particulate matter (dust) in the atmosphere from both the increased volcanic activity of late and from manmade effects (Bryson and Wendland, 1968; Junge, 1963; Mitchell, 1968; and Peterson and Bryson, 1968).

There appears to be a firm foundation for this latter assumption. Mitchell (1961a) has discovered that volcanic dust injected into the atmosphere by the eruptions of Krakatoa (1883), Katmai (1912), and Kamchatka (1957) depressed normal incident radiation by 10% or more for several months following the eruptions. Under these circumstances, resulting variations in surface temperatures are to be expected; however, the duration and magnitude of these effects are still under investigation. A correlation of transient depressions of surface temperature with the dates of major volcanic eruptions has produced highly significant results (Mitchell, 1961a). This lends support to the hypothesis that the low global temperatures of the late nineteenth century were attributable to the 1883 eruption of Krakatoa in Indonesia. In addition, it is conceivable that the rapid rate of cooling in the northern hemisphere within recent years is related to the Mt. Spurr, Alaska, eruption of 1953;

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the great Bezymyannaya, Kamchatka, eruption of 1956; and the more recent eruption of Mt. Agung in the East Indies in 1963 (Mitchell, 1961a).

Global Circulation Changes Since the Late Nineteenth Century

Presently, there is no universal agreement concerning the cause(s) of the recent temperature fluctuations. The three theories previously discussed are perhaps the more widely debated and, hence, the most popular of the many conjectures concocted to explain the climatic changes of late. Although the ultimate cause(s) of these recent and well-documented climatic fluctuations cannot, as of yet, be clearly and unquestionably identified, certain climatological manifestations or ramifications of this unknown causal agent(s) are distinctly evident. In addition to the most obvious change of a thermal nature, each climatic oscillation has been accompanied by a corresponding change in both the large-scale pattern and strength of the global circulation.

Around 1895 there occurred a sudden and pronounced change in the pattern and overall energy level of the global circulation (Kraus, 1956). The subsequent five decades were characterized by accentuated zonal windflow in the belt of the temperate-westerlies (Lamb, 1966b). It has been calculated from measurements of spatial differences in surface pressure that the period from 1900 to 1940-50 was the time of the strongest and most intense global circulation (Lamb, 1966b). Coincidental with this shift from meridional to

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zonal windflow was a marked decrease in precipitation in tropical and equatorial regions (Kraus, 1955). This phenomenon is related to the abating size of the Equatorial Low and the corresponding increase in the spatial magnitude and intensity of the subtropical anticyclones during this same era.

The nature of climatic change since 1940-50 indicates an abrupt return to the circulation patterns and climatic regime which prevailed prior to the prominent warming trend of the first half of the twentieth century. Both Lamb (1966b) and Wahl and Lawson (1970) characterize the present climatic conditions as being similar to those characteristic of the mid-nineteenth century. A reversal of the directional tendency of windflow patterns from zonal to meridional has been observed over extratropical climates (Kalnicky, 1974; Lamb, 1966b). Evidence corroborating this claim comes from Dzerdzeevskii (1971) who has found meridional circulation patterns more prevalent during both summer and winter since the midpoint of the twentieth century. This decline in the strength of the zonal westerlies along with a coincidental increase in the meridional character of the windflow patterns has brought about the recovery of rainfall in the lower latitudes. Prominent increases in the water levels of Lake Victoria, Lake Nyasa, and Lake Tanganyika since 1940-50 have been recorded (Lamb, 1966b).

The reestablishment of rainfall patterns in tropical and equatorial regions following the recent climatic change suggests a shift in the preferred positions of the troughs and ridges in the upper-air westerlies which has worked to weaken the zonal windflow

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and enhance the meridional tendency (Lamb, 1966b). Also indicated is an increase in the north-south amplitude of these features (Lamb, 1966b). The observed temperature fluctuations within the temperate latitudes (yet to be discussed in detail as it applies to the study area) are also related to the semi-permanent displacement of the average ridge-trough systems of the zonal westerlies (Callendar, 1961). One such change--the westward displacement of the ridge-trough system over the Atlantic sector of the northern hemisphere--has previously been documented (Lamb and Johnson, 1959; Lamb, 1966a). In addition, the four "centers of action" (Azores High, Pacific High, Icelandic Low, and Aleutian Low) germane to the climate of the United States have all undergone significant displacements between 1905-65 (Angell and Korshover, 1974). The migration of the two features whose position most influences the climate of the study area--the Pacific High and Icelandic Low--is particularly noteworthy. The Icelandic Low moved northward during the early part of the twentieth century and reached its northermost position in 1940 at the pinnacle of the recent warming trend (Angell and Korshover, 1974). The subsequent southward shift of this feature since 1940 has been documented by Gommel (1963), Kutzbach (1970), and Angell and Korshover (1974). Across the continent the Pacific High has also undergone a marked latitudinal transition. This feature has moved from 31°N to 35°N between 1906 and 1965 (Angell and Korshover, 1974). What effect will these circulation changes have on the spatial pattern of temperature trends in the United

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States?

The Effect of Circulation Changes on Temperature Patterns in the United States

When compared to the climatic normals of the 1931-60 period, the spatial pattern of mean annual temperatures in the United States during the decade 1960-70 bears a close resemblance to that characteristic of the mid-nineteenth century. The eastern and central United States exhibit negative anomalies, whereas the western portion of the nation displays positive ones (Wahl and Lawson, 1970). This dichotomous temperature pattern results from the fact that since 1950 the western third of the United States has undergone warming, while the eastern two-thirds has experienced cooling (Kalnicky, 1974). The immediate causal factors operating to produce this spatial arrangement of temperature characteristics is the westerly wave pattern. Since 1950, the upper-air pattern of Rossby Waves (Rossby, 1939) has consisted of large troughs over the eastern portion of the nation and ridges over the western areas (Kalnicky, 1974). In addition, the aforementioned migrational tendencies of the Pacific High (northward) and the Icelandic Low (southward) during recent years may figure prominently as contributing factors toward the establishment or reinforcement of this circulation pattern.

The climatological ramifications of such a pattern on terrestrial temperatures is at once apparent. Northerly airflow on the backside of such troughs brings cold polar air southward into

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the eastern and central portions of the United States causing negative temperature departures. In much the same way, southerly airflow to the rear of these ridges advects warm tropical air over the western areas of North America, thus creating positive temperature anomalies.

The recent cooling trend in the eastern two-thirds of the United States is particularly well-documented. Eichenlaub (1971) has examined temperature records for a station in the fruitbelt of southwestern Michigan and has found marked summer cooling since the 1930's and rapid winter cooling since the late 1940's and early 1950's. He attributes this temperature decline to a deepening and probable westward migration of the 700-mb trough over the eastern United States. This concurs with the conclusion of Namias (1967, 1970) that this trough has experienced a deepening and intensification during recent years. The discovery of an unusually high incidence of troughs over the eastern portion of the United States during the period 1949-63 further substantiates these findings (Stark, 1965).

Under these conditions, increased cold air advection into the eastern and central United States would be facilitated. Examination of the changes in the upper-air circulation--as represented by radiosonde data from Sault Ste. Marie, Michigan--reveals a recent shift of mean resultant winds at the 700-mb level to more northerly quadrants. At the same time, surface winds at Grand Rapids, Michigan, show a change to more northerly directions since 1950 (Eichen-

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laub, 1971). Bacon (1974) hypothesizes that this change in the character of the circulation from zonal to meridional will not only result in increased cold air advection from more northerly latitudes, but will also be accompanied by an increase in cloudiness. Such an increase has actually been recorded by Changnon (1974) in Urbana, Illinois; by Kerr (1973) in Michigan; and by Landsberg (1951) in Washington, D. C. Mitchell (1953) surmises that this increase may also be paralleled in New England.

Whether this increase in cloudiness in recent years is largely the result of increased cold air advection or the inadvertent modification of the atmosphere by man (see Manabe, 1970; Bryson, 1970; Schaefer, 1970) is not certain, nor is it as important to this study as are the consequences of this increase. Changnon (1974) has discovered that this increase has resulted in pronounced temperature modulation in recent years. This phenomenon reduces the interval between maximum and minimum temperatures by lowering the former and raising the latter. In this fashion, the annual range of temperature may be significantly reduced. Changnon (1974) maintains that the continentality of the midwestern portion of the nation is declining as the result of temperature modulation. If this feature is widespread across the eastern two-thirds of the United States, it may represent the first step toward explaining the observed temporal and spatial variation of continentality over the last 40 years. The previously discussed dichotomous pattern of temperature change in the United States should provide additional information toward this end.

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CHAPTER VIII

EXPLAINING CONTINENTALITY VARIABILITY THROUGH SEASONAL TEMPERATURE VARIATION

From the previous discussion and documentation concerning the character of climatic change in North America during the twentieth century, a rather distinct temporal and spatial pattern of variation emerges. Throughout the first 40 to 50 years of this century the conterminous United States experienced a widespread warming trend. Sometime in the late 1930's or 1940's this rising trend leveled off in the eastern two-thirds of the nation, and since approximately 1950, mean annual temperatures in this region have declined. During the 25 or so years which have elapsed since this reversal, temperatures in the western third of the country have continued their upward tendency of earlier years. The net result of these climatic changes is the creation of a dichotomous regional pattern of temperature variability--warming in the west and cooling in the east--in which the thermal interval between the two regions is expanding.

What effect, if any, have these temperature changes had on the spatial and temporal character of continentality in the conterminous United States? The results of a previous investigation concerning the interdecennial variability of continentality in the conterminous United States made possible the division of the study area into five regions (see Chapter VI). These features were delineated according to the nature of the temporal trend of conti-

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nentality characteristic of each. Does this five-fold division of the United States relate in any way to the dichotomous regional pattern of temperature change? What effect have the recent temperature changes in the United States had on the temporal trends of continentality in each of these five regional divisions?

By examining the annual variation in the mean temperatures of both the warmest and coldest months in each of these five regions, the immediate cause for the observed changes in the annual temperature range may be uncovered. The temporal trend of continentality in each of these five regions may thus be explained by examining the seasonal nature of recent temperature changes in each area. Through examination of data derived from the randomly selected station within each region, subsequent discussion will (1) review the long-range tendency of continentality in each region; (2) explain the observed temporal variation of continentality in terms of the variable character of the mean temperature of the warmest month and/or the mean temperature of the coldest month; and (3) relate these temperature trends to the dichotomous regional pattern of temperature change across the United States.

Reexamination of the Five-Fold Regional Division of the United States

The Far Southwest

Continentality in the Far Southwest has increased more or less continually since 1934. The immediate cause of this rising trend may be discerned by examining Figure 16, which depicts the temporal

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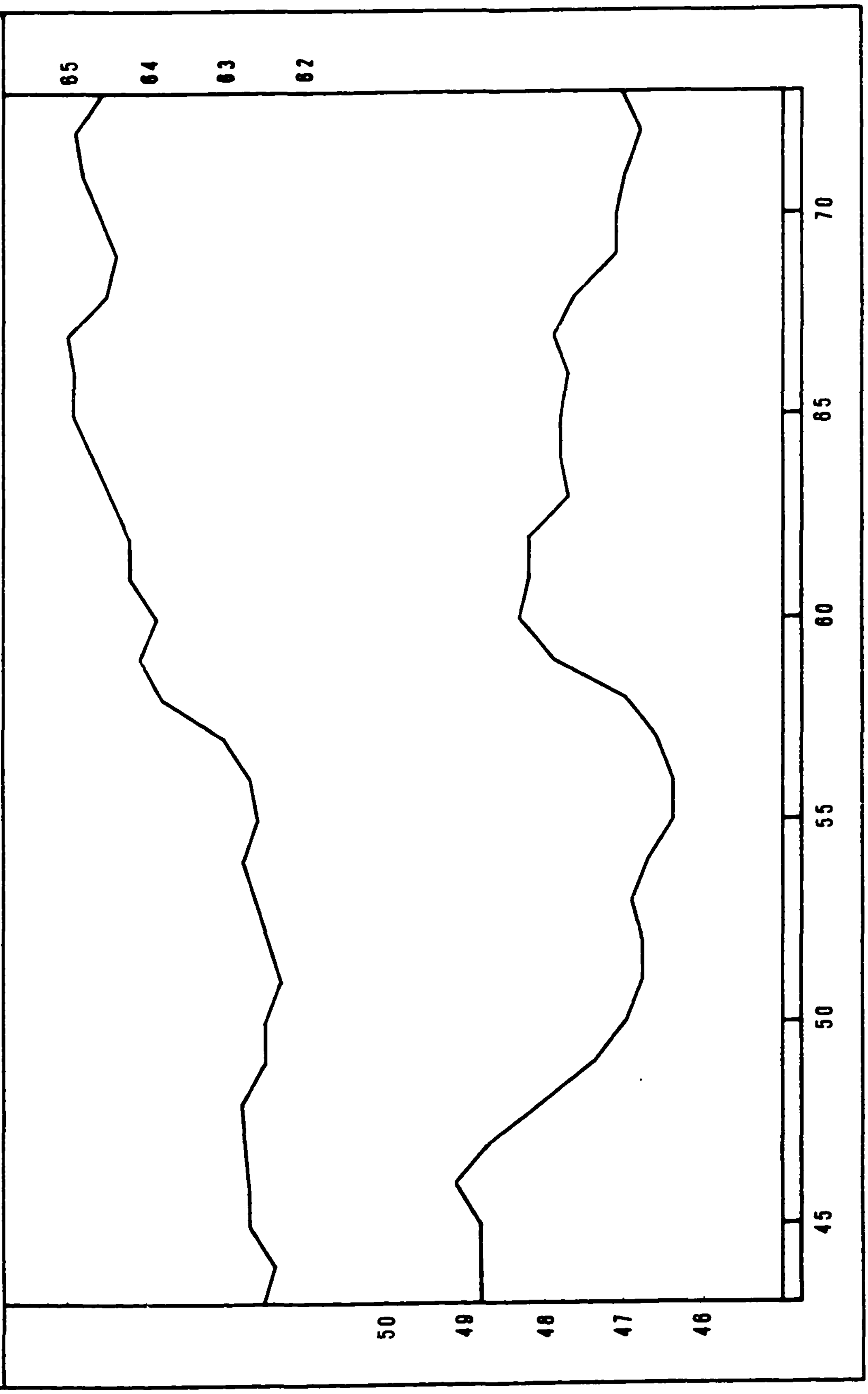
Figure 16 Annual Monthly Temperature Extremes at San Francisco



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trend of both the mean temperature of the warmest month (top line) and the mean temperature of the coldest month (bottom line) at San Francisco, California. Again, a 10-year moving mean is employed so that the linear thermal trends displayed here are more readily comparable with the temporal trend of continentality shown in Figure 11.

The line representing the annual variation of the mean temperature of the warmest month reveals an initial period of relatively constant values extending into the mid-1950's. Since then, warm month temperatures have risen rather steadily by more than 2°. The linear trend depicting the annual variation of cold month temperatures is quite diverse from that of warm month temperatures. Cold month temperatures drop sharply into the mid-1950's. Following this departure there is an acute ascent, followed by a modest, though significant, decline until recent years. It is interesting to note that like the mean temperature of the warmest month, the mean temperature of the coldest month has also experienced a net increase since approximately 1955. Although this rising trend is much more pronounced in the case of the former, the net increase in both monthly temperatures since the mid-1950's supports the claim of Kalnicky that the western portion of the United States is experiencing a warming trend since 1950.

How do these temperature trends account for the temporal variation of continentality in the Far Southwest? A comparison of Figures 11 and 16 reveals a simple two-fold explanation. The initial rise in continentality is due to a prominent decline in cold

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month temperatures. During this era, warm month temperatures remain rather stable; hence, enlargement of the mean thermal amplitude. Following a modest decrease in the late 1950's, continentality again continues its upward tendency. This most recent trend results from waning cold month temperatures and waxing warm month temperatures.

It appears that the upward trend of continentality in the Far Southwest is produced by an increase in the mean temperature of the warmest month and a coincidental decrease in the mean temperature of the coldest month. The former trend is the more prominent of the two, with the latter revealing more irregularities and a greater degree of minor fluctuations. This suggests that (1) the warming trend in the western portion of the United States may be more pronounced during summer months and less recognizable during recent winters, and (2) the character of winter temperatures may determine the year-to-year variation of continentality in this region. If these statements are true, then the Interior Western Corridor and the Interior Northwest should show similar temperature trends since they are both located in the western third of the nation which is experiencing a recent warming trend. Here, then, is the first indication of a relationship between the dichotomous regional pattern of temperature change and the five-fold regional division of the United States according to the temporal character of continentality variability.

The Interior Western Corridor

The temporal trend of continentality in the Interior Western

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Corridor (see Figure 12) may be divided into three distinct phases: an early increase, followed by an abrupt decline, and more recently a steady, continual rise. By magnitude, as well as duration, the largest change is the recent rise of 4.2% since approximately 1959. The net change in continentality over this entire period is +3.2%.

Figure 17 depicts the annual variation of the mean temperature of both the warmest and coldest months at Phoenix, Arizona. The similarity of both linear trends to their respective counterparts in the Far Southwest (San Francisco) is at once obvious. The line representing the annual variation in the mean temperature of the warmest month reveals the same distinct dichotomous pattern discovered earlier in the San Francisco data: an early period of very little change followed by a gradual, though significant, increase through recent years. The magnitude of this increase, which originated in approximately 1957, is on the order of 2.5°. The temporal trend of cold month temperatures at Phoenix also mirrors its more westerly counterpart. After an early decline into the mid-1950's, values increase rapidly until approximately 1959. Since then, cold month temperatures have fallen almost 1°F. The net change in the mean temperature of the coldest month since the upswing of the mid to late 1950's is $+1.0^{\circ}$F.

By comparing Figures 12 and 17, it becomes readily discernible that the character of continentality variability in the Interior Western Corridor is controlled by the character of cold month temperatures. The initial increase in continentality is due to a decline in cold month temperatures while warm month temperatures

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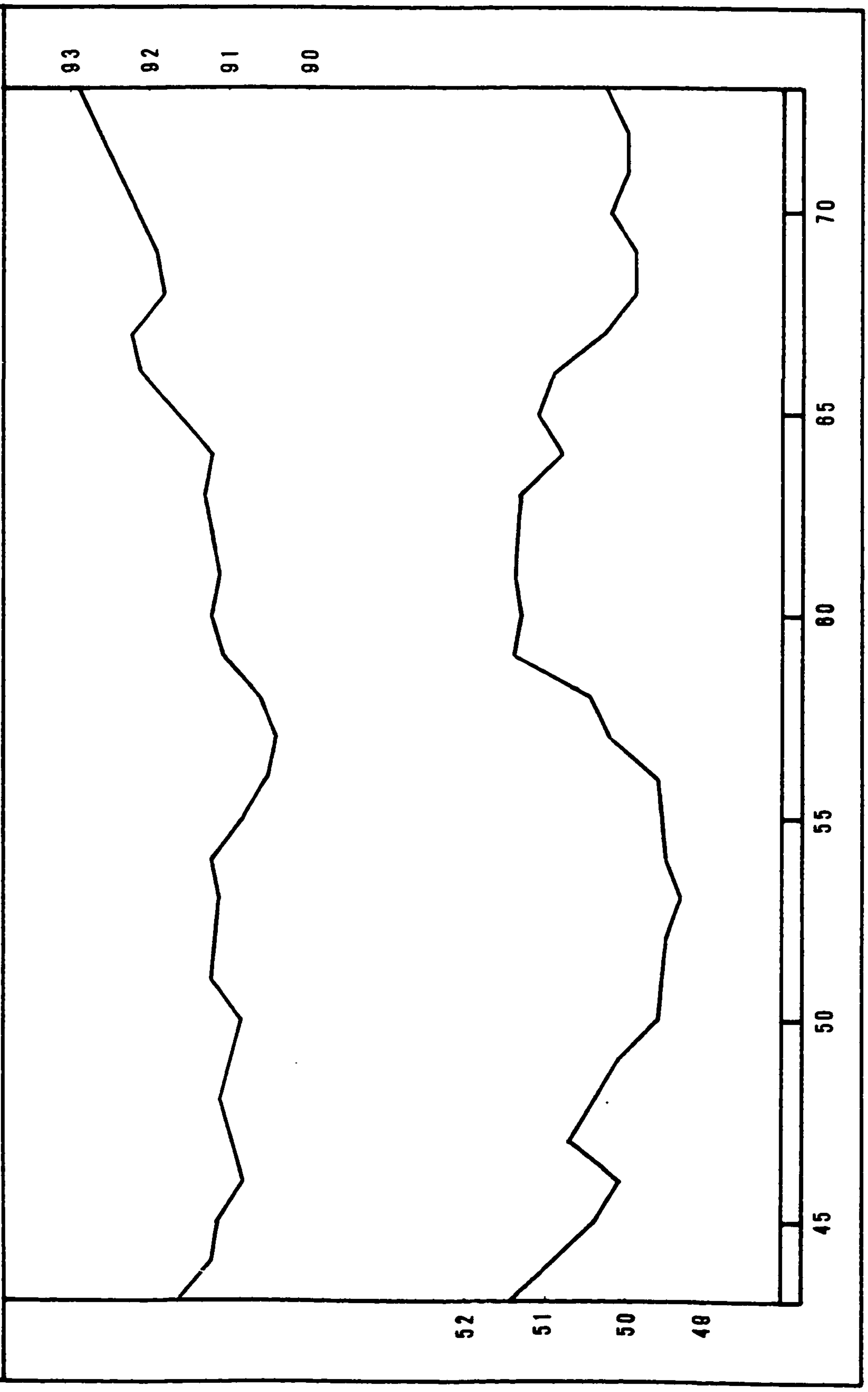
Figure 17 Annual Monthly Temperature Extremes at Phoenix



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remain rather stable. During the mid-1950's, temperature modulation occurs as cold month temperatures increase and warm month temperatures decrease. As a result, continentality declines. The recent increase in continentality since approximately 1959 is the product of rising warm month temperatures and declining cold month temperatures.

Thus, although the temporal trends of continentality characteristic of the Far Southwest and the Interior Western Corridor are distinctly different, the temporal trends of annual monthly temperature extremes are surprisingly similar. Like San Francisco, Phoenix displays net increases in both warm month and cold month temperatures since 1957. This is to be expected, however, since the Interior Western Corridor comprises a large part of the western portion of the nation which is experiencing a warming trend.

The Interior Northwest

The temporal trend of continentality in the Interior Northwest is vastly different from that found in either of the two previous regions. Whereas both the Far Southwest and the Interior Western Corridor are characterized by net increases in continentality over this 40-year period, the Interior Northwest experiences a distinct, though highly erratic, decline throughout this era. The microscale pattern of change (see Figure 13) is actually a type of oscillation with the subsequent decline always exceeding the initial rise. As such, the overall trend of continentality in this region is downward.

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Examination of Figure 18, which displays the annual variation of the mean temperature of both the warmest and coldest months at Lewiston, Idaho, reveals a rather simple two-phase pattern of variability at the macroscale level. The point of division occurs in approximately 1957. Prior to this time, both warm month and cold month temperatures decline. After this time, both temperatures rise.

The long-term trend of continentality in this region is downward largely because the gap between the mean temperature of the warmest month and the mean temperature of the coldest month reaches a maximum during the first few years of the study period. This is attributable to the exceedingly high warm month temperatures during this time. The subsequent decline of both warm month and cold month temperatures beginning in approximately 1947 is nearly of equal magnitude, hence, only a slight decrease in continentality occurs. During the post-1957 increase of both warm month and cold month temperatures, the magnitude of the latter exceeds that of the former. As a result, continentality shows a prominent decline after circa 1957.

The Northern Plains and New England

The temporal trend of continentality characteristic of the Northern Plains and New England (see Figure 14) may be divided into four distinct phases: a rapid decrease during the first few years; followed by a gradual, almost continuous rise; then a second rather abrupt decline; and finally a very erratic and irregular rise. Exam-

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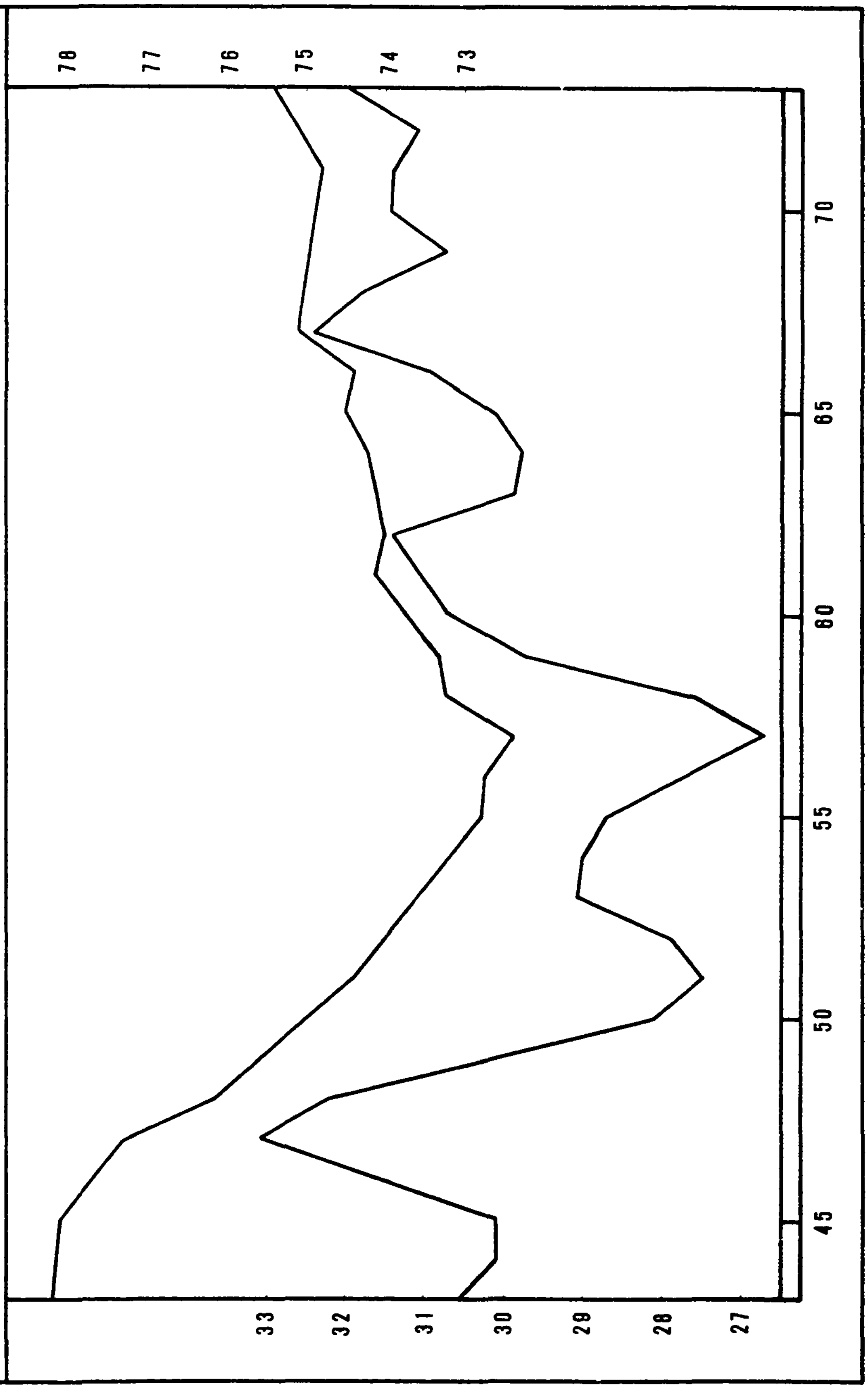
Figure 18 Annual Monthly Temperature Extremes at Lewiston



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ination of the annual variation in the mean temperature of both the warmest and coldest months (Figure 19) discloses that the immediate cause for this pattern of continentality variability resides in the character of cold month temperatures. Like the temporal trend of continentality, the temporal trend of cold month temperatures also reveals a distinct four-phase pattern. The approximate dates on which the trend of this line pivots are nearly identical to those in Figure 14. As a consequence, the temporal trend of cold month temperatures may be thought of as an inverted graph of continentality. When cold month temperatures decline, continentality rises. When cold month temperatures increase, continentality decreases. During the study period, warm month temperatures in this region fluctuate only slightly. As such, they exert very little influence on the temporal trend of continentality.

A further analysis of Figure 19 discloses an additional noteworthy thermal characteristic of this region. Both warm month and cold month temperatures in this region display a distinct downward tendency during recent years. In the case of the former, values have fallen .6^{O}F since approximately 1961. The latter reveals a decline of 3.5^{O}F since about 1962. In lieu of the findings of Kalnicky that the eastern two-thirds of the nation is experiencing a cooling trend since the middle of the century, this downward tendency of both warm month and cold month temperatures as of late is not at all surprising. Indeed, such findings corroborate the conclusions of Kalnicky and lend further credibility to the dichotomous regional pattern of temperature variability in the United States which previous

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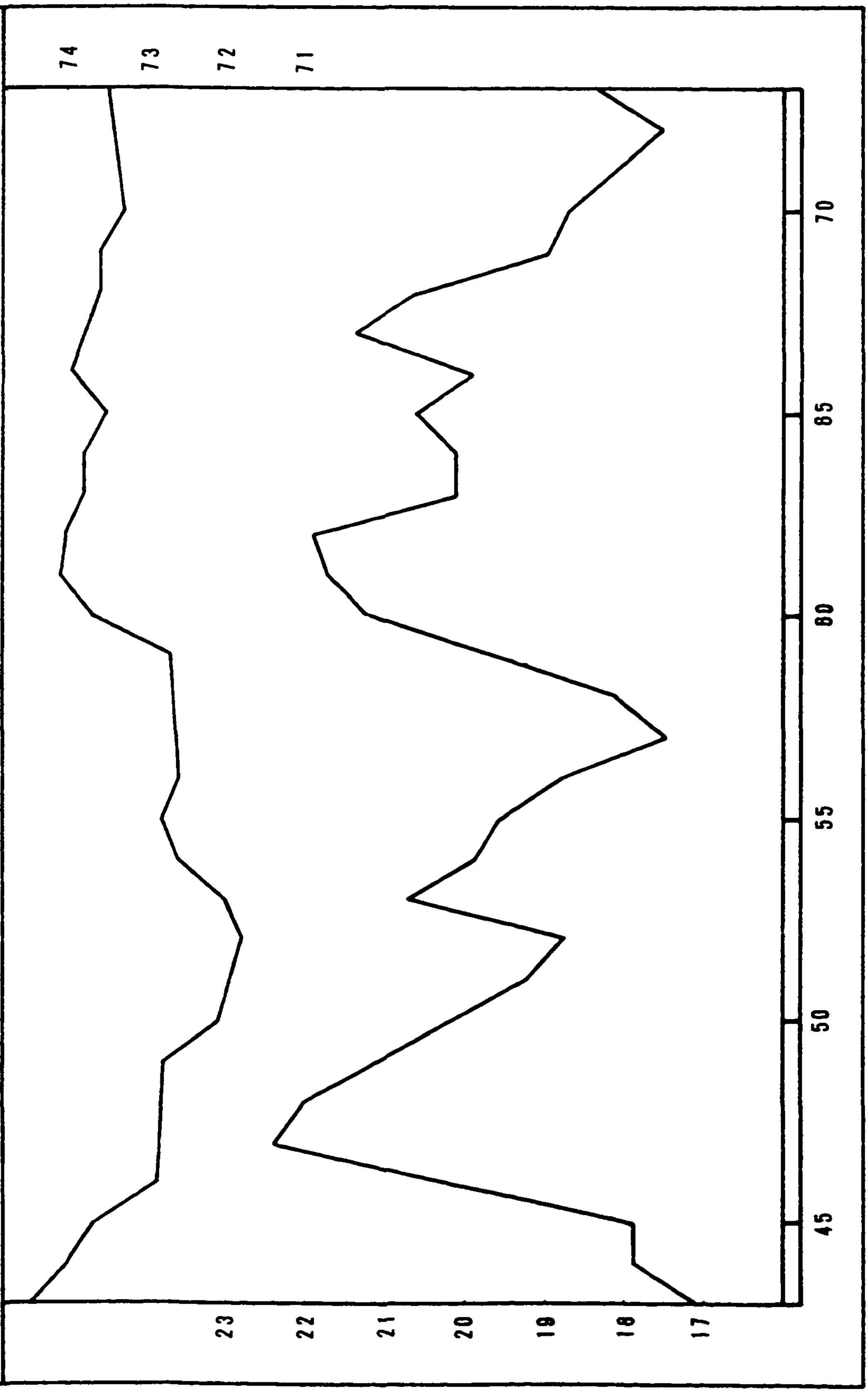
Figure 19 Annual Monthly Temperature Extremes at Billings



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studies, such as those of Lamb (1959) and Wahl and Lawson (1970) have also identified.

The East

The temporal trend of continentality in the East (see Figure 15) is characterized by a simple three-phase pattern: an early decline; followed by an acute rise; and more recently, a moderate drop. The immediate cause of this trend may be discerned from Figure 20 which displays the annual variation in both the mean temperature of the warmest month and the mean temperature of the coldest month. The initial decline in continentality is the result of temperature modulation: warm month temperatures are decreasing and cold month temperatures are rising. During the subsequent decade or so, just the opposite situation develops: cold month temperatures drop while warm month temperatures increase. The result is an abrupt rise in continentality. Since approximately 1964, continentality has declined as the result of a leveling tendency on the part of cold month temperatures and a corresponding decrease of warm month temperatures.

Several additional aspects of the temperature trends portrayed in Figure 20 are noteworthy. Warm month temperatures show very little variability from the beginning of the study period until about 1961. Since this time, the mean temperature of the warmest month has declined 2.0^{o}F. Cold month temperatures, on the other hand, experience much more variation. In addition, the magnitude of such changes is far more pronounced. From the beginning of the

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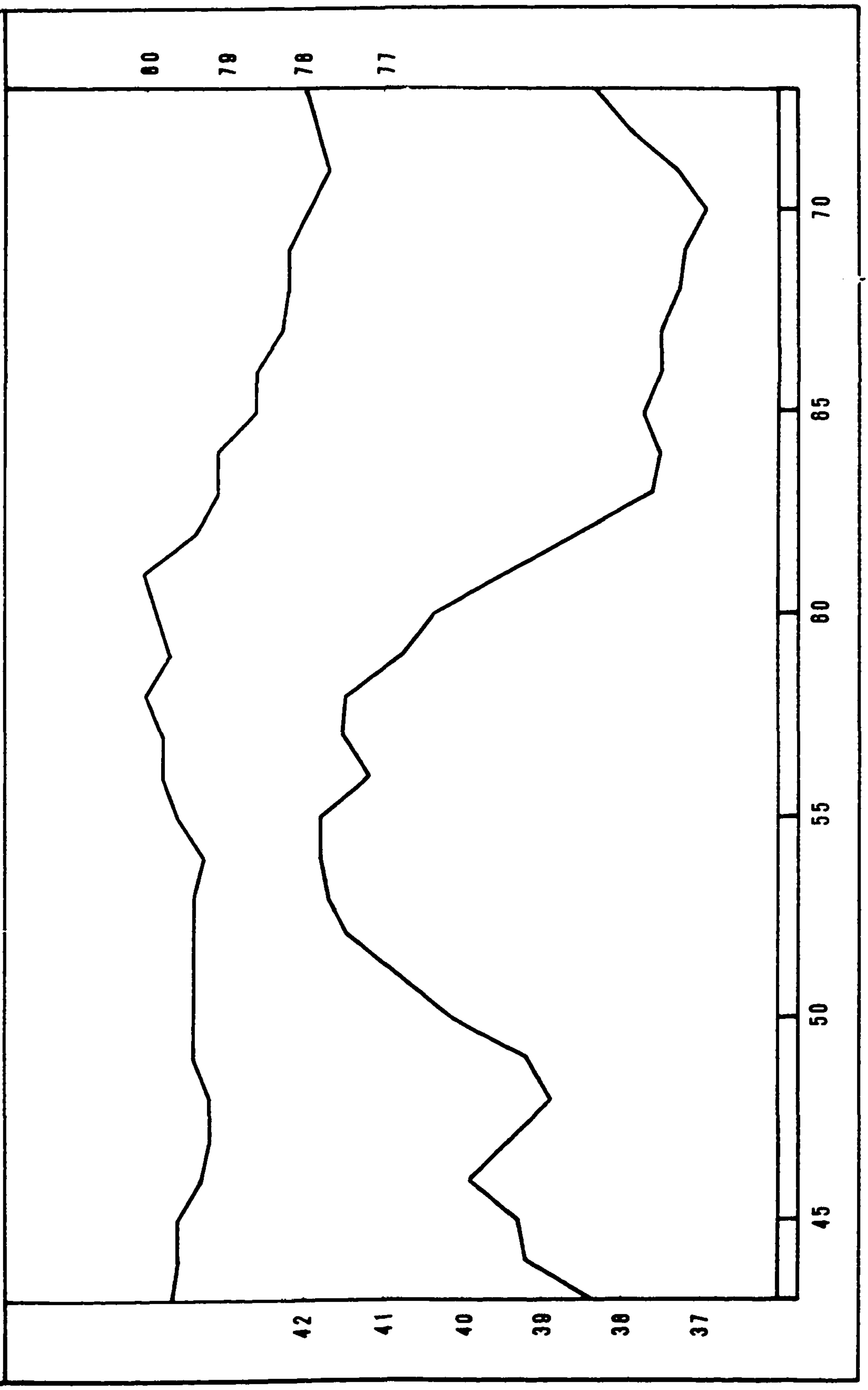

Figure 20 Annual Monthly Temperature Extremes at Norfolk

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study period up until circa 1955, the mean temperature of the coldest month rises almost 3.0°F. The subsequent decline over the next 15 or so years is 4.9°F. Recently, cold month temperatures reveal some hint of an impending increase. Since approximately 1958 when the decline in cold month temperatures accelerated, the net change is -3.2°F.

The temperature trends displayed by the Norfolk data (Figure 20) lend further credence to the claim that the eastern two-thirds of the nation is experiencing a downward temperature trend during recent years. Cold month temperatures have declined since about 1958, while warm month temperatures have dropped since approximately 1961. The dates of these two occurrences suggest that the recent cooling trend in the eastern two-thirds of the nation may have originated later than the 1950 date proposed by Kalnicky. In this respect, it should be recalled that due to the inherent weakness of the smoothing technique employed, dates may be taken as only an approximate indication of the actual occurrence. Thus, the previous suggestion of a thermal lag in the eastern United States should be approached with due caution.

Areal Relationship Between Continentality Change and Temperature Variability

From previous discussion, the relationship between (1) the dichotomous regional pattern of temperature change, and (2) the five-fold regional division of the United States according to the temporal character of continentality is readily recognizable. Exam-

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ination of the temporal temperature trends in each of the five regional delineations--Far Southwest, Interior Western Corridor, Interior Northwest, Northern Plains and New England, and the East--allows for a spatial grouping based on the character of temperature change over this 40-year period. Table 7 shows the noteworthy temperature characteristics of the sample stations selected from these five regional divisions. The consequential spatial groupings are at once obvious.

Table 7

Temperature Characteristics of the Five Regions in the United States

Station	Date 1	Change 1	Date 2	Change 2
San Francisco	1955	+2.0	1956	+0.6
Phoenix	1957	+2.5	1953	+1.0
Lewiston	1957	+3.0	1957	+5.2
Billings	1961	-0.6	1962	-3.5
Norfolk	1961	-2.0	1958	-3.2

Note: All dates indicate only the approximate year of the actual occurrence. Date 1 is the beginning of the recent warming or cooling trend of warm month temperatures. Change 1 is the net change in warm month temperatures since Date 1. Date 2 is the beginning of the warming or cooling trend of cold month temperatures. Change 2 is the net change in cold month temperatures since Date 2. All temperatures are in degrees Fahrenheit.

The Far Southwest, the Interior Western Corridor, and the Interior Northwest--represented by data from San Francisco, Phoenix, and Lewiston, respectively--comprise the western third of the United States which is experiencing a rise in mean annual temperatures

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since approximately 1950. The mean temperature of the warmest month, as well as that of the coldest month, have experienced net increases at all three stations since the mid-1950's. In the western portion of this region, at San Francisco and Phoenix, this rising temperature tendency is most apparent on the line depicting the annual variation of warm month temperatures. Further east at Lewiston, the increase is more prominent on the line displaying the temporal trend of cold month temperatures. This peculiarity probably results from the proximity of Lewiston to the boundary line separating the warmer west from the cooler east. In any case, evidence points to the fact that the warming trend in the western third of the nation during recent years is most pronounced in the summer months. Indeed, both San Francisco and Phoenix have actually undergone a decline in cold month temperatures since approximately 1960 and 1962, respectively.

The data displayed in Table 7 discloses that Norfolk and Billings both belong in the eastern two-thirds of the nation which is experiencing a cooling trend over the past 25 years. The Billings data--representative of the Northern Plains and New England--and the Norfolk records--indicative of temperature trends in the East--show distinct cooling tendencies as of late in both warm month and cold month temperatures. In both regions, this cooling trend is much more evident on the line depicting the annual variation of cold month temperatures. The decline of warm month temperatures originates in each region in approximately 1961, while the decrease in cold month temperatures begins at Billings in about 1962 and at Norfolk in circa 1958. The approximate dates of these occurrences

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suggest that the downward turn of mean annual temperatures in the eastern two-thirds of the nation may have commenced significantly later than the 1950 date proposed by Kalnicky.

In all five regions, the linear trend representing the annual variation of cold month temperatures displays (1) more irregularities, and (2) oscillations of larger amplitude than does the temporal trend of warm month temperature. The distinct difference in the variable nature of these two temperature characteristics may well result from the southerly displacement of the major storm tracks during the winter season. Throughout these months (December, January, and February) marked temperature contrasts may develop along the polar front. Such a situation produces pronounced temperature differences over a relatively short distance. Any variation in the position of this feature results in prominent temperature changes which may tend to complicate the temporal trend of cold month temperature, and may obscure or camouflage any long-term changes which may be occurring in a region. As a result of the more variable nature of cold month temperatures, continentality throughout the United States is clearly controlled by the character of cold month temperatures. Landsberg (1967) has arrived at a similar conclusion.

Corroboration of Previous Conclusions: Examination of Bench-Mark Data

In an attempt to verify the validity of the previous conclusions, temperature records at two additional stations will be examined. These are so-called "bench-mark" stations which are recognized

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by the National Weather Service as possessing climatological records characterized by the highest degree of both continuity and homogeneity. Stations selected for the bench-mark network--recently renamed the Reference Climatological Station Network--are those where location, elevation, and instrument exposure have not, and are not likely to be, changed (Swartz, 1956). The purpose of this group of stations is to monitor the nature and magnitude of slow, secular changes in climatic conditions by serving as a climatological baseline against which genuine climatic trends may be measured. Presently, the RCS program entails 19 fully operational stations across the conterminous United States. Fourteen of these stations, including the two subsequently employed here, are located on university grounds.

For this study, two Reference Climatological Stations need to be selected--one representing the eastern two-thirds of the nation and the other the western third--in order to substantiate the results of earlier investigations concerning the character of recent temperature trends in these two regions. These stations will be chosen according to their geographic proximity to the aforementioned sample stations which represent the five regional divisions of the United States. Of the five reference climatological stations found in the western third of the nation, Union, Oregon, is located nearest to any of the three sample stations (San Francisco, Phoenix, and Lewiston) previously employed from this region. As such, Union, Oregon, which is less than 100 miles from Lewiston, Idaho, will represent the western third of the nation.

In the eastern two-thirds of the United States, the problem of

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selecting a "bench-mark" station is somewhat more complicated. The selection cannot be based merely on the proximity of the "bench-mark" station to either of the two sample stations (Billings and Norfolk) in this region. Instead, the immense size of this area requires that a station be chosen not only according to its proximity to either Norfolk or Billings, but also by considering its location with respect to the geographic center of this region. In view of such restrictions, Lewisburg, Tennessee, an experimental station in the south-central portion of the state, will represent the eastern two-thirds of the nation.

The temperature records at Union, Oregon, and Lewisburg, Tennessee, are then analyzed by employing the same techniques implemented earlier during the analysis of the temperature records of the five sample stations. The annual variation of both the mean temperature of the warmest month and the mean temperature of the coldest month are calculated by using a 10-year floating average. The subsequent values are then plotted on a graph, and the result is a linear representation of the annual variation in the annual monthly temperature extremes. Figure 21 displays the data for Union, Oregon, while Figure 22 shows the data for Lewisburg, Tennessee.

A comparison of the temporal temperature trends at Union, Oregon, (Figure 21) with those of Lewiston, Idaho, (Figure 18) reveals several similarities. The lines displaying the annual variation of cold month temperatures are nearly identical down to the smallest detail. In each case, the line depicts an abrupt rise of short duration; followed by a general decline; and then an erratic,

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Figure 21 Annual Monthly Temperature Extremes at Union, Oregon

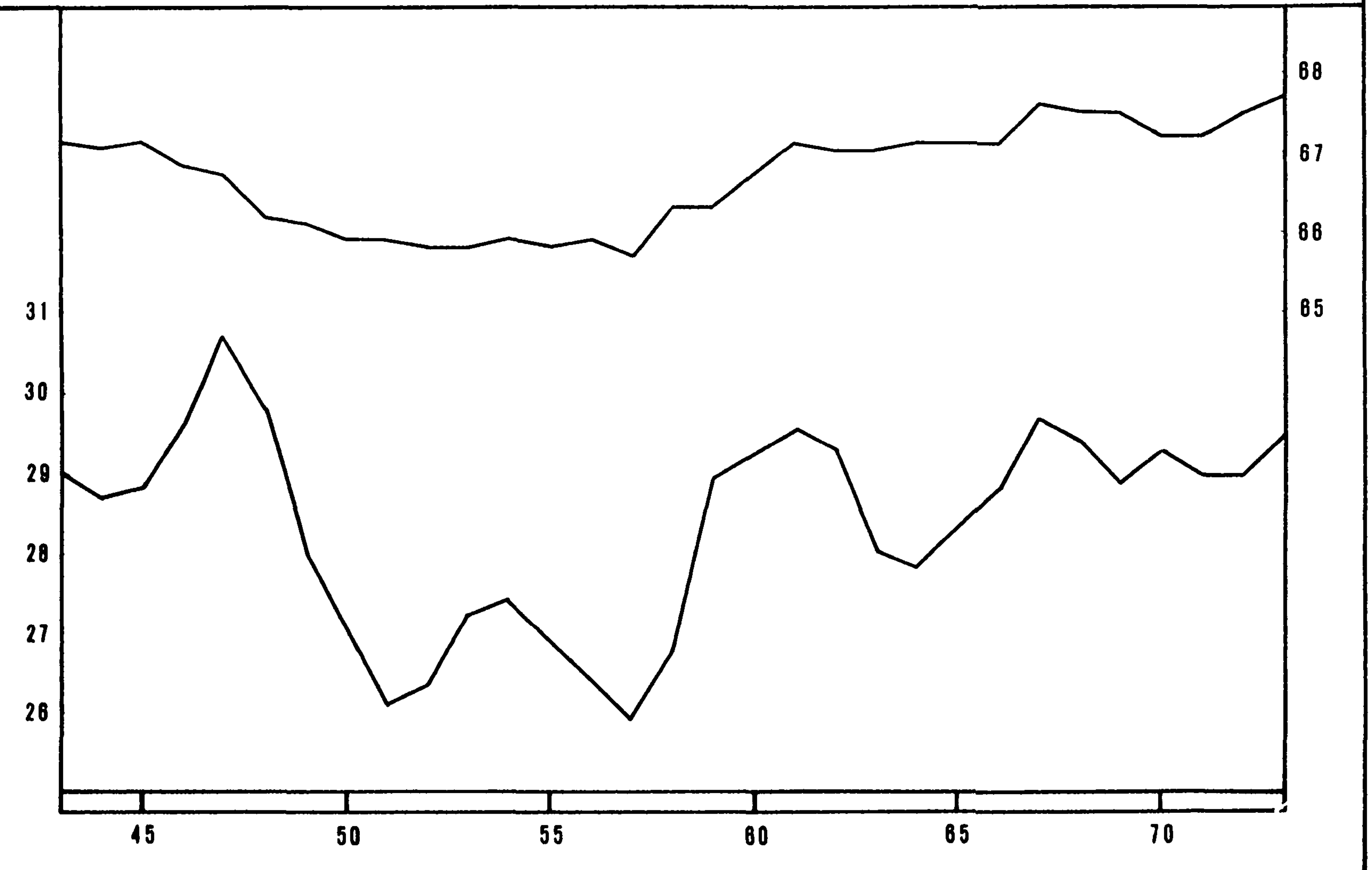

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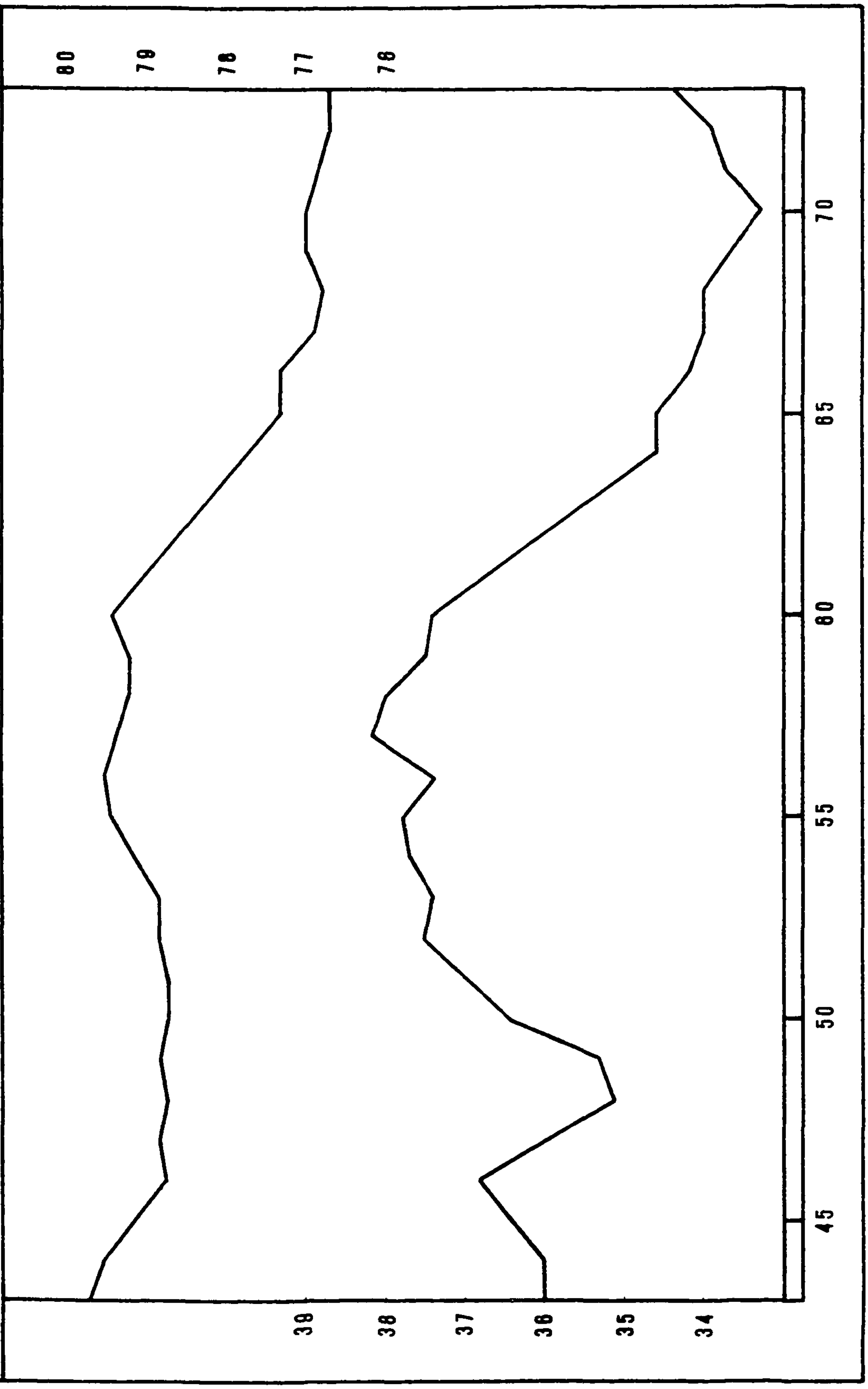
Figure 22 Annual Monthly Temperature Extremes at Lewisburg, Tennessee



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but significant, upward climb. Cold month temperatures at both locations show net increases since circa 1957. The statistical correlation between these two temperature trends is +.96.

The temporal trends of warm month temperatures at these stations contrast much more. Both stations are characterized by a decline in the mean temperature of the warmest month between the beginning of the study period and approximately 1957. However, the magnitude of the decrease is much larger at Lewiston than at Union. After this time, warm month temperatures at both stations increase prominently up until the end of the study period. The pronounced dissimilarity between these two temperature trends during the earlier years accounts for the lower correlation coefficient, +.43, which such a comparison yields.

Table 8 compares the noteworthy temperature characteristics of these two stations. The similarity in all respects is clear corroborating evidence substantiating the earlier conclusions that (1) the warming trend in the western third of the nation is more pronounced during the summer months, and (2) the greater irregularity of cold month temperatures is responsible for the annual variation of continentality in this region (see page 117).

In the eastern two-thirds of the United States, the temperature trends characteristic of Norfolk, Virginia, (Figure 20) and Lewisburg, Tennessee, (Figure 22) may be appropriately compared. Before such a comparison is undertaken, however, it should be pointed out that some significant differences between the temperature records of these two stations are to be anticipated due to the distance be-

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Table 8

Check on Temperature Characteristics
in the Western United States

Station	Date 1	Change 1	Date 2	Change 2
Lewiston, Idaho	1957	+3.0	1957	+5.2
Union, Oregon	1957	+2.0	1957	+3.6

Note: All dates indicate only the approximate time of the occurrence. Date 1 is the beginning of the warming trend of warm month temperatures. Change 1 is the net change in warm month temperatures since Date 1. Date 2 is the beginning of the warming trend of cold month temperatures. Change 2 is the net change in cold month temperatures from Date 2. All temperatures are in degrees Fahrenheit.

tween them. Hence, it is not correct to expect the same degree of correlation between these two data sets as was uncovered in the previous comparison in the western United States.

In spite of this inherent handicap, the temporal temperature trends of Lewisburg compare very favorably with those of Norfolk. The lines depicting the annual variation of cold month temperatures at these stations are almost alike. The trends at both stations show a distinct three-phase pattern: an early rise, followed by a pronounced and prolonged decline, and more recently a suggestion of an impending increase. The relatively high correlation coefficient, +.95, attests to the similarity of these two trends.

The linear representation of the annual variation of warm month temperatures at Lewisburg also nearly matches that found at Norfolk. Prior to about 1960, neither station reveals much varia-

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tion in warm month temperatures. Since this time, the mean temperature of the warmest month has declined at both locations. The statistical correlation between these two temperature trends is +.94.

Table 9 compares the data at Lewisburg with the temperature records of Norfolk. Despite the significantly large distance between these two stations, the temperature values and dates characteristic of each location attest to the high degree of similarity in the temporal temperature trends found at each location. The cooling tendency of recent years is conspicuous on the linear trends of both warm month and cold month temperatures in each location. The similarity of the dates delineating the beginnings of this cooling trend lends credence to the earlier claim that this downturn of temperatures may well have originated after the 1950 date advocated by Kalnicky. The data depicted in Table 9 also supports the earlier contentions that the recent cooling trend in the eastern two-thirds of the United States is more pronounced during the winter months.

Table 9

Check on Temperature Characteristics in the Eastern United States

Station	Date 1	Change 1	Date 2	Change 2
Norfolk, Virginia	1961	-2.0	1958	-3.2
Lewisburg, Tennessee	1960	-2.7	1958	-3.7

Note: All dates indicate only the approximate time of the occurrence. Date 1 is the beginning of the cooling trend of warm month temperatures. Change 1 is the net change in warm month temperatures since Date 1. Date 2 is the beginning of the cooling trend of cold month temperatures. Change 2 is the net change in cold month temperatures since Date 2. All temperatures are in degrees Fahrenheit.

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CHAPTER IX

CONCLUSION

The findings of this study lead to several significant conclusions. First, it appears as though there are distinct seasonal tendencies associated with the dichotomous regional pattern of temperature variability in the contiguous United States. The warming trend in the western third of the nation is more pronounced during the warmest summer month than during the coldest winter month, while the cooling trend in the eastern two-thirds of the country is more prominent during the coldest winter month than during the warmest summer month. This suggests that summers (June, July, and August) in the western United States are becoming warmer, and winters (December, January, and February) in the eastern portion of the nation are becoming colder. Such a pattern of change would indicate a growing thermal rift between the eastern and western portions of the study area.

Second, it appears that these two temperature trends--warming in the west and cooling in the east--originated later than the 1950 date cited by Kalnicky. This is particularly true of the present cooling trend in the eastern realm. However, because of the specific type of analysis employed in this particular phase of the study--a 10-year moving mean--such a conclusion must be approached with due caution. The inherent weakness in the use of the floating average--phase shifting--makes it impossible to make an accurate statement concerning the origination and termination points in a time series

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data set.

Third, there is little doubt that the character of continentality throughout the contiguous United States is clearly controlled by the nature of cold month temperatures. Not only are cold month temperatures much more variable in character than are warm month temperatures, the former also experiences trend reversals of much greater amplitude than does the latter. In addition, in the instances where both warm month and cold month temperatures undergo the same directional change, the magnitude is larger with respect to cold month temperatures. Furthermore, at several stations--notably Norfolk--warm month temperatures vary only slightly over a period of many years. During this same era, cold month temperatures experience marked fluctuations. As such, the annual range of temperature--hence, continentality--is determined by the variability of cold month temperatures.

Fourth, in nearly the entire study area--the exception being the Interior Northwest--continentality is increasing since the occurrence of the general change in circulation patterns circa, 1950. There are, however, distinct regional differences with regard to the cause of this observed increase. In the extreme western portions of the study area, the recent increase in continentality is largely the result of rising warm month temperatures. Cold month temperatures are also increasing; however, the magnitude of this increase is much less. In the eastern realm of the nation, continentality is likewise increasing. Here, however, the rise is

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largely the product of declining cold month temperatures. Warm month temperatures have experienced this same directional tendency; however, it is again of somewhat lesser magnitude. Thus, while continentality continues to increase in both the eastern and western portions of the nation, the immediate cause of this increase is quite different in each region.

Suggestions for Further Research

With respect to this study, perhaps the greatest need for further research is in the area of seasonal temperature trends. Are summers in the western third of the United States indeed becoming warmer? Are winters in the eastern two-thirds of the nation becoming colder? A more in-depth and detailed study of this phenomenon is clearly necessary in order to determine whether or not a growing thermal rift exists between the eastern and western portions of the United States.

It would also be interesting to examine the impact of recent circulation changes on the temporal trends of transition season temperatures (fall and spring). What, if any, directional tendency has developed in the annual variation of either spring or fall temperatures since circa, 1950?

Further research is also needed to determine exactly when the current temporal temperature trends originated. Kalnicky has suggested that 1950 marks the beginning of the recent warming trend in the western portion of the nation and the cooling trend in eastern areas. Evidence presented in this paper, however, suggests that

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these two regional temperature trends--particularly the latter--originated more recently. Perhaps the mean annual temperature did begin to change in 1950 while the seasonal emphasis described in this paper developed slightly thereafter. In any event, this particular facet of the study presents an excellent opportunity for further investigation.

Finally, the seasonal temperature trends in the eastern portion of the study area--at both Billings and Norfolk--suggest a hint of an impending rise. Both warm month and cold month temperatures reveal slight upward tendencies over the last few years. It will be interesting to see whether the temperature characteristics of these few years foreshadow a reversal of the current downward tendency, or whether seasonal temperatures will continue to fall. Have changes occurred in the circulation pattern over the eastern United States during the last few years which would account for such a reversal?

Whether or not such a circulation change has occurred within the last few years, the question may still be asked, "what causes changes in the general circulation?" This is undoubtedly the area which offers the greatest challenge for future research. Up until the present time, an untold number of theories have been propounded in an attempt to answer this question. Among scientists, however, there is no universal acceptance of any one theory or hypothesis. The emphasis shifts periodically from one idea to another as fresh facts and new relationships are uncovered. Here is what appears to be the unexhaustible realm of climatological research.

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APPENDIX

List of Climatological Stations Employed

1 Birmingham, Alabama
2 Montgomery, Alabama
3 Phoenix, Arizona
4 Winslow, Arizona
5 Yuma, Arizona
6 Fort Smith, Arkansas
7 Little Rock, Arkansas
8 Bakersfield, California
9 Red Bluff, California
10 San Diego, California
11 San Francisco, California
12 Santa Maria, California
13 Stockton, California
14 Alamosa, Colorado
15 Denver, Colorado
16 Grand Junction, Colorado
17 Apalachicola, Florida
18 Fort Meyers, Florida
19 Jacksonville, Florida
20 Tallahassee, Florida
21 Augusta, Georgia
22 Columbus, Georgia
23 Savannah, Georgia
24 Boise, Idaho
25 Lewiston, Idaho
26 Pocatello, Idaho
27 Cairo, Illinois
28 Moline, Illinois
29 Evansville, Indiana
30 Fort Wayne, Indiana
31 Indianapolis, Indiana
32 Des Moines, Iowa
33 Waterloo, Iowa
34 Dodge City, Kansas
35 Goodland, Kansas
36 Topeka, Kansas
37 Wichita, Kansas
38 Lexington, Kentucky
39 Louisville, Kentucky
40 New Orleans, Louisiana
41 Shreveport, Louisiana
42 Portland, Maine
43 Worcester, Massachusetts
44 Grand Rapids, Michigan
45 Marquette, Michigan
46 Sault Ste. Marie, Michigan
47 Duluth, Minnesota
48 Saint Cloud, Minnesota
49 Jackson, Mississippi
50 Columbia, Missouri
51 St. Louis, Missouri
52 Springfield, Missouri
53 Billings, Montana
54 Havre, Montana
55 Helena, Montana
56 Miles City, Montana
57 Missoula, Montana
58 Norfolk, Nebraska
59 North Platte, Nebraska
60 Scottsbluff, Nebraska
61 Valentine, Nebraska
62 Elko, Nevada
63 Ely, Nevada
64 Las Vegas, Nevada
65 Winnemucca, Nevada
66 Albuquerque, New Mexico
67 Clayton, New Mexico
68 Roswell, New Mexico
69 Albany, New York
70 Buffalo, New York
71 Cape Hatteras, North Carolina
72 Charlotte, North Carolina
73 Raleigh, North Carolina
74 Bismarck, North Dakota
75 Fargo, North Dakota
76 Williston, North Dakota
77 Cincinnati, Ohio
78 Toledo, Ohio
79 Oklahoma City, Oklahoma
80 Tulsa, Oklahoma
81 Burns, Oregon
82 Eugene, Oregon
83 Medford, Oregon
84 Pendleton, Oregon
85 Allentown, Pennsylvania
86 Erie, Pennsylvania
87 Pittsburg, Pennsylvania
88 Providence, Rhode Island
89 Charleston, South Carolina
90 Aberdeen, South Dakota

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91 Rapid City, South Dakota
92 Sioux City, South Dakota
93 Bristol, Tennessee
94 Chattanooga, Tennessee
95 Memphis, Tennessee
96 Nashville, Tennessee
97 Abilene, Texas
98 Amarillo, Texas
99 Corpus Christi, Texas
100 Dallas, Texas
101 Houston, Texas
102 Lubbock, Texas
103 Port Arthur, Texas
104 San Antonio, Texas
105 Wichita Falls, Texas
106 Milford, Utah
107 Salt Lake City, Utah
108 Burlington, Vermont
109 Norfolk, Virginia
110 Richmond, Virginia
111 Seattle, Washington
112 Spokane, Washington
113 Yakima, Washington
114 Charleston, West Virginia
115 Elkins, West Virginia
116 Green Bay, Wisconsin
117 La Crosse, Wisconsin
118 Madison, Wisconsin
119 Casper, Wyoming
120 Sheridan, Wyoming

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