THE OCCURRENCE AND PERSISTENCE OF WET AND DRY PERIODS IN NEBRASKA, KANSAS AND OKLAHOMA, 1931-1975

by

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ABSTRACT

The occurrence and persistence of wet and dry periods is examined in Nebraska, Kansas and Oklahoma from January, 1931 to December, 1975. Monthly Palmer Index values are used to measure wet and dry conditions for the twenty-six climatic divisions in this three state region. Spatial patterns of wet and dry period occurrence and persistence are shown through a series of maps. Analysis of major wet and dry periods over the period of record reveals that cyclone frequency, 700-mb ridge-trough position and 700-mb height anomalies were all associated with these events. These variables show distinct patterns during the onset, maintenance and cessation of wet and dry periods.

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Finally, I owe special thanks to my family whose example has been a constant source of inspiration. I dedicate this thesis to my parents, Ernest and Louise Carbone, for the financial and moral support which they have so unselfishly provided.

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INTRODUCTION

Nebraska, Kansas and Oklahoma experienced numerous dry periods during the period 1931-1975. Those dry periods, which can be classified as droughts by various criteria, have been well documented. It is relatively unknown, however, that wet periods also have been an important part of the climatic landscape of these states. Wet periods, in fact, have occurred more frequently than dry periods over most of the three-state region. Few studies have examined wet period characteristics despite the fact that these events can have as much social and economic impact as drought through flooding, crop damage and other misfortunes (Diaz, 1983).

Dry and wet period occurrence and persistence in Nebraska, Kansas and Oklahoma from January, 1931 to December, 1975 is analyzed in this study. The three-state region is known to have had significant moisture variability during this period (Borchert, 1971; Karl and Koscielny, 1982). The Palmer Index (PI; Palmer, 1965) is used to characterize moisture conditions.

Although in some respects it parallels previous research this thesis investigates several new areas of climatalogical research. Only one author to date (Diaz,

1983) has given any attention to wet periods. This study includes numerous aspects of wet periods. All major wet periods in the three-state region between 1895 and 1981 are identified. The occurrence and persistence of wet conditions for various degrees of severity are examined for the entire period of record. Middle-level atmospheric flow and surface weather associated with wet periods are analyzed. Because of the paucity of research on wet periods, an attempt is made to discuss wet period characteristics in more detail than dry period characteristics.

The chosen study region is smaller than that used in most drought studies; the use of climatological divisions within the area allows much detail. The spatial distribution of dry and wet period occurrence, at several degrees of severity, and the spatial patterns of dry and wet period persistence are shown in a series of maps. Little previous research has examined spatial patterns of dry or wet period persistence and no study has shown regional distribution of persistence at the scale seen in the present study. The patterns of wet period occurrence and persistence are compared and contrasted with the same characteristics of dry periods -- something not done in previous research.

The study includes analysis of cyclone frequency, 700-mb ridge and trough position and 700-mb height anomalies during dry and wet periods. These variables have been used in various studies on specific droughts. The analysis of this thesis attempts to identify physical features associated with the onset, maintenance and cessation of dry and wet periods.

CHAPTER I. LITERATURE REVIEW

DROUGHT STUDIES

A review of drought studies provides necessary background for understanding the techniques employed in this research of dry and wet periods in Nebraska, Kansas and Oklahoma. Numerous authors have focussed on major North American droughts in the 1890's, 1910's, 1930's, and 1950's (e.g. Borchert, 1971; Warrick, 1980; Felch, 1982 and others). Characteristics of these droughts have been presented frequently in the literature. A few authors have discussed drought persistence on a large scale; no one, however, has shown spatial patterns of persistence. Many have tried to relate drought to the general circulation of the atmosphere with limited success. Wet periods have not been analyzed exclusively although one author (Diaz, 1983) examined both wet and dry periods in the contiguous United States.

SPATIAL AND TEMPORAL ANALYSIS OF DROUGHT

Many authors have described spatial characteristics of dry periods as measured by various indices. Felch (1982) generalized the areal extent of drought patterns in the United States using the Palmer Index. His results were as follows:

1) severe droughts are unlikely to occur in a very small area;
2) severe, large continental droughts have a diameter that ranges between 2300 and 4200 kilometers;
3) the more severe a large continental drought, the larger the area involved.

Other authors have described the characteristics of specific droughts. Borchert (1971) discussed the geographic pattern of summer rainfall deficiency (percentage of normal precipitation) during several droughts. He attempted to show regional similarities between the 1890's and 1930's droughts, and between the 1910's and 1950's droughts. These two pairs of droughts differed in severity, prime location and associated flow patterns. Warrick (1980) showed patterns of Great Plains' droughts between 1931 and 1977 for three degrees of severity (PI values < -4, between -3.99 and -2.00 and between -1.99 and 0.00). This technique provided an overview of the general timing and location of droughts, but did have limitations. PI values were calculated and averaged for only four months (May through August) and specific climatic divisions were not identified. Warrick attempted to portray the severity of drought by accumulating the number of divisions and number of months experiencing PI values < -3 during the summer months of each year. These "division-months" showed the areal extent and magnitude of drought over the entire

Great Plains, but did not describe conditions in individual climatic divisions.

COMBINATION STUDY ON WET AND DRY PERIODS

Diaz' (1983) study is a comprehensive work on the occurrence of dry and wet periods over the contiguous United States. He presented a state-by-state summary of dry ($PI < -2$) and wet ($PI > +2$) events from January 1895 to April 1981. He found that drought occurred most frequently in the seventeen westernmost states. This was in agreement with previous studies (Bark, 1978 and others). Diaz, however, was the first to discover that wet periods also occurred more frequently in the seventeen westernmost states than in the eastern United States.

Diaz further computed the ratio of the combined total number of months under dry or wet episodes to the total number of months within the period of record. His results suggested that dry (PI values < -2) or wet (PI values $> +2$) conditions are simply a climatic characteristic of these western states. This finding was supported by Karl and Koscielny (1982).

Since Diaz used PI data which was spatially averaged over entire states rather than climatic divisions, his results lacked geographical detail. Also, he provided no climatological explanations for dry or wet periods. However, Diaz did show that dry and wet periods can be analyzed using similar methodologies.

STATISTICAL TECHNIQUES AND SPATIAL PATTERNS OF DROUGHT

Statistical methods of various types have been used to describe moisture conditions in more detail. For example, eigenvector analysis has been used widely to demarcate regions which have similar precipitation or drought patterns.

Skaggs (1975) described spatial patterns of drought during the 1930's using a form of principal components analysis. He divided the continental U.S. into seven "moisture regions", showing distinctive spatial and temporal characteristics of moisture availability during the decade. Skaggs showed that the 1930's drought core occurred in the northern Rockies, northern Plains and central Plains with a sharp gradient through eastern Nebraska, eastern Kansas and northwestern Oklahoma. His study lacks detail because he used a limited number of climatalogical divisions in his analysis.

Klugman (1978) also used principal components analysis in her study on wet and dry conditions in the upper midwest from January, 1931 to December, 1969. Using the PI as a measure, she showed that: 1) the 1930's drought was intense and greatly affected most of the upper midwest; 2) the region, and most of the rest of the country, were moist in the 1940's except for parts of Wisconsin and northern Michigan; 3) the 1950's drought, while as intense as the 1930's, was of shorter duration and was centered in the southern Plains, and 4) during the 1960's, wide variation existed in the upper midwest, i.e. border areas were normal to dry and central portions were wet to very wet.

The use of principal components analysis enabled both Skaggs (1975) and Klugman (1978) to show spatial and temporal characteristics of drought based on the PI. Skaggs described fluctuations in moisture conditions during specific years of the 1930's drought. He also observed that dry conditions in the Great Plains advanced from the southwest during this period. Klugman, concluded that, in the upper midwest, drought spread from the west during the 1930's and from the south during the 1950's. Such information, when correlated with upper-air flow and surface weather characteristics, can assist in an understanding of some of the causes of drought. For example, zonal versus meridional flow, cyclonicity and 700-mb height anomalies are all variables which could be associated with wet or dry conditions.

PERSISTENCE

Some authors have dealt with persistence of both wet and dry conditions, as expressed by the PI, in portions of their research efforts, but such treatment is rare. Diaz (1983) computed the ratio of drought duration to wet period duration between 1895 and 1981 to show that certain regions of the country were more prone to prolonged wet or dry conditions. He found that dry periods lasted longer than wet periods in most of the seventeen westernmost states.

Karl and Koscielny (1982) found more rapid PI fluctuation in coastal zones than in continental regions, a rather surprising circumstance given the perceived nature of continental- and marine-influenced climates. They argued that droughts last longer in the central U.S. than in coastal regions.

Walsh et al. (1982) showed that PI values in the central U.S. were sensitive to precipitation over a longer antecedent period than along the east or west coasts. They attributed this sensitivity to greater soil moisture holding capacity in central portions of the country and, therefore, an artifact of the PI itself. In a subsequent study, Karl (1983) disproved this claim by testing the sensitivity of the PI. He showed that modification of constants used to calculate the PI had a negligible effect on the spatial characteristics of drought persistence.

Lawson *et al.* (1978) measured seasonal persistence of temperature and precipitation in Nebraska. By using contingency tables and eigenvector analysis, they detected strong coherence in seasonal precipitation patterns. They also cited an inverse relationship between temperature and precipitation anomalies.

Skaggs (1978) used autocorrelation coefficients to examine persistence of abnormal moisture periods in western Kansas. This technique is based on a comparison between observed and random duration of dry or wet events. Dry (wet) periods were defined as months with PI values less than -2 (greater than +2). Skaggs' results showed that dry or wet events were shorter than expected between 1887 and 1927 and longer than expected between 1928 and 1968. The earlier period experienced numerous wet/dry fluctuations and rapid shifts in PI values, while the latter period was marked by fewer wet and dry periods and slower shifts in PI values. Monthly PI values were more highly correlated with the values from the preceding months in the 1928 to 1968 period than in the 1887 to 1927 period. This implies greater persistence of dry or wet conditions during the latter period. Skaggs stated the need for future research on the spatial patterns of persistence.

DROUGHT AND THE GENERAL CIRCULATION

Many authors have tried to relate abnormal moisture conditions to the general circulation of the atmosphere. Felch (1982) argued that abnormalities in the general circulation could be explained by the physical forces which govern large-scale atmospheric motion and by local factors which are superimposed on this large-scale motion. He contended that the absence of broad-scale vertical motion was the single-most important factor creating dry conditions.

Namias (1983) argued that the persistence and recurrence of subsidence is the immediate drought-producing mechanism across the entire United States. He suggested that Great Plains' droughts are usually associated with a deep warm anticyclone over the central United States. This feature is maintained by subsiding air and weakened westerlies along the Canadian border.

Some authors simply generalize atmospheric circulation characteristics with respect to major droughts. Borchert (1971) divided major United States droughts into two classes based on general circulation patterns. He claimed that the 1890's and 1930's Great Plains' droughts corresponded with strong westerly circulation, frequent cyclone passage and little moisture intrusions from the Gulf. He suggested that the 1910's and 1950's droughts, by contrast, were accompanied by more meridional circulation, fewer mid-latitude cyclones and much intrusion of moist air.

Skaggs (1978) used the concept of meridional and zonal flow to explain the persistence of dry and wet conditions. He claimed that meridional flow is associated with little persistence of dry or wet conditions because it fosters a wide variety of weather conditions and rapid fluctuations. Zonal flow, he argued, is associated with strong persistence because it inhibits a north-south exchange of air. He did not associate wet or dry conditions with either flow type.

Both of the previous authors used Dzerdzeevskii's (1969) classification system of meridional and zonal circulation. Dzerdzeevskii developed the scheme to explain hemispheric changes in temperature and precipitation. He suggested that three climatic epochs have existed in the twentieth century. Meridional circulation existed during the first epoch (1900-1920), zonal circulation during the second (1920-1950) and meridional circulation during the third (after 1950). Kalnicky (1974) supported Dzerdzeevskii's theory in his study on temperature changes during the twentieth century.

SPECIFIC DROUGHTS

Many authors have related specific droughts to the general circulation. Namias (1955), in an early article, attempted to explain the summer droughts of 1952-54 with respect to middle-level atmospheric flow. He concluded that drought occurrence in the central U.S. was frequently the result of a large anticyclonic cell in the south-central portion of the country. Resulting easterly and northeasterly flow along the Gulf Coast inhibits the intrusion of moisture into central portions of the country.

Namias used a qualitative approach to understanding meteorological causes of drought. This method provides descriptive information of the general air circulation during a drought, but is not based upon precise measurement of physical features of the atmosphere. Harman and Harrington (1978) used a more quantitative approach in their study relating rainfall patterns to circulations in the middle troposphere. Frontal activity and surface dew point were measured during the wet August of 1975 and dry August of 1976 in the upper midwest. They showed that a significantly greater number of frontal disturbances crossed the Middle West during August, 1975 (fourteen) than during August 1976 (four). It was also found that average surface dewpoint in Minnesota, Wisconsin and Michigan preceding every cold front passage in 1975 was 65.7^{o} F; the average in 1976 was 59.9^{o} F. The dewpoint difference was significant at the 0.01 level. Harman and Harrington thus illustrated the influence of moisture advection on precipitation in the upper Midwest. While this measure was appropriate for that region, it may not be a useful measure elsewhere. For example, Walsh et al. (1982) suggested that anomalous easterly flow and vorticity are most closely related to precipitation events in the central Plains.

Dey (1982) used a synoptic climatological approach to show the relationship between the general circulation and drought conditions on the Canadian Prairies. He examined the dry summers of 1961 and 1967 using the following measures: a) 500-mb trough-ridge position b) 700-mb height departures and c) frequency of surface pressure systems. Dey showed that divergence of air at lower levels caused subsidence and atmospheric stability during the summers of 1961 and 1967. Positive height departures existed over the Prairies from May to August during those years. At the surface, migratory cyclones were significantly less frequent than normal, and migratory anticyclones were significantly greater than in the wet summers of 1953 and 1954. Dey did not analyze wet summers using any other of the previously mentioned variables.

CHAPTER II. METHODOLOGY

STUDY REGION

The three state study region has twenty-six climatological divisions and was chosen for three reasons (Figure 2-1). First, it is in a part of the country characterized by extreme moisture variability. Borchert (1971) and Skaggs (1975) describe the region as one in which drought frequently occurs. Diaz (1983) showed that Kansas, Nebraska and Oklahoma were among states with the greatest frequency of abnormally wet or dry conditions. The second reason for choosing the study region is for convenient comparison with previous work, as numerous drought studies have focussed on the Great Plains. Finally, the climatic divisions within Nebraska, Kansas and Oklahoma are of comparable size and shape. The nearest neighbor index showed that the centroids of these divisions are organized in a statistically uniform pattern.

THE PALMER INDEX

The Palmer Index was used as the measure of wet or dry conditions. Palmer developed the index to establish a criterion for measuring the beginning, end, and severity of wet and dry periods. The measure incorporates precipitation, temperature and soil

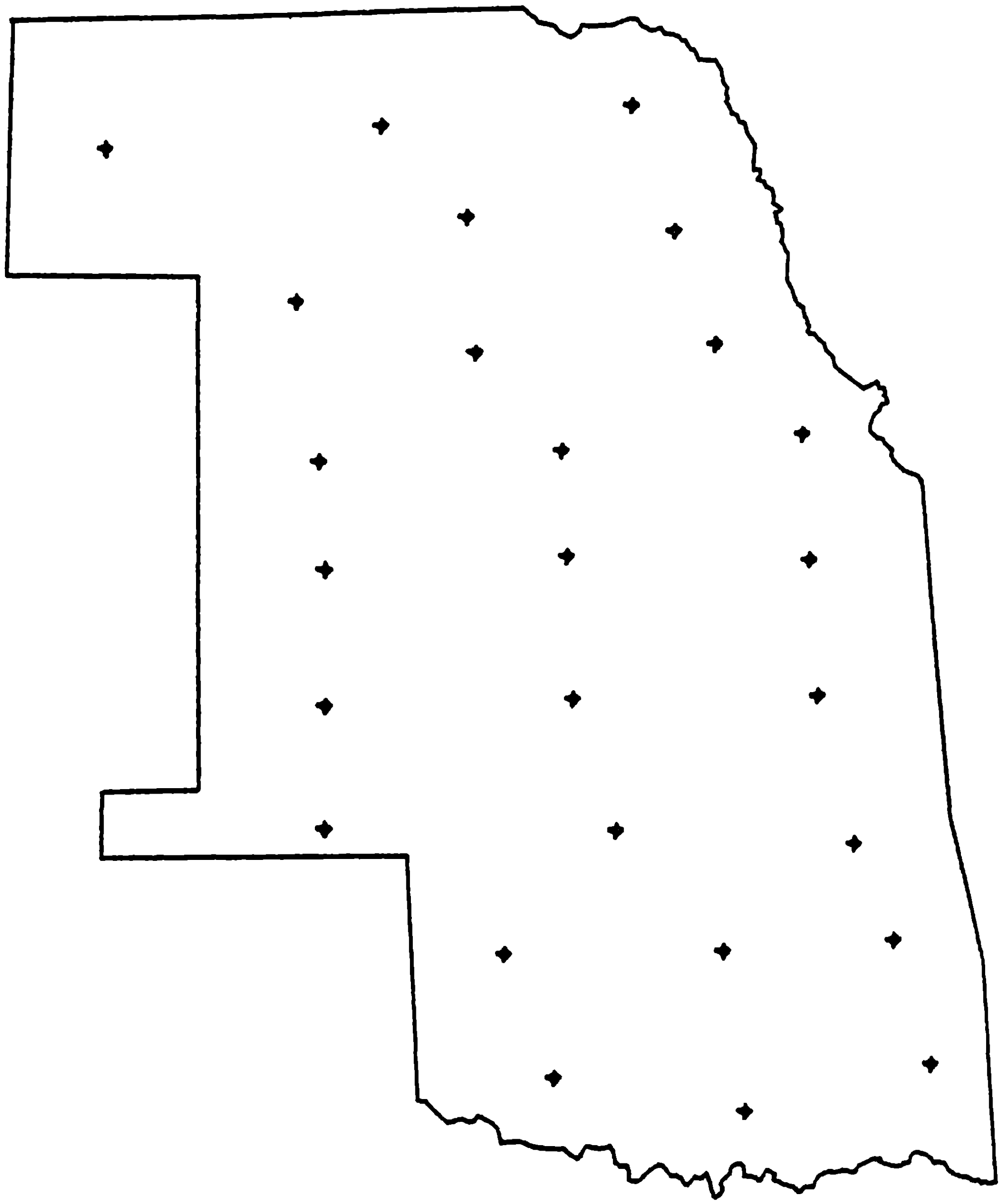

Figure 2-1. Study Region with Centroids of Twenty-six Climatological Divisions.

moisture parameters and considers quantities which are Climatically Appropriate For Existing Conditions (CAFEC, denoted by a circumflex caret) when calculating monthly PI values for specific climatic divisions. These quantities are defined by the following:

$$\hat{ET} = \alpha \hat{PE}$$
$$\hat{R} = \beta \hat{PR}$$
$$\hat{RO} = \gamma \hat{PRO}$$
$$\hat{L} = \delta \hat{PL}$$

where ET is evapotranspiration, PE potential evapotranspiration, R recharge, PR potential recharge, RO runoff, PRO potential runoff, L soil water loss, and PL potential soil water loss. CAFEC values are computed for individual stations within a climatic division and are spatially averaged to the centroid of the division for reporting purposes; they are, consequently, representative of the entire division. The constants α, β, γ, and δ are computed monthly for each climatic division and are based on thirty-year means.

A combination of these CAFEC quantities yields the hydrological water balance equation:

$$\hat{P} = \hat{ET} + \hat{R} + \hat{RO} - \hat{L}$$

where P is precipitation. $\hat{P}$ is compared to P to show precipitation excess or deficit: $d = P - \hat{P}$. From this, the moisture anomaly index is calculated as $Z = dK$ where

K is a weighting factor, unique for each month and each climatic division and based on moisture supply and demand. The actual PI is calculated during normal conditions simply as $X_t = Z_t/3$. During abnormally wet or dry periods however, consideration of past events is made, and the PI is calculated as $X = X_{t-1} + Z_t/3 - .103X_{t-1}$.

Palmer (1965) used arbitrary adjectives attached to objectively defined moisture classes to describe the degree of wetness and dryness (Table 2-1, top). Theoretically, positive and negative values of the same size define commensurate degrees of wetness and dryness (Skaggs, personal communication 1983). The PI, therefore, can be used to measure moisture deficits and surpluses below and above a climatologically normal value.

The PI has been widely used in drought research because it allows for temporal and spatial comparisons of moisture conditions (Skaggs, 1975,1978; Klugman, 1978; Diaz, 1983). Climatological divisions have also been used frequently. Sellers (1968) notes that smooth, consistent distributions of temperature and precipitation can be acquired through the use of climatic divisional data. Work by Marshall (1976), Skaggs (1975,1978) and Klugman (1978) using divisional

TABLE 2-1
DROUGHT CLASSIFICATION BY PALMER INDEX (TOP)
AND BY MODIFIED INDEX (BOTTOM)

PALMER INDEX	CHARACTERISTIC
PI < -3.99	EXTREMELY DRY
-4.00 < PI < -2.99	SEVERELY DRY
-3.00 < PI < -1.99	MODERATELY DRY
+1.99 < PI < +3.00	MODERATELY WET
+2.99 < PI < +4.00	SEVERELY WET
+3.99 < PI	EXTREMELY WET

PALMER INDEX	CHARACTERISTIC
PI < -3.99	EXTREMELY DRY
PI < -2.99	SEVERELY DRY
PI < -1.99	MODERATELY DRY
PI > +1.99	MODERATELY WET
PI > +2.99	SEVERELY WET
PI > +3.99	EXTREMELY WET

data in drought studies proves Seller's conclusion.

Some alteration of Palmer's classification scheme was made in this study (Table 2-1, bottom). All PI values less than -2 (moderate or worse drought) were described as moderate drought; all PI values less than -3 represented severe drought and ; all values less than -4 represented extreme drought. A similar classification scheme was employed for wet periods.

Monthly PI values were obtained on magnetic tape from the National Center for Atmospheric Research (NCAR). The data were computed for the centroid of each climatic division over the period of record, January, 1931 - December, 1975.

MEASURING OCCURRENCE

A computer program was used to sort monthly PI data into the previously defined classes. The number of months experiencing each of the moisture classes was counted. Additionally, a count was made of the combined number of wet and dry occurrences at each degree of severity. This information on the frequency of combined wet or dry periods provided a measure of the number of months with generally abnormal moisture conditions. From these counts, the percentage occurrence over the entire period of record was computed to facilitate comparisons between different classes of events.

MEASURING PERSISTENCE

Persistence of abnormal moisture conditions was measured as a series of runs. For this purpose, the length of a run of positive (wet) and negative (dry) moisture deviations from average was computed for each division. Since divisions had several runs of wet and dry conditions, the average length of run for each event was computed for each of the twenty-six divisions.

Two degrees of severity were used in quantifying wet and dry period persistence. PI values one standard deviation below (above) the mean were referred to as slightly dry (wet) conditions and PI values 1.5 standard deviations below (above) the mean were called intensely dry (wet) conditions. The average length of run was calculated for each of the four classes.

The cutoff values of 1 and 1.5 standard deviations from the mean were chosen because they adequately define two levels of acuteness. A departure of one standard deviation was considered significant when experienced in several consecutive months. A departure of 1.5 standard deviations offers a further degree of severity without exceeding reasonable limits; such PI values occurred with some regularity.

The use of standard deviations assumes that PI values have a mean of zero and a normal distribution. A Kolmogorov-Smirnoff goodness-of-fit test of PI distributions revealed that ten climatic divisions scattered throughout the study area meet this requirement. Those divisions showing a normal distribution were in the northwestern, northeastern and southeastern divisions of Nebraska; the northern divisions of Kansas; and the central and east-central divisons of Oklahoma. Further support for these assumptions was found in the literature. A mean PI value of zero was assumed by Skaggs (1978) in his study on drought persistence from 1887 to 1968.

The Surface II computer mapping routine was used to show spatial patterns of wet and dry period occurrence and persistence. Isoline mapping was considered to be the most appropriate technique to show percentage occurrence of specific PI values because it more clearly incorporates gradients between divisions (Bark, 1984 and Jenks, 1984, personal communications).

CHAPTER III. RESULTS

The results of this study are presented in both written and map form. Written descriptions provide information on regions of highest and lowest percentage occurrence and longest and shortest persistence. The maps are designed to supplement these descriptions with detailed illustration of spatial patterns. Isolines are drawn at four percent intervals on maps showing percent occurrence; they are drawn at intervals of four months on maps showing monthly persistence. Such spacing allows gradients between high and low occurrence to be shown most clearly.

OCCURRENCE OF DROUGHT

Moderate Drought --(Figure 3-1)--

Moderate drought occurred most frequently in southwestern Kansas and the Oklahoma panhandle where over thirty-two percent of all months within the total period of record experienced such conditions. Relatively high frequencies extended from this locus to the northeast; over twenty-four percent occurrence was found throughout the eastern two-thirds of Kansas. The northern and southeastern portions of the study region, had moderately dry conditions least frequently (under twenty percent of all months).

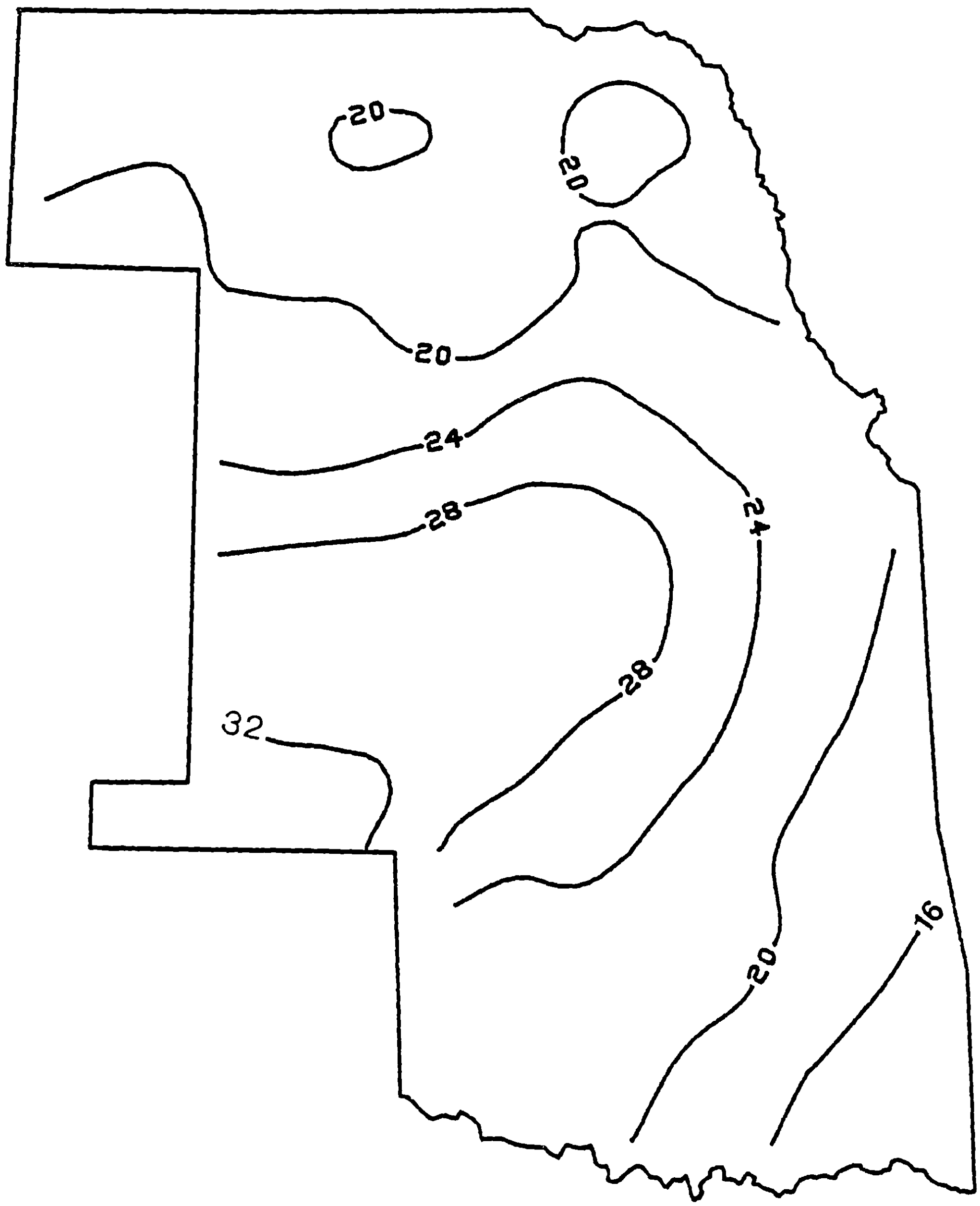

Figure 3-1. Percent Occurrence of Moderate Drought, 1931 - 1975.

Severe Drought --(Figure 3-2)--

Severe drought had two loci, including southwestern Kansas and the panhandle of Oklahoma; and the northwest, northcentral and central climatic divisions of Kansas. Over sixteen percent of all months had severely dry conditions in these two regions. Over twelve percent occurrence was seen in a broader region extending from the Oklahoma panhandle to eastern Nebraska. A weak gradient separated this broad region from the southeast and northwest portions of the study region where severe drought was least common (less than eight percent).

Extreme Drought --(Figure 3-3)--

The greatest occurrence of extremely dry conditions was in eastern Nebraska where more than eight percent of the total months had PI values less than -4. Particularly low occurrence was found in extreme northwestern Nebraska and throughout most of Oklahoma.

Summary of Drought Occurrence

Similarities were found amongst the three degrees of drought severity. High percentage occurrence was found in a SW-NE path across the middle of the study area in each case. Low percentage occurrence was found in the southeast and northwest margins of the study region.

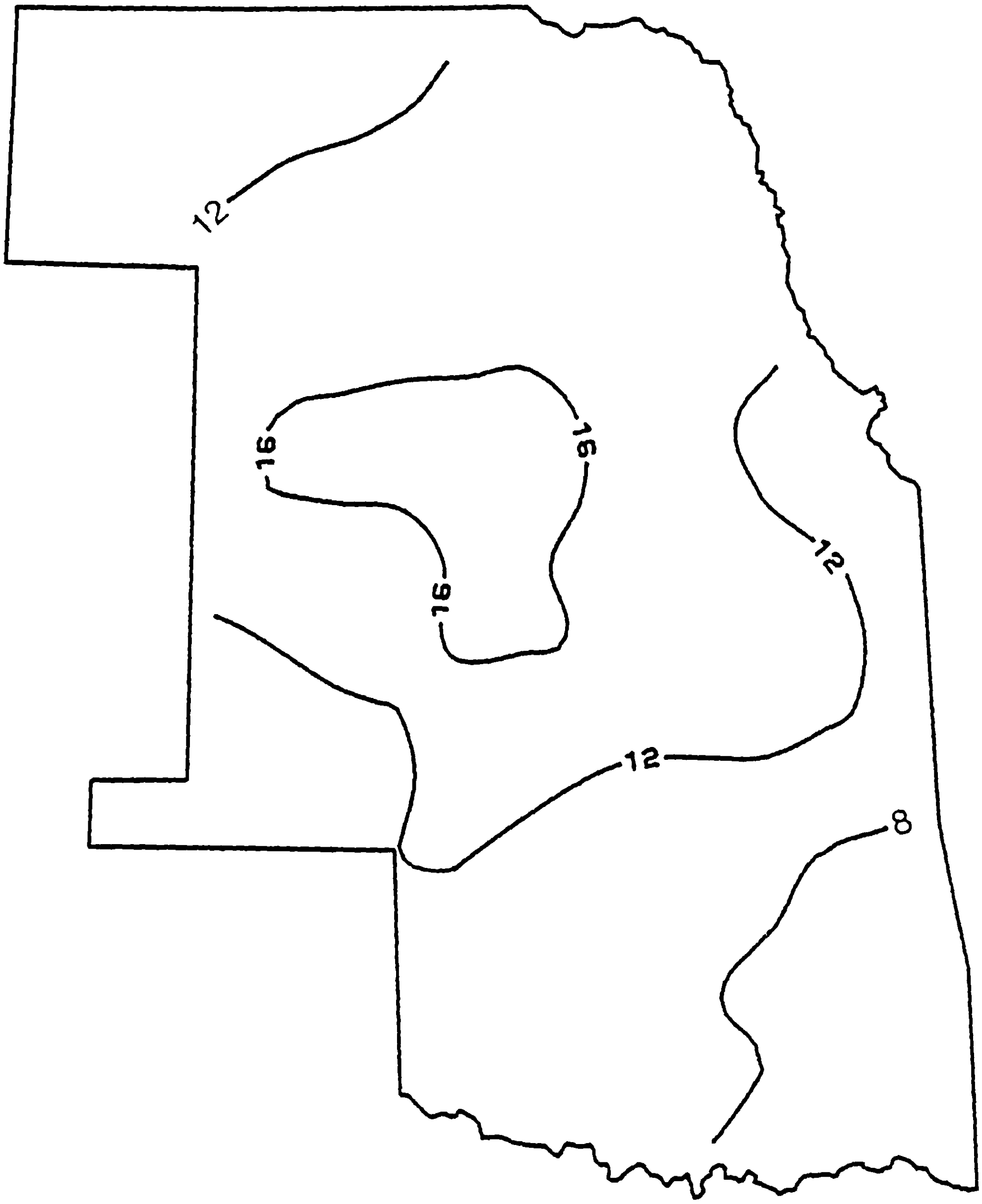

Figure 3-2. Percent Occurrence of Severe Drought, 1931 - 1975.

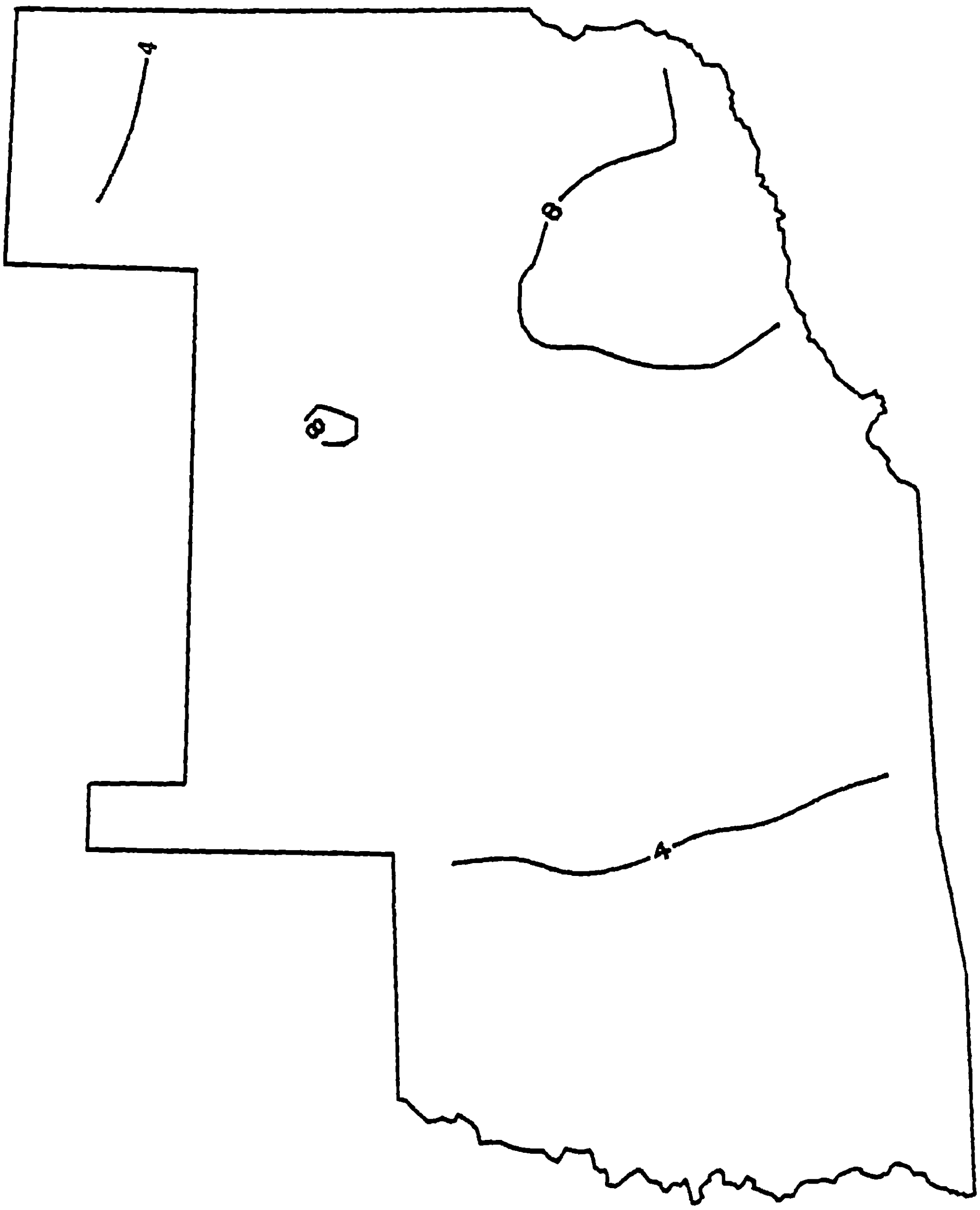

Figure 3-3. Percentage Occurrence of Extreme Drought, 1931 - 1975.

A significant difference existed between the various degrees of drought severity, however. The locus of highest occurrence had a systematic shift to the northeast with increasing severity. Highest percentages of moderate drought were found in the southwest portion of the study region; highest percentages of severe drought in southwest and central portions of the region; and highest percentages of extreme drought in the northeast portion of the region.

OCCURRENCE OF WET PERIODS

Moderate Wet Periods --(Figure 3-4)--

Percentage occurrence of moderately wet conditions had two loci. One, in southeastern Nebraska, had PI values greater than +2 during thirty-six percent of all months, while the second, in central Kansas, had over forty percent occurrence. These high percentages created a sharp gradient to the west and south of both loci. A broad region of relatively high occurrence existed across the eastern two-thirds of Nebraska and Kansas where over thirty-two percent of all months experienced moderately wet conditions. Lowest frequency was found in eastern Oklahoma and northwestern Nebraska.

Severe Wet Periods --(Figure 3-5)--

The regional pattern of severely wet conditions (PI

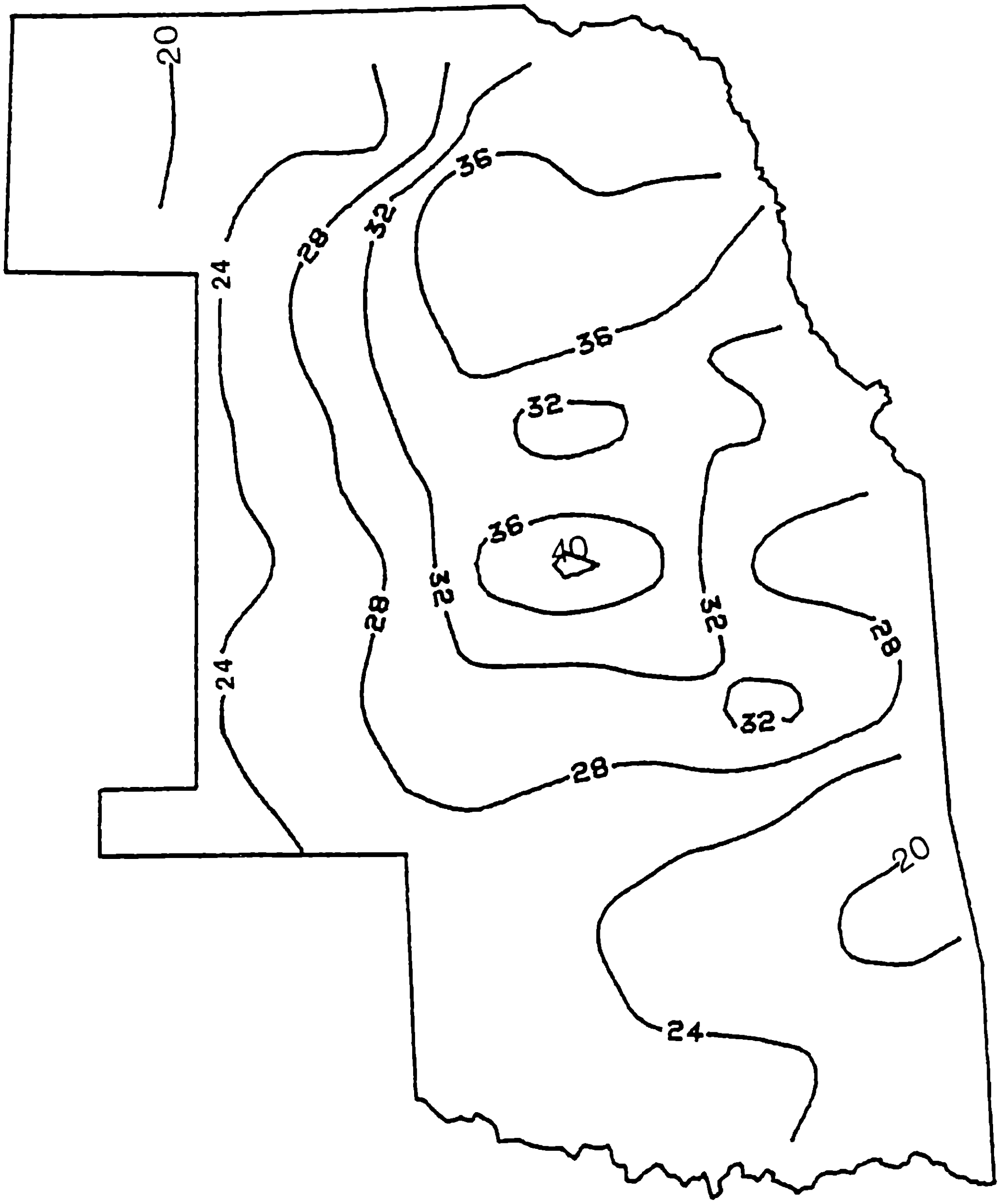

Figure 3-4. Percent Occurrence of Moderate Wet Periods, 1931 - 1975.

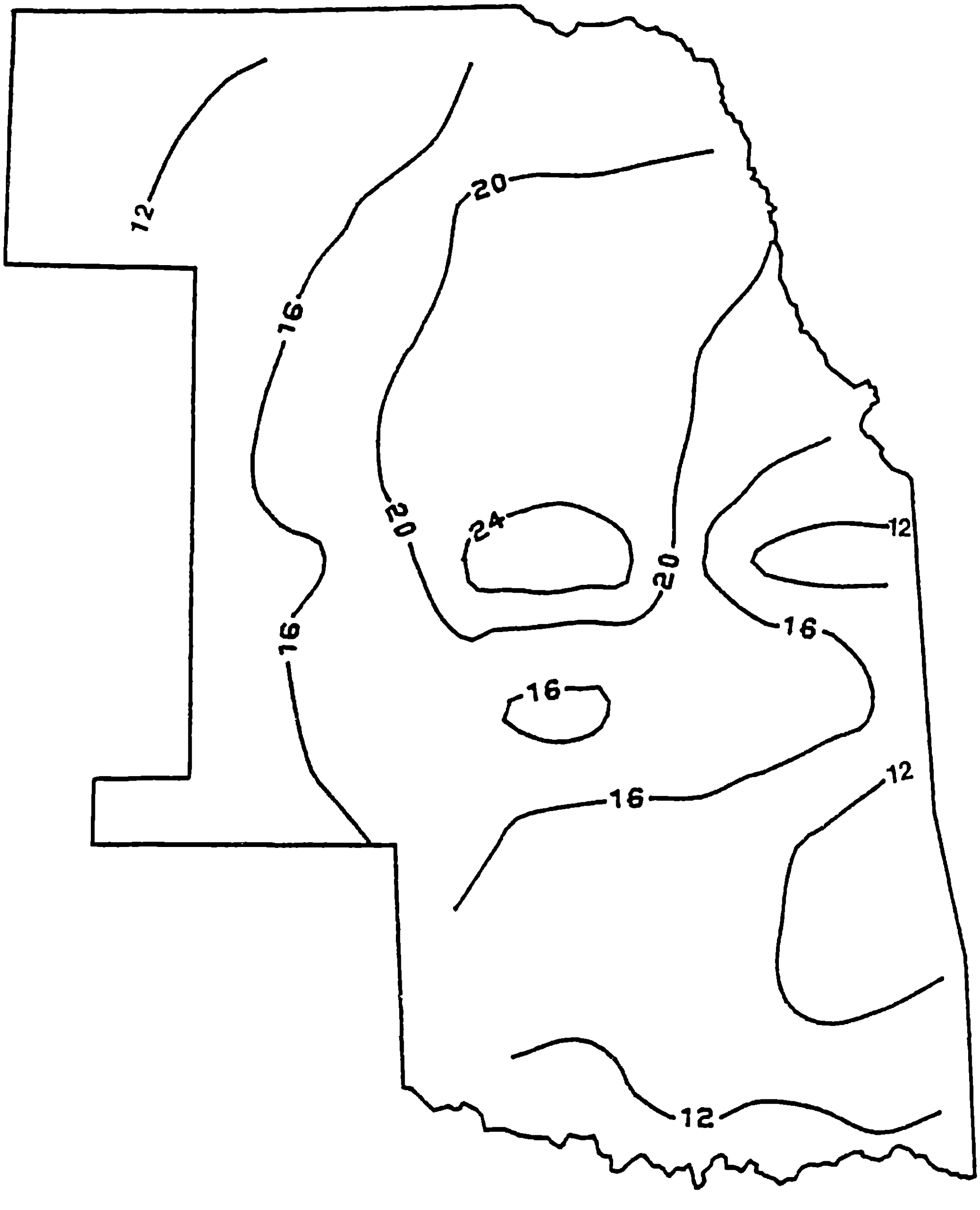

Figure 3-5. Percent Occurrence of Severe Wet Periods, 1931 - 1975.

> +3) showed similarities to the previous example. Most frequent occurrence again was seen in central Kansas (over twenty-four percent of all months) and a sharp gradient existed to the east of this locus. A broad region of high occurrence again extended from east-central Nebraska to central Kansas where twenty percent of all months had severely wet conditions. Relatively low percentages were repeated in eastern Oklahoma and northwestern Nebraska.

Extreme Wet Periods --(Figure 3-6)--

Extreme wet conditions showed spatial uniformity across the study region. The central division of Nebraska had such conditions in over twelve percent of all months, the highest in the three-state region. A broad region with SW-NE orientation, extended from eastern Nebraska to the Oklahoma panhandle and had over eight percent occurrence. Lowest values were seen in southeastern Oklahoma.

Summary of Wet Period Occurrence

The regional patterns of wet period occurrence were similar at each degree of severity. Loci were found consistently in central Nebraska and central Kansas. A broad outline of relatively high occurrence extended from the northeast of the study region towards

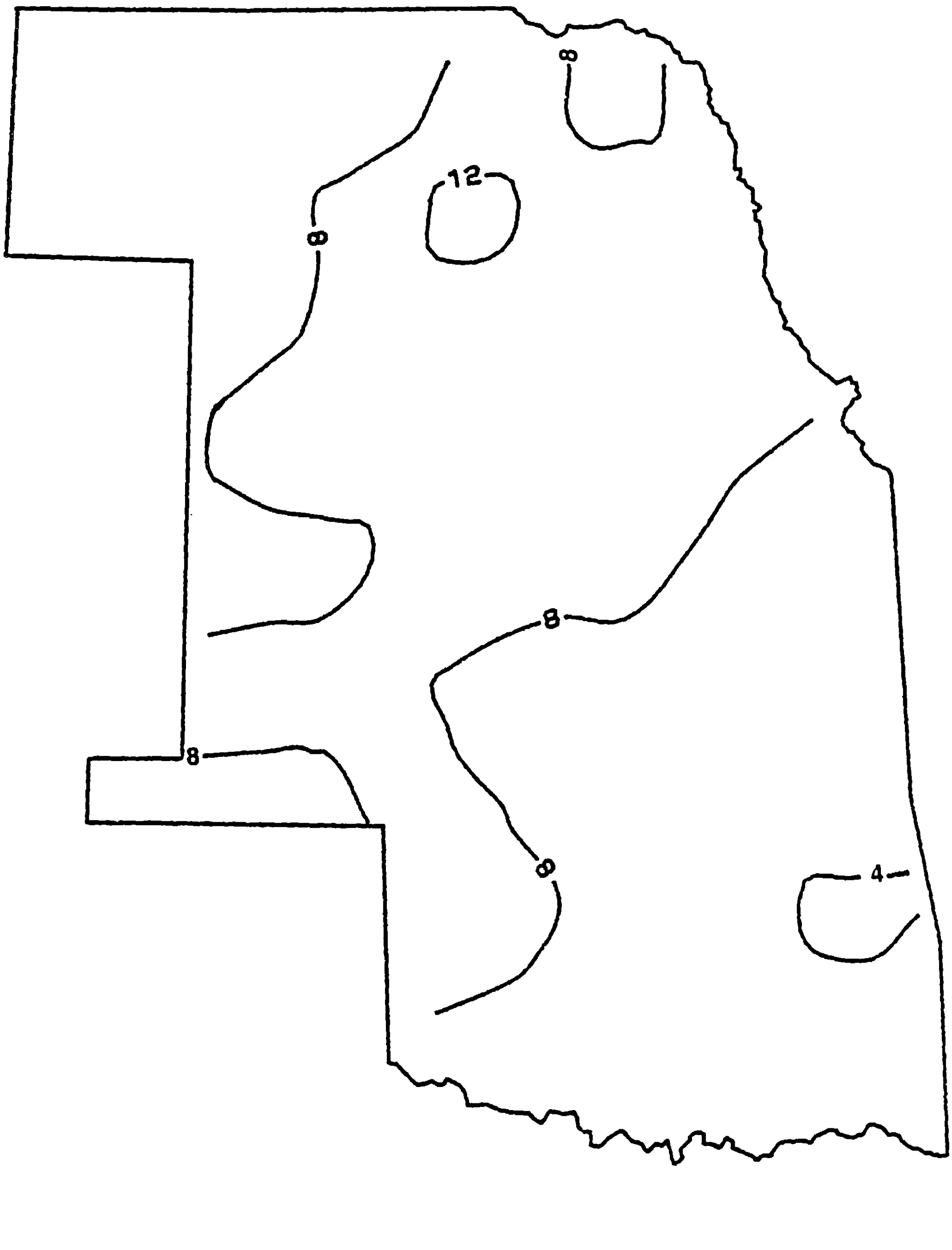

Figure 3-6. Percent Occurrence of Extreme Wet Periods, 1931 - 1975.

the southwest. Wet conditions were most infrequent in southeastern Oklahoma and northwestern Nebraska.

The results of several studies aid in an understanding of the regional patterns of wet period occurrence. Klein (1957) showed the frequency of cyclone formation and occurrence in the Northern Hemisphere between 1899 and 1939. He constructed prevailing storm tracks based on regions of highest cyclone occurrence. His maps showed that cyclones typically develop to the west of the central Plains region and move towards the northeast. Exceptions occur during the summer months when storm tracks are displaced northward. Examples of Kleins maps of the four mid-season months are seen in Figures 3-7 - 3-10. Reitan (1974) similarly suggested a cyclone path from southwest to northeast across the central Plains based on regions of highest frequency. Zishka and Smith (1980) later showed that cyclone events occurred most frequently in a region with the same orientation extending from the Oklahoma panhandle to eastern Nebraska.

Walsh et al. (1982) offered additional evidence to support this southwest-northeast orientation. They delineated precipitation regions based on the greatest spatial coherence of monthly amounts. One established region centered on the central Plains and had the

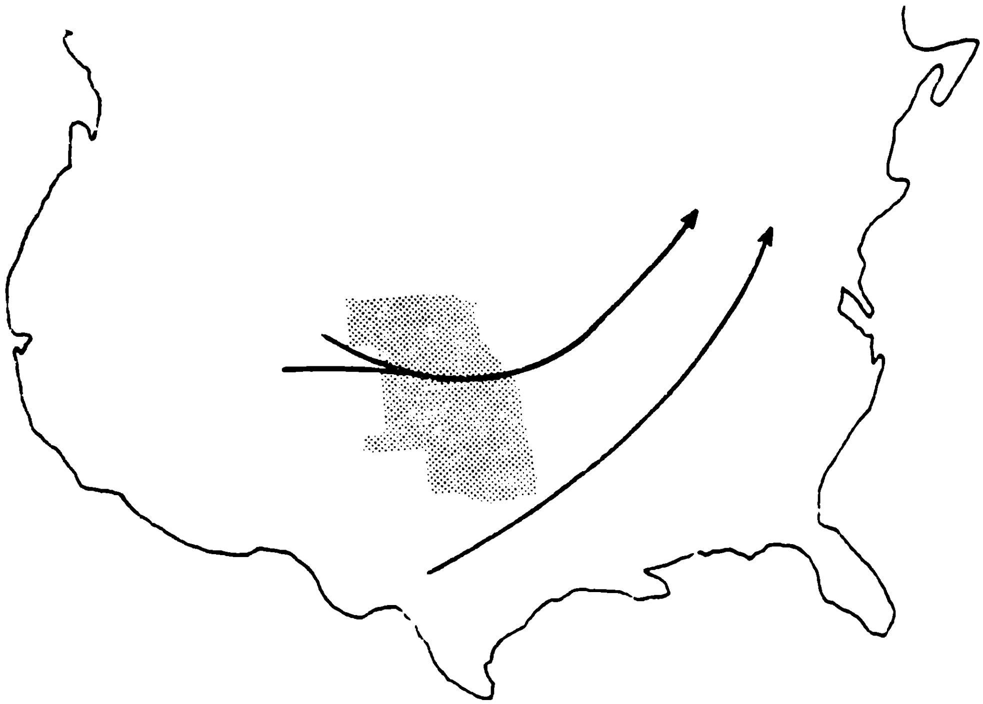

Figure 3-7 (above). January Cyclone Tracks.
Figure 3-8 (below). April Cyclone Tracks.
(Source: Klein, 1957)

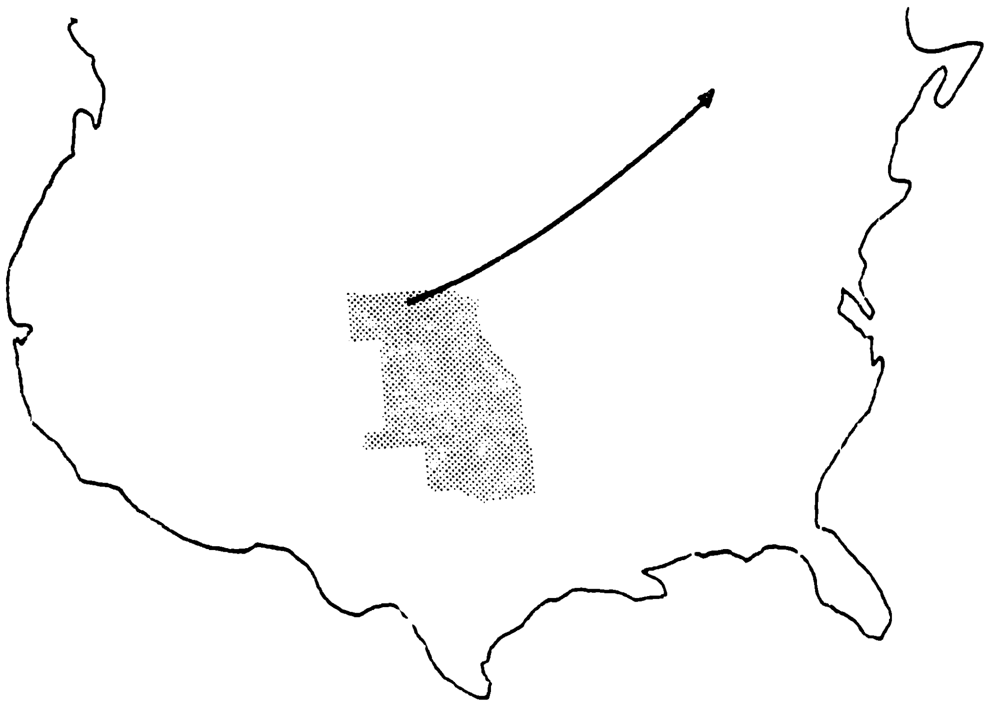

Figure 3-9 (above). July Cyclone Tracks.
Figure 3-10 (below). October Cyclone Tracks.
(Source: Klein, 1957)

familiar southwest-northeast orientation. This region excludes southeastern Oklahoma and extreme northern and northwestern Nebraska.

COMPARISON AND CONTRAST OF WET AND DRY PERIOD OCCURRENCE

Marked similarities were found between the frequency of drought and the frequency of wet periods. High and low frequencies were not in isolated divisions, but showed broad-scale patterns. In both wet and dry periods, and for all degrees of severity, high occurrence was found in a portion of the study region extending from eastern Nebraska to the Oklahoma panhandle. Least frequent occurrence was almost exclusively on the northwest and southeast margins of this path.

Some differences did exist between wet and dry events. The progressive shift of a drought locus, with increasing severity, contrasted with the relatively stable locus exhibited with increasing severity of wet conditions. Another difference was that wet periods occurred more frequently at each degree of severity. Moderately wet periods existed as often as forty percent of the total record in some divisions, while moderately dry periods reached a maximum frequency of only thirty-two percent. Severely wet conditions occurred in over twenty-four percent of all months in central Kansas, while severely dry periods occurred in only sixteen percent of all months. Extremely wet conditions had maximum values of thirteen percent and extremely dry conditions reached maximum values of ten percent.

OCCURRENCE OF WET OR DRY PERIODS

The isoline maps of wet or dry periods were constructed simply as a combination of previous maps. Percentages of wet and dry events were computed at each degree of severity, to show patterns of "abnormal moisture" conditions. The resulting regional patterns illustrated marked diversity of such condtions within the study region.

Moderately Wet or Dry Conditions --(Figure 3-11)--

Occurrence of moderately wet or dry conditions was greatest in central Kansas where over sixty-eight percent of the entire period of record was marked by such events. A sharp gradient existed to the northwest and southeast of this locus. A broader region, extending from the Oklahoma panhandle to east-central Nebraska, had over fifty-six percent occurrence and maintained a sharp gradient towards southeastern Oklahoma and northwestern Nebraska where moderately wet or dry conditions existed less than forty percent of all

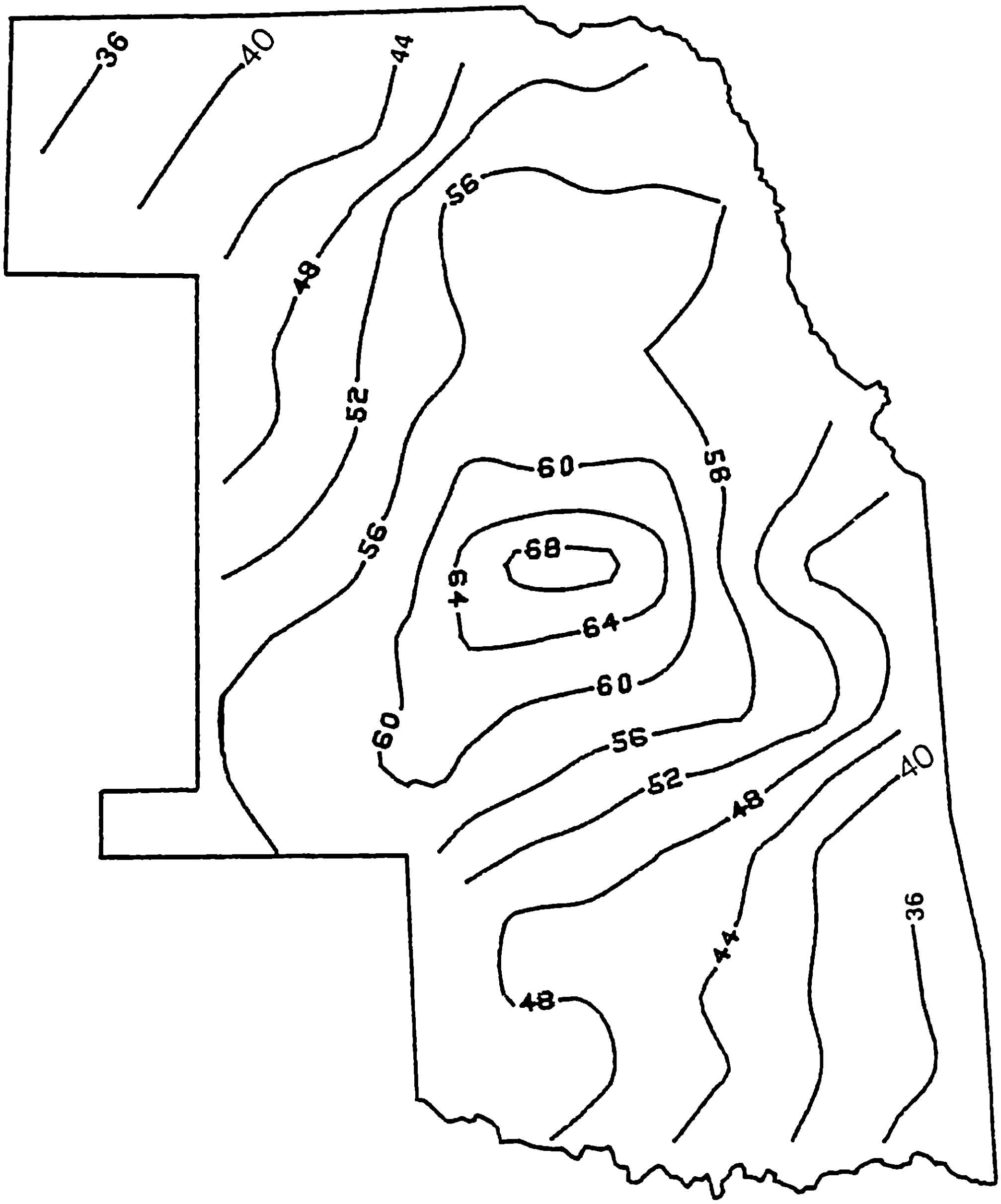

Figure 3-11. Percent Occurrence of Moderately Wet or Dry Conditions, 1931 - 1975.

months.

Severely Wet or Dry Conditions --(Figure 3-12)--

As with the previous example, the highest percentage occurrence was found in central Kansas; over forty percent of all months had PI values greater than +3 or less than -3. The familiar NE-SW orientation and sharp gradient to northwestern and southeastern portions of the study region were also present. Values dropped below twenty percent in these margins.

Extremely Wet or Dry Conditions --(Figure 3-13)--

The region of highest percentage occurrence shifted to east-central Nebraska at this degree of severity; over twenty percent of all months had PI values either in excess of +4 of below -4 in this region. Over sixteen percent of all months had extremely wet or dry conditions in a region extending from eastern Nebraska to northwestern Kansas. Values in southeastern and northwestern portions of the study region, however, were below eight percent.

PERSISTENCE OF DROUGHT

Persistence of Slight Drought --(Figure 3-14)--

Slight drought conditions persisted longest in central and south-central Nebraska where the average length of each event was over twenty consecutive

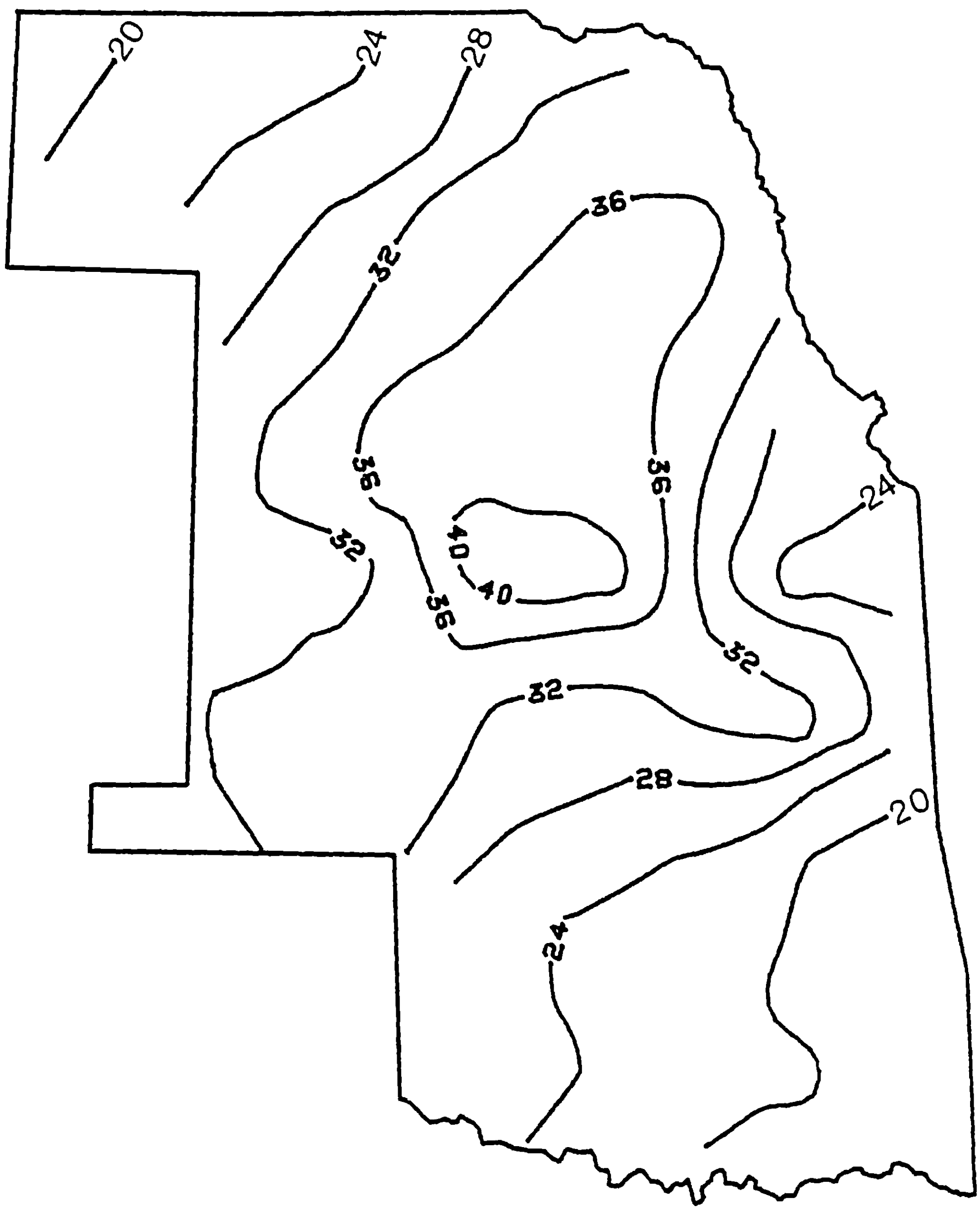

Figure 3-12. Percentage Occurrence of Severely Wet or Dry Conditions, 1931 - 1975.

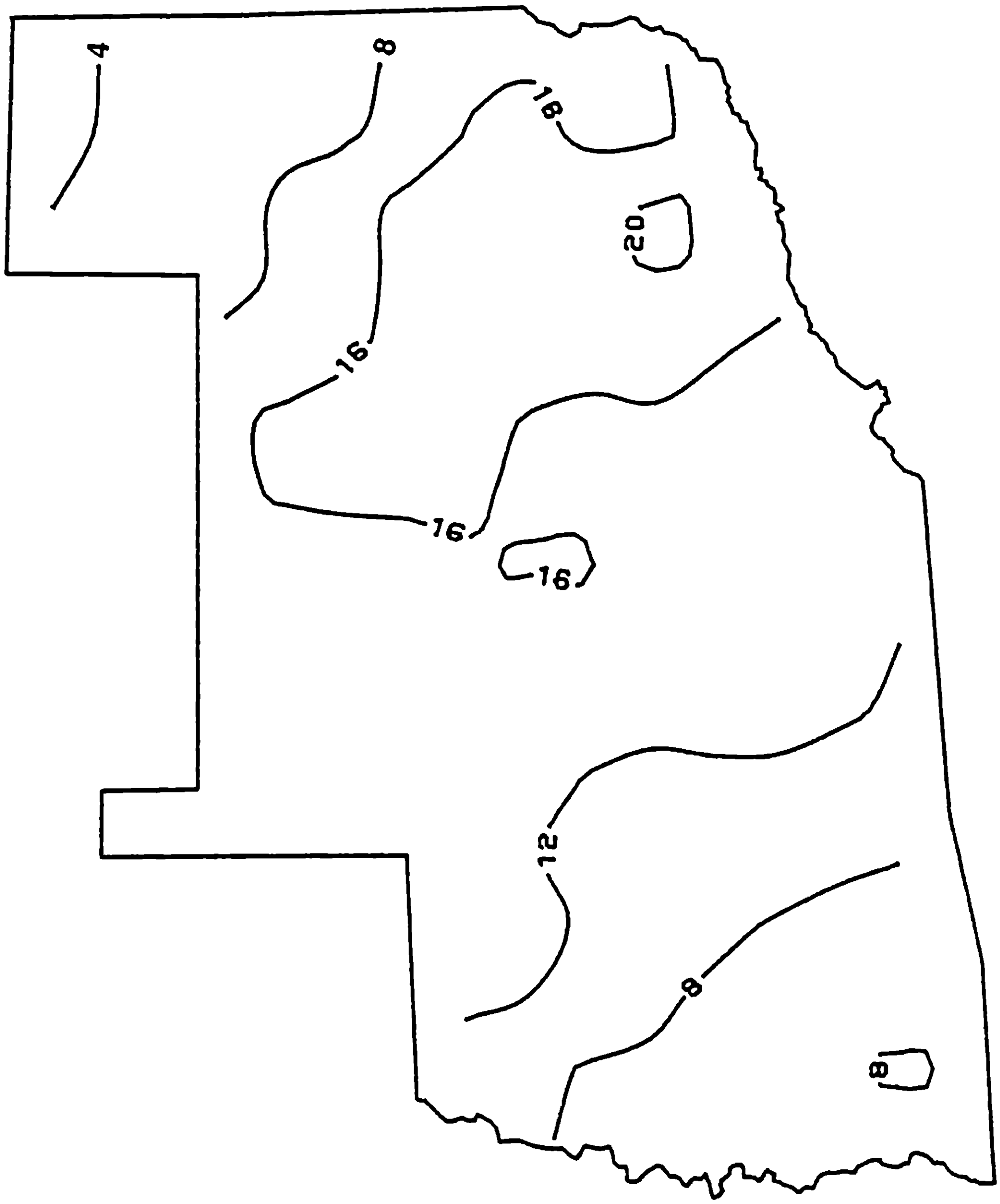

Figure 3-13. Percent Occurrence of Extremely Wet or Dry Conditions, 1931 - 1975.

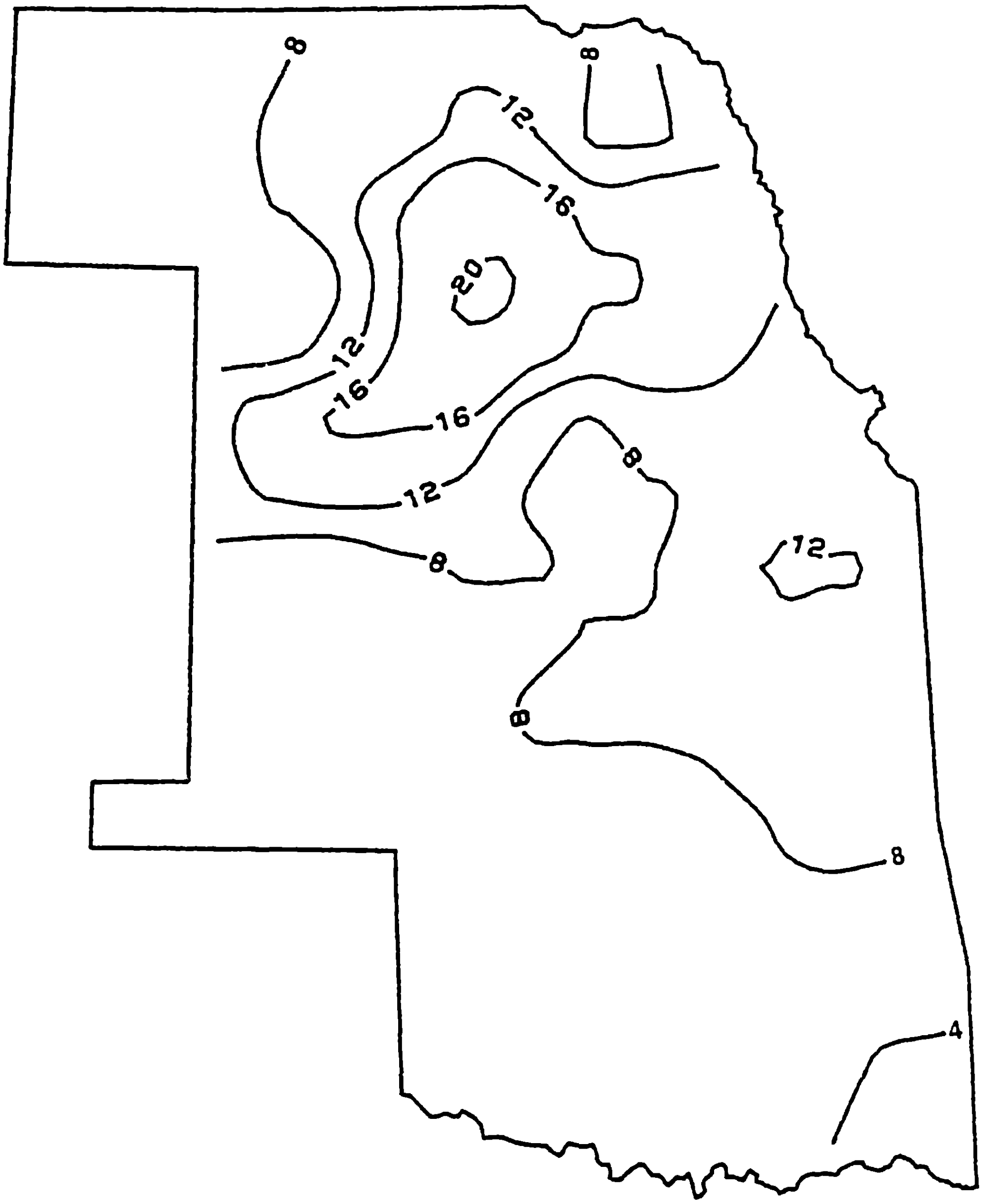

Figure 3-14. Average Duration (months) of Slight Drought.

months. A steep gradient existed in all directions away from this core. Persistence was weakest in Oklahoma, southern Kansas and extreme northern and western Nebraska, where averages were less than eight consecutive months.

Persistence of Intense Drought --(Figure 3-15)--

Persistence of intense drought showed less regional variation than slight drought; three general areas were distinguishable. Central and southeastern Nebraska had longest average persistence of drought (over eight months). Southwestern Nebraska, western Oklahoma and southwestern Kansas all had relatively low averages (less than four months). Remaining portions of the study region were relatively uniform, with averages between four and eight months.

PERSISTENCE OF WET PERIODS

Persistence of Slight Wet Spells --(Figure 3-16)--

The persistence of slightly wet conditions had little regional diversity. The average length of slight wet spells is between four and eight months over nearly all climatic divisions. Two isolated divisions (east-central Oklahoma and east-central Kansas) were the only exceptions and had less than four consecutive months with such PI values.

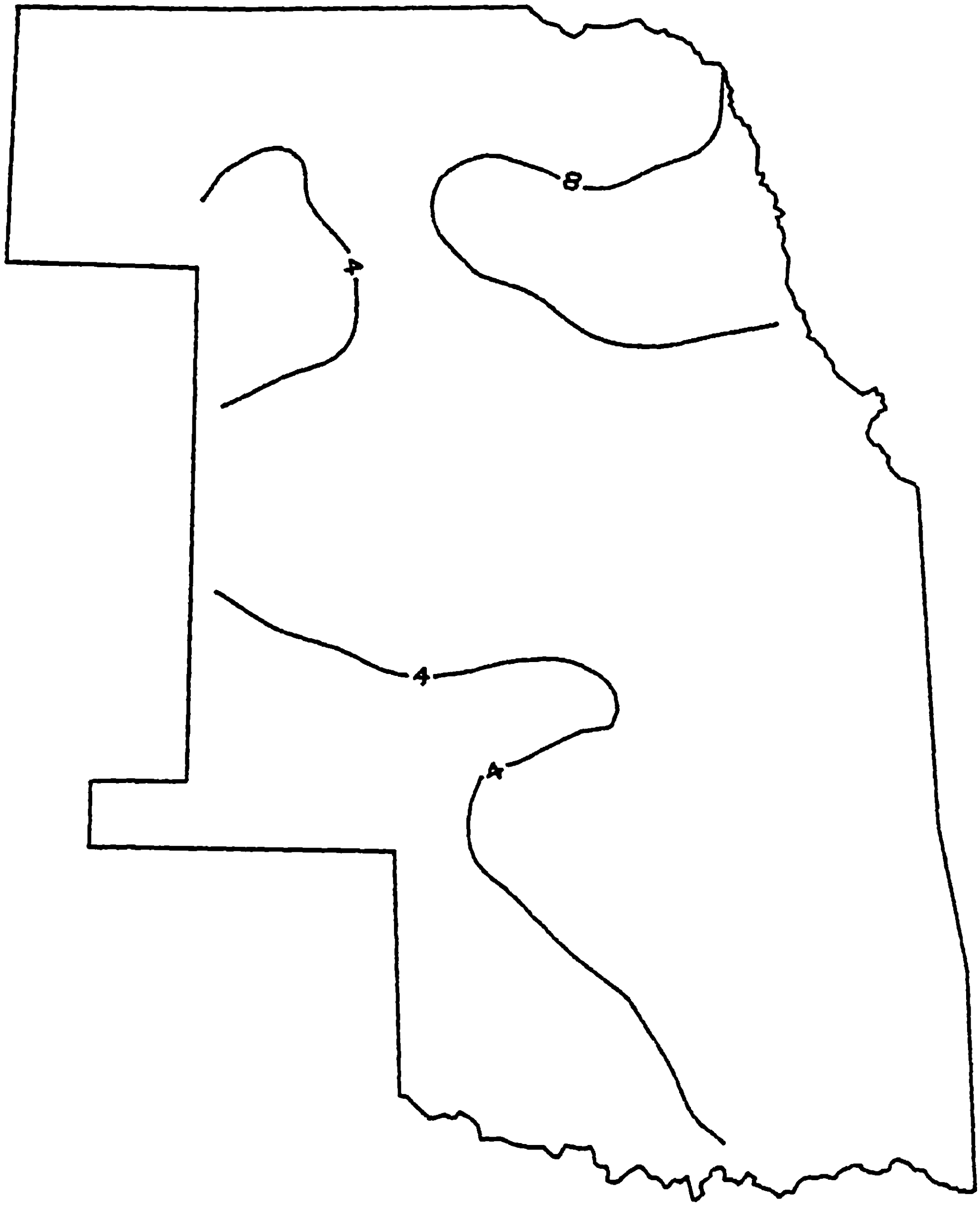

Figure 3-15. Average Duration (months) of Intense Drought

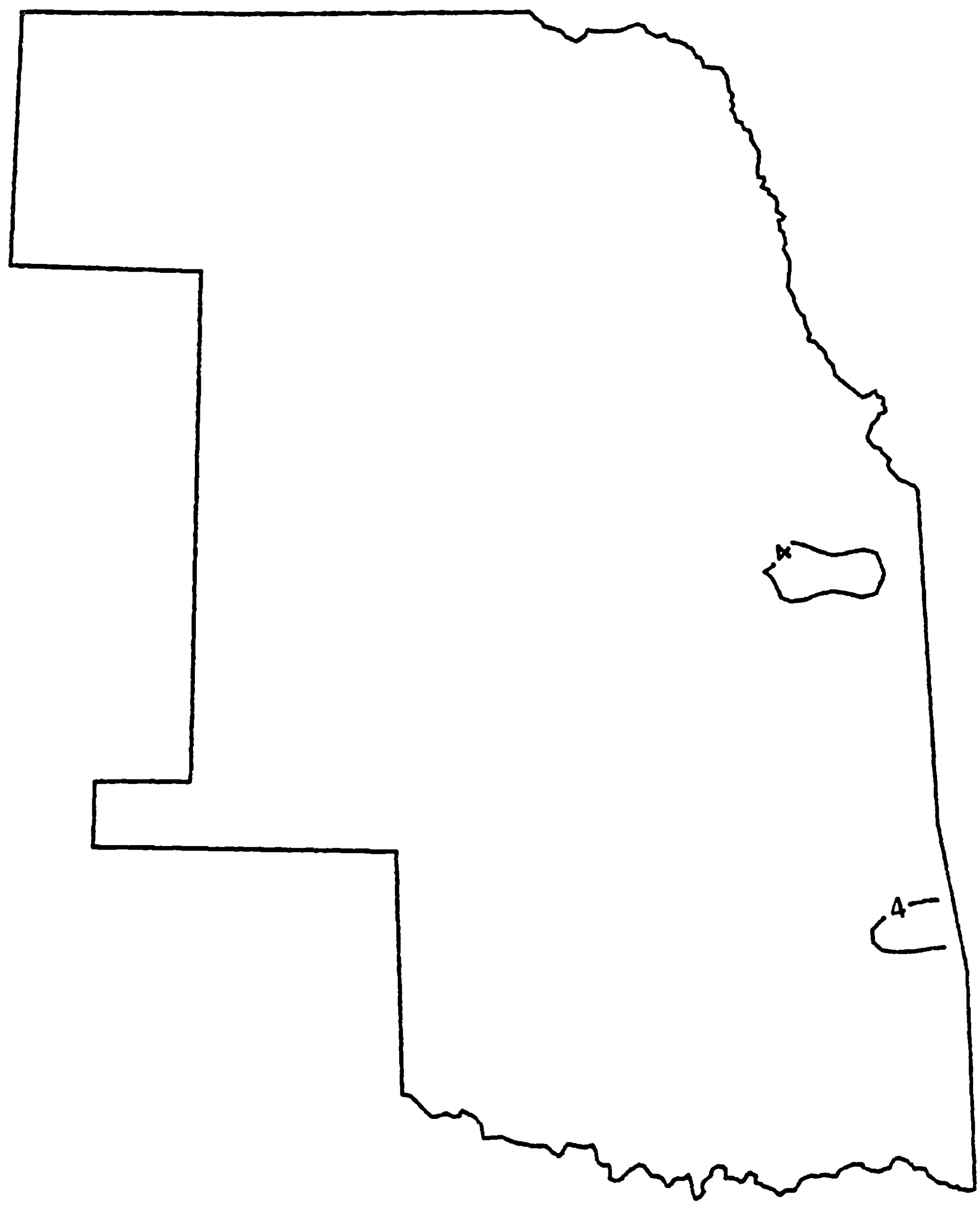

Figure 3-16. Average Duration (months) of Slight Wet Periods.

Persistence of Intense Wet Spells --(Figure 3-17)--

The persistence of intense wet spells showed more regional variation than slight wet spells. The longest average was found in west-central Kansas where major wet spells lasted over eight months. Average length in the central portion of the study region and in southwestern Oklahoma was between four and eight months. The lowest average persistence is found in northern and southern portions of the study region.

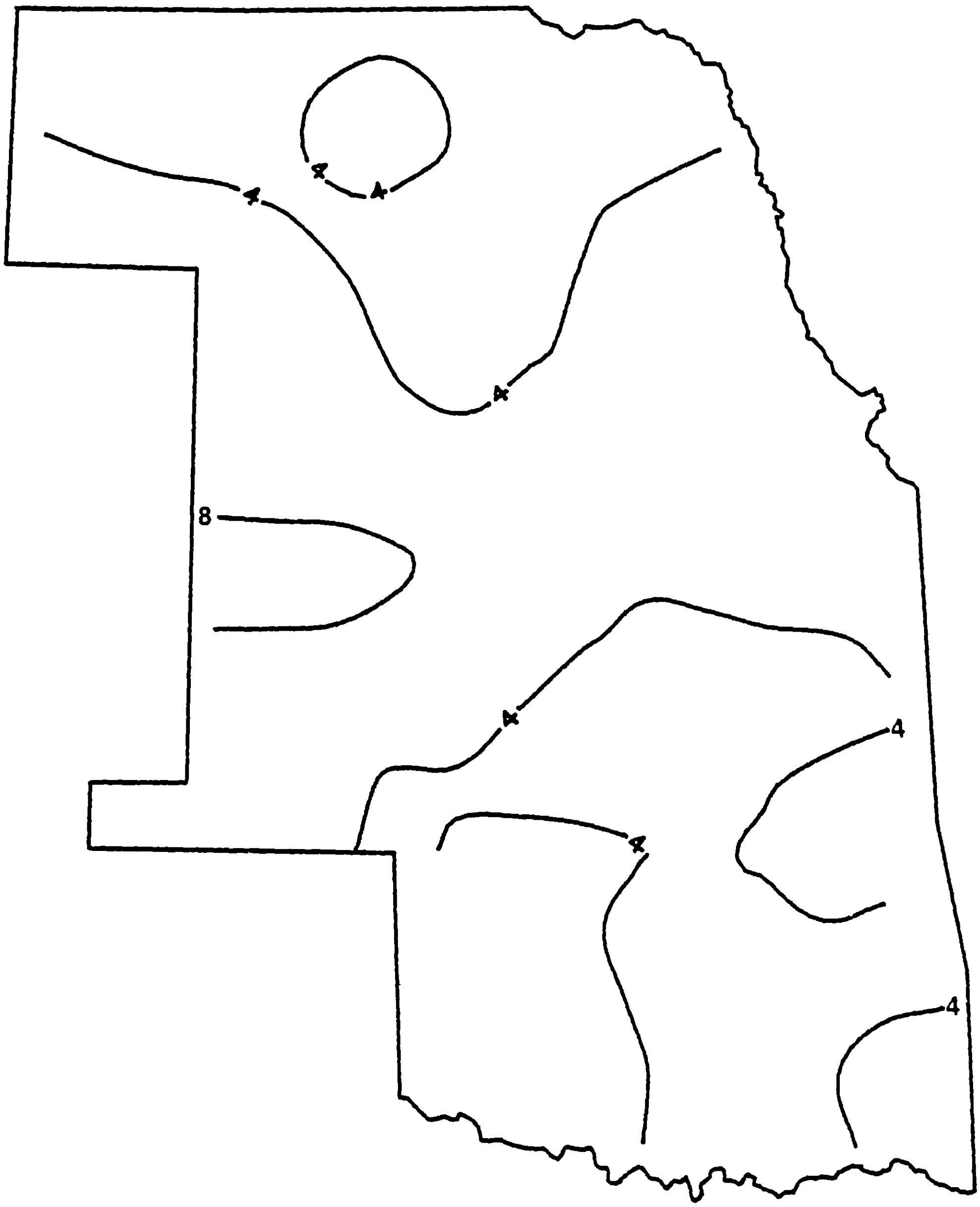

Figure 3-17. Average Duration (months) of Intense Wet Periods.

CHAPTER IV. ANALYSIS

IDENTIFICATION OF WET AND DRY PERIODS

For analysis purposes wet(dry) periods were defined as consecutive months in which at least six divisions had PI values greater than +2 (less than -2).[1] This definition was similar to Diaz' (1983) classification. The threshold of six climatic divisions represents less than twenty-five percent of the study region. Classification produced wet (dry) periods of different length; variable numbers of months with normal conditions immediately preceded or followed such periods (Table 4-1). No more than four normal months before or after each wet or dry period were analyzed. Since there was a variable number of normal months before and after such events this technique provided uniformity in the analysis. The specific number of normal months considered was similar for each individual wet or dry event.

TABLE 4-1
MAJOR WET AND DRY PERIODS, 1931 - 1975 AND
NUMBER OF NORMAL MONTHS PRECEDING AND FOLLOWING EACH

NORMAL	FIRST WET MONTH		LAST WET MONTH	NORMAL
4	4/41	-	3/43	4
3	4/44	-	9/45	4
2	10/46	-	3/48	3
3	1/49	-	10/49	3
1	5/57	-	12/60	2
2	3/61	-	11/62	4
4	7/65	-	2/66	2
4	8/68	-	10/69	4
4	11/72	-	8/75	4

NORMAL	FIRST DRY MONTH		LAST DRY MONTH	NORMAL
2	10/33	-	10/35	4
4	3/36	-	11/40	4
4	7/46	-	8/46	4
3	9/52	-	3/57	2
4	5/63	-	10/64	4
2	5/66	-	7/66	2
2	10/66	-	5/67	4

Synoptic-scale climatological analysis provides information on the causes of abnormal moisture conditions. Features of middle-level flow and surface weather are related to the initiation, persistence and cessation of wet and dry periods in the three state region between 1931 and 1975.

VARIABLES USED IN THE ANALYSIS

The variables used in the analysis are a combination of dynamic and thermodynamic measures. All are associated with abundant or little precipitation, and, thus, provide a useful measure in demarcating wet and dry periods. Measurements of each are made on a monthly basis to correspond with PI data. Despite the generalization which occurs when averaging the variables, they should reflect monthly changes in moisture conditions.

The number of mid-latitude cyclones passing through the study region i.e. (cyclonicity) was a surface measure used in the analysis. It is an appropriate measure because of the close association between storms and precipitation events (Dey, 1982). The position of a 700-mb ridge or trough was one variable used to describe mid-atmospheric conditions. The number of months in which a mean ridge was established over the interior West and central Plains was counted before, during and after dry periods. The frequency of trough establishment in the southwestern U.S was counted before during and after wet periods. These variables were based on Namias' (1957) work showing close correlation between these 700 mb features and dry and wet events. Seven-hundred mb height departures from normal and monthly height departure change were other variables which were measured in the southwestern United States. Hawkins (1956) discussed the importance of height anomalies in this region on surface weather conditions in central portions of the country.

All three are interrelated variables and cannot be interpreted as completely independent measures. They provide an overview of mean monthly surface and middle-level conditions. Case studies provide an approach to understanding the complimentary nature of these variables and to show changes in the variables during the initiation, persistence and termination of wet and dry periods.

CYCLONICITY

The basic theories relating precipitation patterns to mid-latitude cyclones have been accepted for many years (Namias, 1981). Cyclonicity should be significantly greater during a wet period versus the normal months preceding or following that wet period. Conversely, there should be fewer cyclones during a dry period than during the normal months immediately preceding or following such an event.

The number of cyclones passing through the study region in months before, during and after wet and dry periods was counted using National Weather Service maps published in Monthly Weather Review. These maps were available for the entire period of record. Cyclonicity provided a dynamic measure in the study.

Months preceding and following all wet/dry events were classified into two separate samples; months within all wet/dry events formed a third sample. Chi-square tests were used to assess statistical differences between normal and wet/dry months.[2]

RIDGE/TROUGH POSITION

The number of studies on the climatology of mean trough and ridge positions reflects their importance in explaining surface conditions (Klein and Winston, 1958; Stark, 1965). Mean monthly flow patterns have been used to explain surface weather phenomenon especially for predictive purposes (Klein, 1948; Namias, 1948; Lawson *et al.*, 1978). Klein (1949) associated cold, wet weather anomalies in the 1948-49 winter with a deep trough in the central United States. Namias (1955) used average monthly flow to explain the intensification of drought in October, 1952, and in the summers of 1953 and 1954.

The onset, persistence and cessation of wet and dry periods in Kansas, Nebraska and Oklahoma should be related to ridge and trough positions. Ridge-trough position is a thermodynamic measure since atmospheric thickness is dependent on temperature. During dry periods a ridge should exist over the central or western United States inhibiting mid-latitude cyclones and the influx of Gulf moisture (Harman and Harrington, 1978) During wet periods a 700-mb trough axis should be established to the southwest of the study region. These regions of ridge or trough axis were based on Klein's schematic precipitation model for central North America (Klein, 1948)

The critical region for the center of a ridge axis extended from 95 to 115^{o} W longitude and 45 to 55^{o} N latitude to account for ridges of varying amplitude. The number of months in which the mean monthly 700-mb ridge axis existed within this region was counted. Statistical analysis was used to determine whether or not there was a difference in the proportion of ridges within the critical area during dry periods than in either the months preceding or following these dry periods.

The critical region for the center of a trough axis was established to the southwest of the study area between 100 and 115° W longitude and 30 and 40° N latitude. The number of months with a trough axis within this region was tallied for months before, during and after the wet periods for which data was available (after 1938). Tests determined the statistical difference between wet and normal months.

HEIGHT ANOMALIES

Another thermodynamic measure used to distinguish wet and dry periods was 700-mb height anomalies. Anomalies provide additional information when used in conjunction with the mean monthly 700-mb chart, principally, the location and intensity of flow abnormalities.

Since wet and dry periods are abnormal occurrences, they should be associated with the abnormal flow implied by height anomalies. For example, certain height anomaly patterns have consequences for Great Plains' precipitation. Negative 700-mb height departures to the west of the region favor more meridional flow and an influx of Gulf moisture. Positive height departures to the west are frequently associated with ridging and anticyclonic movement aloft. Martin and Hawkins (1950) showed the close relationship between positive height anomalies and dry conditions and negative height anomalies and wet conditions.

The onset and termination of a wet (dry) period should be marked by changes in height anomalies to the west of the study region. Specifically, increases in the height anomalies should accompany the initiation of drought and the termination of wet periods, and decreases in the height anomalies should occur near the onset of wet periods and the termination of drought. Normal months before and after a wet (dry) period, and the months within a wet (dry) period, should not be marked by significant departures from normal height patterns.

To test these hypotheses, monthly height anomalies and height anomaly changes were computed for the months preceding, during and following wet/dry periods after 1950.[3] These values were recorded at three grid points forming a triangle to the west of the study area and spatially averaged to the center of the triangle, a point in central New Mexico (35^{o} N, 105^{o} W). This site was chosen because it is upstream of the study region. Height anomalies in this location provide information about cyclonic or anticyclonic air flow likely to affect the study region (Klein, 1949). Height anomalies were compared between months preceding, during and following wet (dry) events. Height anomaly changes were compared between the first month marking the onset of a wet (dry) period, months within a wet (dry) period and the first month after a wet (dry) period.

OCCURRENCE OF WET PERIODS

TROUGH POSITION

Mean 700-mb troughs were located in the critical region in sixty-two percent of the months within a wet period. This proportion of months with troughs was significantly greater during wet spells than in normal months preceding (twenty-six percent) or following (twenty percent) wet spells. Both differences were significant at the 0.01 level.

Analysis of mean monthly trough positions during the March 1961 - November 1962 wet period offers detailed information on the role of the western trough. Fifty-seven percent of all months within this wet period had a trough in the critical location. Thus a wet period can be maintained without the presence of long-wave troughs during every month. The recurrence of such troughs, however, was characteristic of most wet periods.

The importance of a western United States trough to specific wet periods has been shown by many authors. Blasing and Lofgren (1980) suggested that the wet seasons in the fall of 1945, 1946, and 1961, and during the winter of 1948-49, were associated with an upper air trough over western North America. Klein argued that the anomalous wet period in the central United States during the winter of 1948-1949 was the result of a 700-mb trough, which favored abundant cyclonic activity. Namias suggested that the wet month of January, 1959 was due to a 700-mb trough in the western United States.

CYCLONICITY

Average cyclonicity was greater during wet periods (3.0 per month) than during either normal months preceding (2.3 per month)[4], or following (1.7 per month), wet periods. The difference between months before, and months during a wet period, was significant at the 0.05 level, and the difference between months during, and months after a wet period, was significant at the 0.01 level. Increased cyclonicity was closely associated, as expected, with shifts in the mean 700-mb flow pattern. Cyclone formation was favored by increased frequency of troughs to the west of the study region. Storms typically crossed the study region producing wet conditions during such times. Monthly cyclonicity during the March, 1961 to November, 1962 wet period is seen in Table 4-2. Ample moisture was supplied to the region with the frequent passage of mid-latitude cyclones.

TABLE 4-2
CYCLONICITY DURING 1961-62 WET PERIOD

	J	F	M	A	M	J	J	A	S	O	N	D
1961			6	8	6	3	3	4	9	4	5	4
1962	3	9	4	3	6	2	4	2	2	3	3	

Several authors provide support for increased cyclonicity during specific wet periods. Harman and Harrington (1978) contrasted the great number of cyclones during August, 1975 (a wet month) with the small number during August, 1976 (a dry month). Blasing and Lofgren (1980) showed that increased cyclonicity occurred in the central United States during wet periods in spring, 1947 and summer, 1950. Namias reported increased cyclonicity across the central Plains during January, 1959.

HEIGHT ANOMALIES

Height anomalies to the west of the study region had a close relationship with the occurrence of wet periods. The average 700-mb height in central New Mexico was 0.64 decameters below normal during the five wet periods since 1950. In the combined months preceding and following wet periods, the average was 0.41 decameters above normal. This difference was statistically significant at the 0.01 level. Examination of the height anomalies during the 1961-1962 wet period revealed that sixteen of the twenty-one months had negative height anomalies (Table 4-3).

TABLE 4-3
HEIGHT ANOMALIES DURING THE 1961-1962 WET PERIOD

	1961	1962
J		+0.6
F		-0.3
M	-2.5	-2.2
A	-1.5	+2.3
M	-0.5	-0.9
J	+2.3	-0.6
J	-0.9	-0.9
A	-0.3	+0.9
S	-3.7	-0.6
O	+0.6	-0.3
N	-2.3	-0.3
D	-3.1	

Negative height anomalies have been associated with specific wet spells in several studies. Blasing and Lofgren (1980) cited negative height anomalies in the western United States during the wet summers of 1950 and 1968. Klein (1949) found that negative 700-mb height departures in the southwest during January, 1949 led to extremely high precipitation across most of the country. Over four-hundred percent of normal precipitation fell in the central Plains.

The above statistical results, combined with a specific case study, illustrate conditions which are conducive to wet period occurrence. To summarize: 1) The presence of a 700-mb trough was more frequent during wet periods than during the normal months preceding or following; 2) Height departures at 700-mb were below normal and were significantly lower during wet periods; and 3) Mid-latitude cyclones were more frequent during wet periods than in the normal months preceding or following.

ONSET OF WET PERIODS

TROUGH POSITION

Palmer (1965) stated that:

> "the end of a meteorologic drought (or wet spell) should coincide with the time when some rather major and fairly abrupt readjustments in the large-scale circulation pattern begins to produce weather which is normal or wetter (drier) and continues so for a significant length of time."

One dramatic change associated with the beginning of a wet period is the shift of the 700-mb trough position. A new trough was established in the previously defined "critical area" at the onset of seven of the nine wet periods. Figures 4-1 and 4-2 show trough development to the west of the study region at the onset of a wet period in March, 1961. A westward shift of the mean 700-

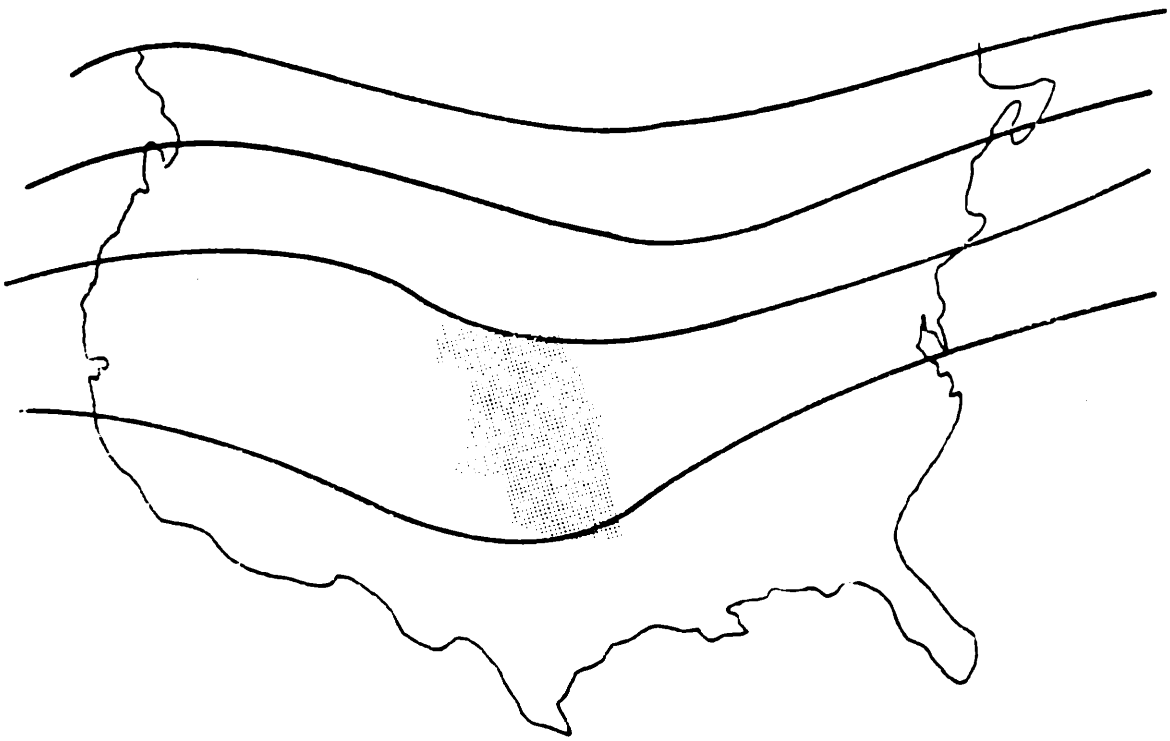

Figure 4-1 (above). Mean 700-mb Flow, February, 1961.
Figure 4-2.(below). Mean 700-mb Flow, March, 1961.
(Source: Monthly Weather Review)

mb trough occurs between February 1961 and March 1961.

CYCLONICITY

The shift of a 700-mb trough also has a clear association with changes in the frequency of mid-latitude cyclones. The establishment of a mean 700-mb trough in the southwestern United States favored the formation of mid-latitude cyclones which frequently passed through the central Plains. The onset of a wet period in March 1961 offers an example of this phenomenon (Figures 4-3 and 4-4) cyclonicity sharply increases at the month of onset. Such increased cyclonicity was seen at the onset of six other wet periods.

HEIGHT ANOMALY CHANGE

A negative change in height departure accompanied the onset of each wet period as seen in Table 4-4.

TABLE 4-4
HEIGHT ANOMALY CHANGE AT ONSET AND TERMINATION OF WET PERIODS (in decameters)

WET PERIOD	AT ONSET	AT TERMINATION
7/50 - 5/52	-2.5	+0.9
5/57 - 12/60	-1.5	+2.5
3/61 - 11/62	-4.0	+0.9
8/68 - 10/69	-0.9	+4.9
11/72 - 8/75	-3.8	+1.2

The magnitude of height anomaly changes was

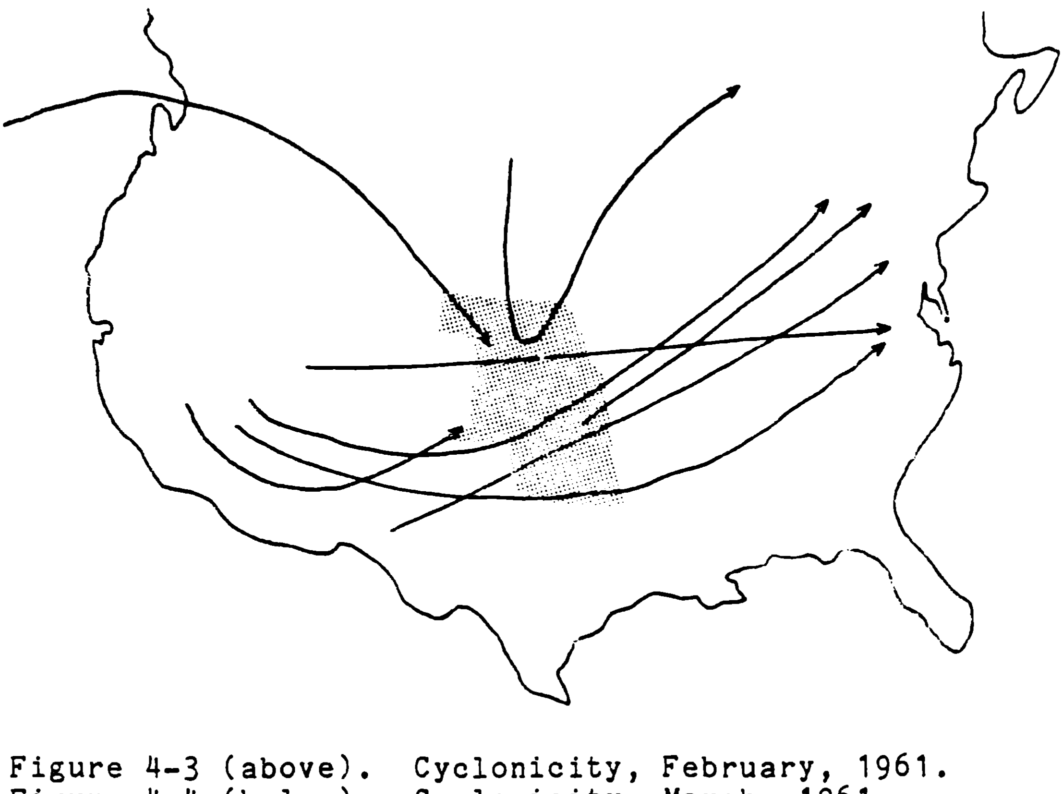

Figure 4-3 (above). Cyclonicity, February, 1961.
Figure 4-4 (below). Cyclonicity, March, 1961.
(Source: Monthly Weather Review)

significantly greater at the month of onset than in the preceding normal months; the differences were valid at the 0.01 level.

The wet period beginning in March 1961 again serves as a representative example of the changes which typically occur. Heights at the New Mexico cite during February, 1961 averaged 2.5 decameters above normal and contrasted sharply with the negative height anomalies during March 1961 (2.5 decameters below normal).

CESSATION OF WET PERIODS

TROUGH POSITION

The 700-mb flow changes at the termination of most wet periods contrasted with those seen at the initiation of wet periods. The proportion of troughs established to the west of the study region decreased from fifty-seven percent of all months during wet periods to only twenty percent following wet periods. This difference was statistically significant at the 0.01 level.

In support of Palmer's (1965) theory on circulation change at the end of a wet period, 700-mb troughs did not exist continuously for several months following the wet period. Sharp changes in 700-mb flow provided the triggering mechanism for onset of drier conditions and the maintenance of these different flow patterns led to wet period termination.

An example of such flow pattern shift occurred at the termination of a wet period in fall, 1969. During October, 1969, a mean 700-mb trough in the southwest favored wet conditions. By November, 1969, however, a trough was established in the east and a ridge dominated western North America. The mean monthly ridge in the west continued through December, 1969, January, 1970 and February, 1970.

CYCLONICITY

As noted previously, cyclonicity at the termination of wet periods showed a decrease, which was significant at the 0.01 level. An example is found at the termination of a wet period in November, 1949. Four mid-latitude cyclones passed through the study region in October, 1949, while a trough was established in the southwestern United States. In contrast, only one cyclone passed through the study region in November when a mean 700-mb ridge existed in the western United States and a mean trough existed in the eastern United States.

HEIGHT ANOMALY CHANGE

Height anomaly change also was distinct at the termination of wet periods as seen above. Average heights rose 2.2 decameters for the five wet periods examined. The magnitude of monthly height anomaly change was significantly greater (at the 0.01 level) at the month of termination than during the normal months after the shift to drier conditions.

OCCURRENCE OF DROUGHT

RIDGE POSITION

Seventy-three percent of all months within a dry period had an established ridge in either the central or western United States. Ridges were less frequent in the normal months preceding a drought (eleven percent) and in the normal months following a drought (twenty-one percent). The proportion of ridges within a dry period was greater than the proportion either before or after at the 0.01 level of significance.

The May 1963 - October 1964 drought serves as an example of the role of the mean 700-mb ridge during dry periods. A mean 700-mb ridge existed over the central or western United States during sixty-one percent of all months within this dry period. This relatively low frequency suggests that dry periods can be maintained without an established ridge in every month. Although some readjustment of 700-mb flow patterns occurred within the dry period, ridges recurrently were established in the critical region.

Previous authors have associated mean 700-mb ridge position with some of these dry periods. Blasing and Lofgren (1980) suggested that a 700-mb ridge in the western United States led to dry conditions in winter, 1955-56 and fall, 1937. Namias (1956) and Hawkins (1956) both argued that a western ridge creating anticyclonic curvature and northwesterly flow above the central Plains favored drought in fall, 1952 and fall, 1956. Blasing and Lofgren suggested that drought in spring, 1934, 1936, 1938, 1963, 1964 and 1967, and summer, 1938, and 1963 were due to ridge formation over the Great Plains. Namias (1956) similarly associated several droughts (summer, 1936, 1952, 1953, and 1954) with a ridge in the central United States.

CYCLONICITY

Cyclonicity within the study area was significantly lower during dry periods than during precedent or antecedent normal months. The average number of cyclones within a drought was 1.6 per month, while the averages for months preceding and following were 2.3 and 2.1, respectively. The differences were statistically significant at the 0.05 level.

Decreased cyclonicity was likely the result of displacement of the mean storm track. During the months in which a ridge was established in the western United

States, northwesterly flow suppressed the formation and development of mid-latitude cyclones; i.e., anticyclonic curvature resulting from a central United States ridge inhibited mid-latitude cyclogenesis. The storm track during the two month drought in July and August 1946 reinforces this point. Two major storm tracks are seen during both months of this drought. One extended from the Canadian Prairie Provinces eastward along the United States - Canadian border and the second was present along the United States east coast. This pattern accounted for the absence of cyclones through the central Plains.

Several authors have made reference to displacement of the mean storm track during these same dry periods. Blasing and Lofgren (1980), for example, attributed dry conditions in winter, 1955-56, spring, 1963, 1964 and 1967 and summer, 1935 and 1937 to a northward displacement of the storm track. Namias (1956) associated drought in fall, 1952, with a northward displacement also. Hawkins (1956) explained dry conditions in fall, 1956, with respect to storm track displacements.

HEIGHT ANOMALIES

Positive height anomalies in the western United States were found to be clearly associated with drought.

Average 700-mb height for all months within a drought was 1.0 decameter above normal. The average for the months prior to a drought was 0.0 decameters, and was significantly lower than the average during dry months at the 0.05 significance level. Heights during the months following drought were 0.2 decameters below normal, which was significantly lower than dry months at the 0.01 level.

Height departures were not above normal during every month within a drought. The 1963-64 drought illustrates this point (Table 4-5).

TABLE 4-5
HEIGHT DEPARTURE FROM NORMAL DURING DROUGHT, 1963-64
(in decameters)

	1963	1964
J		-0.9
F		-2.3
M		-3.1
A		-1.5
M	+3.4	+0.9
J	+0.3	+0.9
J	+0.3	+0.9
A	+0.6	-1.2
S	+3.1	-0.9
O	+3.7	+2.5
N	+0.9	
D	+2.5	

Although the average height departure during this drought was 0.6 decameters above normal, only eleven of the eighteen months had above normal heights. Below normal heights during the first four months of 1964 were accompanied by the absence of a 700-mb ridge and by increased cyclonicity. The wetter conditions during those four months were not sufficient for drought termination, however.

Some authors have used mean height anomalies to explain the occurrence of specific droughts. Namias (1955) discussed the association between height anomalies and drought in August, 1936, and the summers of 1952-54. His analysis did not focus on values of height departure themselves, but emphasized the abnormal flow implied by these departures. Hawkins (1956) described the drought during fall 1956 with respect to above normal 700-mb heights. He reported a relationship between western United States height anomalies and a northward displacement of the ridge axis. No author has analyzed height departures over continuous months of drought or height anomaly changes at the beginning and end of drought.

ONSET OF DROUGHT

The three measures used to explain the onset of drought included 700-mb ridge position, cyclonicity and height anomaly changes. Each showed differences between the normal months preceding a dry period and the months within a dry period. The sharp changes in these variables which occur at the initiation of drought provide information on the physical processes leading to dry conditions.

RIDGE POSITION

The statistical differences in ridge frequency between normal months preceding a drought and months within a drought have been reported above. Abrupt changes in 700-mb flow occurred with the onset of most droughts. An example is the change that occurred in May 1963. The first dry month following the formation of a ridge in the central United States (Figures 4-5 and 4-6). The ridge persisted for several months after the onset of drought.

CYCLONICITY

As expected, changes in cyclonicity occurred in conjunction with changes in mid-level flow. The development of a western ridge in May, 1963 led to a sharp decrease in cyclonicity during that month (Figures 4-7 and 4-8). Such a decrease in cyclonicity was associated with most dry periods.

HEIGHT ANOMALY CHANGES

Sharp changes in the mean 700-mb height anomaly occurred at the onset of the four droughts for which data was available as seen in Table 4-6.

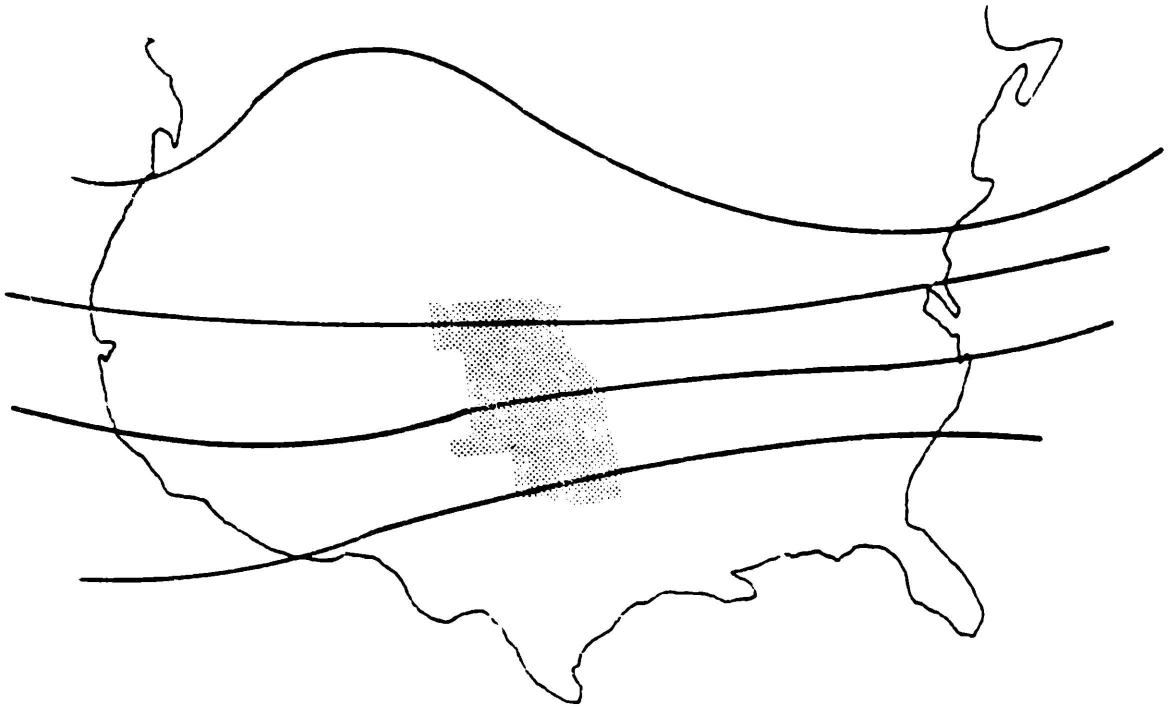

Figure 4-5. Mean 700-mb Flow, April, 1963.
Figure 4-6. Mean 700-mb Flow, May, 1963.
(Source: Monthly Weather Review)

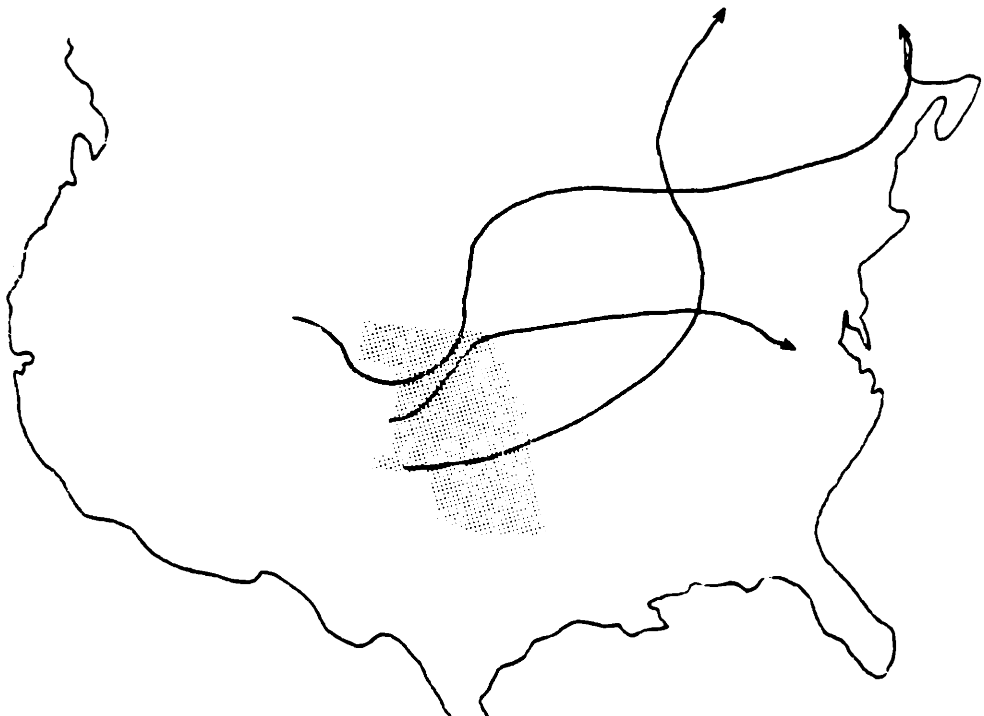

Figure 4-7. Cyclonicity, April, 1963.
Figure 4-8. Cyclonicity, May, 1963.
(Source: Monthly Weather Review)

TABLE 4-6
HEIGHT ANOMALY CHANGE AT THE ONSET OF MAJOR DROUGHTS

FIRST DRY MONTH	HEIGHT ANOMALY CHANGE AT ONSET (in decameters)
9/52	+1.7
5/63	+3.4
5/66	+2.0
10/66	+0.9

The average height anomaly increase was 2.0 decameters. Height anomaly changes were statistically greater at the month of onset than in the preceding normal months at the 0.05 significance level. Figure 4-9 illustrates the dramatic height anomaly change which occurred at the onset of the May 1963 drought. This change was related to the amplification of a ridge in the western United States (Figure 4-6).

CESSATION OF DROUGHT

The variables used to explain the onset of drought also were used to describe drought cessation. A reversal of the pattern seen at onset was found for each of these variables. Although general differences in these variables were seen between months within a drought and normal months following a drought, abrupt changes sometimes did not occur at the month of termination. Dry periods sometimes ended after dramatic changes in the variables. No consistent lag was observed for any one variable, however.

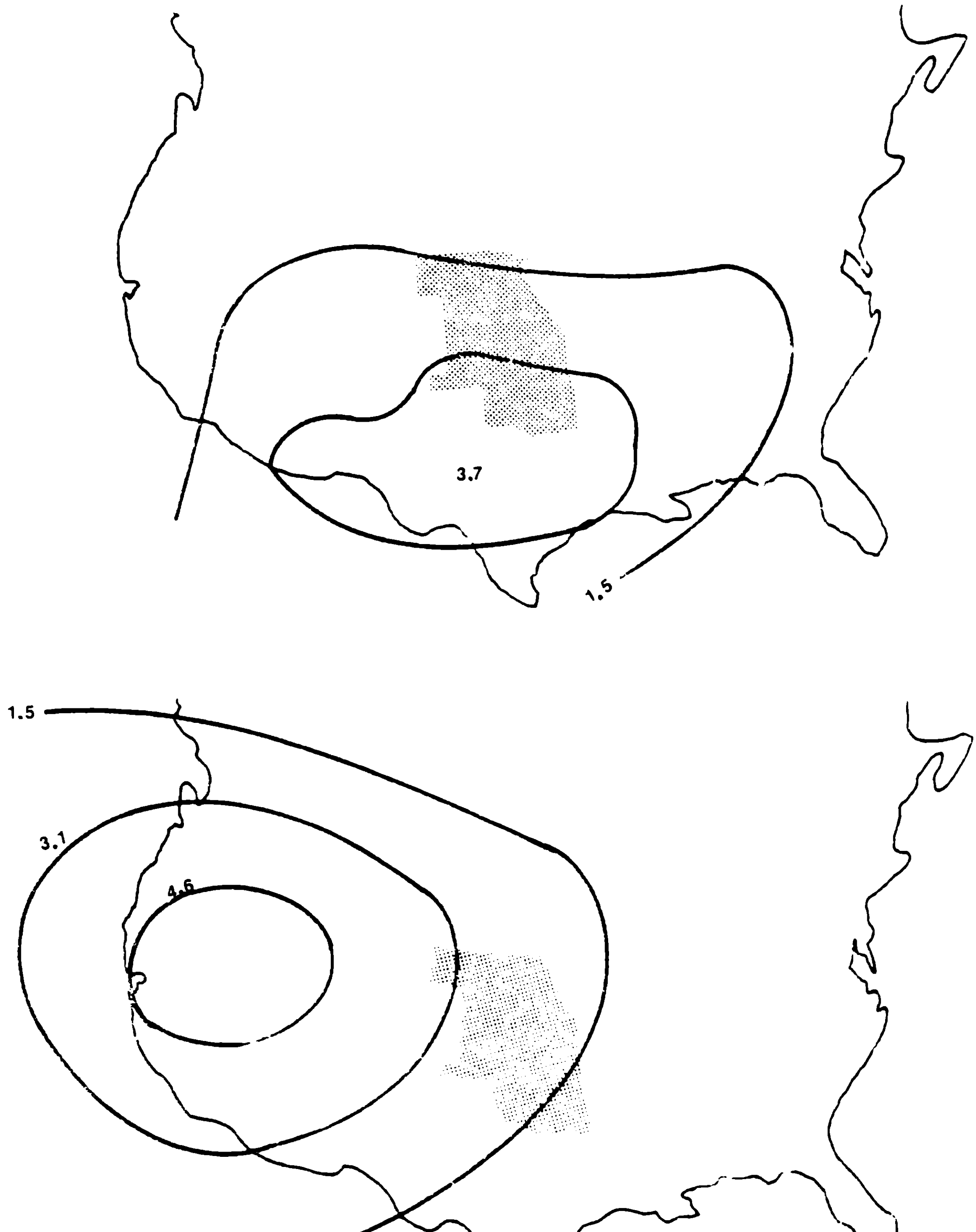

Figure 4-9. Height Anomaly Change at Onset of Drought, May, 1963. (Source: <u>Monthly Weather Review</u>)

RIDGE POSITION

The final months of a dry period frequently were associated with the breakdown of a mean 700-mb ridge. Only twenty-one percent of all normal months following a drought had an established ridge in the western or central United States. The difference was significant at the 0.01 level. Sharp adjustments occurred between October and November, 1964 and between August and September, 1946. By contrast, drought ended two months after the amplified western ridge of February, 1967, decreased in amplitude, thereby leading to zonal flow in March, 1967.

CYCLONICITY

Cyclonicity also showed a change at the termination of drought. The pattern corresponded with 700-mb flow changes. Drought termination was associated with increased cyclonicity in fall, 1940, spring, 1957, fall, 1964 and spring, 1967. High cyclone frequency continued for several months in each case.

HEIGHT ANOMALY CHANGES

Height anomaly decreased an average of 1.5 decameters at drought termination. The magnitude difference in height change was significantly greater (at the 0.05 level) at drought termination than in the normal months following termination. These statistics are somewhat misleading, however, as large decreases sometimes occurred prior to termination. Drought cessation in 1957 exemplifies this point: although a 5.2 decameter height drop occurred in March, 1957, the drought did not end until the following month.

The lag of drought cessation may be explainable with respect to the PI. Droughts of great severity or of long duration will have an impact on moisture conditions for several months. Recovery from such events requires an adequate period over which wetter conditions prevail.

SUMMARY AND RECOMMENDATIONS

Summary of Findings

Many aspects of wet and dry periods in the central Plains have been presented in this thesis. Many results were heretofore undiscovered because of the limited research which has been done on wet periods or persistence of abnormal moisture conditions. Comparisons and contrasts made between wet and dry period characteristics provided a better understanding of synoptic-scale variables associated with such events.

It was found that wet conditions most frequently occurred in the central portion of the study area. Greatest occurrence was oriented in a SW-NE path from the Oklahoma panhandle to eastern Nebraska. Persistence of wet periods was greatest in western Kansas. These results were similar to those for dry periods where highest frequency of occurrence was also in a SW-NE path. Thus it was concluded that climatic divisions in this core area frequently had abnormal moisture conditions. Diaz (1983) reported on the individual states which had abnormally wet or dry conditions most frequently but no study previously has shown this phenomenon on a scale smaller than the contiguous United States. Wet periods were found to be more frequent than dry periods in

Nebraska, Kansas and Oklahoma at all degrees of severity. This observation was unexpected in a region which experienced two major droughts in the 1930's and 1950's.

The spatial patterns of highest wet period occurrence were successfully related to climatological features observed in other studies. For example, Klein (1957), Reitan (1974) and Zishka and Smith (1980) all argued that cyclone frequency in the central Plains was greatest in a SW-NE path. Walsh et al. (1982) showed a distinct precipitation region across the central Plains with similar orientation.

It was found that specific wet and dry periods between 1931 and 1975 could be related to synoptic-scale variables. The variables chosen include dynamic and thermodynamic measures which are directly and indirectly associated with precipitation events. They were: cyclonicity within the study region, 700-mb ridge or trough position and 700-mb height anomalies.

Initiation of wet periods was closely associated with increased cyclonicity, the establishment of a 700-mb trough in the southwestern United States and a sharp decrease in 700-mb heights. Cessation of wet periods occurred in association with decreased cyclonicity, the absence of an established 700-mb trough and rises in the

700-mb height anomaly.

Dry periods frequently were initiated when cyclonicity decreased for a period of several months, a 700-mb ridge was established in the central United States or interior West and sharp rises in 700-mb height anomalies occurred. Relatively low cyclonicity, a recurrent 700-mb ridge and above normal height departures all contributed to the maintenance of drought. Cessation of drought was marked by increased cyclonicity, the absence of a 700-mb ridge and a sharp drop in 700-mb height anomaly.

Recommendations

This study has offered preliminary results which may assist in a variety of future research projects. Skaggs (1978) and Diaz (1983) cited the need for research on the spatial patterns of wet and dry period occurrence and persistence. The importance of such work, Skaggs noted, is to relate these events to surface-atmosphere conditions. This study has examined spatial patterns on a small scale and has associated several meteorological variables with the occurrence wet and dry events.

Future research could examine the spatial patterns of wet and dry period occurrence and persistence in other regions. Other variables could be examined in an attempt to better understand the causes of abnormal moisture conditions. The most important variables could be incorporated into a model. Such a model could be used as a predictive tool to determine the probability of the onset or persistence of wet or dry periods.

FOOTNOTES

[1] PI values between +2 and -2 were considered representative of normal conditions under this classification scheme.

[2] Certain test requirements have been violated due to the limited number of normal months preceding and following wet or dry periods. Although these violations must be considered, they do not invalidate test results. Dey (1982) also used small samples in his study on drought in the Canadian Prairie.

[3] Height anomaly data was not available before 1950.

[4] A complete listing of cyclonicity is provided in the Appendix.

APPENDIX
CYCLONICITY, 1931-1975

	J	F	M	A	M	J	J	A	S	O	N	D
1931	2	1	2	2	3	2	3	2	2	2	3	3
1932	4	3	3	6	3	1	2	1	1	4	2	3
1933	1	2	4	3	4	1	0	1	0	1	0	1
1934	0	1	0	1	1	1	2	0	3	2	2	1
1935	0	3	2	1	6	2	1	1	1	1	1	2
1936	1	4	2	2	3	0	2	0	1	2	1	4
1937	3	2	2	3	2	2	2	1	0	1	1	1
1938	1	0	1	4	8	2	3	1	1	0	2	3
1939	5	3	3	2	2	3	1	1	1	1	1	1
1940	1	2	3	2	2	2	2	2	1	2	4	2
1941	5	1	1	4	2	4	0	2	6	6	3	3
1942	3	5	5	3	4	0	1	3	4	2	2	0
1943	0	2	2	2	1	1	0	1	1	4	1	1
1944	2	2	2	6	2	2	2	1	2	2	2	1
1945	2	1	4	4	3	2	0	2	1	1	3	2
1946	3	2	6	3	6	1	0	1	1	5	3	2
1947	2	1	3	6	5	3	1	0	1	1	4	2
1948	0	2	2	4	1	4	1	0	1	1	3	3
1949	4	2	6	4	2	3	0	0	1	4	1	1
1950	3	2	4	4	2	2	1	0	1	1	1	2
1951	9	4	6	7	1	4	0	6	4	6	4	10
1952	7	7	10	5	5	6	2	2	0	0	3	2
1953	3	3	4	3	2	3	0	1	0	1	1	2
1954	0	3	1	1	3	1	3	3	1	1	0	3
1955	1	2	1	2	1	2	1	0	2	0	1	1
1956	1	0	0	3	1	2	0	2	0	1	2	2
1957	1	0	4	4	3	5	3		2	1	5	6
1958	1	2	2	3	3	2	3	1	1	0	1	1
1959	2	2	5	2	4	3	1	1	2	2	3	5
1960	2	1	2	4	2	3	1	2	1	0	1	4
1961	3	2	6	8	6	3	3	4	9	4	5	4
1962	3	9	4	3	6	2	4	2	2	3	3	0
1963	2	1	4	3	2	3	3	1	1	1	2	0
1964	1	3	2	3	3	0	1	4	1	4	3	4
1965	4	1	1	3	2	5	3	3	2	1	4	2
1966	1	2	3	4	1	2	0	1	0	1	1	0
1967	2	1	2	10	4	2	0	2	1	3	4	6
1968	1	1	1	5	2	1	0	1	1	6	5	6
1969	5	4	3	4	0	6	2	4	1	2	0	0
1970	1	0	2	2	2	3	0	1	2	2	3	5
1971	1	2	1	3	4	1	0	0	2	3	2	4
1972	1	0	1	2	3	0	1	2	1	2	4	4
1973	2	4	9	5	4	2	1	1	4	3	6	4
1974	3	5	5	7	8	2	0	2	1	4	3	3
1975	5	1	5	6	2	4	0	2	0	0	3	1

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