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ABSTRACT

CHARACTERISTICS OF 20TH CENTURY DROUGHT IN THE UNITED STATES AT MULTIPLE TIME SCALES

Characteristics of drought and wet periods were analyzed in terms of areal coverage, intensity, duration, frequency, and variability at different space and time scales. This provided insight not only into the historical perspective of anomalously dry and wet conditions, but also into the long-term variation of climate in the United States. The Standardized Precipitation Index (SPI) provided the means to analyze drought and wet periods at different time scales, a perspective that is not achieved with typical drought indices. The National Climatic Data Center and the Carbon Dioxide Information Analysis Center compiled the U.S. Historical Climatology Network (USHCN) for the purpose of analyzing climate in the United States. The USHCN includes monthly precipitation data for 1,221 stations in the contiguous United States. The distribution of stations provided the means to examine the areal coverage of drought and wet events both nationally and regionally, and the climate record of the USHCN provided the means to analyze the frequency and variability of drought and wet events for the years 1911 through 1995.

The contiguous United States as a whole has become wetter over the period 1911-1995. Additionally, all nine major regions studied for the United States have also become wetter over the period. As a result, there has been a lower frequency of both short- and long-term droughts and a higher frequency of both short- and long-term wet periods

during the last 25 years of the period of record. Also, for the country as a whole, the areal coverage and intensity of long-term droughts between 1911 and 1970 are unmatched by the long-term droughts of the last 25 years of the period. On the other hand, the short-term droughts of the last 25 years of the period do compare in intensity and areal coverage to short-term droughts of the first 60 years of the period.

For the country as a whole, the average duration and frequency of short-term wet periods have increased at a magnitude opposite to the decreasing average duration and frequency of short-term droughts over this period. Moreover, the percentages of stations experiencing drought at all time scales have decreased at rates nearly opposite to the increasing percentages of stations experiencing anomalously wet conditions at all time scales. Nevertheless, the contiguous United States was never entirely in or out of drought at any time scale during this period. Additionally, the contiguous United States was never entirely experiencing or entirely without anomalously wet conditions.

Regionally, the most dramatic increase in the frequency of long-term wet anomalies over the last 25 years of the period has occurred in regions along the Mississippi and Ohio river valleys. Despite the occurrence of a few intense short-term droughts, these regions have all experienced long-term wet periods in the 1970s, the 1980s, and again in the early 1990s. Furthermore, from 1970 through 1995, the most consistent seasonal wet anomalies for these regions have occurred in the autumn.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

When June was half gone, the big clouds moved up out of Texas and the Gulf, high heavy clouds, rainheads. The men in the fields looked up at the clouds and sniffed at them and held wet fingers up to sense the wind. And the horses were nervous while the clouds were up. The rainheads dropped a little spattering and hurried on to some other country. Behind them the sky was pale again and the sun flared. In the dust there were drop craters where the rain had fallen, and there were clean splashes on the corn, and that was all.

--John Steinbeck,
from his Pulitzer Prize winning The Grapes of Wrath

Drought may be the most devastating, yet least understood of all weather phenomena. Drought can erupt in a matter of months, or it can gradually creep up on an unsuspecting society over several seasons. Drought is rarely forecasted with any skill, and goes unobserved by the public until impacts from the drought have already occurred. Inevitably, officials charged with mitigating those impacts want and need to know how a current drought measures up historically to other droughts in terms of intensity, areal coverage, variability, and duration. Additionally, these factors differ in relative time and space scales from drought to drought.

1.1 Background on Drought

Numerous interpretations of drought have been offered through the years. However, the most significant determinant of drought is the amount of precipitation an area gets compared to normal. Dracup *et al.* (1980b) state that in order to determine the cause of drought events, attention should be focused on precipitation drought. Landsberg (1982) states that droughts are brought about meteorologically by a prolonged lack of precipitation and that they occur even in regions of usually ample rainfall. Felch (1978) distinguishes drought from aridity where aridity is permanent low average rainfall and where drought is temporary lower than average rainfall. Palmer (1965) states that a drought period is generally on the order of months or years, for they occur when the moisture supply of a region consistently falls short of what is climatologically expected. Ogallo (1994) states that meteorological drought generally occurs when there is a prolonged absence or deficiency or poor distribution of precipitation. Furthermore, Ogallo (1994) states that meteorological drought has far-reaching impacts on water-use systems and therefore others have defined drought according to the degree of impact on different water-use systems. For example, an agricultural drought is one in which soil moisture is inadequate and those sources of water normally used to replenish soil moisture are unavailable. A hydrological drought is one in which reservoirs have been depleted or streamflows are inadequate for hydroelectric production. Still further, Dracup *et al.* (1980b) define an economic drought in the context of a period of low water supply which affects society's productive and consumptive activities. These distinct perspectives on drought fall in line with Subrahmanyam's (1967) reasoning that drought is interpreted variously, though not conflictingly, according to the experiences of individuals, communities, or nations. Moreover, since impacts from drought differ with location, time scale, and viewpoint; Wilhite and Glantz (1985) contend that available definitions of drought simply illustrate the varying and unique perspectives on drought (meteorologic, agricultural, hydrologic, and socio-economic) and they subsequently conclude that there can not and should not be a universal definition of drought.

Defining the beginning and ending of a drought may be more challenging than defining what a drought is. Tannehill (1947) states that the first rainless day in a spell of fine weather contributes as much to the drought as the last day. Felch (1978) states that drought does not necessarily begin with the cessation of rain, but when available stored water supplies (whether soil, reservoir, streams, etc.) are depleted. Similarly, a drought does not necessarily end when normal rains return, for water storage systems must first be replenished.

Causes of drought are dependent upon the climatic zone of interest, but overall, causes are complex and interwoven. Felch (1978) claims the greatest factor in the prolongation of drought is the absence of large scale vertical motion. Landsberg (1982) states that the incidence of drought is dominated by circulation anomalies in long wave patterns and by a weakening of the intertropical convergence zone. For example, Karl and Quayle (1981) state that the emergence of a 700 millibar pressure ridge over the southern Great Plains in June 1980 strengthened into an anticyclone by July resulting in the summer drought of 1980 in the southern United States. Trenberth and Guillemot (1996) found that during the summer drought of 1988 in the central United States, the jet stream and storm track were displaced further northward than normal resulting in weak transient eddy activity over North America. On the other hand, they found that during the summer floods of 1993 in the central United States, the storm track was displaced southward of its usual summer position and this resulted in an increased number of cyclonic disturbances that were able to tap into the rich moisture source from the Gulf of Mexico. Soil moisture feedbacks also appear to have influence on anomalously wet or dry conditions. Landsberg (1982) calls the soil moisture feedback process "a phenomenon of self-perpetuation". Oglesby (1991) found that reduced soil moisture in the spring can induce drought in the summer. Similarly, Trenberth and Guillemot (1996) calculated that much of the precipitation associated with the floods of 1993 in the central United States appeared to result from local evaporation and a recycling of moisture. They further state that these soil moisture feedbacks may be more important in the summer when prevailing westerlies weaken. Air-sea interactions also play a key role in droughts and anomalously wet periods. Tannehill (1947) states the oceans, especially the Pacific Ocean, are the medium through which persistent controls of rainfall are maintained in the United States. Oglesby (1991) concluded from general circulation model (GCM) simulations that moisture transport from the Gulf of Mexico plays an important role in modulating or ameliorating drought conditions for much of the south-central United States. Namias (1966) hypothesized that the 1960s drought in the northeast United States was associated with abnormal hemispheric wind patterns from the surface to the mid-troposphere that led to a cold anomaly in the surface waters along the continental shelf that in turn provided a reinforcing feedback on the abnormal circulation of the overlying atmosphere, thereby perpetuating the drought. Still others have suggested links to El Niño, La Niña, and the Southern Oscillation. For example, Piechota and Dracup (1996) found relationships between El Niño and extreme drought years in the Pacific Northwest of the United States as well as a relationship between La Niña and dry conditions in Texas. The Climate Prediction Center (1996) states that La Niña conditions in the tropical Pacific Ocean plus an extremely persistent negative phase of the North Atlantic Oscillation contributed to the development of a planetary scale circulation pattern that included strong upper level ridging across the southwest United States that led to the spring 1996 drought in the Southern Plains and Southwest of the United States.

Furthermore, Landsberg (1982) states that droughts are a standard part of the climatic system and they should not be interpreted as a symptom of climate change because they will inevitably be replaced by years of near average or excessive rainfall. Hence, droughts are very much a part of the natural variability of climate. Most years will be near normal, but there will also be some wet years and some dry years, or as Namias (1966) puts it, abnormality of cumulative weather is in fact a "normal" condition.

1.2 Time Scales of Drought

In the context of drought, a time scale is the period over which precipitation events are analyzed and compared to what is normal for the period during the history of a location. Dracup *et al.* (1980b) state that the selection of the averaging period or time scale for a particular drought study is dependent almost entirely on the purpose for which the study is intended. McKee *et al.* (1993) explain that the time scale over which precipitation deficits accumulate functionally separates different types of drought. For example, a 3 month precipitation deficit (seasonal drought) may have drastic impact on agriculture with no significant impact on city water supplies. Or as Piechota and Dracup

(1996) put it, what may be a critical drought for farmers may be only a mild dry spell for an urban water consumer. For example, the Climate Prediction Center (1996) found that the short-term spring drought of 1996 in the Southwest and Southern Plains of the United States deteriorated the region's crops and pastures with the unirrigated winter wheat crop in New Mexico almost totally lost. However, the Climate Prediction Center (1996) found regional reservoir, lake, and river impacts from the drought to be relatively minor. Fortunately, the summer monsoon season was wetter than normal and ended this short-term drought before the hydrologic community experienced significant impact. On the other hand, even if a current season has normal precipitation, a preceding series of seasons with below normal precipitation may have depleted the holdings of a reservoir causing a city to ration water while a farmer who is primarily dependent upon that season's precipitation for dryland crops may be less affected (the Climate Prediction Center (1996) states that topsoil responds primarily to short-term moisture anomalies). For example, Moore *et al.* (1993) reported that while California experienced varying degrees of short-term drought at different times and locations of the state in the late 1980s and early 1990s, the cumulative effect of these droughts culminated in severe water supply cutbacks and increased water prices. And while the winter precipitation for 1992-1993 was 155% of average and represented the best water outlook in six years, the Association of California Water Agencies (1993) stated that storage in major reservoirs remained well below normal and that groundwater basins in the San Joaquin Valley would need several years to recover. Kingery (1992) gives examples of how drought impacts change with time scale. For example, a dry summer (seasonal or 3 month time scale) in an agricultural region negatively impacts crop yield. A dry autumn and winter (6 month scale) in the mountains results in a light snowpack and therefore reduces the upcoming spring's resultant streamflow. Below normal precipitation over four years (48 month or long-term time scale) results in aquifer drawdown.

For this study, monthly precipitation data for individual stations is utilized. Hence, a time scale for this study is the number of months (i) over which the precipitation is totaled and compared to what is normal for i months in the climate record. For example, a precipitation total for March, 1992 comprises a one month time scale for which the data for March, 1992 is compared to what is normal for the month of March for the location in question. This analysis provides a short-term perspective on precipitation for the station. Likewise, a precipitation total for the period February, 1967 through January, 1971 is a 48 month time scale for which the precipitation total for this period is compared to what is normal for this 48 month period in the station's history. This provides a long-term perspective on precipitation for the station.

1.3 Purpose

The purpose of this study is to define the occurrence and variability of drought in the United States in order to furnish climatologists and drought mitigation planners with information on how to put current drought into historical perspective. The opposite of drought is a period of anomalously wet conditions. Analyses of both drought and wet periods on national and regional scales are provided. Also included are analyses of these drought and wet periods at different time scales, a perspective that is not achieved with typical drought indices. Analysis of drought and wet periods in terms of areal coverage, intensity, duration, and variability at these different space and time scales provides valuable insight not only into the historical perspective of anomalously dry and wet conditions, but also into the long-term variation of climate in the United States.

2.0 DATA

2.1 The USHCN Data Set

The National Climatic Data Center (NCDC) along with the Carbon Dioxide Information Analysis Center (CDIAC) compiled the United States Historical Climatology Network (USHCN) for the expressed purpose of analyzing long-term climate variation. In fact, Easterling *et al.* (1996a) claim the USHCN is the best data set available for analyzing long-term climate trends in the United States on regional scales. The third revision of this data set is used for this study. The USHCN provides the opportunity to investigate the occurrence of drought in the contiguous United States during the 20th century. As shown by figure 2.1 from Easterling *et al.* (1996a) (used with permission from CDIAC), the 1221 weather stations included in the USHCN are distributed fairly homogeneously nationwide. Easterling *et al.* (1996a) state that the USHCN has been subjected to extensive quality assurance procedures by NCDC and CDIAC to remove biases, discontinuities, and inhomogeneities that may have developed during a station's history due to station moves or instrument changes. Additionally, the quality assurance process provides estimates for missing or outlier data. As described by Easterling *et al.* (1996b), these data adjustments are made to improve the homogeneity of the data, a critical characteristic for data sets that are used to study climate variation. Peterson and Easterling (1994) state that using data that have not been adjusted adequately for

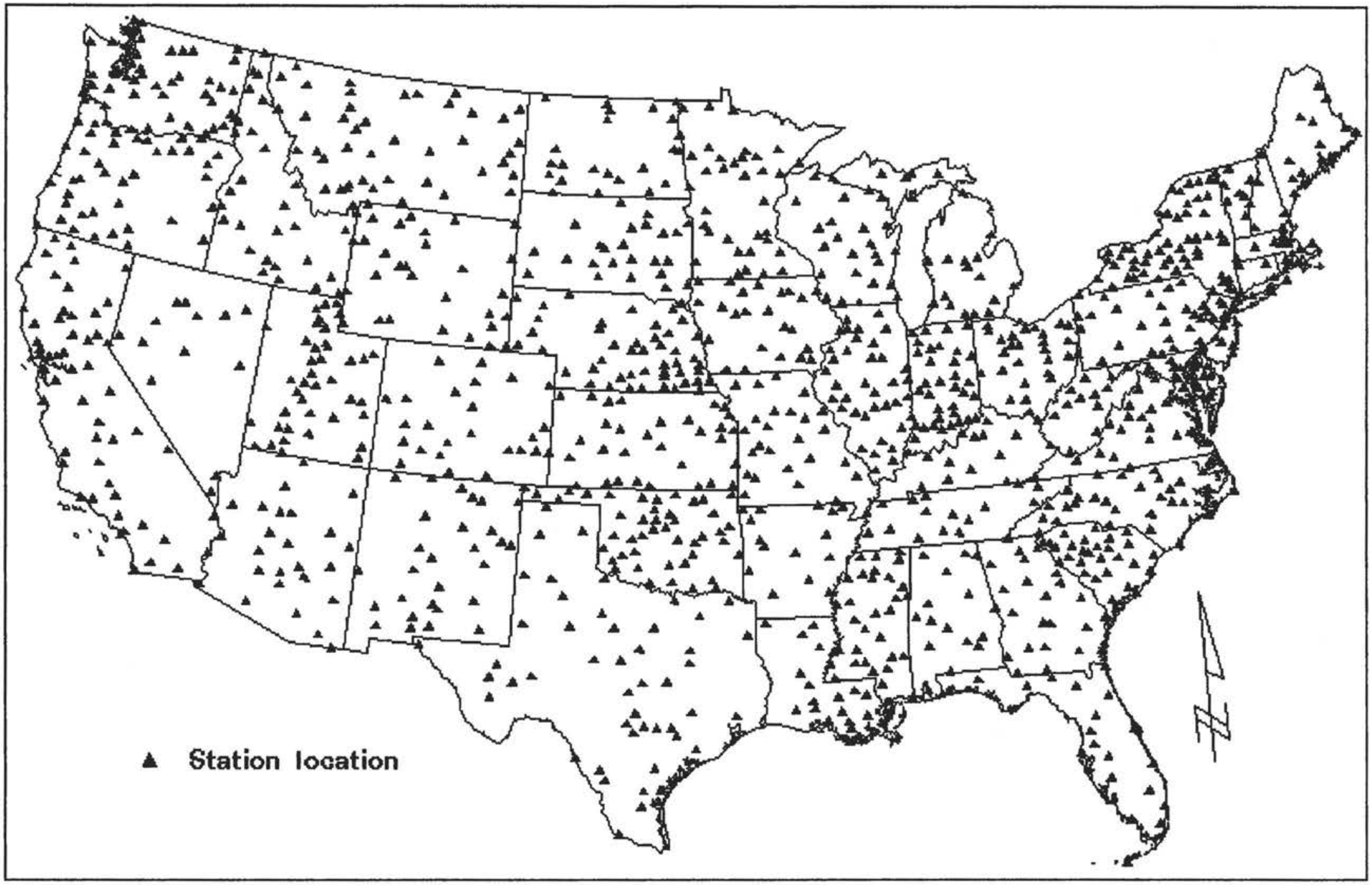


Fig. 2.1 Distribution of USHCN stations across the contiguous U. S. (from Easterling *et al.* (1996a)) (used with permission).

inhomogeneities can often lead to erroneous conclusions because the climate change signal can be artificially obscured or enhanced by discontinuities in the data. For an example, Peterson and Easterling (1994) cited an analysis from Hansen and Lebedeff (1988) that indicated a considerable warming trend in the 1980s around St. Helena Island when this 'warming' was actually due to an inhomogeneity in the St. Helena Island time series caused by the station moving to a lower elevation. For the purpose of this analysis, the USHCN provides a reliable and representative data base that includes a mostly complete and long-term climate record.

The precipitation portion of the USHCN is a gauge-based data set. Xie *et al.* (1996) state that gauge observations have the longest recording period, making them the most suitable source from which a climatology of precipitation can be defined. Furthermore, they state that gauge observations are the only source that are obtained through direct measurements, and that satellite estimates and model predictions that are indirect in nature need to be calibrated or examined using gauge observations in one way or another.

Monthly precipitation data from the USHCN is available for most stations in three forms. The "Areal Edited" data is the original raw data that have been screened for suspect observations or outliers (over 3 standard deviations from the period of record mean monthly precipitation). Any suspect or outlier observations are flagged. The "Time of Observation" data is the "Areal Edited" data that have been adjusted so that all the data will be consistent with a midnight-to-midnight observation schedule (this adjustment is made for temperature data in the USHCN and is a moot point for the precipitation portion of the data set). Finally, the "Filnet" data is the "Time of Observation" data that have been adjusted for biases and inhomogeneities due to instrument change or station relocation. Additionally, the "Filnet" data contains estimated values for missing or outlier data.

For this study, precipitation data was analyzed covering the period January, 1911 through December, 1995. Monthly precipitation data from the USHCN is available for all 1221 stations, and figure 2.2 shows that there is minimal missing data for this time period.

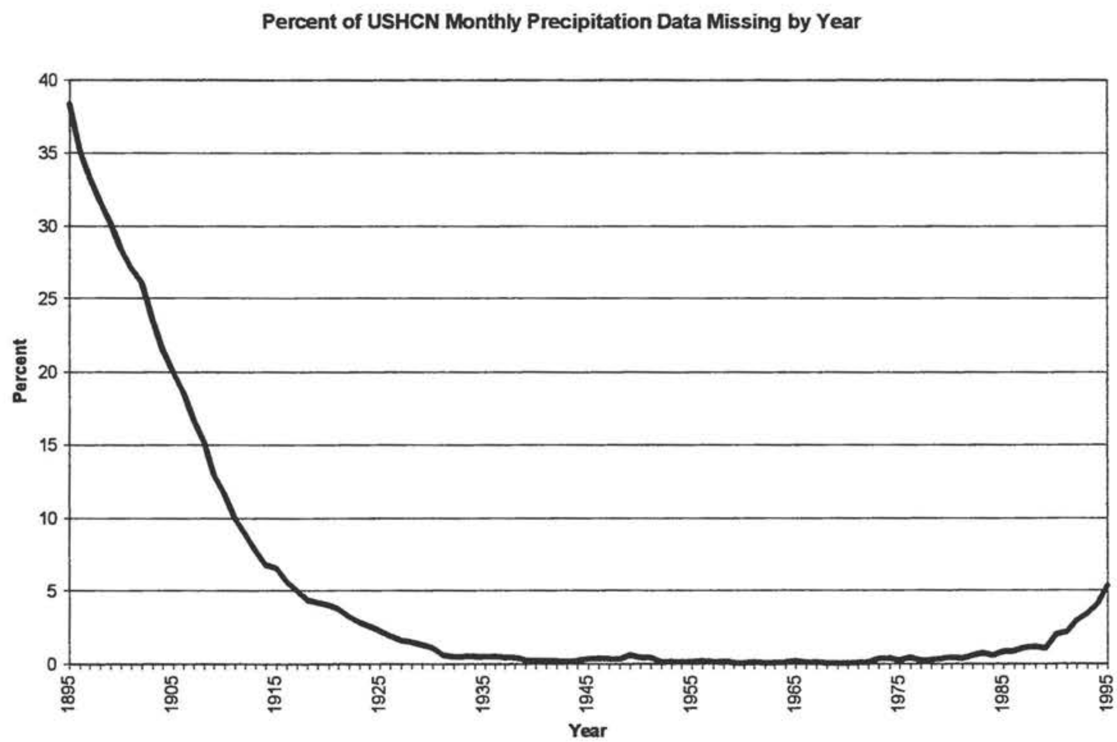


Fig 2.2 Percent of USHCN monthly precipitation data missing by year for the period 1895 through 1995.

Whenever available, the "Filnet" data was used for this analysis. The "Filnet" data contains the adjusted time series of monthly precipitation for the individual stations. An assertion is made by Easterling *et al.* (1996b) that the use of an adjusted climatological time series such as this provides the basis for more robust regional analyses which is a goal of this study. If the "Filnet" data was missing or unavailable, the "Areal Edited" data was used. If both sources of monthly precipitation data were missing for a station for a given month/year, then the data was estimated.

2.2 Estimation of Missing Data

In order to preserve continuity of the monthly precipitation time series for this study, estimates of missing data were made. Data from a station's nearest neighbors in the USHCN were used to make the estimations. A modified version of the Normal-Ratio Method that was introduced by Paulhus and Kohler (1952) was the procedure used to estimate the missing data. The Normal-Ratio Method uses the mean annual precipitation at the target station divided by the mean annual precipitation at the nearest neighbor (index station) as a weighting factor. Paulhus and Kohler used 3 index stations. This method was modified to use mean monthly precipitation values instead of mean annual values since mean annual values mask the distribution of precipitation throughout the year:

$$P_x = \frac{1}{3}\left[\left(\frac{N_x}{N_1}\right)P_1 + \left(\frac{N_x}{N_2}\right)P_2 + \left(\frac{N_x}{N_3}\right)P_3\right] \tag{2.1}$$

where:

P_x = estimated precipitation at the target station for a given month/year

P_1, P_2, and P_3 = precipitation at a respective index station for a given month/year

N_x = mean precipitation at the target station for a given month

N_1, N_2, and N_3 = mean precipitation at respective index station for a given month

Additionally, the modification suggested by Young (1992) was used to further weigh the nearest neighbor monthly precipitation values by the square of the *t* statistic. The *t* statistic is computed using the correlation coefficient for the month in question between the target station and the nearest neighbor. The *t* statistic is a test statistic for testing the significance of the linear association between two variables. The square of the *t* statistic represents the significance of the correlation coefficient:

$$t^2 = W_i = \frac{r_i^2 (n_i - 2)}{1 - r_i^2} \qquad (2.2)$$

where:

W_i = weight of *i*th index station attributed to linear correlation

r_i = correlation coefficient for month in question between target station and *i*th index station

n_i = number of observations used from each population to determine the correlation coefficient

One degree of latitude was assumed to be approximately equal to one degree of longitude. A search for the nearest neighbors within a 0.1 degree radius of the target station was accomplished. The radius was extended incrementally by 0.1 degree until at least 10 nearest neighbors were found. Similar to a method used by Eischeid *et al.* (1995), from the 10 or more nearest neighbors, a maximum of 4 index stations were chosen that had the highest correlation coefficients for the month in question of at least 0.35 with the target station and that did not have missing precipitation data for the month/year in question. (If none of the 10 or more nearest neighbors met those requirements, then the precipitation data for the month/year in question remained missing for the target station). The month/year precipitation values from the qualifying index stations were then weighted by the ratio of the mean monthly precipitation of the target station to the corresponding mean monthly precipitation of the index station (Paulhus and Kohler, 1952) and by the corresponding square of the *t* statistic (Young, 1992) in order to estimate the missing month/year precipitation value for the target station:

$$P_x = \frac{1}{\sum W_i}\left[W_1\left(\frac{N_x}{N_1}\right)P_1 + W_2\left(\frac{N_x}{N_2}\right)P_2 + W_3\left(\frac{N_x}{N_3}\right)P_3 + W_4\left(\frac{N_x}{N_4}\right)P_4\right] \qquad (2.3)$$

In the end, this method ensures that the station with a missing observation will have a monthly precipitation estimate that will emulate the drought (or non-drought) characteristics of those neighbors it is highly correlated with.

2.3 Time Series of Monthly Precipitation

Landsberg (1982) calls precipitation "fickle" and states that certain people even have the audacity to designate mean values of precipitation as "normals". Actually, a typical frequency distribution of precipitation for a given time scale (monthly, seasonal, annual, ...) is not Gaussian, but rather skewed towards larger values of precipitation (skewed to the right). This implies that the mean precipitation for a given period is larger than the median. Hence, more than half of the time, precipitation totals are below average. For example, figure 2.3(A) is a histogram showing the frequency distribution of 3 month (January, February, March) precipitation totals for Fort Collins, CO for the period 1911 through 1995. This figure illustrates the skewness of precipitation frequency distributions. The mean precipitation for this period is 2.03 inches while the median is only 1.73 inches. However, with increasing time scale (ie. 2 year or 4 year precipitation

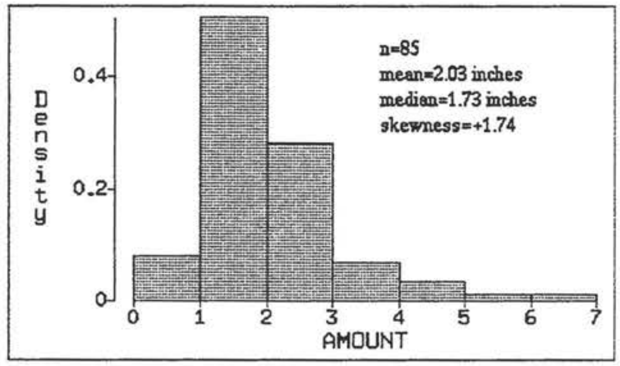


Fig. 2.3 (A) Frequency distribution of 3 month precipitation amounts (inches) for the month of March (totals for January, February, and March) for Fort Collins, CO for the years 1911 through 1995.

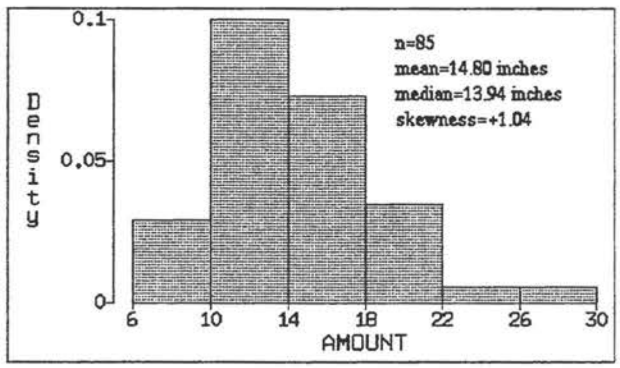


Fig. 2.3 (B) Frequency distribution of 12 month precipitation amounts (inches) for the month of March for Fort Collins, CO for the years 1911 through 1995.

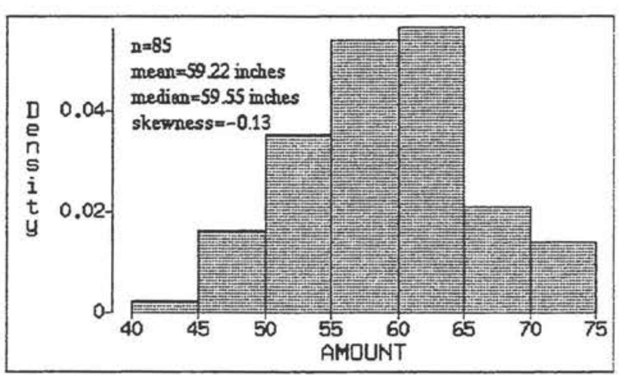


Fig. 2.3 (C) Frequency distribution of 48 month precipitation amounts (inches) for the month of March for Fort Collins, CO for the years 1911 through 1995.

amounts), Katz and Glantz (1986) found precipitation frequency distributions to become approximately Gaussian. For example, figures 2.3(A-C) are histograms showing the frequency distribution of precipitation for Fort Collins at time scales of 3 months, 12 months, and 48 months. A statistical software package (SAS) was used to calculate the *coefficient of skewness*:

$$\alpha_3^* = \frac{\mu_3}{(\sigma)^3} \tag{2.4}$$

where:

$\alpha_3^* =$ coefficient of skewness

$\mu_3 = E(X-\mu)^3 =$ third moment about the mean

$\sigma =$ standard deviation

This measure of skewness is negative for distributions skewed to the left and positive for distributions skewed to the right. A Gaussian distribution has a skewness of zero. In figures 2.3(A-C), skewness decreases between the 3 month and 12 month time scales from +1.74 to +1.04 and actually goes slightly negative at the 48 month time scale. Nevertheless, the frequency distributions of 48 month precipitation amounts for most stations are nearly Gaussian.

3.0 METHODOLOGY

3.1 SPI Defined

McKee *et al.* (1993) developed the Standardized Precipitation Index (SPI) for the purpose of defining and monitoring drought. Among others, the Colorado Climate Center, the Western Regional Climate Center, and the National Drought Mitigation Center use the SPI to monitor current states of drought in the United States. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location in the world that has a precipitation record.

Thom (1966) found the gamma distribution to fit climatological precipitation time series well. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{for } x>0 \tag{3.1}$$

where:

$$\alpha > 0 \qquad \alpha \text{ is a shape parameter} \tag{3.2}$$

$$\beta > 0 \qquad \beta \text{ is a scale parameter} \tag{3.3}$$

$$x > 0 \qquad x \text{ is the precipitation amount} \tag{3.4}$$

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \qquad \Gamma(\alpha) \text{ is the gamma function} \tag{3.5}$$

For example, figure 3.1 shows the gamma distribution with parameters α =2 and β=1. This distribution is skewed to the right with a lower bound of zero much like a precipitation frequency distribution.

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station. The alpha and beta parameters of the gamma probability density function are estimated for each station, for each time scale of interest (3 months, 12 months, 48 months, etc.), and for each month of the year. From Thom (1966), the maximum likelihood solutions are used to optimally estimate α and β:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{3.6}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{3.7}$$

where:

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{3.8}$$

n = number of precipitation observations (3.9)

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability is given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1}e^{-x/\hat{\beta}}dx \tag{3.10}$$

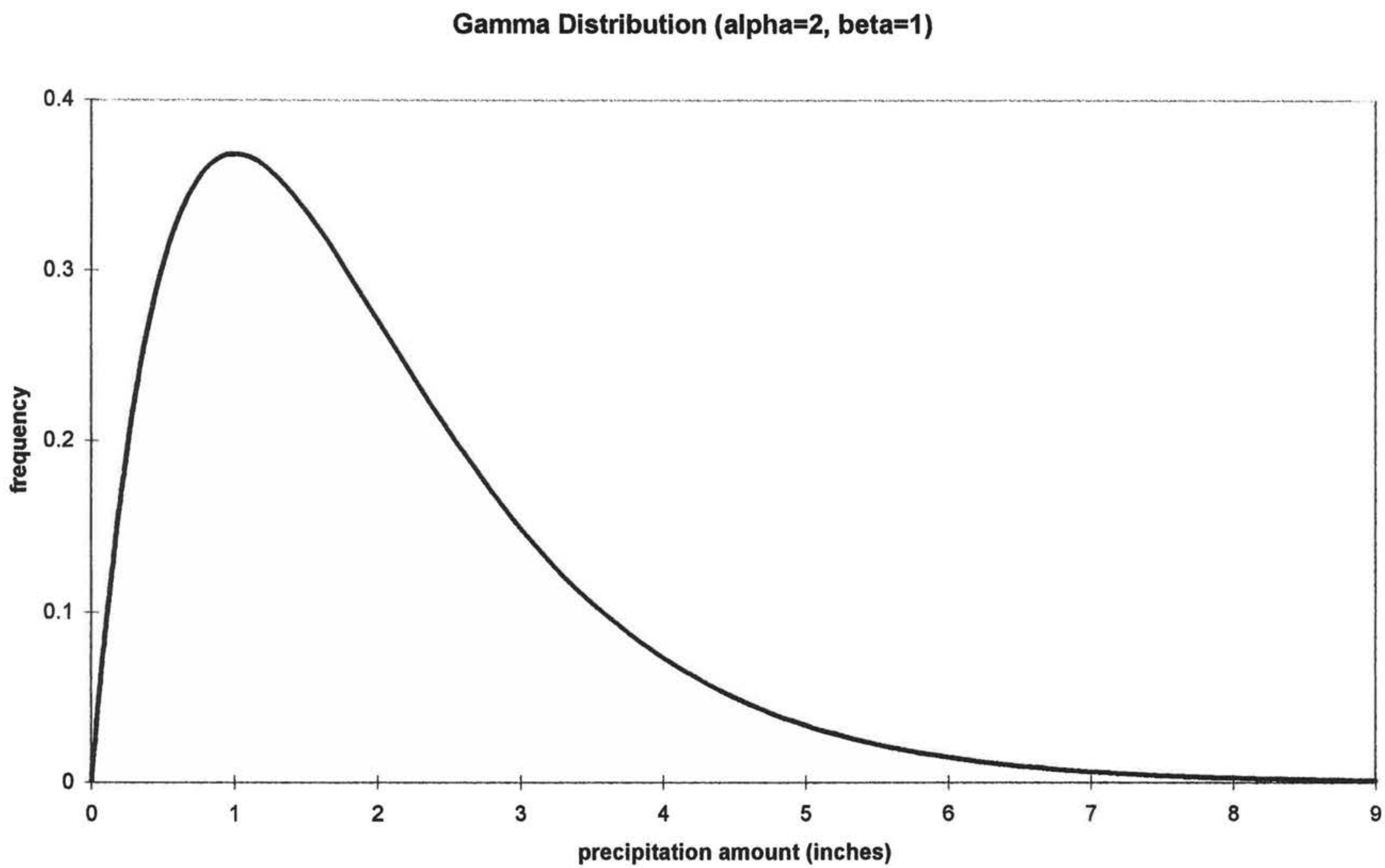


Fig. 3.1 Gamma frequency distribution with parameters alpha=2 and beta=1.

Letting $t = x / \hat{\beta}$, this equation becomes the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1} e^{-t} dt \tag{3.11}$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \tag{3.12}$$

where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/n. Thom (1966) uses tables of the incomplete gamma function to determine the cumulative probability G(x). McKee *et al.* (1993) use an analytic method along with suggested software code from Press *et al.* (1988) to determine the cumulative probability.

The cumulative probability, $H(x)$, is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. This is an equiprobability transformation which Panofsky and Brier (1958) state has the essential feature of transforming a variate from one distribution (*ie.* gamma) to a variate with a distribution of prescribed form (*ie.* standard normal) such that the probability of being less than a given value of the variate shall be the same as the probability of being less than the corresponding value of the transformed variate. This method is illustrated in figure 3.2. In this figure, a 3 month precipitation amount (January through March) is converted to a SPI value with mean of zero and variance of one. The left side of figure 3.2 contains a broken line with horizontal hash marks that designate actual values of 3 month precipitation amounts (x-axis) for Fort Collins, Colorado for the months of January

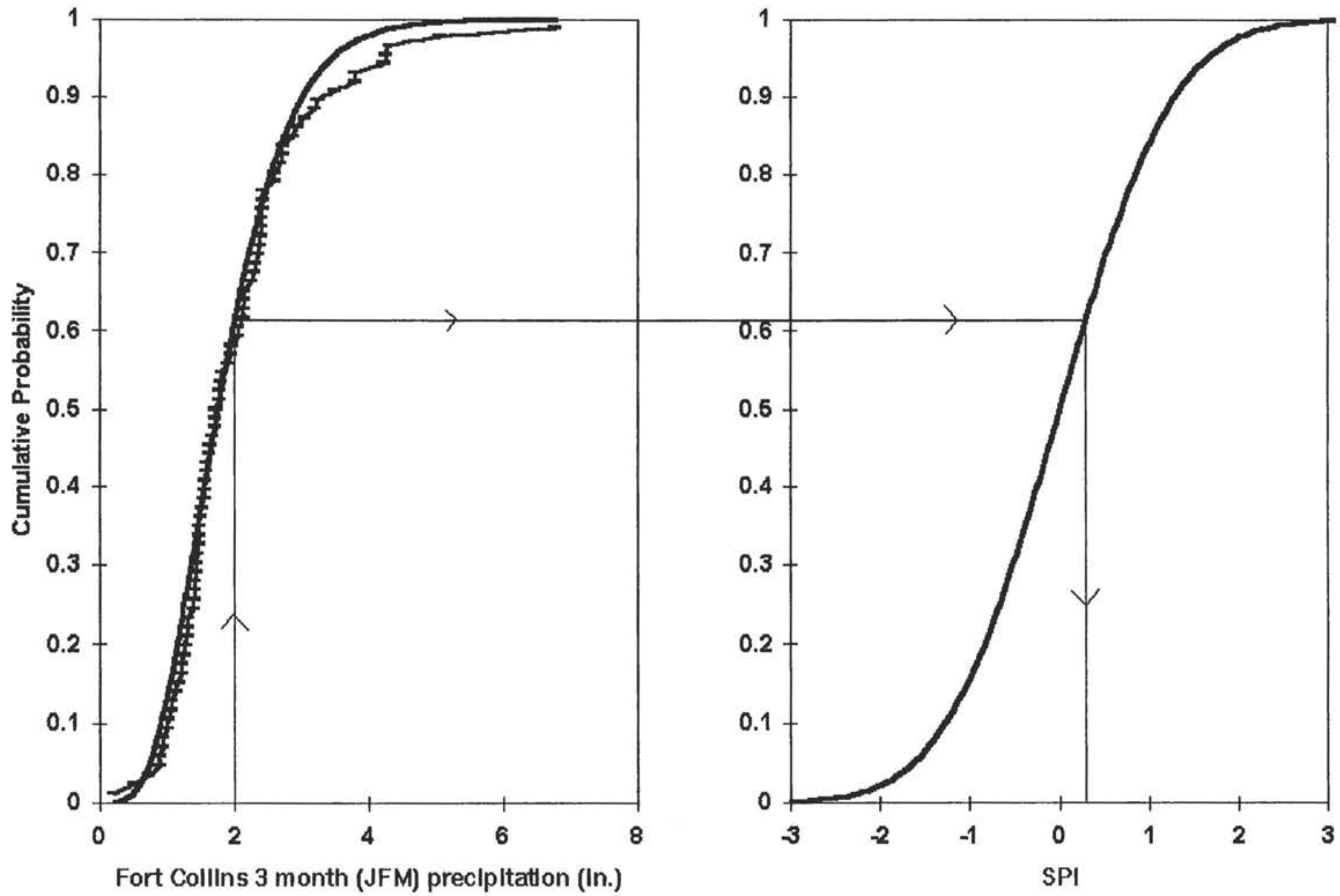


Fig. 3.2 Example of equiprobability transformation from fitted gamma distribution to the standard normal distribution.

through March for the period 1911 through 1995. The broken line also denotes the empirical cumulative probability distribution (y-axis) for the period of record. The empirical cumulative probabilities were found optimally as suggested by Panofsky and Brier (1958) where the precipitation data is sorted in increasing order of magnitude so that the kth value is k-1 values from the lowest and where n is the sample size:

$$\text{empirical cumulative probability} = \frac{k}{n+1} \tag{3.13}$$

The smooth curve on the left hand side of figure 3.2 denotes the cumulative probability distribution of the fitted gamma distribution to the precipitation data. The smooth curve on the right hand side of figure 3.2 denotes the cumulative probability distribution of the standard normal random variable Z using the same cumulative probability scale of the empirical distribution and the fitted gamma distribution on the left hand side of the figure. The standard normal variable Z (or the SPI value) is denoted on the x-axis on the right hand side of the figure. Hence, this figure can be used to transform a given 3 month (January through March) precipitation observation from Fort Collins, Colorado to a SPI value. For example, to find the SPI value for a 2 inch precipitation observation, simply go vertically upwards from the 2 inch mark on the x-axis on the left hand side of figure 3.2 until the fitted gamma cumulative probability distribution curve is intersected. Then go horizontally (maintaining equal cumulative probability) to the right until the curve of the standard normal cumulative probability distribution is intersected. Then proceed vertically downward to the x-axis on the right hand side of figure 3.2 in order to determine the SPI value. In this case, the SPI value is approximately +0.3.

Since it would be cumbersome to produce these types of figures for all stations at all time scales and for each month of the year, the Z or SPI value is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z:

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0 < H(x) \le 0.5 \tag{3.14}$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0.5 < H(x) < 1.0 \tag{3.15}$$

where:

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \qquad \text{for } 0 < H(x) \le 0.5 \tag{3.16}$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \qquad \text{for } 0.5 < H(x) < 1.0 \tag{3.17}$$

$$\begin{aligned} c_0 &= 2.515517 \\ c_1 &= 0.802853 \\ c_2 &= 0.010328 \\ d_1 &= 1.432788 \\ d_2 &= 0.189269 \\ d_3 &= 0.001308 \end{aligned} \tag{3.18}$$

Conceptually, the SPI represents a z-score, or the number of standard deviations above or below that an event is from the mean. However, this is not exactly true for short time scales since the original precipitation distribution is skewed. Nevertheless, figure 3.3 shows that during the base period for which the gamma parameters are estimated, the SPI will have a standard normal distribution with an expected value of zero and a variance of one. Katz and Glantz (1986) state that requiring an index to have a fixed expected value and variance is desirable in order to make comparisons of index values among different stations and regions meaningful.

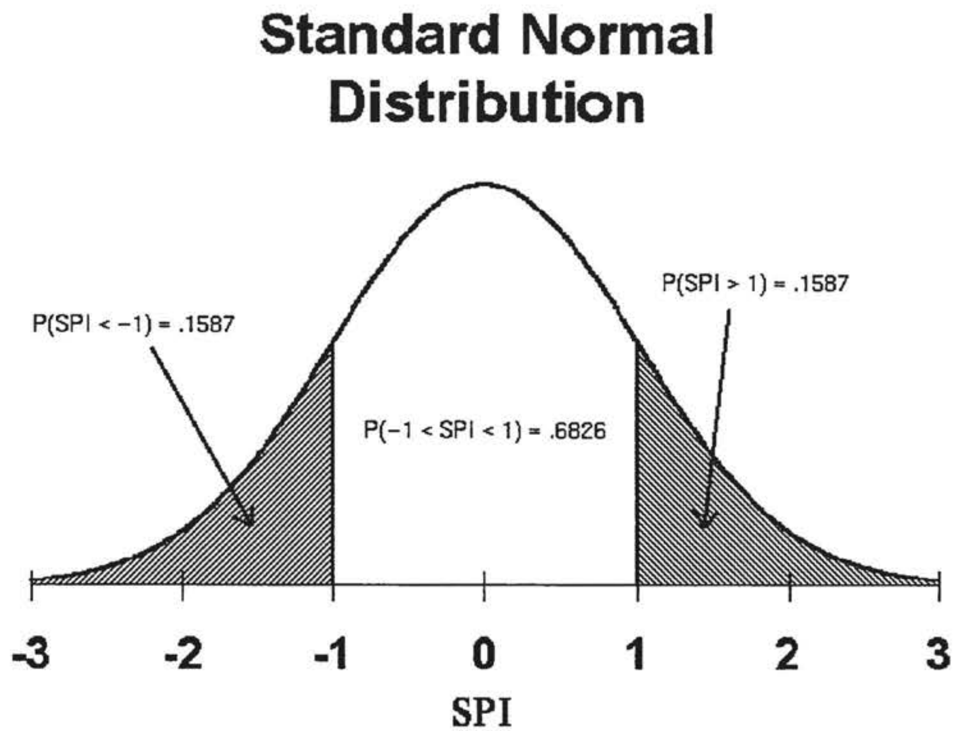


Fig. 3.3 Standard normal distribution with the SPI having a mean of zero and a variance of one.

Tannehill (1947) states that rainfall in the worst drought ever experienced in Ohio would be abundant rainfall in Utah. Akinremi *et al.* (1996) state that the spatial and temporal dimensions of drought create problems in generating a drought index because not only must an anomaly be normalized with respect to location, but the anomaly must also be normalized in time if it is to produce a meaningful estimate of drought. The SPI accomplishes both. The SPI is normalized to a station location because it accounts for the frequency distribution of precipitation as well as the accompanying variation at the station. Additionally, the SPI is normalized in time because it can be computed at any number of time scales, depending upon the impacts of interest to the analyst. Additionally, no matter the location or time scale, the SPI represents a cumulative probability in relation to the base period for which the gamma parameters were estimated. Table 3.1 is a table of SPI and its corresponding cumulative probability.

Table 3.1: SPI and Corresponding Cumulative Probability in Relation to the Base Period

SPI	Cumulative Probability
-3.0	0.0014
-2.5	0.0062
-2.0	0.0228
-1.5	0.0668
-1.0	0.1587
-0.5	0.3085
0.0	0.5000
+0.5	0.6915
+1.0	0.8413
+1.5	0.9332
+2.0	0.9772
+2.5	0.9938
+3.0	0.9986

An analyst with a time series of monthly precipitation data for a location can calculate the SPI for any month in the record for the previous i months where i=1, 2, 3, ..., 12, ..., 24, ..., 48, ... depending upon the time scale of interest. Hence, the SPI can be computed for an observation of a 3 month total of precipitation as well as a 48 month total of precipitation. For this study, a 3 month SPI is used for a short-term or seasonal drought index, a 12 month SPI is used for an intermediate-term drought index, and a 48 month SPI is used for a long-term drought index. Therefore, the SPI for a month/year in the period of record is dependent upon the time scale. For example, the 3 month SPI calculated for January, 1943 would have utilized the precipitation total of November, 1942 through January, 1943 in order to calculate the index. Likewise, the 12 month SPI for January, 1943 would have utilized the precipitation total for February, 1942 through January, 1943 while the 48 month SPI would have utilized the precipitation total for February, 1939 through January, 1943.

Figure 3.4 is a graph of the SPI calculated for McPherson, Kansas for the period 1911 through 1995. Three time scales are shown: 3 months, 12 months, and 48 months. As stated by McKee *et al.* (1993) as well as being evident in the figure: the frequency, duration, and intensity of drought at any particular point during the historical record is dependent upon time scale. The long-term drought index (48 month SPI) shows that McPherson was impacted by the long-term droughts of the 1930s and 1950s. Further inspection at the short-term (3 month SPI) shows that the 1930s for McPherson was a series of several short-term droughts with some intermediate normal periods. Skaggs (1975) described this as "waves" of drought. For the 1950s, even though the long-term drought was shorter in duration, the short-term droughts were more consecutive and resulted in a more intense long-term drought (with the 48 month SPI going below a -3.0). Overall, the late 1940s and early 1950s was a long-term wet period. But looking at the short-term drought index, it is evident that some short-term droughts did occur during this period. For example, the summer drought of 1947 is similar in magnitude to droughts that occurred during the 1930s and 1950s. In fact, United States Department of Agriculture (1951) records show that the corn yield per harvested acre was at a 7 year low in Kansas following this dry summer. However, this drought was preceded and followed by anomalously wet conditions and therefore this drought does not show up at the longer

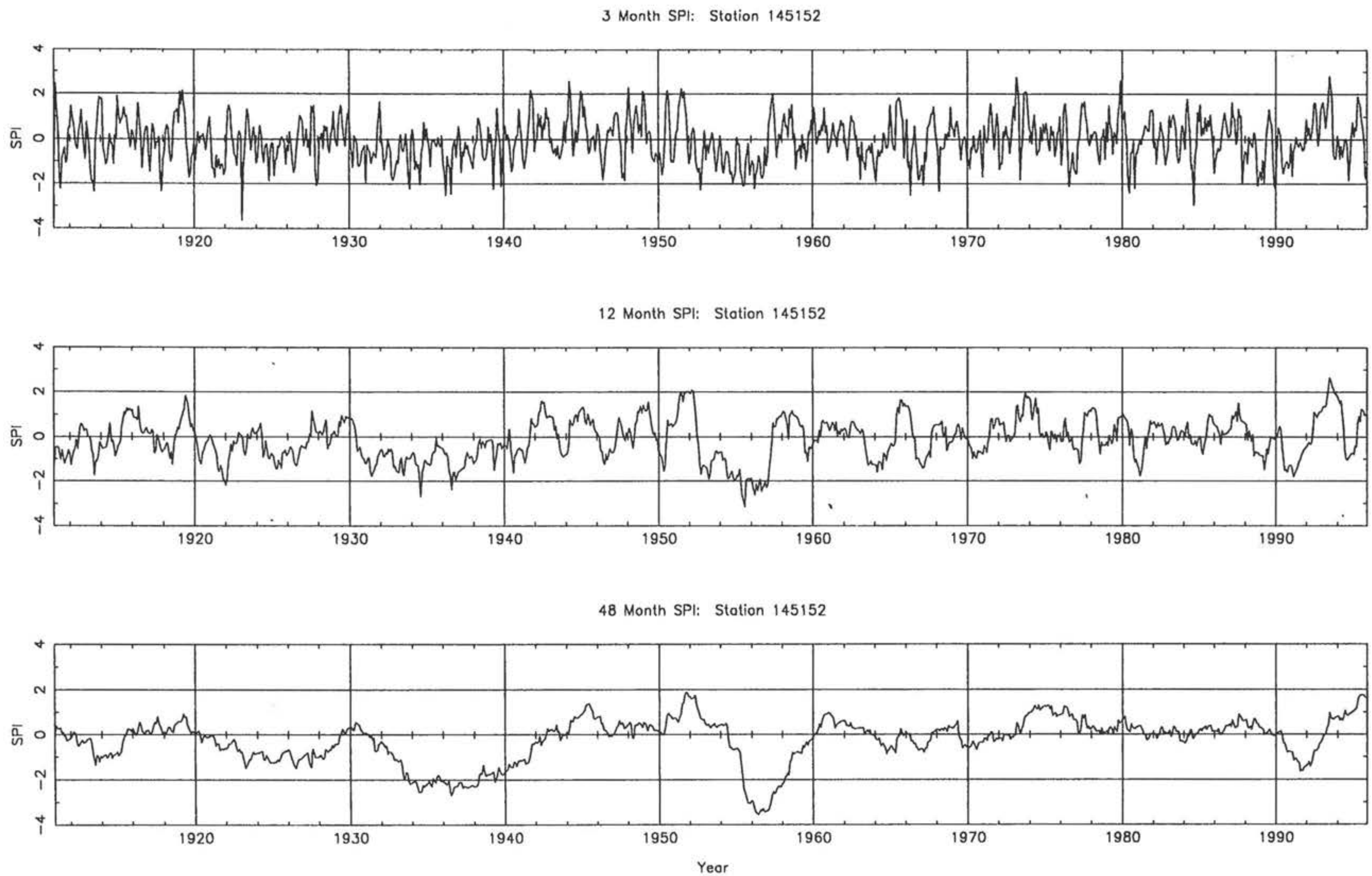


Figure 3.4 Time series of 3 month, 12 month, and 48 month SPI for McPherson, Kansas for the period Jan 1911 through Dec 1995.

time scales. This is a similar situation to the 1980 summer drought in the southern United States. Karl and Quayle (1981) state that the ample rains during the spring of 1980 prevented the 1980 summer drought in the southern United States from being far worse (hence, a short-term drought that didn't translate into a long-term drought). They state that the difference between the summer drought of 1980 and the summer droughts of the 1930s and 1950s was that the summer droughts of the 1930s and 1950s occurred when a very high moisture demand had already developed (in other words, long-term drought).

3.2 Climatological Base Period (1941-1980)

For this analysis, a base period of 1941 to 1980 was utilized to estimate the gamma parameters that are used to calculate the cumulative probabilities of precipitation events. One reason for doing this is that missing data is minimal in the USHCN for this period (figure 2.2). Also, most stations in the USHCN experienced at least one long-term drought and one long-term wet period during this timeframe. Since the cumulative probability is converted to the standard normal random variable Z, the SPI will have a standard normal distribution during the base period. Figure 3.3 shows that about 16% of the time the SPI will be -1.0 or below indicating drought conditions. Similarly, about 16% of the time the SPI will be +1.0 or above indicating anomalously wet conditions. About 68% of the time, the SPI will be between -1.0 and +1.0 indicating normal conditions.

3.3 Relationship of SPI to Palmer Drought Severity Index

Most people that have an interest in current or past conditions of drought are familiar with the Palmer Drought Severity Index (PDSI). A commonly asked question is how the SPI compares with the PDSI. Although the PDSI is also dependent upon soil moisture and temperature data in order to estimate evapotranspiration, McKee *et al.* (1995) found that much of the variation in the PDSI is driven by the variation in precipitation. Additionally, Stern and Dale (1982) state that the variability in a drought index will largely be a reflection of the variability of rainfall such that drought indices can be calculated using average values of evapotranspiration. Hence, methods of analysis of these indices are then the same as for rainfall totals themselves (which the SPI utilizes exclusively). Unlike the SPI, time scale is not explicitly defined for the PDSI and most other drought indices. However, McKee *et al.* (1995) found that time scale does inherently exist in the PDSI. McKee *et al.* (1995) found that for most individual stations in the United States, the PDSI correlates highest to an SPI with a 10 to 14 month time scale. The Climate Prediction Center (1996) finds that the PDSI is relevant for hydrologic concerns and water-supply applications, but is less indicative of agricultural stress which is usually a shorter term drought phenomenon. Of course, the advantage of the SPI is that it can be used to monitor drought over a wide variety of time scales. In fact, Wilhite (1996) contends that the SPI is a more reliable indicator of developing drought conditions than the PDSI because the SPI at shorter time scales is more responsive to emerging precipitation deficits based on experience with the spring 1996 drought in the Southern Plains and Southwest of the United States. For example, the top of figure 3.5 shows the

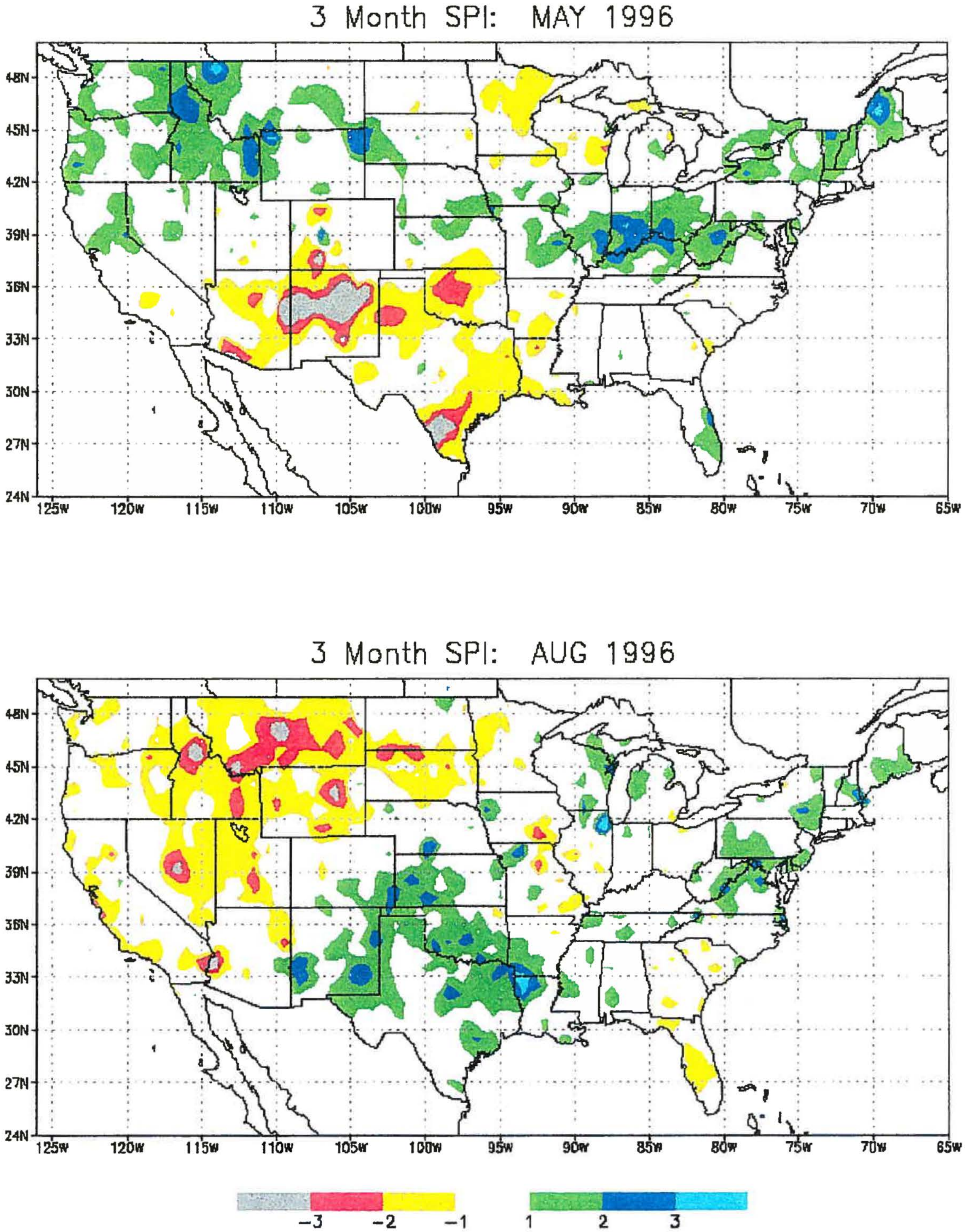


Fig 3.5 Comparison of spring drought of 1996 and summer wet period of 1996 in the Southern Plains and Southwest.

areal extent and intensity of the spring 1996 drought utilizing the 3 month SPI for May 1996. Short-term drought regions are shaded in yellow for SPI ≤ -1.0, red for SPI ≤ -2.0, and gray for SPI ≤ -3.0. Anomalously wet regions are shaded in green and blue. The bottom of figure 3.5 shows the areal extent and intensity of the summer 1996 wet period in the Southern Plains and Southwest that prevented the 1996 spring drought from translating into a longer term drought. Indices such as the PDSI that inherently contain an intermediate or longer time scale are unable to respond as quickly or as accurately to short-term drought and wet period events especially if a short-term drought is preceded or followed by a short-term wet period such as occurred during the spring and summer of 1996.

4.0 ANALYSIS

You know what kinda years we been havin'. Dust comin' up an' spoilin' ever'thing so a man didn't get enough crop to plug up an ant's ass.

--Muley the preacher,
from Nobel Prize winner John Steinbeck's The Grapes of Wrath

For both the national and regional analyses in this study, expansive areal averages are used. As Karl and Quayle (1981) state, it is important to remember that small areas of even abnormal conditions are not likely to have substantial impact on areal averages if other areas are near normal or opposite in sign. Nevertheless, the intent of this study is to detect and contrast anomalies over large regions of the United States.

4.1 National Perspective

4.1.1 Distribution of Precipitation

Figure 4.1 shows the average annual distribution of monthly average precipitation of all USHCN stations. The chart shows for the country as a whole, there is a June maximum with a secondary maximum in December. Minima are in February and October.

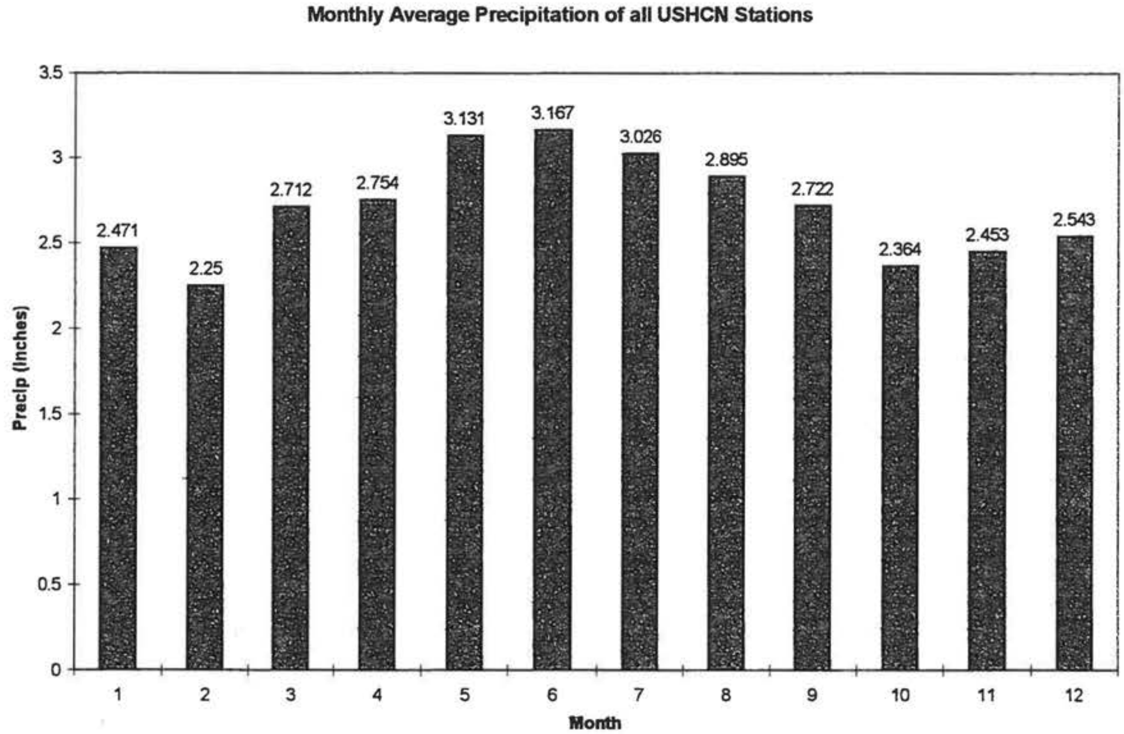


Figure 4.1 Annual distribution of monthly average precipitation of all USHCN stations for the period January, 1911 through December, 1995.

Figure 4.2 shows the running 12 month mean precipitation of all USHCN stations. Overall, the last 25 years of the record have been wetter than any other 25 year period during the record. In fact, in the 1970s and again in the 1980s, the running 12 month mean precipitation exceeds 38 inches unlike any other point in the record. Additionally, there is a peak in the running 12 month mean precipitation in the early 1990s that also exceeds all other maximum peaks experienced during the first 60 years of the record. Minimums in the running 12 month mean precipitation over the last 25 years are similar in magnitude to the minimums achieved during the notorious drought decades of the 1930s, 1950s, and 1960s; however, these minimums are comparatively less frequent over the last 25 years of the record. The overall mean of the running 12 month mean precipitation of all USHCN stations for the period 1911 through 1995 is 32.49 inches. The mean for the period 1970 through 1995 alone is 33.81 inches.

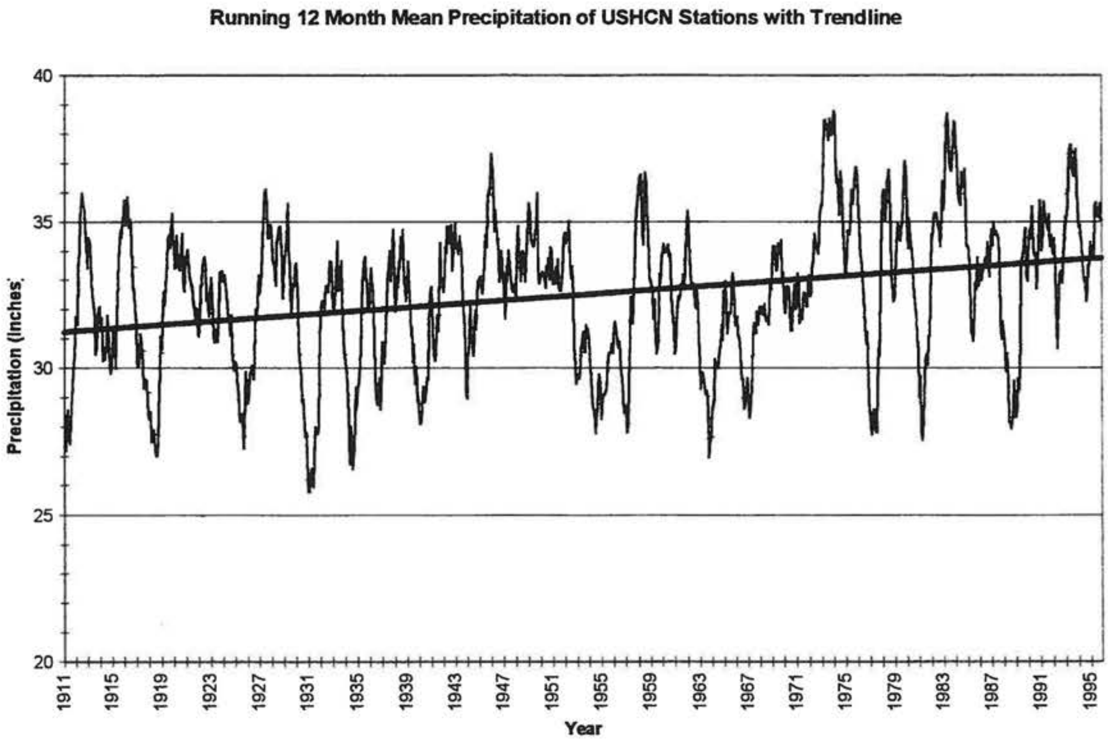


Fig 4.2 Running 12 month mean precipitation of all USHCN stations with trend line for the period January, 1911 through December, 1995.

Dracup *et al.* (1980a) suggest a method to determine stationarity in terms of the linear trend of a time series. They test the slope of the least squares regression line by using a *t* statistic and the resulting p-value. The p-value is the probability, when assuming the slope is zero (stationary), of obtaining a sample result that is at least as unlikely as what was observed. Hence, they state that a p-value less than 0.01 indicates the time series is very nonstationary (trend, or rejecting the assumption that the slope is zero), while a p-value greater than 0.20 indicates the time series is very stationary (no trend, or failing to reject the assumption that the slope is zero).

In the case of figure 4.2, the slope of the least squares regression line is +0.0301 (indicating a linear increase of 0.0301 inches per year over the 85 year period of record). The least squares regression line is depicted as a trend line in figure 4.2. The slope indicates that the 12 month running mean precipitation of all USHCN stations has risen 2.56 inches over this 85 year record (hence, an average increase in each station's annual mean precipitation of 2.56 inches). The p-value was calculated to be 0.0001, indicating that the time series is very nonstationary, and hence, there appears to be a positive trend in the running 12 month mean precipitation of all USHCN stations for this period of record. This supports the conclusion that the country as a whole has become progressively wetter over this particular period of record.

4.1.2 Areal Coverage of Drought/Wet

Figure 4.3 shows the percentage of all USHCN stations with SPI less than or equal to -1.0 for the period January, 1911 through December, 1995. Three different time scales are shown (3 month, 12 month, and 48 month SPI for short-term, intermediate-term, and long-term drought respectively). Since the USHCN stations have fairly homogeneous coverage across the contiguous United States, this figure provides a reasonable estimate of the areal coverage of drought at different time scales over the period. Similarly, figure 4.4 shows the percentage of all USHCN stations with SPI greater than or equal to +1.0 for the period January, 1911 through December, 1995. This figure provides a reasonable

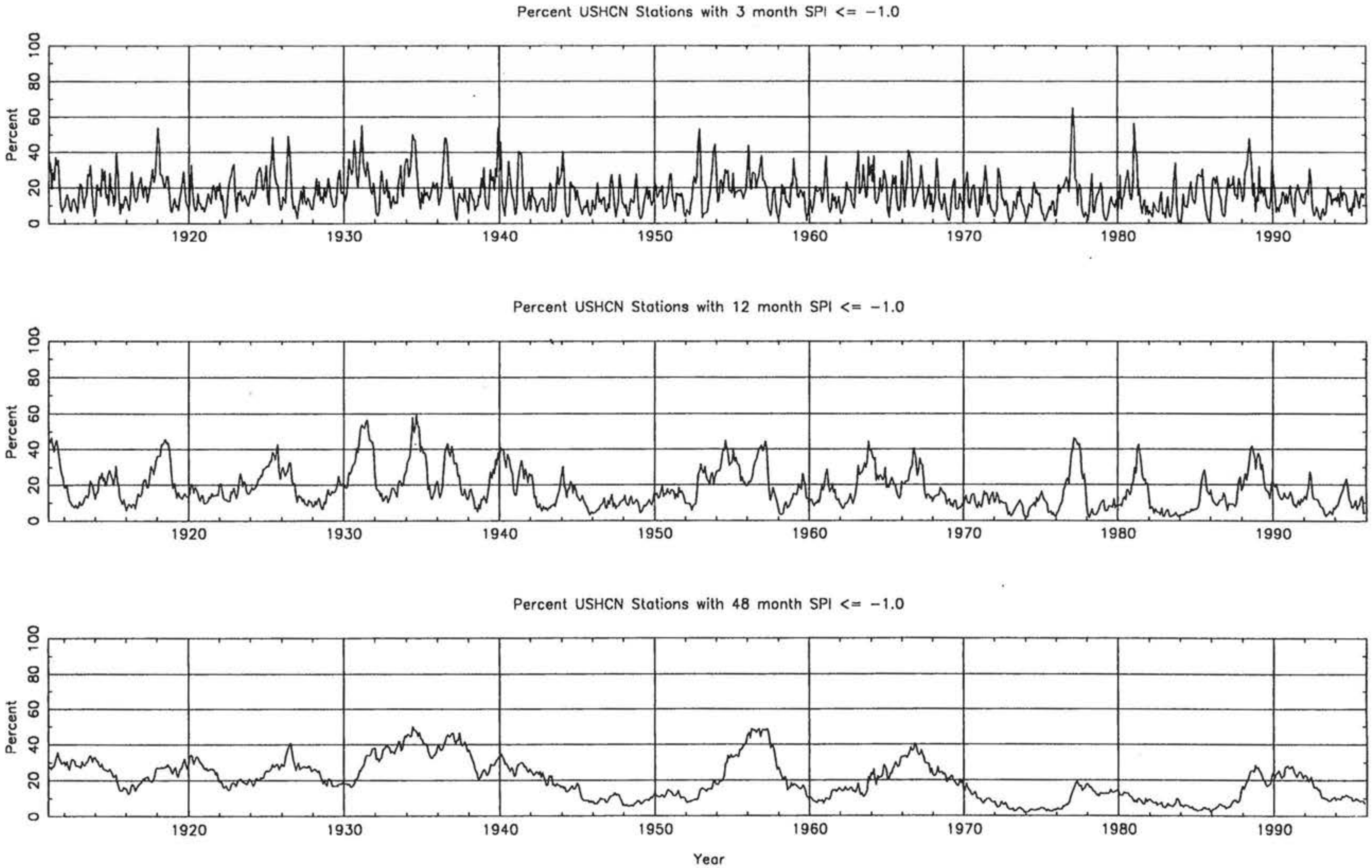


Fig 4.3 Time series of percent of all USHCN stations with SPI ≤ -1.0 by time scale for the period Jan 1911 through Dec 1995.

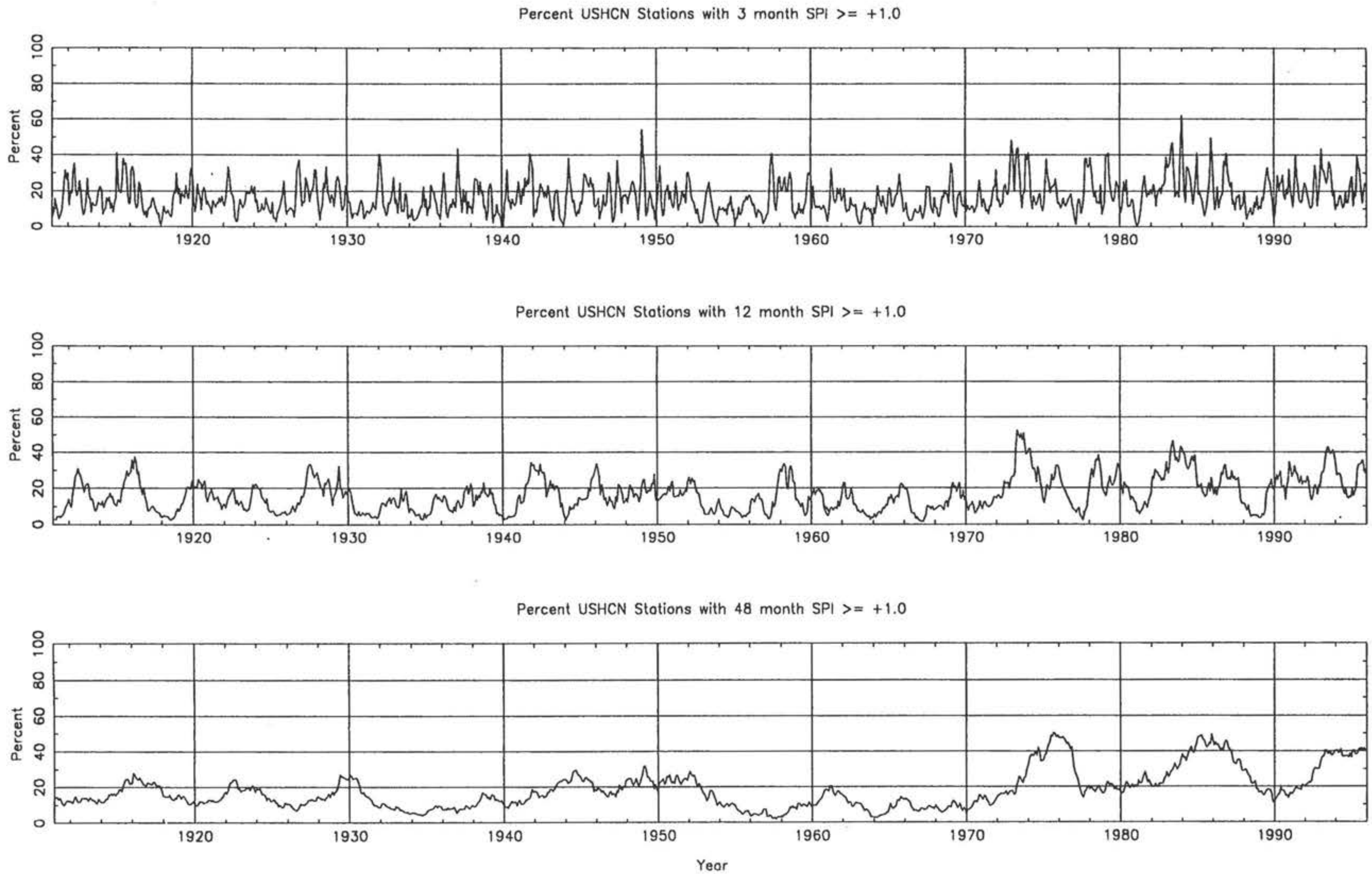


Fig 4.4 Time Series of percent of all USHCN stations with SPI ≥ +1.0 by time scale for the period Jan 1911 through Dec 1995.

estimate of the areal coverage of anomalously wet conditions at different time scales over the period.

Since the SPI has a standard normal distribution within the base period, the percent of all USHCN stations with SPI less than or equal to -1.0 should average about 16%. However, as can be seen in figure 4.3, often the percentages are higher or lower than 16% depending upon if the country as a whole is experiencing wet or dry conditions. Nonetheless, table 4.1 shows that the maximum percentage of stations with SPI less than or equal to -1.0 never exceeds 65% at the short-term, 60% at the intermediate-term, or 55% at the long-term. Also, the minimum percentage of stations with SPI less than or equal to -1.0 approaches, but never reaches 0% for all five time scales.

Table 4.1: Maximum and Minimum Percentages of USHCN Stations Experiencing Anomalously Wet or Dry Conditions by Time Scale for the Period January, 1911 through December, 1995

% USHCN Stations	Anomaly (wet/dry)	Time Scale (months)	Max (%)	Max Month/Year	Min (%)	Min Month/Year
SPI <= -1.0	dry	3	64.95	Jan 1977	0.49	Dec 1983
SPI <= -1.0	dry	6	54.30	Jul 1934	0.98	Jun 1975
SPI <= -1.0	dry	12	59.05	Aug 1934	1.56	Jan 1974
SPI <= -1.0	dry	24	55.77	Jun 1931	1.31	May 1983, Dec 1983
SPI <= -1.0	dry	48	49.80	May 1934	1.88	Nov 1973
SPI >= +1.0	wet	3	62.08	Dec 1983	0.25	Dec 1939
SPI >= +1.0	wet	6	58.07	Apr 1973	1.47	Oct 1952, May 1963
SPI >= +1.0	wet	12	52.33	Apr 1973	1.39	Feb 1967
SPI >= +1.0	wet	24	51.02	Apr 1974	2.05	Nov 1967
SPI >= +1.0	wet	48	50.37	Aug 1975	2.05	Aug 1957

At the 48 month time scale, it is quite evident from figure 4.3 that the long-term droughts of the period 1970 through 1995 have not been as widespread as the long-term droughts of the previous 60 years. The long-term droughts of the late seventies in the

West, the late eighties in the Southeast, and late eighties/early nineties in the West are evident in the time series. However, none of these most recent long-term droughts match the areal extent of the long-term droughts of the teens, twenties, thirties, fifties, and sixties. It comes as no surprise that the long-term droughts of the thirties and fifties were the most widespread.

However, the short-term drought index (3 month SPI) tells a different story for the period 1970 through 1995. Figure 4.3 shows for this index that the short-term droughts of the winter of 1976-1977 and the summer of 1980 were the two most widespread short-term droughts of the period of record. Additionally, the intermediate-term drought index (12 month SPI) shows that the drought of 1988 is similar in areal coverage to intermediate-term droughts of the fifties and sixties.

Moreover, some extraordinary comparisons can be made between short-term droughts of the past 25 years to the notorious droughts of the thirties and fifties. For example, figure 4.5 shows a comparison between the winter drought of 1930-1931 and the winter drought of 1976-1977. Both droughts cover large portions of the northern one half of the United States as well as much of the Mississippi and Ohio river valleys. In fact, the color shading indicates that the winter drought of 1976-1977 was more intense overall. Figure 4.6 shows a comparison between the summer drought of 1980 and the summer drought of 1954. Both of these droughts cover similar portions of the Southern Plains and Southeast of the United States and the overall intensities of these droughts are similar. Figure 4.7 shows a comparison between the spring drought of 1988 and the spring drought of 1936. Both droughts cover large portions of the Northern Plains as well as

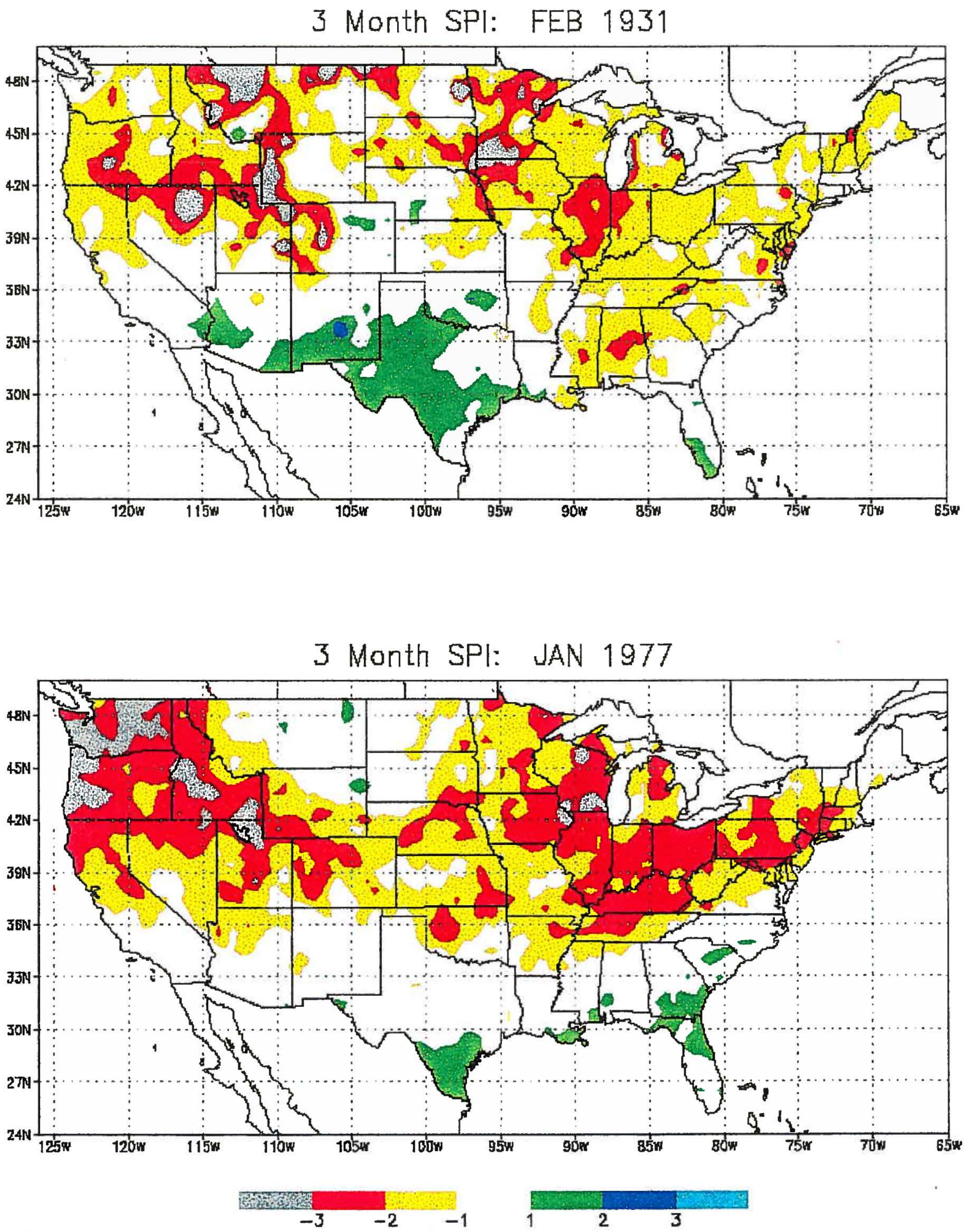
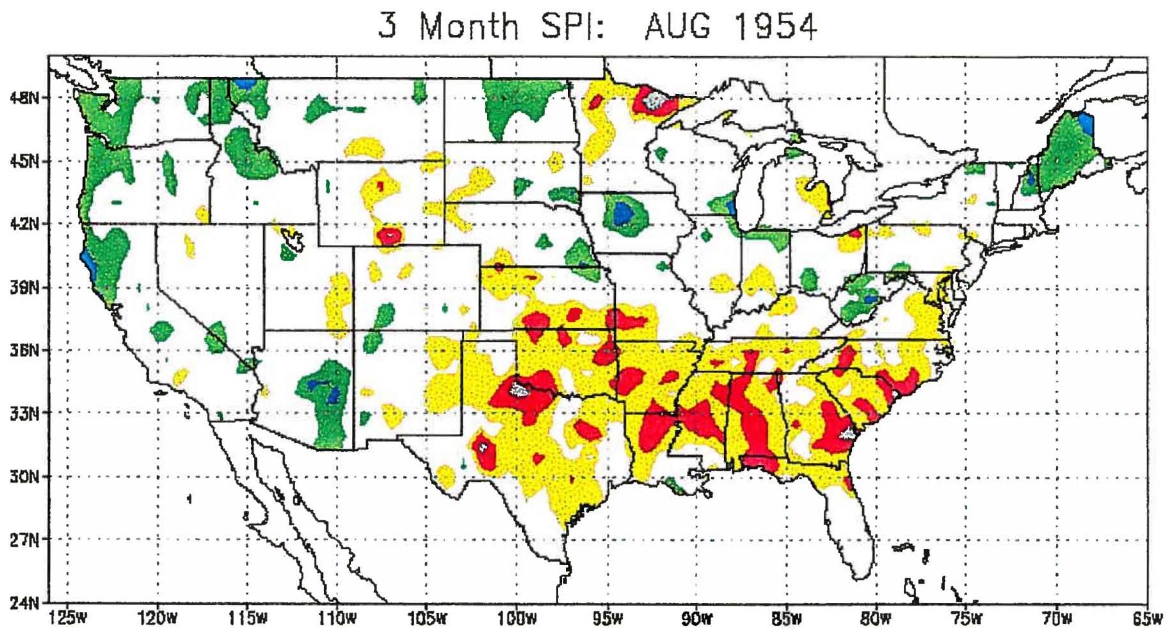


Fig 4.5 Comparison of winter drought of 1930-1931 and winter drought of 1976-1977.



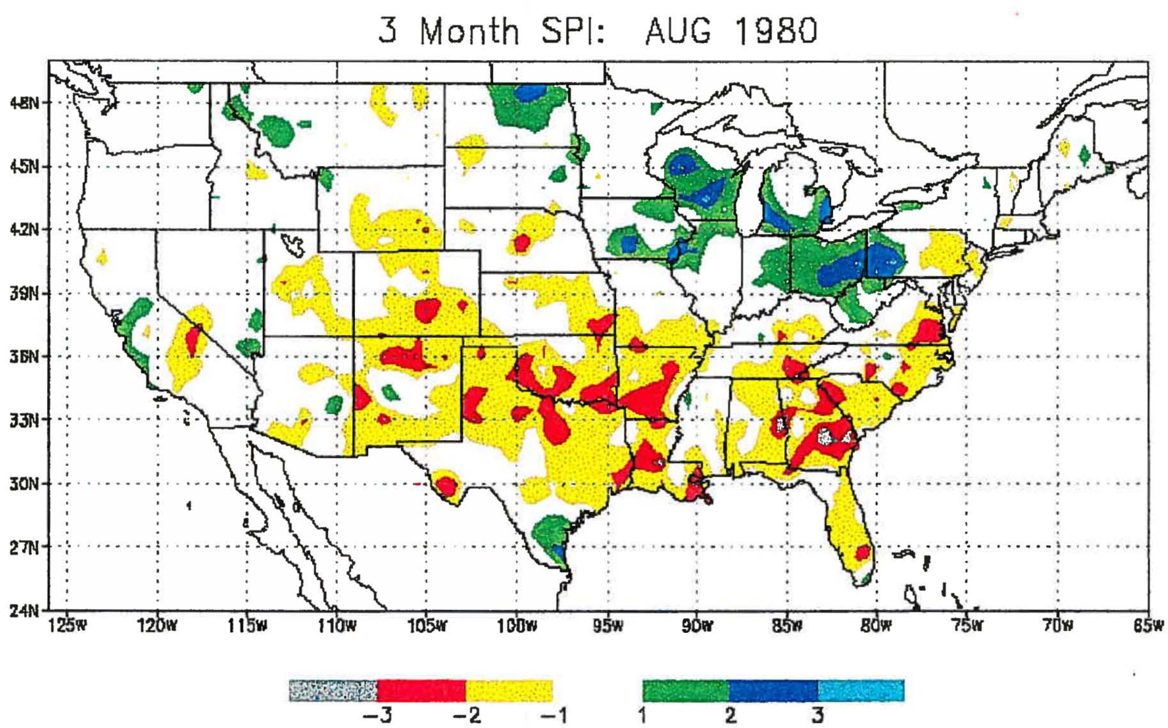
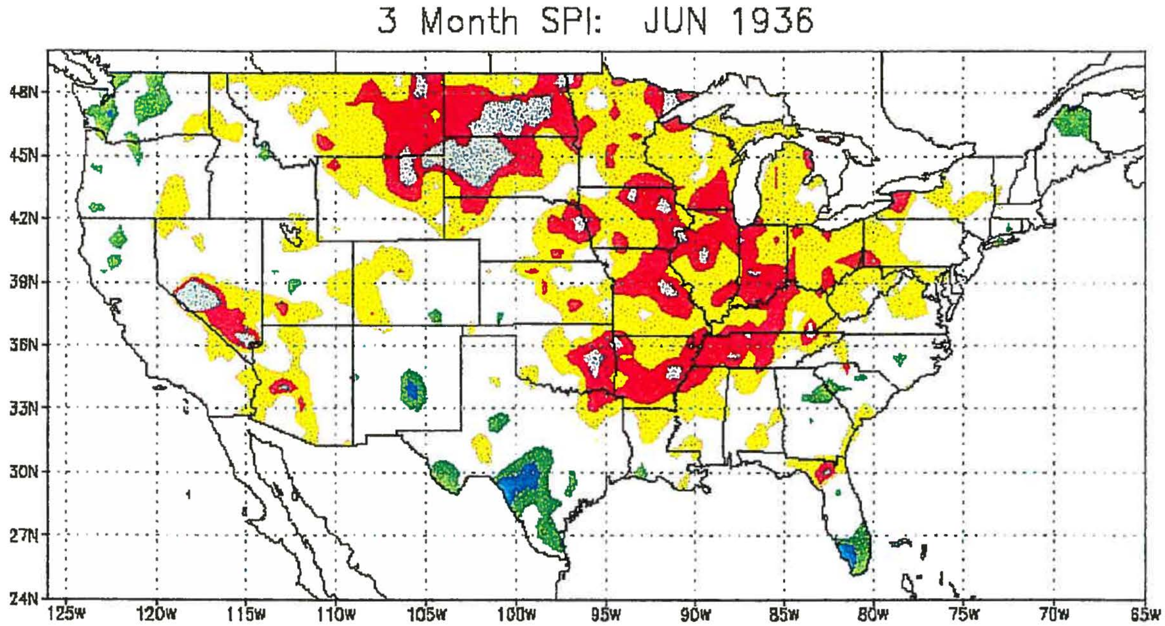


Fig 4.6 Comparison of summer drought of 1954 and summer drought of 1980.



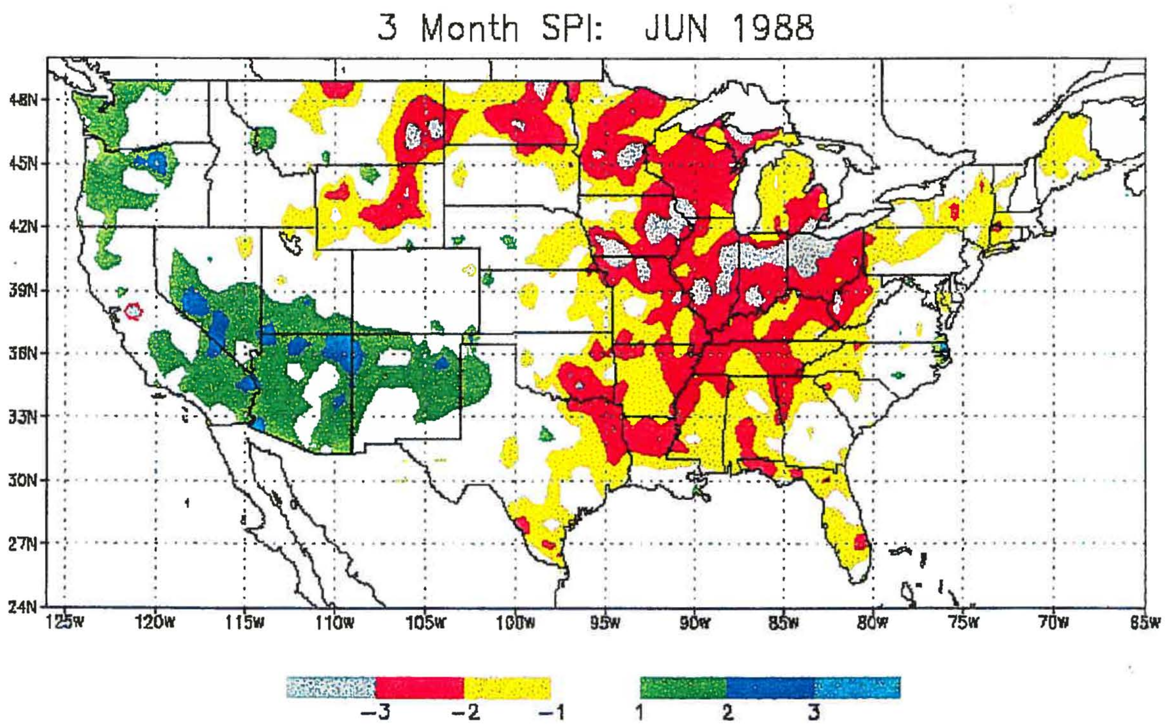


Fig 4.7 Comparison of spring drought of 1936 and spring drought of 1988.

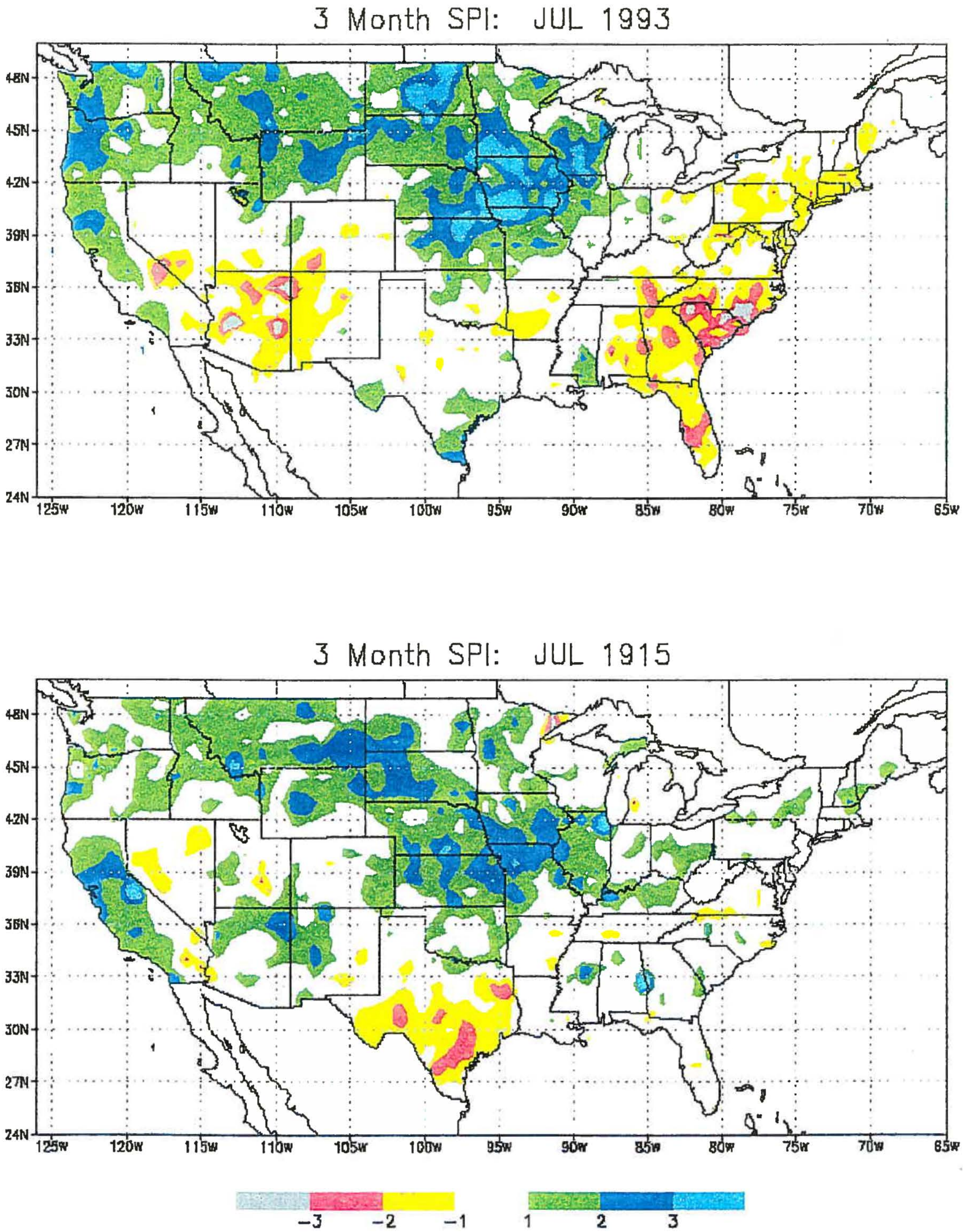


Fig 4.8 Comparison of early spring/late summer wet period of 1993 and early spring/late summer wet period of 1915.

large portions of the Mississippi and Ohio river valleys. Also, both droughts are of similar intensity. Therefore, despite the lower frequency of short-term droughts during the period 1970 through 1995, these three figures illustrate that the short-term droughts that did occur over this most recent period do match the areal coverage and intensity of the droughts of the previous 60 years.

Figure 4.4 is the complement to figure 4.3. This figure shows that there have been intermediate- and long-term wet periods during the 1970s, 1980s, and again in the early 1990s exceeding the areal coverage of all other intermediate- and long-term wet periods during the previous 60 years. At the short-term, there has been an increased frequency of widespread short-term wet periods during the period 1970 through 1995 compared to the previous 60 years. However, figure 4.4 does show that the most widespread short-term wet periods of the first 60 years of the record are of similar areal coverage to the most widespread short-term wet periods of 1970 through 1995. For example, figure 4.8 shows a comparison between the early spring and late summer wet period of 1915 and the early spring and late summer wet period of 1993. Both of these wet events have similar areal coverage in the Northwest as well as the Northern Plains and Missouri Valley. The main difference between these two short-term wet events is that the one in 1993 occurred during a period of a high frequency of short-term wet events that led to a long-term wet period for much of this region during the early 1990s. The short-term wet event of 1915 occurred during a period of a lower frequency of short-term wet events and therefore did not translate into a long-term wet period for much of this region.

Similar to the percent of USHCN stations in drought, table 4.1 shows that the percent of stations experiencing anomalously wet conditions never exceeds 65% at the short-term, 60% at the intermediate-term, and 55% at the long-term. Likewise, the percentage of USHCN stations experiencing anomalously wet conditions approaches, but never reaches 0% at all three time scales.

Therefore, while there have been periods of widespread drought or anomalously wet conditions, this analysis shows that neither drought nor anomalously wet conditions ever cover the entire contiguous United States. Additionally, this analysis shows that the country is never completely without drought or anomalously wet conditions at any time scale.

Similar to the last section, regression lines were fit to the different time series of percent USHCN stations greater than or equal to +1.0 as well as for the time series of percent USHCN stations less than or equal to -1.0. Table 4.2 below summarizes the results. These results indicate that the period of record has seen increasing percentages of USHCN stations experiencing anomalously wet conditions at all time scales and decreasing percentages of USHCN stations experiencing drought conditions at all time scales. Additionally, the slopes of the fitted regression lines are nearly opposite in magnitude at each respective time scale indicating that the percentages of USHCN stations experiencing anomalously wet conditions are increasing at rates opposite to the decreasing percentages of stations experiencing drought.

Table 4.2: *t* Test for Nonstationarity of Percent of all USHCN Stations by Time Scale with SPI $\leq$ -1.0 or SPI $\geq$ +1.0 for the Period January, 1911 through December, 1995

% Stations	Time Scale (months)	Slope (percent/year)	P-value	Conclusion
SPI <= -1.0	3	-0.060959	0.0001	nonstationary
SPI <= -1.0	12	-0.121953	0.0001	nonstationary
SPI <= -1.0	48	-0.224491	0.0001	nonstationary
SPI >=+1.0	3	0.065281	0.0001	nonstationary
SPI >=+1.0	12	0.120558	0.0001	nonstationary
SPI >=+1.0	48	0.192795	0.0001	nonstationary

4.1.3 Intensity of Drought/Wet

Figure 4.9 shows the average SPI of all USHCN stations for the period January, 1911 through December, 1995. Three different time scales are shown (3 month, 12 month, and 48 month SPI). Since the USHCN stations have fairly homogeneous coverage across the contiguous United States, this figure provides a reasonable estimate of the intensity of drought and wet periods at different time scales for the nation as a whole over this period.

For the long-term, the 48 month SPI shows that the drought of the 1930s was the most intense for the nation overall, reaching an average SPI of -1.0 in both 1934 and again in 1936. The drought of the 1950s reached a similar intensity. However, since the 1960s drought in the Ohio Valley and Northeast, the United States as a whole has not experienced an intense long-term drought such as those that occurred between 1911 and 1970. In fact, the average national SPI has approached +1.0 in the 1970s, 1980s, and

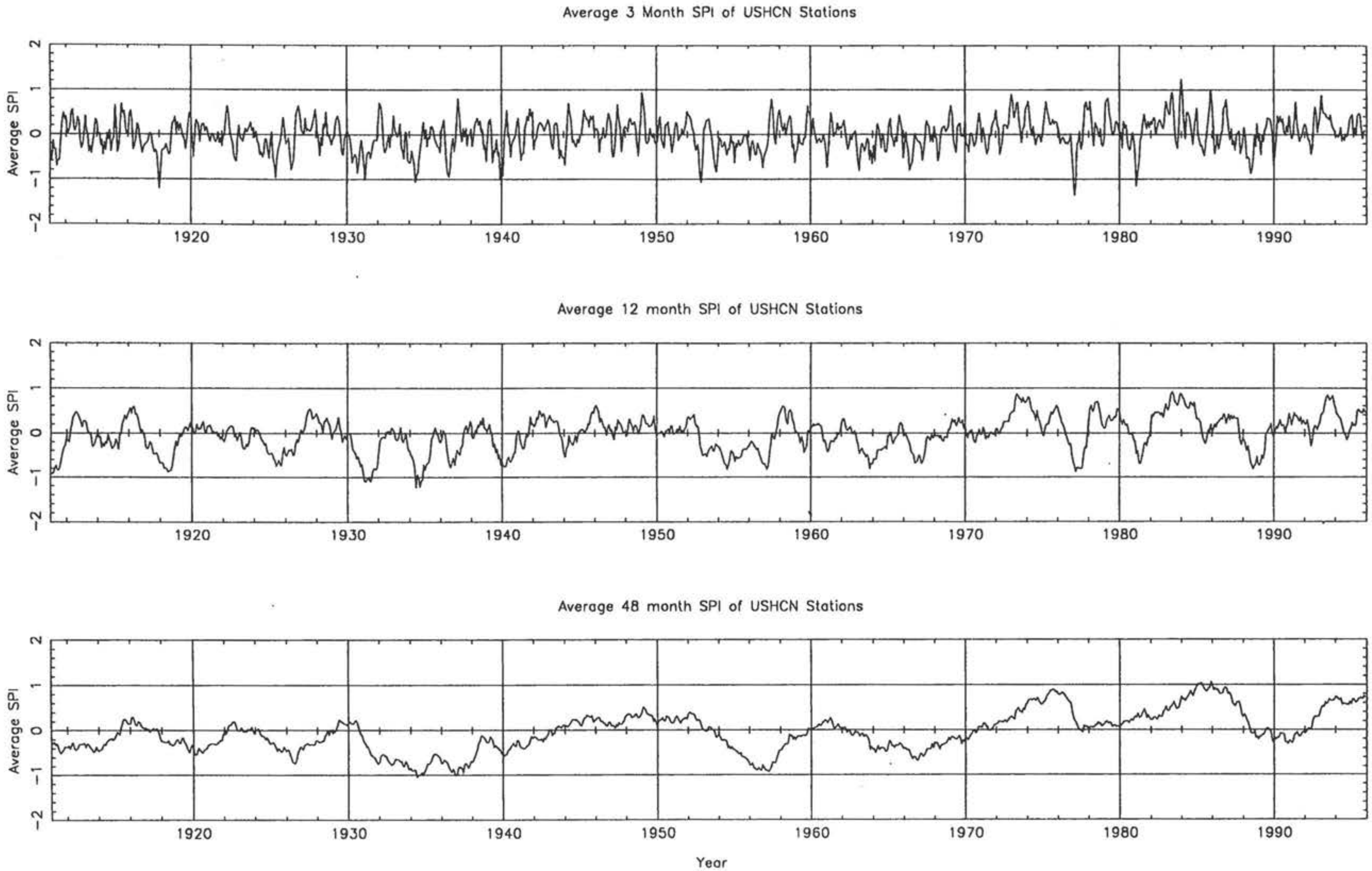


Fig 4.9 Time series of average SPI of all USHCN stations by time scale for the period January, 1911 through December, 1995.

again in the early 1990s. Not even the long-term wet period of the late 1940s and early 1950s matches the intense wet periods experienced between 1970 and 1995.

The short-term drought index (3 month SPI) shows that the nation has experienced short-term droughts during the period 1970 through 1995 matching the intensity of short-term droughts of the previous 60 years. It was shown in figure 4.3 and figures 4.5 through 4.7 that the intense short-term droughts of the period 1970 through 1995 also match the areal coverage of the intense short-term droughts of the previous 60 years. Likewise, figure 4.9 shows that the first 60 years of the period contain short-term wet periods matching the intensity of short-term wet periods of the following 25 years. It is also shown in figure 4.4 that the intense short-term wet periods of the first 60 years of the record match in areal coverage the intense short-term wet periods of the following 25 years. However, overall the nation has experienced an increased frequency of intense short-term wet periods the last 25 years of the record and a lower frequency of intense short-term dry periods. This led to the nation as a whole experiencing long-term wet periods for much of the last 25 years of the record despite the occurrence of intense short to intermediate term droughts in 1976-77, 1980-81, and 1988-89.

Least squares regression lines were fit to the time series in figure 4.9 to support these conclusions. Table 4.3 below shows that all three time scales show a positive, very nonstationary trend that supports the conclusion that there has been a decreasing number of intense droughts and an increasing number of intense anomalously wet periods at least during the period 1970 through 1995 at all time scales. The slopes of the regression lines are in terms of units of SPI per year.

Table 4.3: *t* Test for Nonstationarity of Average SPI of all USHCN Stations by Time Scale for the Period January, 1911 through December, 1995

Time Scale (months)	Slope (units of SPI/year)	P-value	Conclusion
3	0.002623	0.0001	nonstationary
12	0.005048	0.0001	nonstationary
48	0.009286	0.0001	nonstationary

4.1.4 Duration/Variability of Drought/Wet

Mckee *et al.* (1993) define an event a drought when the SPI becomes -1.0 or less. The beginning of this drought is then defined as when the SPI first went negative. The end of the drought does not occur until the SPI goes back to zero or above. An anomalously wet period can be similarly defined when the SPI becomes +1.0 or greater.

Figure 4.10 shows a graph of the mean duration of drought (solid line) of all USHCN stations by time scale during the period January, 1911 through December, 1995. Also shown is a graph of the average number of droughts (dashed line) per USHCN station by time scale in the 85 year period of record (1911 through 1995). This figure essentially shows that drought duration increases with increasing time scale, but drought frequency decreases with increasing time scale. This is not surprising since longer term droughts are essentially made up of multiple shorter term droughts. Additionally, not all shorter term droughts translate into longer term droughts. A figure comparing the frequency and duration of anomalously wet periods at different time scales would be similar.

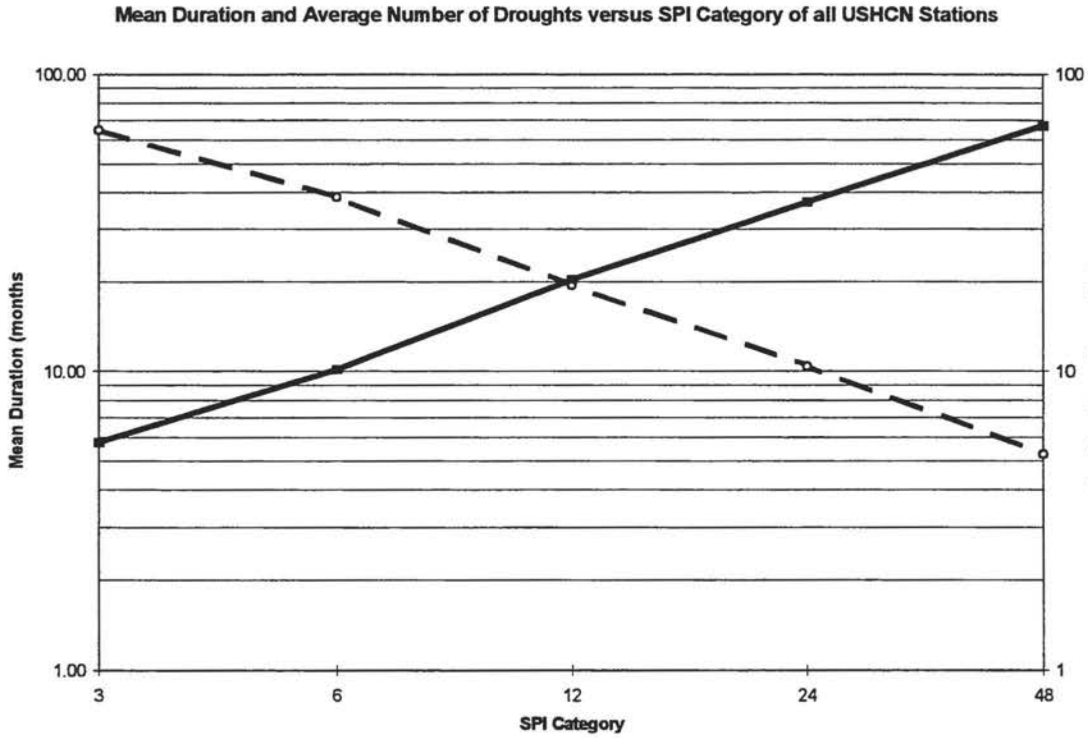


Fig 4.10 Mean duration (solid line) and average number of droughts (dashed line) versus SPI category of all USHCN stations for the period 1911 through 1995.

Figures 4.11(A) and 4.11(B) show a breakdown of the duration of the 1930s and 1950s droughts respectively for McPherson, Kansas at different time scales. Each tick mark on the x-axis represents one month. Five time scales are shown starting with the 3 month time scale at the bottom and progressing to the 48 month time scale at the top of each chart. The shaded areas represent the duration of drought at each time scale according to the definition from McKee *et al.* (1993). Both of these charts illustrate that major droughts begin with short-term droughts, which translate into intermediate-term droughts and finally into long-term droughts. At the end of the drought period, generally the short-term droughts end first, then the intermediate-term droughts, and finally the long-term droughts. Overall, these charts show that longer term droughts are made up of

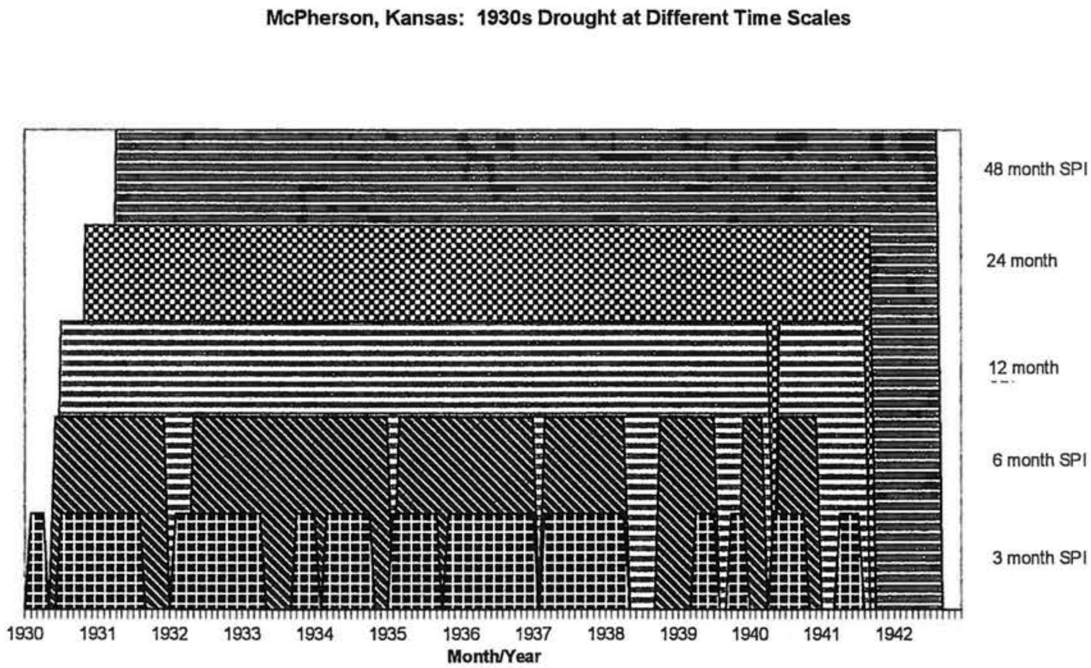


Fig 4.11 (A) 1930s drought at different time scales for McPherson, Kansas.

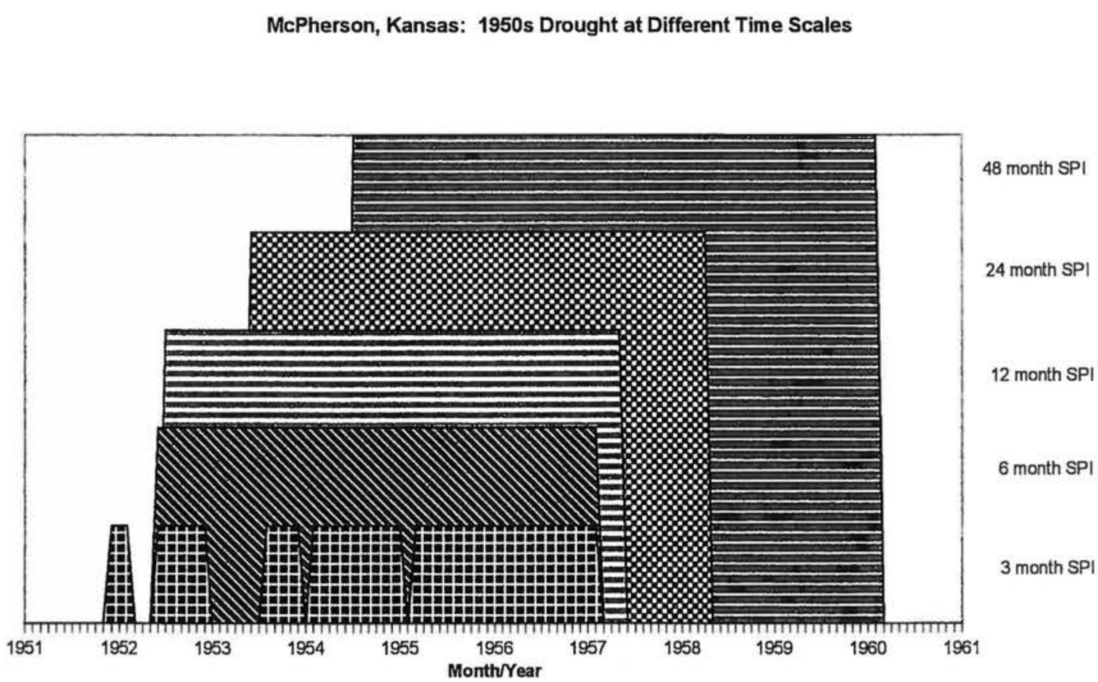


Fig 4.11 (B) 1950s drought at different time scales for McPherson, Kansas.

multiple shorter term droughts. For example, the 1930s drought for McPherson, Kansas was made up of 12 short-term droughts at the 3 month time scale, 7 short-term droughts at the 6 month time scale, and 2 intermediate-term droughts at the 12 month time scale. There was only one drought at the 24 month time scale and one drought at the 48 month time scale; but both of these droughts lasted more than 10 years with the drought at the 48 month time scale lasting the longest. Figure 4.11(B) shows that the drought of the 1950s was shorter in duration at the longer time scales and contained fewer short-term droughts, however, as was shown in figure 3.4 for McPherson, the intermediate- and long-term droughts of the 1950s were more intense than the intermediate- and long-term droughts of the 1930s. One reason for this is the short-term drought at the 3 month time scale between 1955 and 1957 lasted just more than 2 years, about 1.5 times longer than any of the longest short-term droughts at the 3 month scale McPherson experienced in the 1930s.

Table 4.4 shows summary statistics for all drought and wet periods of all USHCN stations for the period January, 1911 through December, 1995. Statistics are shown for five different time scales (3 month SPI, 6 month SPI, 12 month SPI, 24 month SPI, and 48 month SPI). Also shown are summary statistics for drought/wet period start and drought/wet period end. The start of a drought is defined as the number of months it takes for the SPI to go from zero or above to -1.0 or less. The end of a drought is then defined as the number of months it takes for the SPI to go from -1.0 or less to zero or above. Similar logic applies to wet period end/start except the threshold is +1.0.

At all time scales, there have been more droughts than wet periods. This is because for the country as a whole, the period 1911-1940 was drier than the base period

Table 4.4: Summary Statistics for Drought and Wet Periods of all USHCN Stations by Time Scale for the Period Jan 1911 - Dec 1995

Time Scale (SPI)	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
3 months	drought duration	79346	5.76	5	55	1	3	7	4	3.76	15.70
3 months	wet duration	73313	5.90	5	42	1	3	7	4	3.37	16.99
3 months	drought start	79346	2.27	2	21	1	1	3	2	1.37	
3 months	wet start	73313	2.32	2	18	1	1	3	2	1.34	
3 months	drought end	79346	2.26	2	16	1	1	3	2	1.35	
3 months	wet end	73313	2.30	2	18	1	1	3	2	1.35	
6 months	drought duration	46965	10.11	8	80	1	6	13	7	6.65	26.52
6 months	wet duration	43543	10.16	9	73	1	6	12	6	5.89	28.60
6 months	drought start	46965	3.19	3	22	1	2	4	2	1.98	
6 months	wet start	43543	3.23	3	23	1	2	4	2	1.94	
6 months	drought end	46965	3.19	3	23	1	2	4	2	1.96	
6 months	wet end	43543	3.21	3	22	1	2	4	2	1.97	
12 months	drought duration	23686	20.27	16	263	1	12	25	13	14.33	52.58
12 months	wet duration	21797	19.92	16	155	1	12	24	12	11.64	57.14
12 months	drought start	23686	5.17	4	39	1	3	7	4	3.53	
12 months	wet start	21797	5.19	4	39	1	3	7	4	3.39	
12 months	drought end	23686	5.14	4	39	1	3	7	4	3.49	
12 months	wet end	21797	5.16	4	37	1	3	7	4	3.47	
24 months	drought duration	12712	36.94	30	315	1	21	46	25	26.94	97.97
24 months	wet duration	11787	35.72	30	220	1	24	43	19	20.65	105.66
24 months	drought start	12712	8.09	7	70	1	4	11	7	5.49	
24 months	wet start	11787	8.36	7	69	1	4	11	7	5.41	
24 months	drought end	12712	8.19	7	61	1	4	11	7	5.51	
24 months	wet end	11787	8.34	7	67	1	4	11	7	5.51	
48 months	drought duration	6436	66.85	56	390	2	36	85	49	47.32	193.51
48 months	wet duration	6006	63.91	56	366	3	40	81	41	36.53	207.36
48 months	drought start	6436	13.68	11	110	1	7	18	11	9.96	
48 months	wet start	6006	13.79	12	91	1	7	18	11	9.60	
48 months	drought end	6436	13.77	11	231	1	7	18	11	10.14	
48 months	wet end	6006	13.81	12	122	1	7	18	11	9.72	

1941-1980. This outweighs the fact that 1981-1995 was wetter than the base period for the country as a whole.

Overall, the mean length of wet periods and drought periods are similar. In fact, the medians are nearly identical. On the other hand, both the interquartile range and the standard deviation are larger for drought periods compared to wet periods. This indicates that the length of droughts are more variable than the length of wet periods for the country as a whole for this period of record and base period.

Summary statistics for the starting and ending of droughts and wet periods show that both droughts and wet periods take about as long to start as they do to end. In fact, both the means and medians of the time it takes a drought or wet period to start at a given time scale are nearly identical to the means and medians respectively of the time it takes a drought or wet period to end. Additionally, these statistics indicate that droughts generally take the same time to start and end as do wet periods at the same time scale (again, the respective means and medians are nearly identical).

Table 4.4 also contains information on the average period of a drought or wet event at a station for each time scale. This is essentially the average number of months from the beginning of one drought to the beginning of the next drought. This was calculated by multiplying the total number of months in the period of record times the total number of stations in the USHCN and dividing the result by the total number of droughts (or wet periods) at the given time scale. The average period of a long-term drought (48 month SPI) was calculated to be 193.51 months (about 16.1 years) while the average period of a short-term drought (3 month SPI) was calculated to be 15.70 months (about 1.3 years).

The definition from McKee *et al.* (1993) allows the SPI to go below zero without a drought necessarily occurring. A common question from those who use the SPI to monitor drought is: "If the SPI is below zero now, what are our chances of going into drought?" Table 4.5 below shows the percent of time by index that the SPI goes below zero and ends up in drought as computed for all stations in the USHCN. In general, the percent of the time that the index goes below zero and results in drought increases with decreasing time scale. For the 3 month SPI, this table states that about half of the time a drought will occur at the short-term when the 3 month SPI goes below zero.

Table 4.5: Percent of Time SPI Goes Below Zero and Ends in Drought of all USHCN Stations by Time Scale for the Period January, 1911 through December, 1995

Time Scale (months)	Percent
3	50.2%
6	44.2%
12	36.7%
24	29.4%
48	22.4%

Long-term droughts are essentially made up of a series of short-term droughts, either consecutive (indicating one or two short-term droughts that are long in duration) or intermediate with no major intervening wet periods (indicating several short-term droughts that are shorter in duration). Figure 4.12(A) shows the running mean duration of all short-term droughts in the USHCN (as defined by the 3 month SPI) for the period January, 1916 through December, 1990. The running mean includes the average duration of short-term droughts that either began, ended, or were occurring during the month/year in question. Since table 4.4 shows that the maximum length of short-term droughts and wet periods never reaches 5 years, the period of record for this time series is January, 1916 through December, 1990 to ensure that no drought or wet period is missed due to the period of record. This graph shows that the running mean duration reached peaks during the major long-term drought periods of the teens, twenties, thirties, fifties, and sixties. Since 1970, the running mean duration of short-term droughts has not peaked as high as it did during these other periods. In fact, the slope of the least squares regression line for this time series is -0.020325 months per year (indicating that the running mean duration of short-term droughts has decreased 1.73 months over this 85 year period). The p-value from the *t* test assuming the slope is zero is 0.0001, indicating the time series is very nonstationary. This supports the conclusion that the average duration of all short-term droughts in the United States has steadily decreased during this period of record.

Figure 4.12(B) shows a time series of the fraction of USHCN stations experiencing short-term drought for the period January, 1916 through December, 1990 according to the McKee *et al.* (1993) definition of drought. Here, the slope of the fitted linear regression line is -0.001344 stations in short-term drought per total number of stations per year. The p-value from the *t* test assuming the slope is zero is 0.0001, indicating that this time series is also very nonstationary. This supports the conclusion that the average frequency of short-term drought has also decreased during this period of record.

Figure 4.13(A) contains a graph of the running mean duration of short-term wet periods (3 month SPI) of all USHCN stations and figure 4.13(B) contains a graph of the fraction of USHCN stations experiencing short-term wet periods for the period January, 1916 through December, 1990. The upper graph shows that the running mean duration of short-term wet periods peaked during the long-term anomalously wet periods of the 1940s, 1970s, and 1980s shown previously in figure 4.9. Additionally, the lower graph shows that the fraction of USHCN stations experiencing short-term anomalously wet conditions reached its highest peaks between 1970 and 1990. The slope of the least squares regression line for the running mean duration of short-term wet periods is +0.012524 months/year (indicating that the running mean duration of short-term wet periods has increased 1.06 months over this 85 year period). This indicates that the duration of short-term wet periods has been increasing at a magnitude nearly opposite to the decreasing magnitude of the duration of short-term drought periods shown in figure 4.12(A). The p-value from the associated *t* test assuming the slope is zero is 0.0001. This indicates that the time series is very nonstationary (there is an apparent trend in the data for this period of record). Likewise, the time series in figure 4.13(B) has a fitted slope of +0.001528 stations experiencing short-term wet periods per total number of stations per year. Again, this is nearly opposite in magnitude to the decreasing fraction of stations experiencing short-term drought. The p-value from the associated *t* test is 0.0001, also indicating a very nonstationary, positive trend over this period of record. Hence, figures 4.12 and 4.13 indicate that for the country as a whole, short-term wet periods have increased in frequency and duration at rates nearly opposite to the decreasing frequency and duration of short-term droughts for the period January, 1916 through December, 1990.

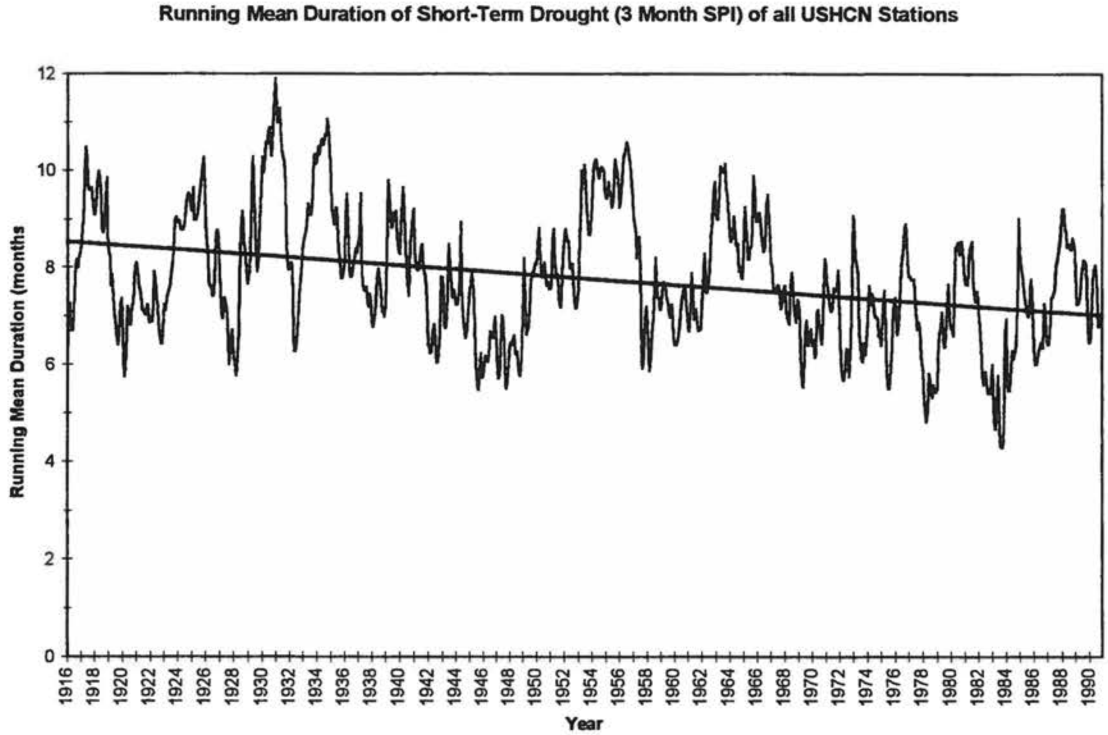


Fig 4.12 (A) Running mean duration of short-term drought (3 month SPI) of all USHCN stations for the period Jan 1916 thru Dec 1990 with trend line.

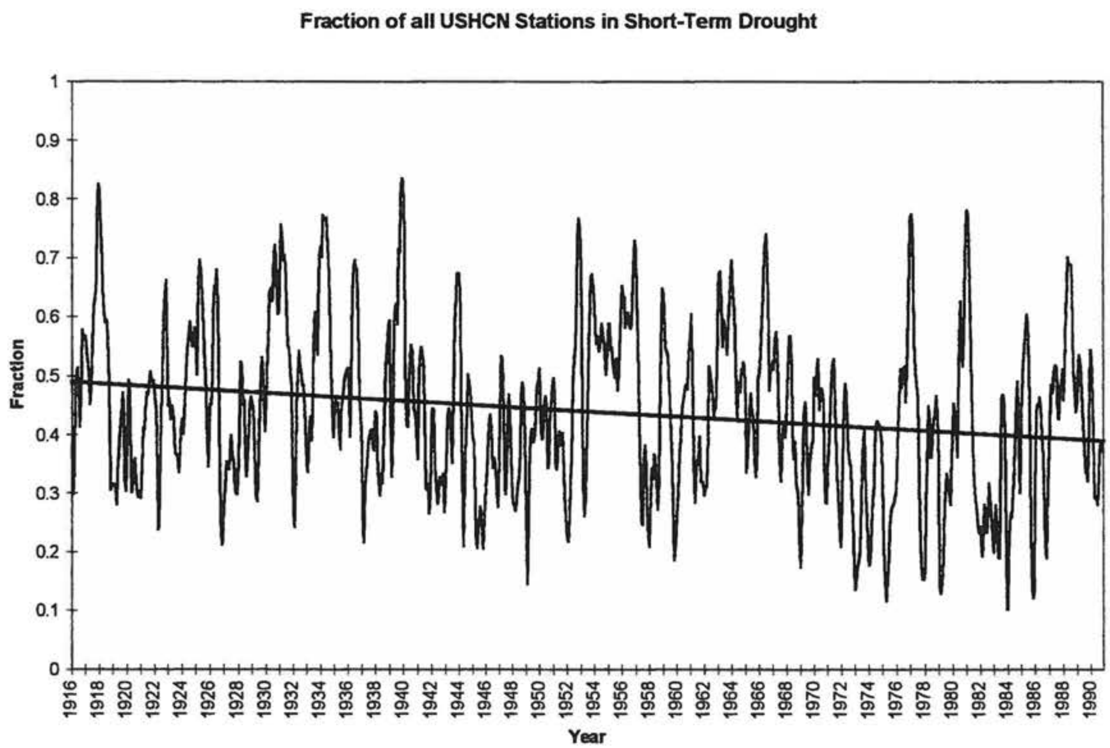


Fig 4.12 (B) Time series of the fraction of USHCN stations in short-term drought (3 month SPI) for the period Jan 1916 thru Dec 1990 with trend line.

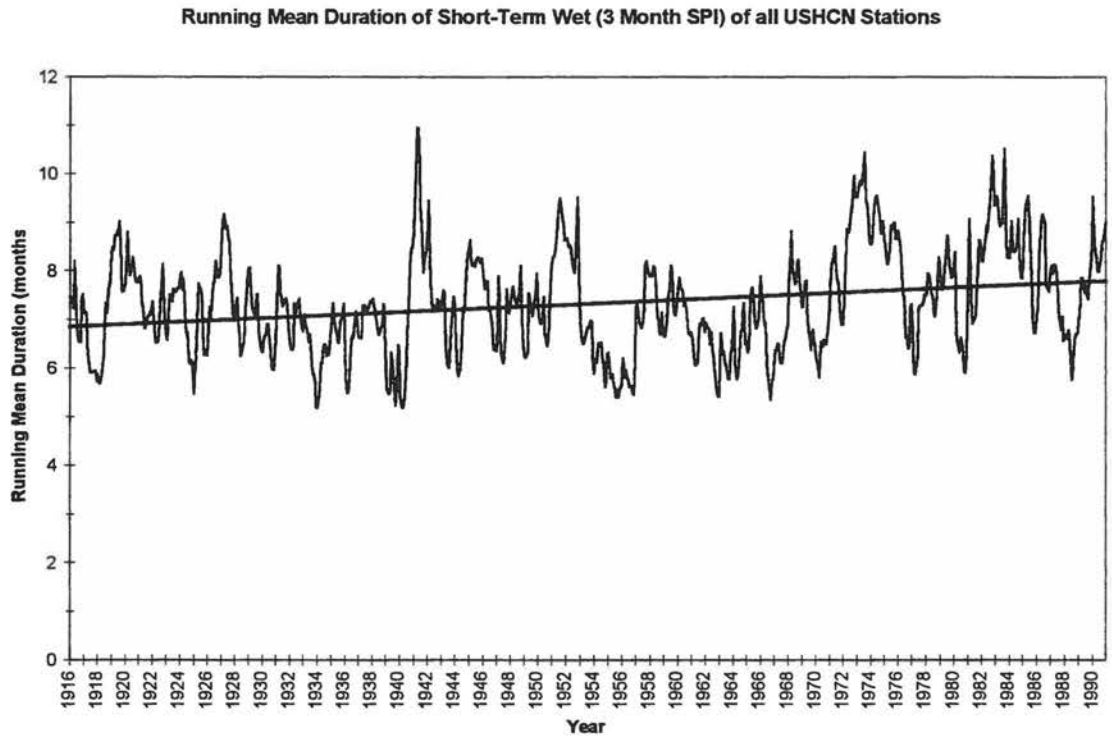


Fig 4.13 (A) Running mean duration of short-term wet (3 month SPI) of all USHCN stations for the period Jan 1916 thru Dec 1990 with trend line.

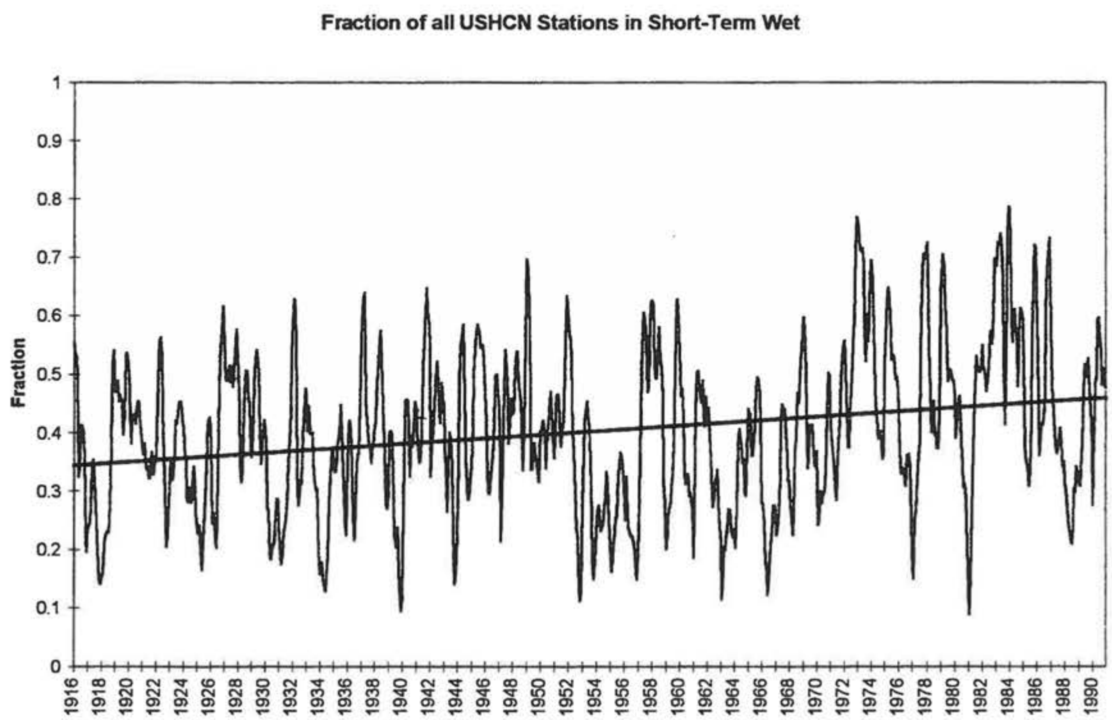


Fig 4.13 (B) Time series of the fraction of USHCN stations in short-term wet (3 month SPI) for the period Jan 1916 thru Dec 1990 with trend line.

4.1.5 Seasonal Drought/Wet

Figure 4.14(A) shows a time series of the average 6 month SPI of all USHCN stations for the month of September. This index is basically an indicator of the drought or wet conditions of the previous spring and summer for the country as a whole. Figure 4.14(B) is similar except it is for the month of March as an indicator of the previous fall and winter drought or wet conditions. These figures show that both timeframes have had more wet periods than droughts during the period 1970 through 1995. However, the fall/winter index (figure 4.14(A)) shows larger anomalies both wet and dry during the period 1970 through 1995 than the spring/summer index (figure 4.14(B)).

Figures 4.15(A-D) further breakdown the seasonal anomalies for the country as a whole. Shown are average 3 month SPI of all USHCN stations for the months of February (winter index), May (spring index), August (summer index), and November (autumn index). Figure 4.15(A) shows the winter index where the anomalies for the period 1970 to 1995 don't differ significantly from other 25 year periods. The spring index, figure 4.15(B), shows that there has been an increased frequency of wet anomalies for the country as a whole during the spring for the period 1970 to 1995. However, there have been several dry anomalies as well especially in the mid to late 1980s. The summer index, figure 4.15(C), shows only a slight increase in anomalously wet periods for the country as a whole for the period 1970 to 1995. The autumn index, figure 4.15(D), shows the most dramatic increase in anomalously wet periods between 1970 and 1995. Additionally, the occurrence of anomalously wet autumn periods coincides well with the long-term wet periods of the 1970s, 1980s, and 1990s shown in figure 4.9.

Table 4.6 below provides some perspective on the overall trend of precipitation by season for the country as a whole. For this table, a season is considered a 3 month time scale ending with the month shown in the table. For the entire period of record, all seasons except for the December, January, and February season (month 2) have a positive slope. However, the only season with a very nonstationary trend is the May, June, and July season (month 7) that has a positive slope. Hence, only the late spring and early summer appears to have a trend towards becoming progressively wetter over the period of record. Looking back at figures 4.15(B) and 4.15(C), the spring and summer had a high frequency of short-term dry anomalies during the first 30 years of the record, and a comparatively lower frequency of short-term dry anomalies the last 55 years of the record. Table 4.6 shows that the winter and early spring seasons (months 2, 3, and 4) have been very stationary. This is evident in figure 4.15(A). Table 4.6 shows the largest positive slopes are during the autumn season (months 11 and 12). However, as seen in figure 4.15(D), since this positive trend is mostly contained in the last 25 years of the record, the p-values are not below the threshold to call the trends very nonstationary.

Table 4.6: *t* Test for Nonstationarity of Average 3 Month SPI of all USHCN Stations by Season and by Time Scale for the Period January, 1911 through December, 1995

month	time scale (months)	slope (units of SPI/year)	p-value	conclusion
1	3	0.003571	0.0669	none
2	3	-0.000241	0.8852	stationary
3	3	0.000886	0.5441	stationary
4	3	0.001794	0.2366	stationary
5	3	0.003960	0.0222	none
6	3	0.002554	0.0929	none
7	3	0.003645	0.0097	nonstationary
8	3	0.002960	0.0146	none
9	3	0.002459	0.0448	none
10	3	0.001630	0.2376	stationary
11	3	0.004090	0.0198	none
12	3	0.004102	0.0383	none

Time Series of Average 6 Month SPI (September) of all USHCN Stations (POR: 1911-1995)

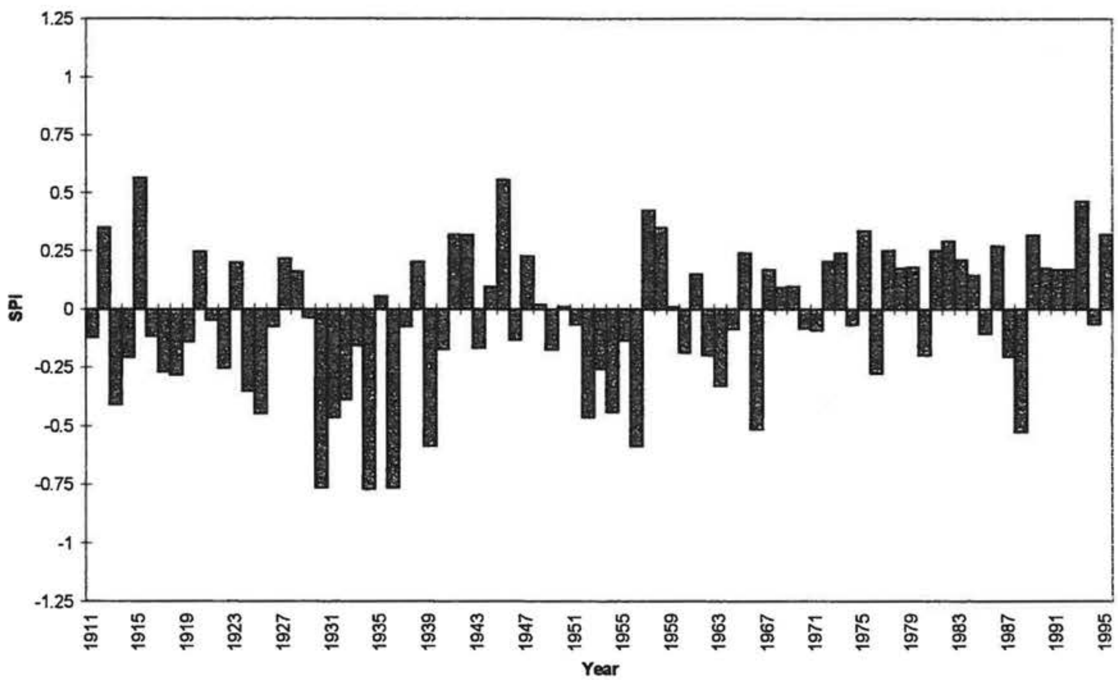


Fig 4.14 (A) Time series of average 6 month SPI for September (spring and summer) of all USHCN stations for the period January, 1911 through December, 1995.

Time Series of Average 6 Month SPI (March) of all USHCN Stations (POR: 1911-1995)

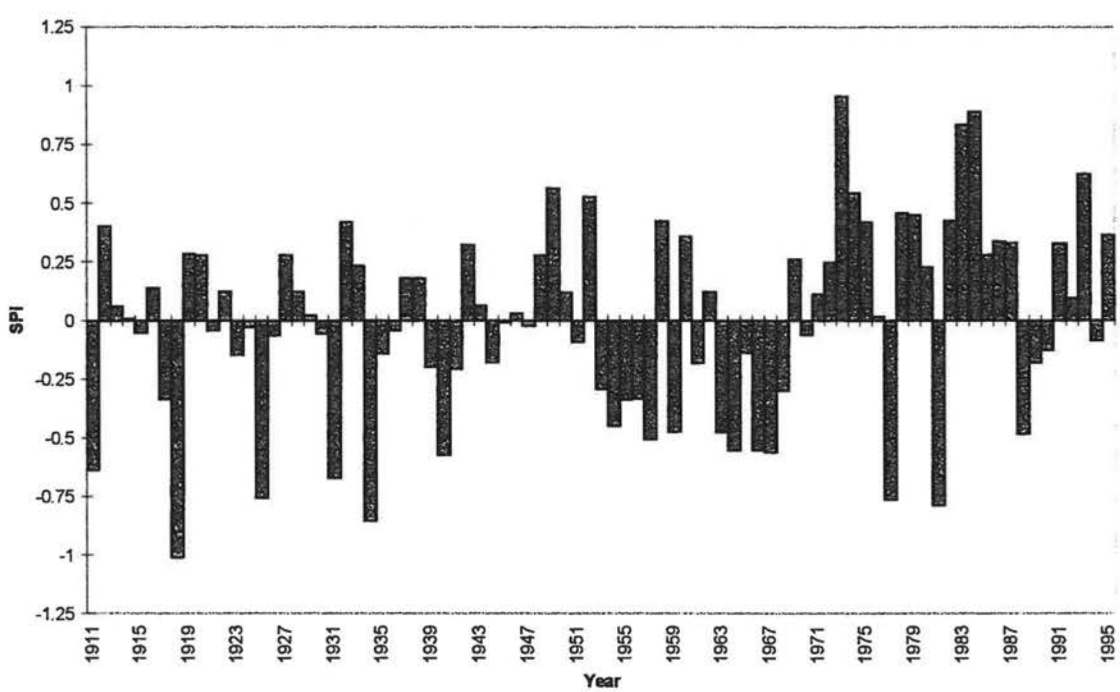


Fig 4.14 (B) Time series of average 6 month SPI for March (fall and winter) of all USHCN stations for the period January, 1911 through December, 1995.

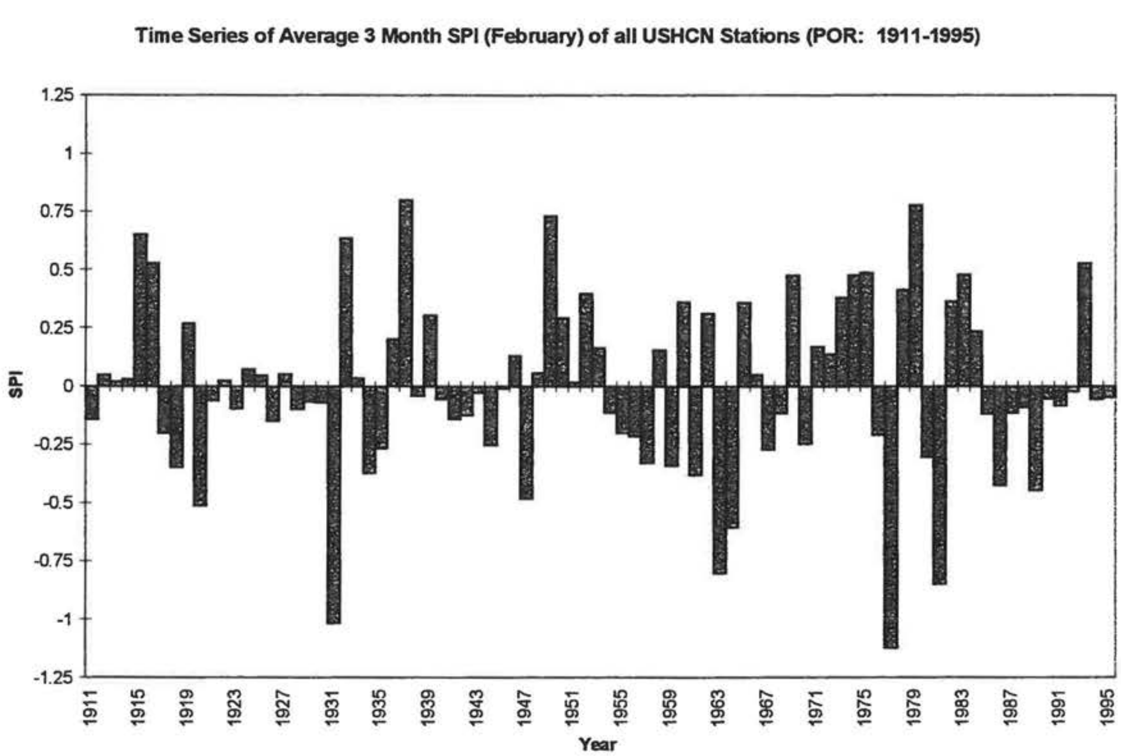


Fig 4.15 (A) Time series of average 3 month SPI for February (winter) of all USHCN stations for the period January, 1911 through December, 1995.

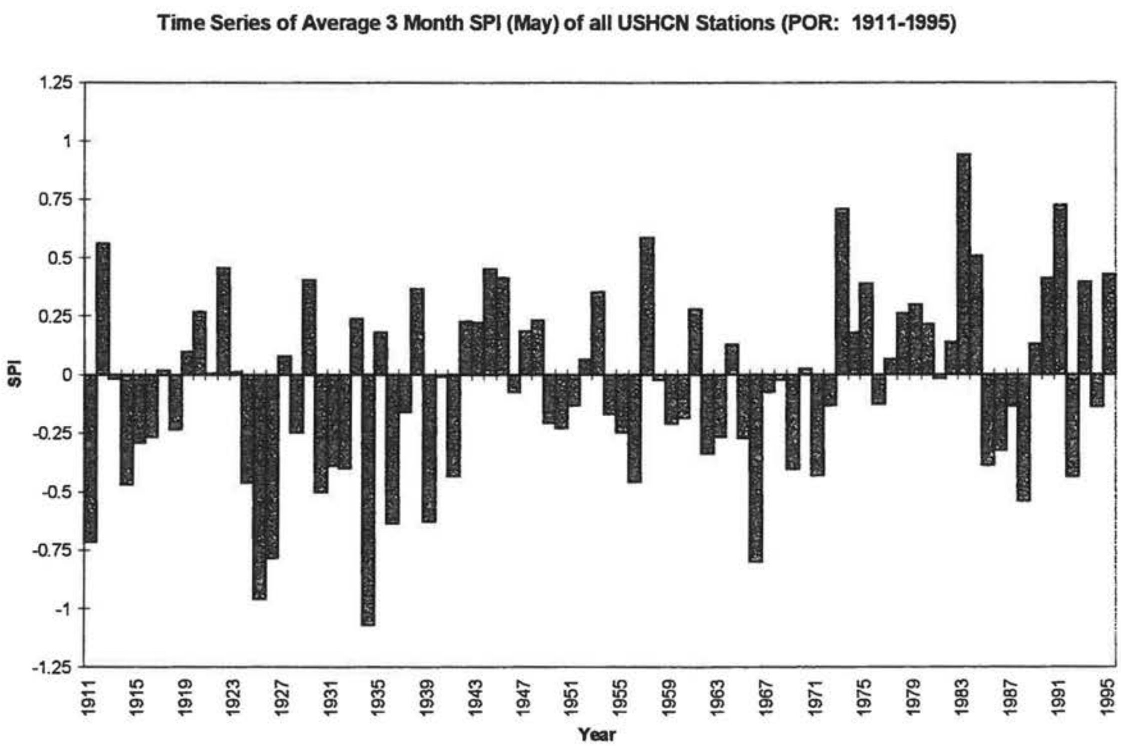


Fig 4.15 (B) Time series of average 3 month SPI for May (spring) of all USHCN stations for the period January, 1911 through December, 1995.

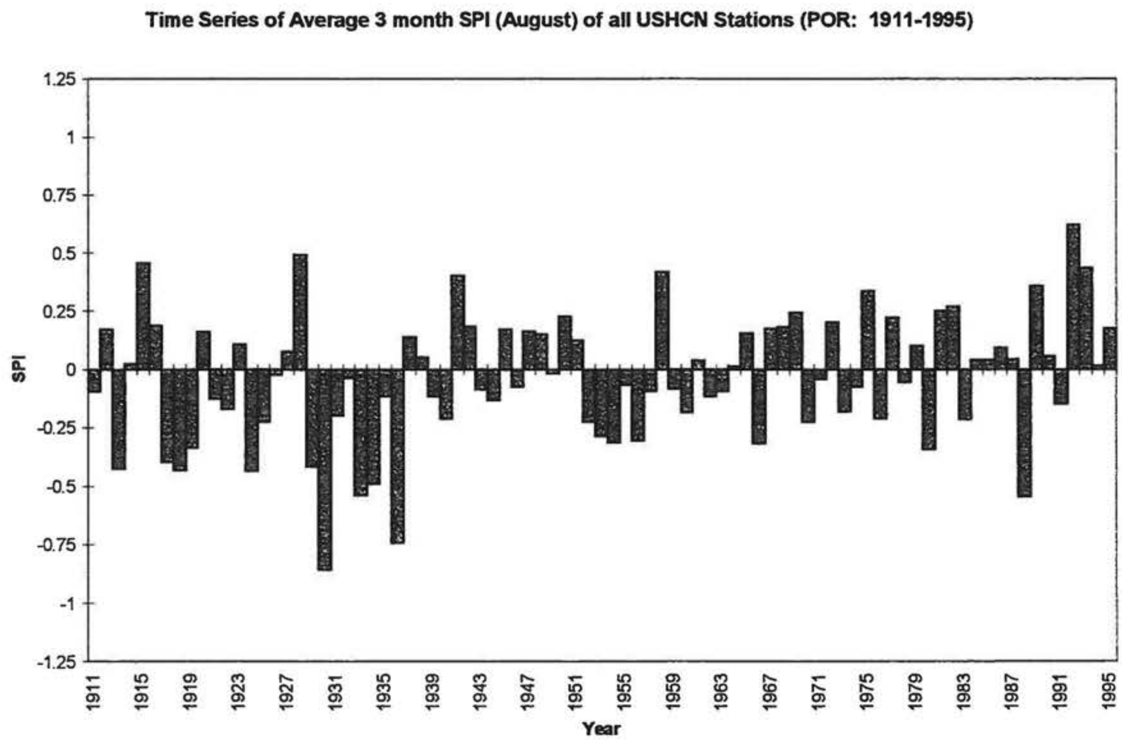


Fig 4.15 (C) Time series of average 3 month SPI for August (summer) of all USHCN stations for the period January, 1911 through December, 1995.

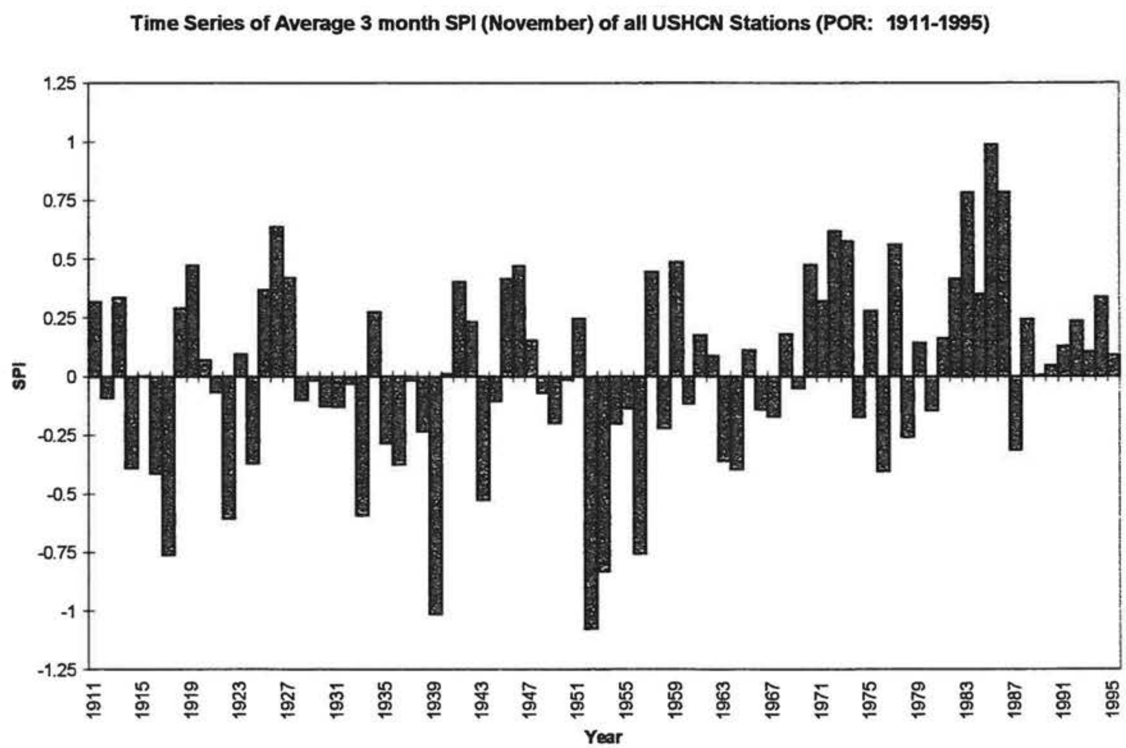


Fig 4.15 (D) Time series of average 3 month SPI for November (autumn) of all USHCN stations for the period January, 1911 through December, 1995.

4.2 Regional Perspective

As Dracup *et al.* (1980b) state, droughts are inherently regional in nature. Additionally, long-term droughts are made up of short-term droughts which typically don't cover the same exact region from drought to drought. For example, even though a large portion of the country experienced the 1930s drought, different regions experienced short-term drought at different times during this decade. For example, both the Northwest and the Central Plains experienced intense long-term drought in the 1930s. However, the short-term droughts that occurred did not always cover both of these regions at the same time, nor did the short-term droughts that occurred have the same spatial coverage within these major regions.

Additionally, the regions in which drought occur aren't necessarily independent of each other. For example, in which region does McPherson, Kansas belong? It experienced both the long-term drought of the Northern Plains in the 1930s as well as the long-term drought of the Southern Plains in the 1950s. However, McPherson doesn't necessarily experience every Southern Plains drought nor does it always experience every Northern Plains drought.

Karl and Koscielny (1982) performed a principal component analysis on gridded values of the Palmer Drought Severity Index (PDSI) and determined nine identifiable patterns of drought in the contiguous United States. Diaz (1983) then grouped states according to these findings into the 9 regions shown in figure 4.16. The number of USHCN stations in each region is also shown in figure 4.16. National Climatic Data Center analysts still use this grouping for regional drought studies utilizing the PDSI

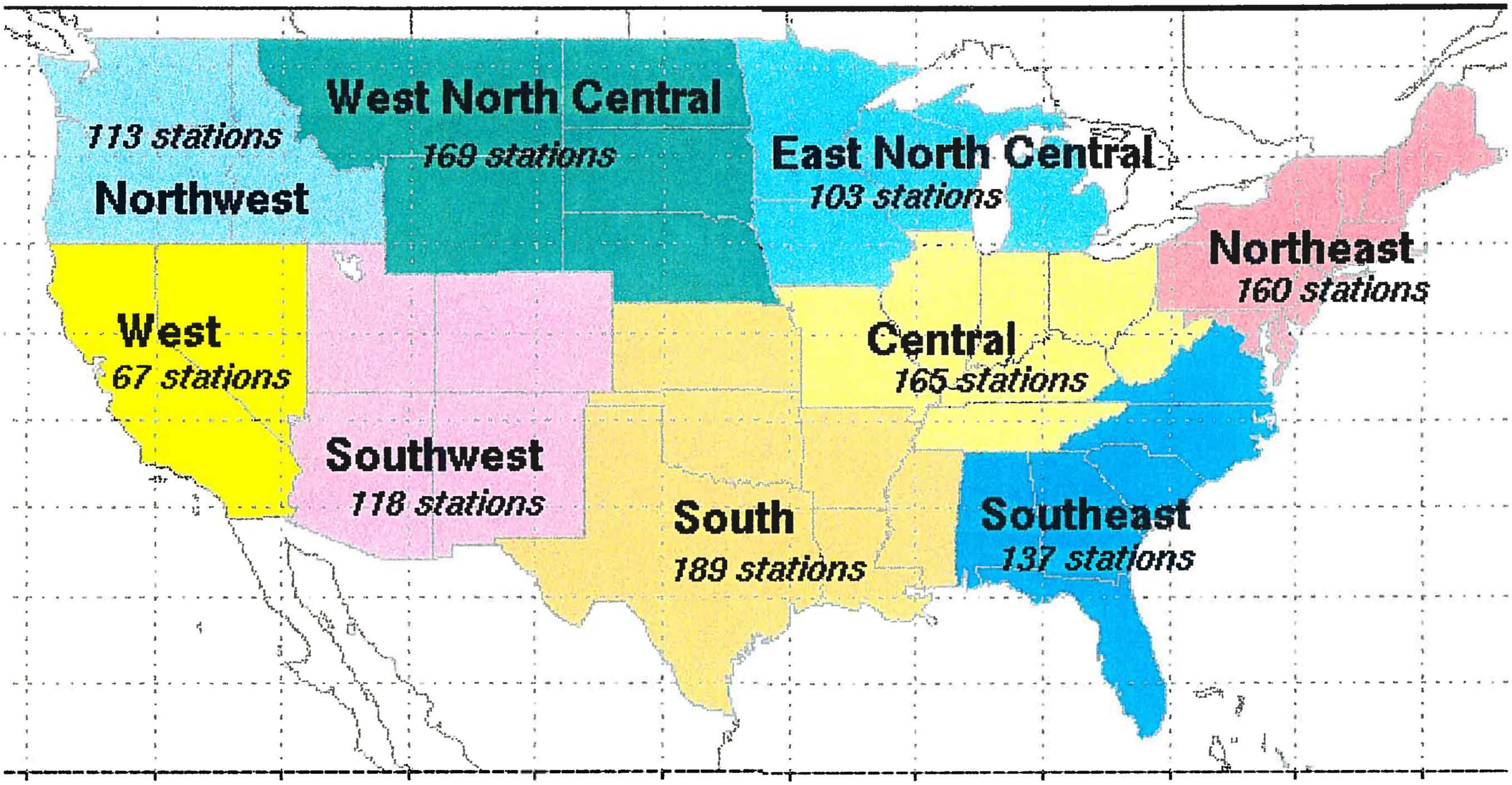


Fig 4.16 Homogeneous drought regions as determined by Karl and Koscielny (1982).

(Brown and Heim, Jr., 1997). For the purpose of performing a regional analysis in this study, Diaz's grouping is adopted here. As Dracup *et al.* (1980b) state, the small sample size of drought events is often a limiting factor in their analysis, and regionalization provides a means for increasing this sample size. Bear in mind, however, that droughts don't obey regional boundaries and that other groupings may be just as valid for purposes of analysis.

4.2.1 Distribution of Precipitation

Figures 4.17(A-I) show the average annual distribution of monthly precipitation for USHCN stations by each of the nine different regions. Stations in the Northwest and West generally have a winter maximum which explains the secondary maximum in figure 4.1. Stations in the West North Central, South, Central, and East North Central generally have a late spring maximum while stations in the Southwest, Southeast, and Northeast generally have a summer maximum.

Figures 4.18(A-I) show time series of the running 12 month mean precipitation of USHCN stations by region. Table 4.7 shows the results of t tests performed on the slopes of the fitted regression lines to these time series. All 9 regions show a positive, very nonstationary trend for this period of record. This includes the West which experienced a long-term drought in the late 1980s and early 1990s. However, the West has also experienced peaks of the running 12 month mean precipitation above 30 inches three times during the period 1970 to 1995, where this occurred only twice in the previous 60 years. The Southwest region has the smallest increase over the period of record, while the East

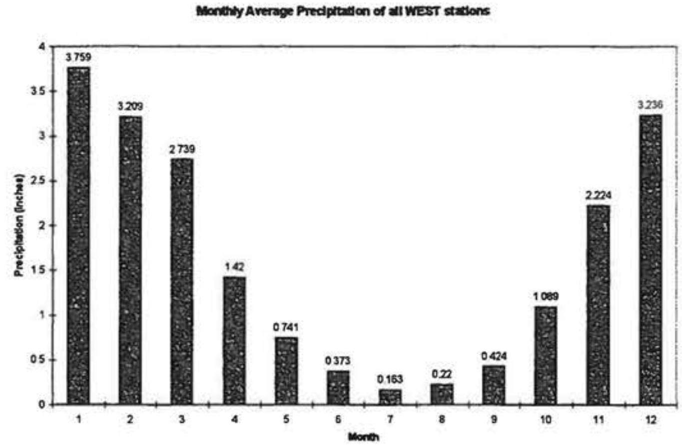


Fig 4.17(A) Annual distribution of monthly average precipitation of all West stations for the period January, 1911 through December, 1995.

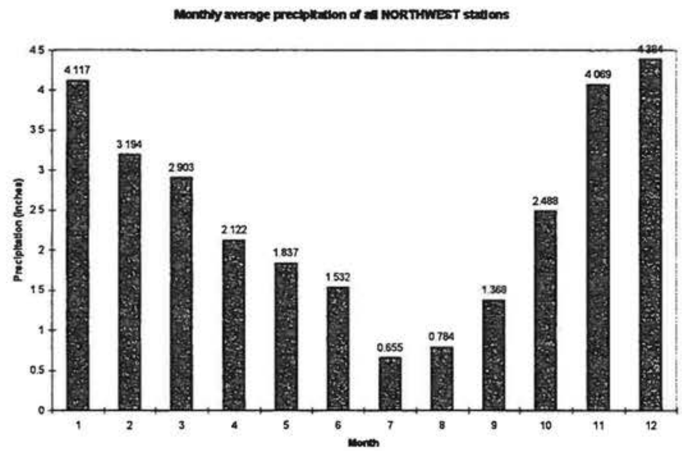


Fig 4.17(B) Annual distribution of monthly average precipitation of all Northwest stations for the period January, 1911 through December, 1995.

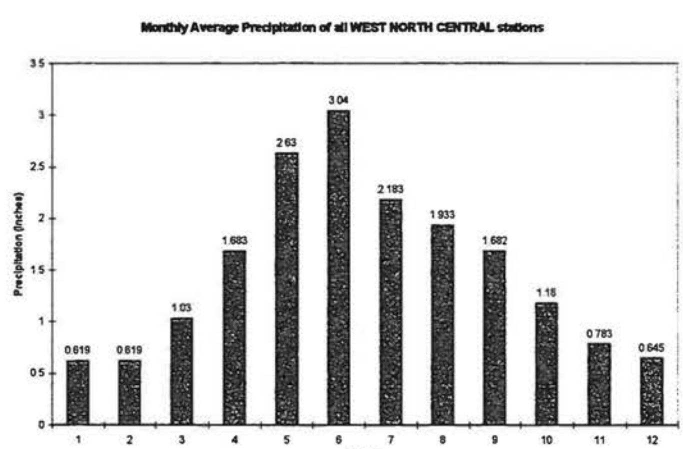


Fig 4.17(C) Annual distribution of monthly average precipitation of all West North Central stations for the period January, 1911 through December, 1995.

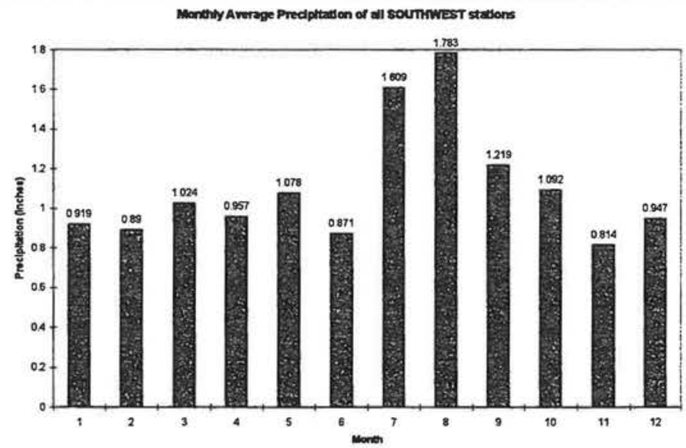


Fig 4.17(D) Annual distribution of monthly average precipitation of all Southwest stations for the period January, 1911 through December, 1995.

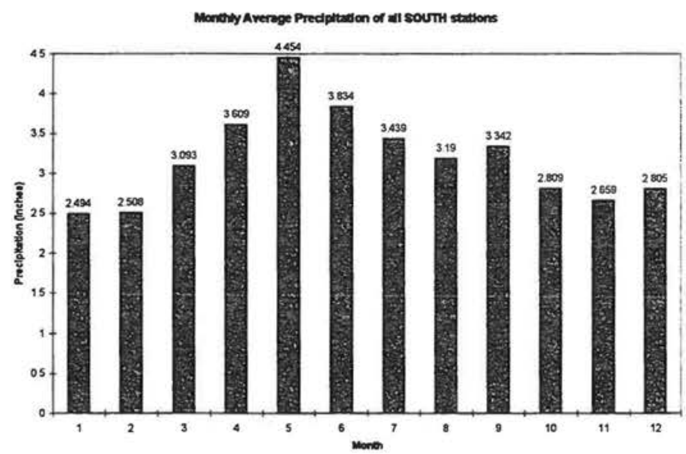


Fig 4.17(E) Annual distribution of monthly average precipitation of all South stations for the period January, 1911 through December, 1995.

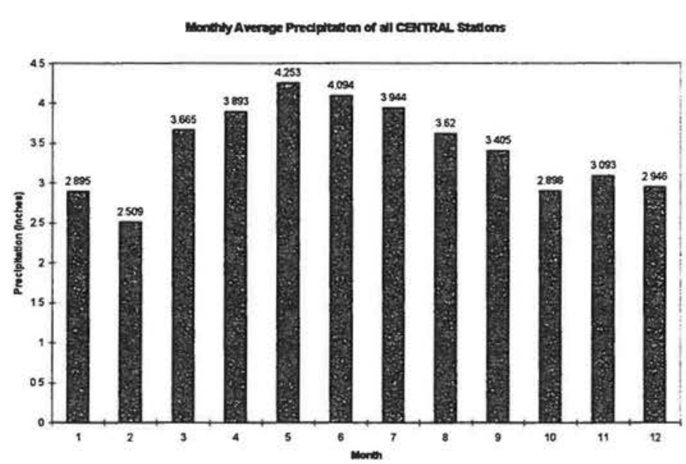


Fig 4.17(F) Annual distribution of monthly average precipitation of all Central stations for the period January, 1911 through December, 1995.

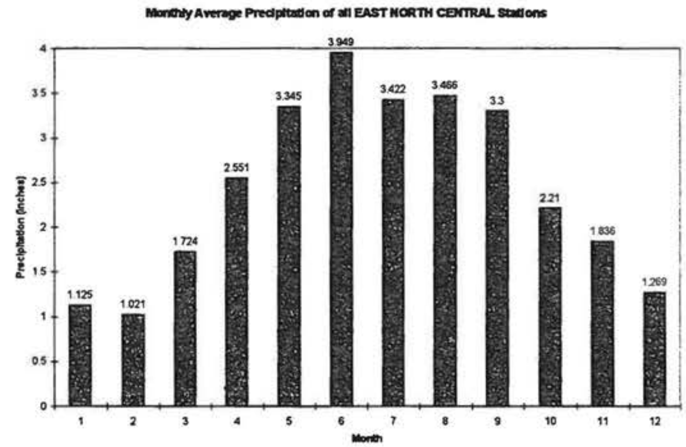


Fig 4.17(G) Annual distribution of monthly average precipitation of all East North Central stations for the period January, 1911 through December, 1995.

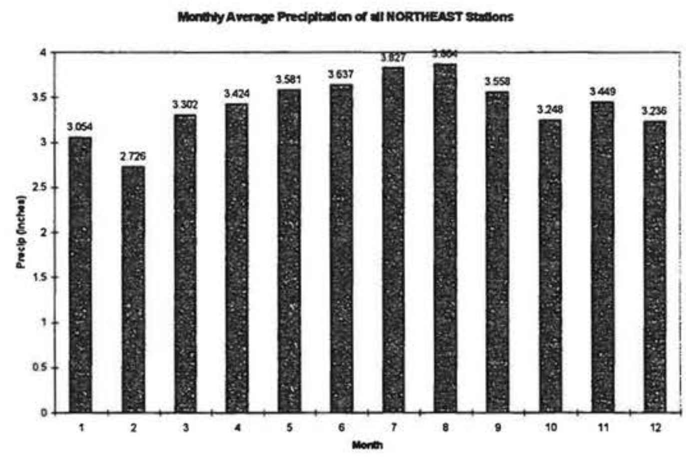


Fig 4.17(H) Annual distribution of monthly average precipitation of all Northeast stations for the period January, 1911 through December, 1995.

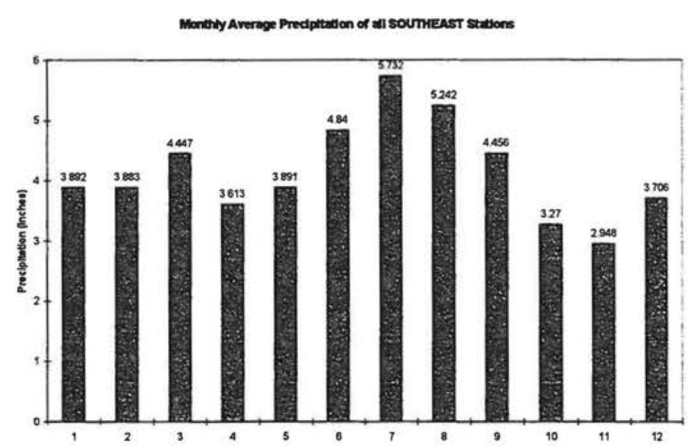


Fig 4.17(I) Annual distribution of monthly average precipitation of all Southeast stations for the period January, 1911 through December, 1995.

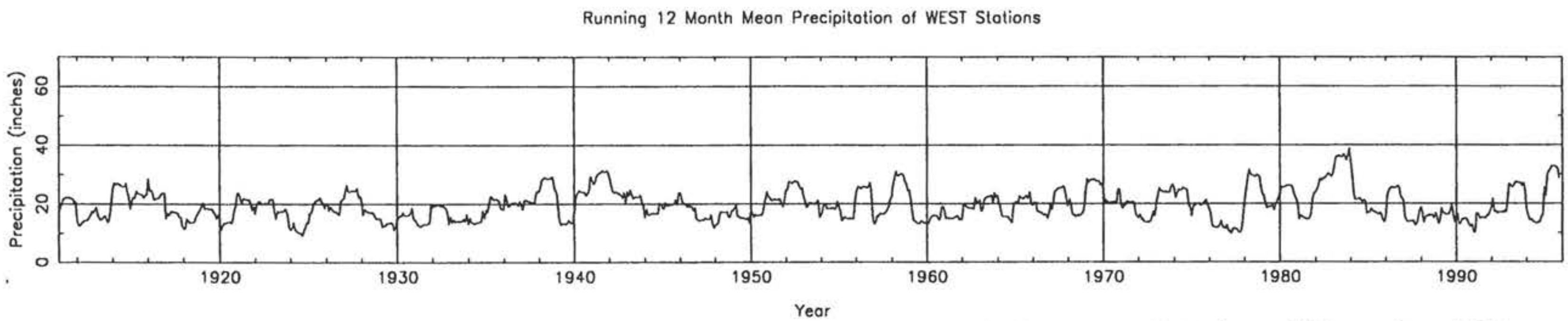


Fig 4.18(A) Running 12 month mean precipitation of all West stations for the period January, 1911 through December, 1995.

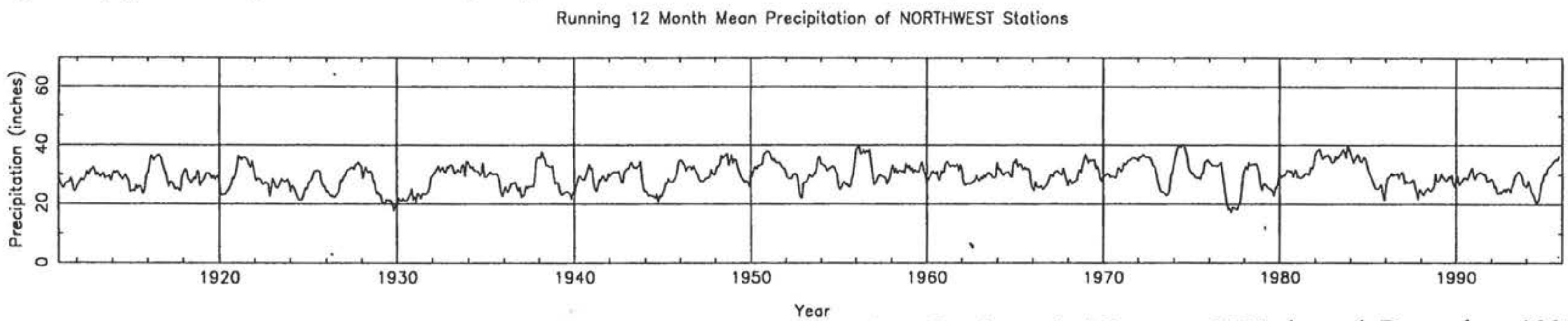


Fig 4.18(B) Running 12 month mean precipitation of all Northwest stations for the period January, 1911 through December, 1995.

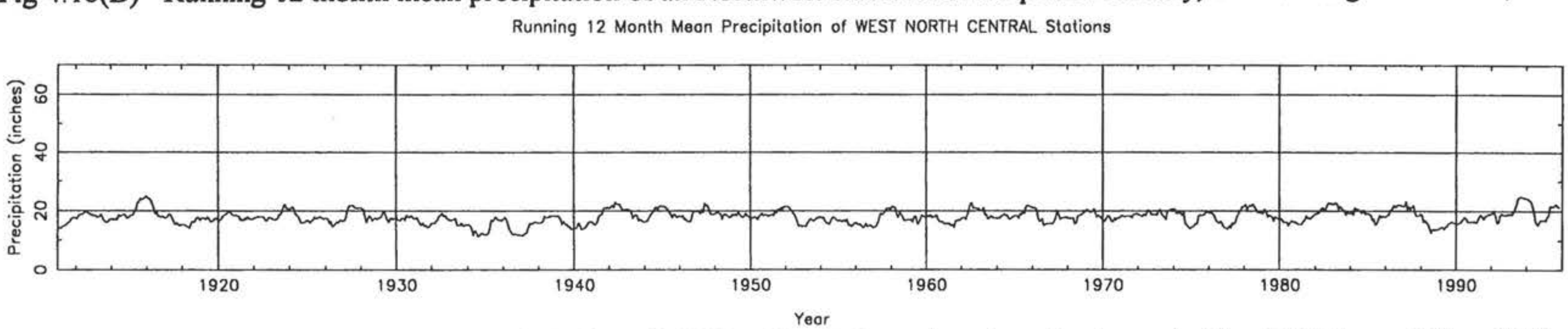


Fig 4.18(C) Running 12 month mean precipitation of all West North Central stations for the period Jan 1911 through Dec 1995.

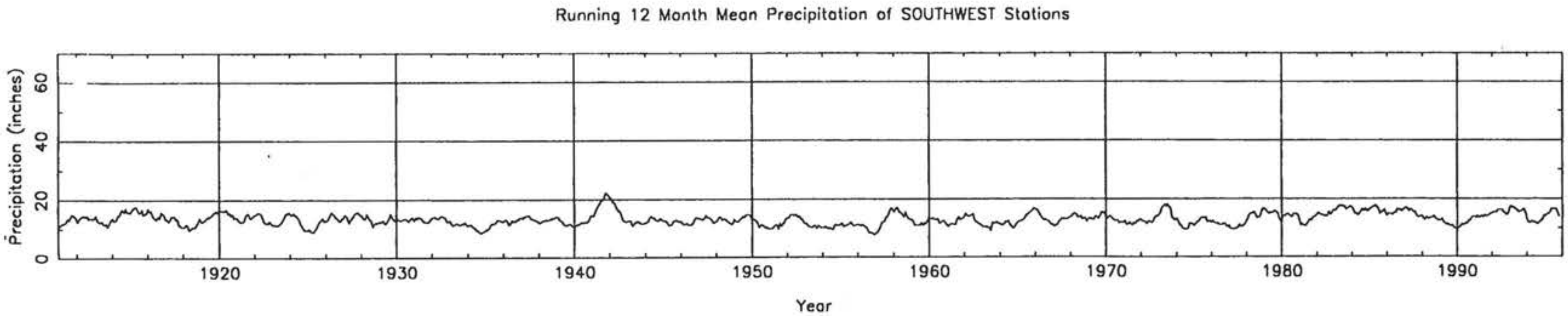


Fig 4.18(D) Running 12 month mean precipitation of all Southwest stations for the period January, 1911 through December, 1995.

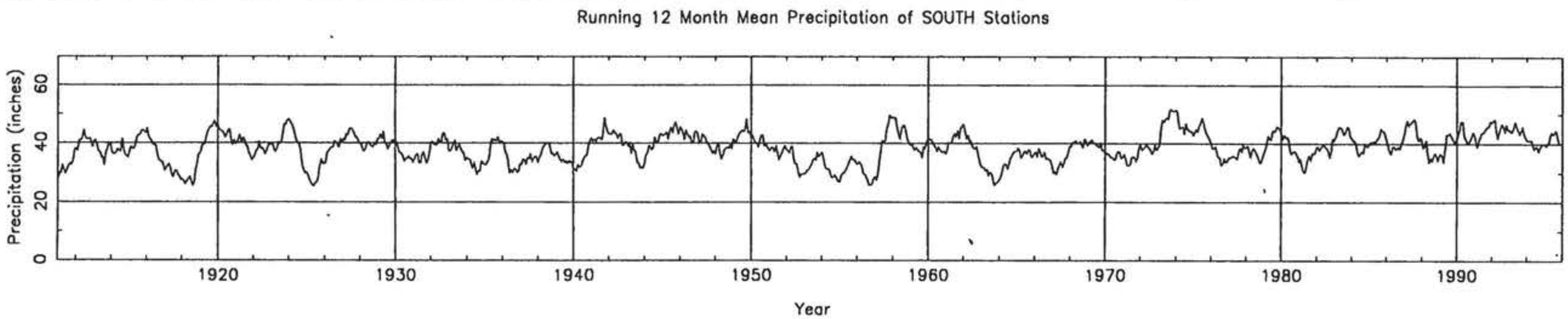


Fig 4.18(E) Running 12 month mean precipitation of all South stations for the period January, 1911 through December, 1995.

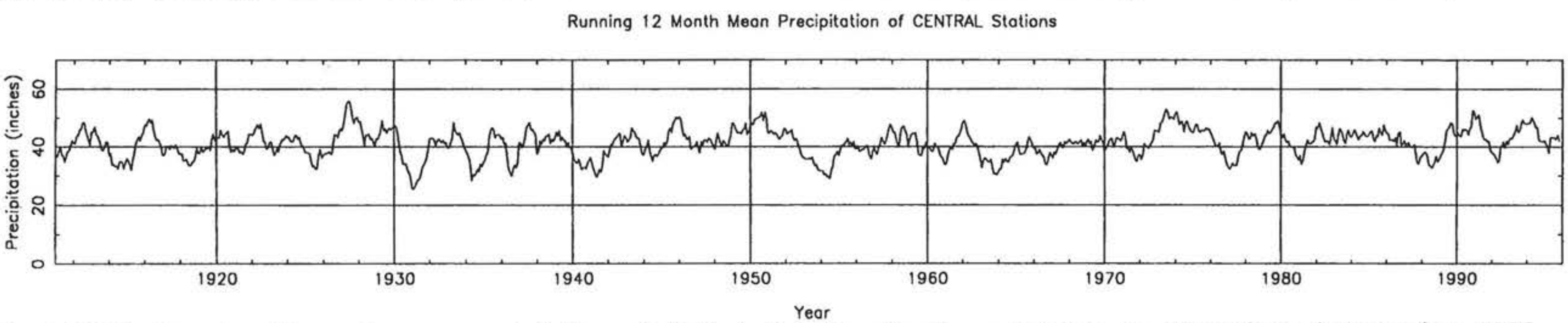


Fig 4.18(F) Running 12 month mean precipitation of all Central stations for the period January, 1911 through December, 1995.

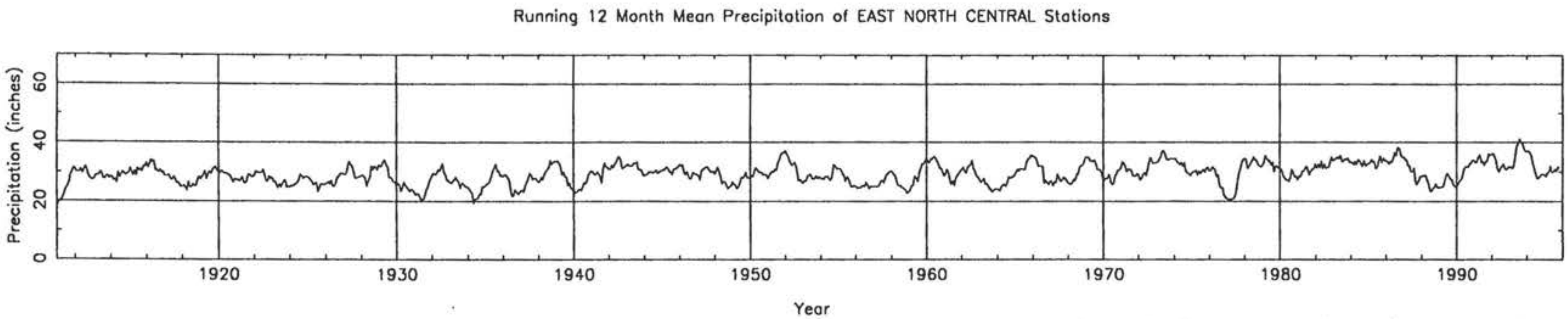


Fig 4.18(G) Running 12 month mean precipitation of all East North Central stations for the period Jan 1911 through Dec 1995.

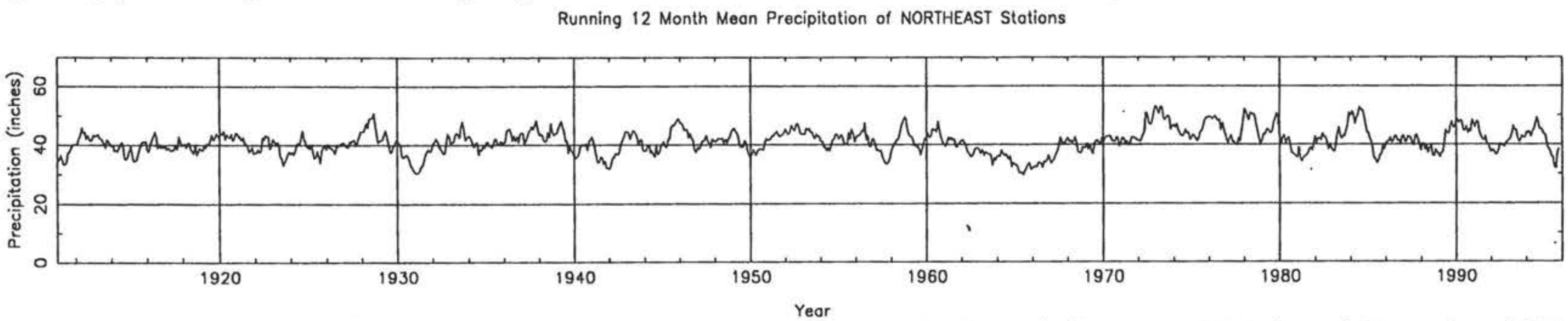


Fig 4.18(H) Running 12 month mean precipitation of all Northeast stations for the period January, 1911 through December, 1995.

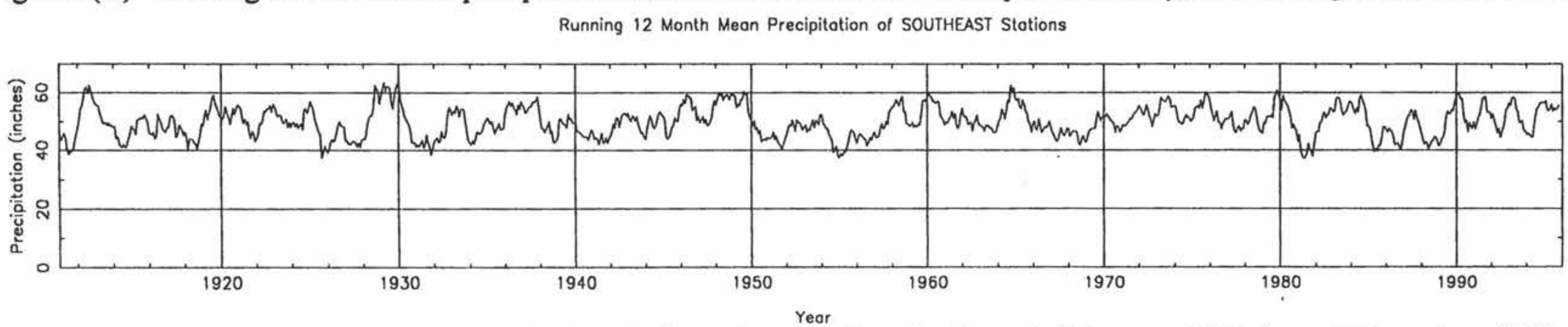


Fig 4.18(I) Running 12 month mean precipitation of all Southeast stations for the period January, 1911 through December, 1995.

North Central and South regions have the largest increases. Also shown in table 4.7 are the total increases over the period of record as a percentage of that region's annual average. The East North Central, West, and South have the largest increases in the running 12 month mean precipitation as a percentage of their annual average.

Table 4.7: *t* Test for Nonstationarity of Running 12 Month Mean Precipitation of USHCN Stations by Region for the Period January, 1911 through December, 1995

Region	Slope (inches/year)	Total Increase (inches)	Total Increase Percent of Ann. Avg.	P-value	Conclusion
West	0.030457	2.59	13.20	0.0001	nonstationary
Northwest	0.027338	2.32	7.88	0.0001	nonstationary
West North Central	0.016990	1.44	8.00	0.0001	nonstationary
Southwest	0.007344	0.62	4.72	0.0055	nonstationary
South	0.046805	3.97	10.39	0.0001	nonstationary
Central	0.030262	2.57	6.23	0.0001	nonstationary
East North Central	0.052489	4.46	15.25	0.0001	nonstationary
Northeast	0.034046	2.89	7.07	0.0001	nonstationary
Southeast	0.022705	1.93	3.86	0.0007	nonstationary

4.2.2 Areal Coverage of Drought/Wet

Figures 4.19(A-I) show the percent of stations by region with SPI less than or equal to -1.0 for the period January, 1911 through December, 1995. Similarly, figures 4.20(A-I) show the percent of stations by region with SPI greater than or equal to +1.0 for the period January, 1911 through December, 1995. Three different time scales are shown (3 month SPI for short-term drought/wet, 12 month SPI for intermediate-term drought/wet, and 48 month SPI for long-term drought/wet). A brief synopsis of each region follows.

A look at the 48 month SPI for the West region in figure 4.19(A) shows that widespread long-term droughts have occurred throughout the period of record, with the most recent widespread long-term drought occurring in the early 1990s. The first 30 years of the period (1911-1940) appear to be the driest overall, but the frequency of occurrence and areal extent of drought at all time scales is similar from decade to decade. Figure 4.20(A) shows that widespread short-term and intermediate-term wet periods have occurred intermittently through most of the period of record. However, the intermediate-term wet periods of the late teens through early thirties were not as widespread as other intermediate-term wet periods experienced outside of this time period. There have been two major widespread long-term wet periods, once in the early 1940s, and another one in the early to mid 1980s. However, in 1995, there was a widespread wet period at all time scales that peaked as the third most widespread long-term wet period. Hence, though the West has experienced widespread drought at all time scales during the period 1970-1995, wet periods are comparatively more frequent at all time scales during the period 1970-1995 than during any other 25 year period of the record.

Up in the Northwest, it is evident from figure 4.19(B) that the long-term drought of the early 1930s was the most extensive. Like the West region, the period 1911-1940 is the most persistent period of widespread long-term drought. While there were some widespread short-term droughts from 1950 to 1975, the areal extent of intermediate- and long-term droughts was small compared to other periods of the record. Figure 4.20(B) shows that the intermediate- and long-term wet periods of the mid 1980s were the most widespread of the period of record. However, figures 4.19(B) and 4.20(B) show that this wet period was sandwiched between fairly widespread intermediate- and long-term droughts in the late 1970s/early 1980s and the late 1980s/early 1990s.

Figure 4.19(C) shows the most widespread long-term drought for the West North Central occurred in the 1930s. The most frequent occurrence of widespread drought was between 1911 and 1940 (like the West and Northwest regions). The least frequent occurrence of widespread drought was between 1965 and 1990. Figure 4.20(C) shows for the West North Central that the period 1980 through 1995 contained the highest frequency of widespread intermediate- and long-term wet periods compared to any other 15 year period during the record despite widespread long-term drought in the early 1990s.

Of the nine regions, the Southwest appears to be the least "homogeneous" in terms of drought. Portions of the region depend upon the summer monsoon, other areas depend on systems migrating out of the Pacific, some areas can tap into the Gulf of Mexico when low level flows are southeasterly, and still other areas depend upon orographic effects. Figure 4.19(D) shows that only during 1956-1957 did long-term drought cover more than 60% of the region (a period when much of the southern United States was experiencing long-term drought). Furthermore, there are only a few times in the entire period that short-term and intermediate-term droughts cover greater than 60% of the region. Lack of areal homogeneity is not as evident for wet periods as shown in figure 4.20(D). The most widespread long-term wet period occurred during the mid to late 1980s with another widespread long-term wet period in the mid 1990s. Furthermore, like the West North Central, the period 1980 through 1995 for the Southwest contains the highest frequency of widespread intermediate- and long-term wet periods compared to any other 15 year period during the record.

Figure 4.19(E) shows that the areal extent of long-term drought in the South was most dramatic in the mid to late 1950s. Other widespread long-term droughts have occurred, but none since the 1960s. While there have been widespread short-term droughts such as the spring drought of 1996 (not evident in this graph), there has been a low frequency of widespread drought at all time scales during the period 1970-1995. Figure 4.20(E) shows that the most widespread long-term wet periods occurred in the mid 1970s and the early 1990s. The long-term wet periods of the first 60 years of the period of record never reached 50% areal coverage while these two periods both exceeded 60%.

Figure 4.19(F) shows that the Central region has been affected by many of the major long-term droughts of the century. For example, portions of the Central were impacted by the long-term drought of the 1930s. Another portion was impacted by the long-term drought of the 1950s in the southern United States. Additionally, a large portion of the region was impacted by the long-term drought of the 1960s in the northeastern United States. However, since 1970, there has not been widespread long-term drought such as those experienced during the first 60 years of the period. However, at the short- and intermediate-term there have been widespread droughts such as those experienced during the spring of 1988 and the winter of 1976-77. Much like the South, figure 4.20(F) shows that the Central has experienced a high frequency of widespread wet periods at all time scales between 1970 and 1995 unlike any other 25 year period during the record.

For the East North Central region, figure 4.19(G) shows the period 1911-1940 also saw the highest frequency of widespread drought at all time scales with the 1930s being the most dramatic. Between 1970 and 1995, there have been widespread short- and intermediate- term droughts matching the areal coverages of the droughts of the 1930s. However, the long-term droughts that have occurred since 1960 have not matched the areal coverage of previous long-term droughts. On the other hand, like the South and Central regions, figure 4.20(G) shows for the East North Central that the frequency of widespread wet periods at all time scales was highest for the 25 year period 1970 through 1995. In fact, there have been three widespread long-term wet periods during the 1970s, 1980s, and 1990s unlike any single other long-term wet period during the record.

For the Northeast, figure 4.19(H) shows the long-term drought of the mid to late 1960s was the most widespread. At the short-term, widespread droughts occurred at other periods matching the areal extent of the short-term droughts of the 1960s, however, there was a high frequency of widespread short-term droughts from 1963 to 1967 which lead to the long-term widespread drought of this period. Figure 4.20(H) shows that the widespread long-term drought of the 1960s was followed by the most widespread intermediate- and long-term wet periods of the record. The period 1970 through 1985 contains a high frequency of widespread wet periods at all time scales unlike any other 15 year period during the record.

Figure 4.19(I) shows the Southeast region experienced its most widespread long-term drought in the mid to late 1950s. However, widespread long-term droughts are fairly evenly distributed throughout the period of record with the most recent occurring in the late 1980s. Additionally, widespread short- and intermediate-term droughts are also distributed fairly homogeneously throughout the period of record. Figure 4.20(I) shows that widespread wet periods at all time scales are also distributed fairly homogeneously throughout the period of record with the possible exception that the Southeast did not experience a widespread long-term wet period exceeding 40% areal coverage between 1911 and 1945.

Least squares regression lines were fit to all of the regional time series of areal coverages of drought/wet at different time scales. Additionally, *t* tests of the slopes of the regression lines were performed to check for stationarity. Results are in table 4.8. From the analysis in this section, it was not surprising to find that all regions show a positive slope for areal coverage of wet periods at all time scales and all regions show a negative slope for areal coverage of droughts at all time scales. The p-values resulting from the *t* tests show that most of these trends are very nonstationary, especially at the longer time scales.

4.2.3 Intensity of Drought/Wet

Figures 4.21(A-I) show the average SPI of stations by region for the period January, 1911 through December, 1995. This is a reasonable assessment of the overall drought/wet period intensity for each region as a whole. Three different time scales are shown.

For the West, figure 4.21(A) shows intense droughts at all time scales are distributed fairly homogeneously through the period of record. Intense wet periods are also distributed homogeneously through the period, however, the most intense intermediate- and long-term wet periods occurred in the early to mid 1980s. The three most intense long-term droughts occurred in the early 1930s, the late 1940s/early 1950s, and the early 1990s.

In the Northwest, figure 4.21(B) shows the long-term drought of the 1920s and 1930s was the most intense. However, the long-term drought of the late 1980s and early 1990s follows as the next most intense long-term drought. Outside of these periods, there have been very intense short- and intermediate-term droughts such as those in 1944 and 1977. Like the West, the most intense long-term wet period for the Northwest occurred in the early to mid 1980s.

For the West North Central, figure 4.21(C) shows the long-term drought of the 1930s was the most intense. No other long-term drought during the period of record comes close to matching the intensity of the 1930s drought. Even the short- and intermediate-term droughts of the 1930s were the most intense for their respective time scales, with the droughts of 1934 and 1936 being the most intense. Outside of the 1930s, there have been intense droughts, especially at the short- and intermediate-term. Intense wet periods are distributed throughout the period of record, but the most intense long-term wet period occurred in 1995. Additionally, there was another intense long-term wet period as recently as the mid 1980s. From the late 1970s through the early 1990s, there was a high frequency of intense intermediate-term and long-term wet periods unlike any other period during the record. However, intense drought also occurred at different time scales during this period, especially in the late 1980s and early 1990s.

In the last section, the Southwest region appeared to be less homogeneous than other regions in terms of drought coverage. This bears out as well in figure 4.21(D) where areal drought intensity at all time scales rarely goes below -1.0. The most intense long-term drought occurred in 1956-1957. On the other hand, there has been a higher frequency of long-term intense wet periods (late 1910s, early 1940s, 1980s, and early to mid 1990s). This is apparently true since the period 1910-1940 (before the base period) and the period 1980-1995 (after the base period) are wetter overall than the base period. Like the West and Northwest, the mid 1980s contained the most intense long-term wet period of the record for the Southwest.

Although the South did experience intense short-term droughts during the period 1970-1995, figure 4.21(E) shows there have been no intense long-term droughts during this period. Additionally, the intermediate-term droughts that occurred were overall less intense than those of the previous 60 years. Not surprisingly, the mid to late 1950s was the most intense long-term drought period, made up of a series of very intense short- and intermediate-term droughts. On the other hand, the mid 1970s and the late 1980s into the early 1990s contain the most intense long-term wet periods.

Figure 4.21(F) shows the Central region is similar to the South region in that the last 25 years of the record are marked by an increased frequency of intense long-term wet periods. And like the South, the Central has had intense droughts during this time period at the short- and intermediate-term. The Central experienced intense long-term drought in the 1930s, early 1940s, mid 1950s, and the mid 1960s; but since the 1960s the Central has not experienced intense long-term drought.

In the East North Central region, figure 4.21(G) shows the first 30 years of the period are marked by a high frequency of intense droughts at all time scales with the 1930s being the most intense overall. On the other hand, like the South and Central regions, the last 25 years of the record for the East North Central are marked by a high frequency of intense wet periods at all time scales. Over the last 25 years of the record, there were 3 intense long-term wet periods with one in the 1970s, one in the 1980s, and one again in the early 1990s. Despite the increased frequency of wet periods, there have been a few intense droughts at the short- and intermediate-term matching the intensities of droughts of the previous 60 years.

Figure 4.21(H) shows the Northeast is similar to the East North Central in that the first 30 years of the period of record contain a high frequency of intense drought at all time scales. Nevertheless, the 1960s was the most intense long-term drought period. Overall, the Northeast has not experienced long-term drought over the last 25 years of the record matching the intensity that it experienced during the previous 60 years. The most intense long-term wet period occurred in the 1970s with another intense intermediate-term wet period in the mid 1980s.

Figure 4.21(I) shows the Southeast has experienced intense long-term drought as recently as the late 1980s. In fact, the 1980s was marked by very intense short- and intermediate-term droughts with some intervening short- and intermediate-term wet periods. The most intense long-term drought overall for the Southeast occurred in the 1950s. However, intense droughts and wet periods at all time scales are distributed fairly homogeneously through the period of record.

Figures 4.22(A) and 4.22(B) show periods of long-term drought and long-term wet by region. To qualify as a regional long-term drought period, the average SPI of all stations in the region had to reach -1.0 or less sometime during the period. The period denotes the length of time that the average SPI remained continuously negative. Determining periods of regional long-term wet is similar except that the average SPI had to reach +1.0 or above sometime during the period. Periods of regional long-term drought or wet that occurred between 1970 and 1995 are highlighted in red. Of particular note is the overall increase in long-term wet periods and the overall decrease in long-term droughts over the last 25 years of the record for the country as a whole. This is particularly true for the 3 regions along the Mississippi and Ohio river valleys (East North Central, Central, and South). All three of these regions have experienced intense long-term wet periods in the 1970s, 1980s, and the early 1990s. None of these three regions experienced intense long-term drought during this time period. Additionally, figure 4.22(A) shows that only four of the nine regions experienced intense long-term drought between 1970 and 1995 while figure 4.22(B) shows that all nine regions experienced at least one intense long-term wet period between 1970 and 1995.

Least squares regression lines were fit to all of the time series of regional average SPI at different time scales. Additionally, *t* tests of the slopes of the regression lines were performed to check for stationarity. Results are in table 4.9. From the analysis in this section, it is again not surprising to find that all regions show a positive slope for SPI indicating a wet trend at all time scales for this period of record. The p-values for many of the tests show that these slopes are very nonstationary, especially at the longer time scales.

4.2.4 Duration/Variability of Drought/Wet

Summary statistics showing the length and variability of drought at different time scales for the 9 different regions are shown in tables 4.10(A-E). Since the SPI inherently accounts for the natural variability of monthly precipitation at a given station, it is not surprising to see that these statistics are comparable between regions at the different time scales.

Summary statistics for the starting and ending of drought and wet periods by region are also shown in tables 4.10(A-E). Overall, these statistics are similar between regions. Again, all regions show that it takes approximately the same time to end a drought or wet period than it takes to start one. Additionally, starting times and ending times are comparable between drought and wet periods at each respective time scale for the different regions.

Tables 4.10(A-E) also contain information on the average period of a drought or wet period by region and by time scale. There are some differences, but the differences change with time scale. For example, while the Northwest has the shortest average period at the 48 month time scale, the Southeast has the shortest average period at the 24 month time scale. Hence, since the SPI inherently standardizes the variability of precipitation between stations, it also appears to standardize the frequency, duration, and variability of drought and wet periods between stations.

Within regions, there appears to be little difference between the duration of a drought and the duration of a wet period, especially at the shorter time scales where there have been more occurrences of droughts and wet periods per station.

Unlike what was seen in table 4.4 with the summary statistics for all USHCN stations, some of the regions have wet periods that have greater variability in their duration than droughts. For example, in the Southwest at the 24 month time scale (24 month SPI), both the interquartile range (IQR) and standard deviation of the wet periods at this time scale are greater than the IQR and standard deviation of droughts respectively at this time scale. There are other examples for other regions at different time scales where either the IQR or standard deviation (or both) is greater for wet periods than it is for droughts.

4.2.5 Seasonal Drought/Wet

Figures 4.23(A-D) show time series of the average 3 month SPI of all stations in the West region for the period of record 1911 through 1995 for the months of February (winter index), May (spring index), August (summer index), and November (autumn index). Again, the West had a widespread long-term wet period in the early to mid 1980s and a widespread long-term drought in the late 1980s to early 1990s. While figure 4.17(A) shows that this region has a winter maximum in precipitation, it is also apparent that the early spring and late autumn are also important contributors to the annual cycle of precipitation. This bears out in these most recent widespread long-term events. While figure 4.23(A) shows wet winters played an integral role in the widespread long-term wet period in the early to mid 1980s, figure 4.23(B) shows 6 straight spring seasons with positive anomalies between 1978 and 1983 also played a key role. Figure 4.23(D) shows 5 straight autumn periods between 1981 and 1985 where the average regional 3 month

SPI was greater than +0.8 also played a key role in the long-term wet period of the early to mid 1980s. Once again, figure 4.23(A) shows the winter played a key role in the long-term drought of the late 1980s and early 1990s in the West region, but figure 4.23(D) shows that 4 straight autumn periods between 1990 and 1993 where the average regional SPI was below 0.0 also played a key role. It appears from figure 4.23(B) that the spring played little role in the West region's long-term drought of the late 1980s and early 1990s.

Figures 4.24(A-D) show time series of the average 3 month SPI of all stations in the Northwest region for the period of record 1911 through 1995 for the four different seasons. It is shown in figure 4.17(B) that the Northwest region has a similar annual precipitation distribution to the West region where the maximum in seasonal precipitation occurs in the winter, but that the spring and autumn seasons play important roles. Similar to the West region, the Northwest experienced widespread long-term wet in the mid 1980s and widespread long-term drought in the late 1980s and early 1990s. Figure 4.24(A) shows that anomalies in the winter match up well with the long-term anomalies experienced in the 1980s and 1990s. Again, like the West region, it appears from figure 4.24(B) that the spring season correlates well with the widespread long-term wet period in the mid 1980s, but the spring does not appear to have contributed to the long-term drought of the late 1980s and early 1990s. However, figure 4.24(D) shows that the autumn period appears to have contributed to both long-term anomalies. For example, there were 6 anomalously wet autumn seasons between 1981 and 1986 that certainly contributed to the long-term wet period of the mid 1980s where the average regional SPI was above +0.5 each year. Additionally, the anomalously dry autumn seasons of 1987, 1989, and 1993 appear to have contributed to the long-term drought period of the late 1980s and early 1990s.

Figure 4.17(C) shows that the West North Central has a late spring and early summer seasonal precipitation maximum. The summer drought of 1988 and summer wet anomaly of 1993 are quite evident in figure 4.25(C). The most widespread long-term drought of the period of record for the West North Central occurred in the 1930s. It is apparent from figures 4.25(A-D) that all four seasons were anomalously dry at different times during this period with the summer season being the most consistently dry season (figure 4.25(C)) and the winter season (figure 4.25(A)) being the least consistently dry. During the mid 1980s, the West North Central had its longest running, widespread wet period. It looks from these figures that the winter and summer seasons had little to do with this wet anomaly, while the spring and autumn seasons had several anomalously wet occurrences that contributed to this long-term wet period.

Figure 4.17(D) shows the importance of the summer monsoon to the Southwest region. The year with the most widespread drought at all time scales occurred in 1956 where figures 4.26(B-D) show the spring, summer, and autumn seasons were all anomalously dry. The most widespread long-term wet period for the Southwest occurred in the mid to late 1980s where all four seasons played a role in contributing to this long-term wet anomaly.

From figure 4.17(E), the South region has a maximum seasonal distribution of precipitation in the late spring and early summer. Figure 4.19(E) shows the mid 1950s had the most widespread long-term drought of the record for the South. Analysis of the seasonal distribution of anomalies in figures 4.27(A-D) shows that while all regions contributed to this long-term drought at some point during the process, figure 4.27(C) shows that the autumn was the season with the most consistent series of anomalously dry periods that corresponded well with this long-term drought. Figure 4.20(E) shows that the mid 1970s and the late 1980s/early 1990s were two periods with widespread long-term wet anomalies in the South. There appears to be no overall trend over the past 25 years for the summer index (figure 4.27(C)). Figure 4.27(B) shows a high frequency of anomalously wet spring seasons in the 1970s and early 1980s while figure 4.27(A) shows a high frequency of anomalously wet winters in the late 1980s and early 1990s. However, the most dramatic increase in anomalously wet periods between 1970 and 1995 occurs in the autumn (figure 4.27(C)) corresponding with the widespread long-term wet periods shown for the South in figure 4.22(B).

Figures 4.28(C) shows for the Central region that the autumn season has been the most consistent anomalously wet period over the last 25 years of the record. Figure 4.20(F) shows for the Central region there have been three widespread long-term wet periods between 1970 and 1995 that correspond well with the short-term anomalously wet autumn periods of the past 25 years.

Figure 4.22(B) shows that the East North Central has also experienced three widespread long-term wet periods between 1970 and 1995. While figures 4.29(A-D) show that different seasons contributed at different times to these long-term wet periods, like the South and Central regions, the autumn period has been anomalously wet more consistently than the other seasons.

Figure 4.17(H) shows that the seasonal distribution of precipitation throughout the year for the Northeast region is fairly homogeneous with a slight maximum in the summer. Figure 4.19(H) shows the most widespread long-term drought for the Northeast occurred in the mid to late 1960s. It is apparent from figures 4.30(A-D), that all of the seasons were anomalously dry during different points of this major drought and all seasons played a key role. Figure 4.20(H) shows that the most widespread long-term wet period for the Northeast occurred in the mid 1970s. Again, all four seasons were anomalously wet at different points within this long-term wet period with the winter season being the most consistently wet.

Figure 4.17(I) shows the Southeast also has a summer maximum in seasonal precipitation. Figures 4.31(A-D) show that only the autumn season didn't contribute significantly to the widespread long-term drought of the late 1980s. All seasons had a fair number of anomalously wet periods and anomalously dry periods between 1970 and 1995 with no apparent trends.

Table 4.11 provides some perspective on the overall trend of precipitation by season and by region. Like for table 4.6, a season is considered a 3 month time scale ending with the month shown in the table.

In the West, table 4.11 shows that most seasons have a positive slope, but that most seasons are very stationary. The two largest positive slopes are for the summer season (months 8 and 9). However, summer is also the dry season for the West. The next largest positive slope is the autumn season (month 11).

Table 4.11 shows that the Northwest has a very nonstationary positive slope for the summer season (month 8). However, like the West, the summer is the Northwest's dry season. Nonetheless, all seasons have a positive slope.

From table 4.11, most of the seasons for the West North Central have positive slopes except for the winter season (months 1 and 2). However, most seasons are also very stationary. The largest positive slopes occur in the spring (month 5) and the late spring/early summer (month 7).

Most seasons for the Southwest have very stationary time series of average 3 month SPI. Only the late autumn/early winter season (month 1) which has a positive slope is not very stationary.

For the South, table 4.11 shows that the late spring/early summer season (month 7) is very nonstationary. All seasons have a positive slope, but most have very stationary time series. And while figure 4.27(D) shows that the South has had a high frequency of anomalously wet autumn periods between 1970 and 1995, this time series is still not very nonstationary.

For the Central, most seasons have positive slopes, but are very stationary. The largest positive slopes occur in the summer season (months 7 and 8). Despite the occurrence of a high frequency of wet anomalies in the autumn season between 1970 and 1995 (figure 4.28(D)), the slope for the autumn season (month 11) from table 4.11 is still very stationary. This is true because the negative trend between 1911 and 1965 counters a portion of the positive trend between 1965 and 1995.

Table 4.11 shows that the East North Central has a very nonstationary time series for the summer season (months 8 and 9) where the slopes are positive. This is true primarily because of the high frequency of anomalously dry summers (figure 4.29(C)) between 1911 and 1940.

Unlike the other regions in the eastern United States, the Southeast has negative slopes during the summer season (months 7, 8, and 9). However, these time series are very stationary. The largest positive slopes are primarily in the autumn and winter seasons (months 11, 12, 1 and 3).

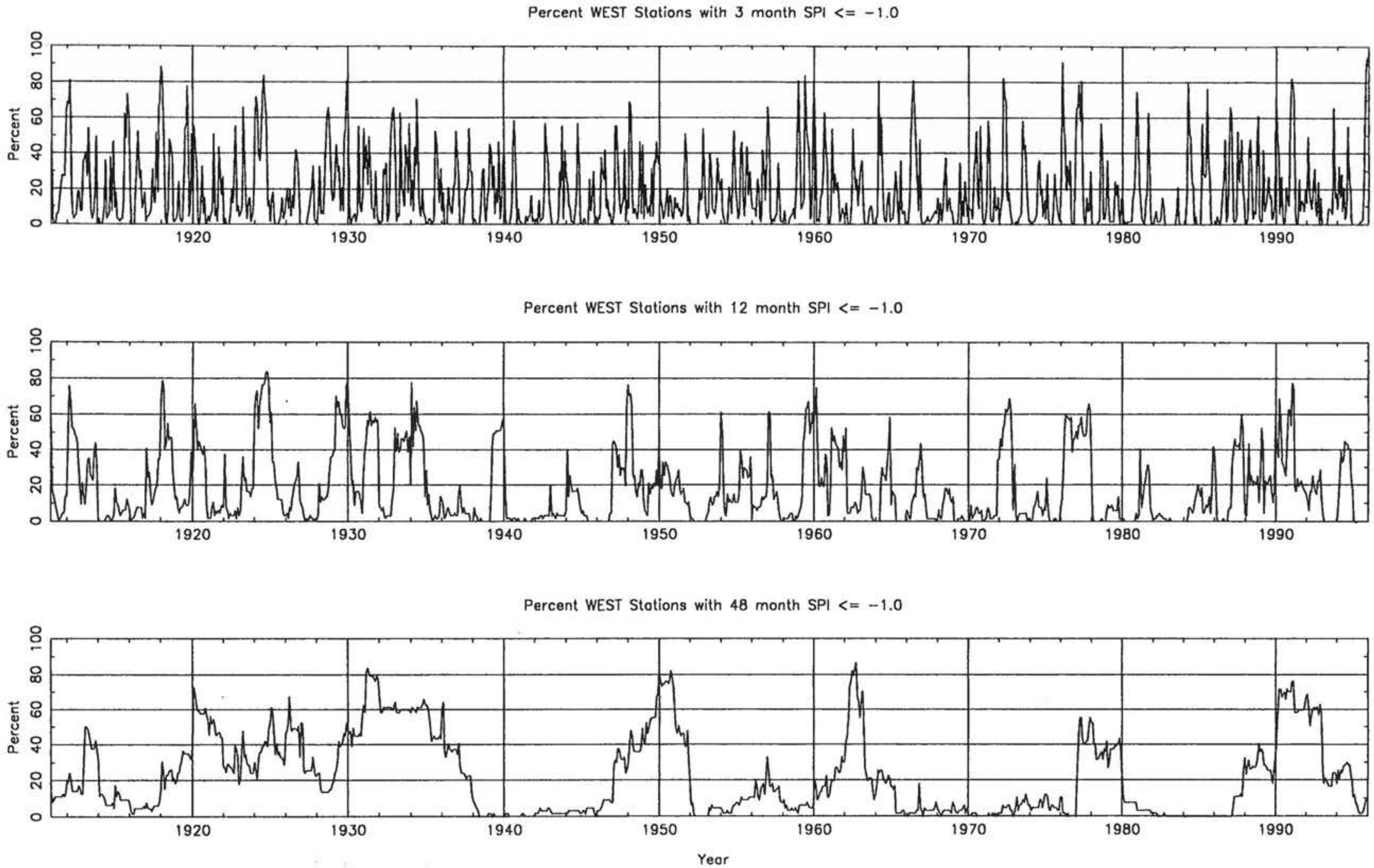


Fig 4.19(A) Time series of percent of all West stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

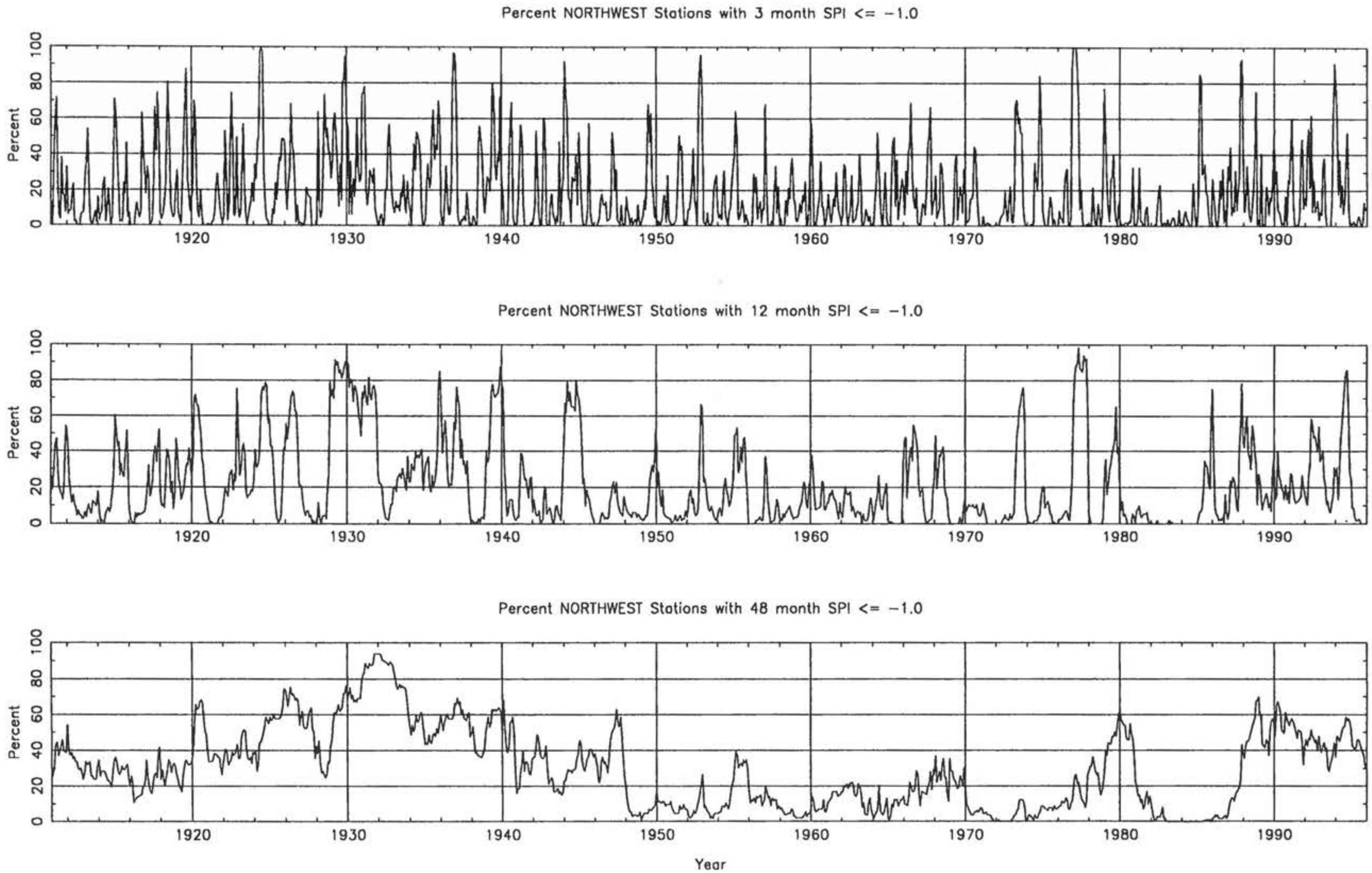


Fig 4.19(B) Time series of percent of all Northwest stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

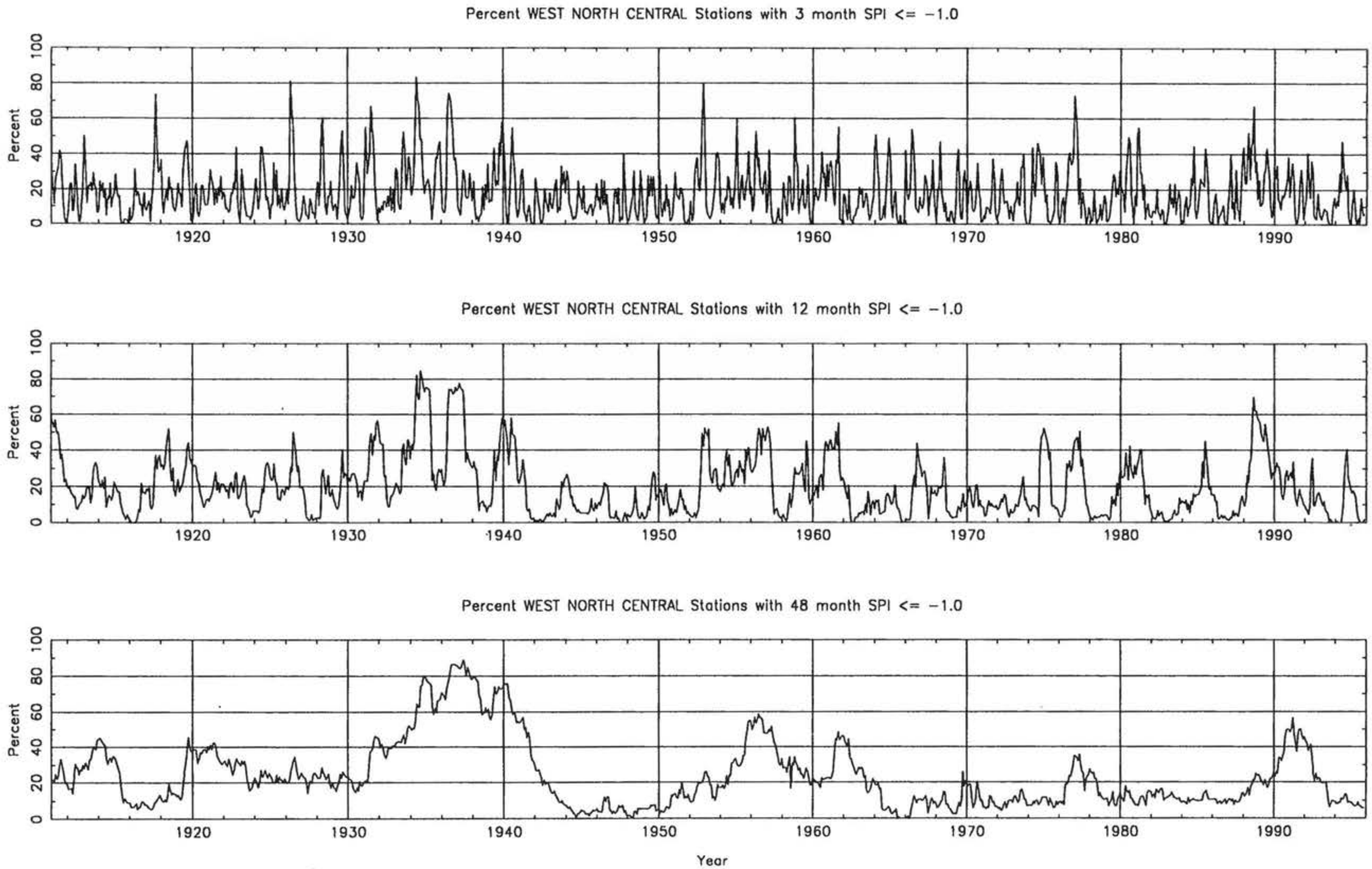


Fig 4.19(C) Time series of percent of all West North Central stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

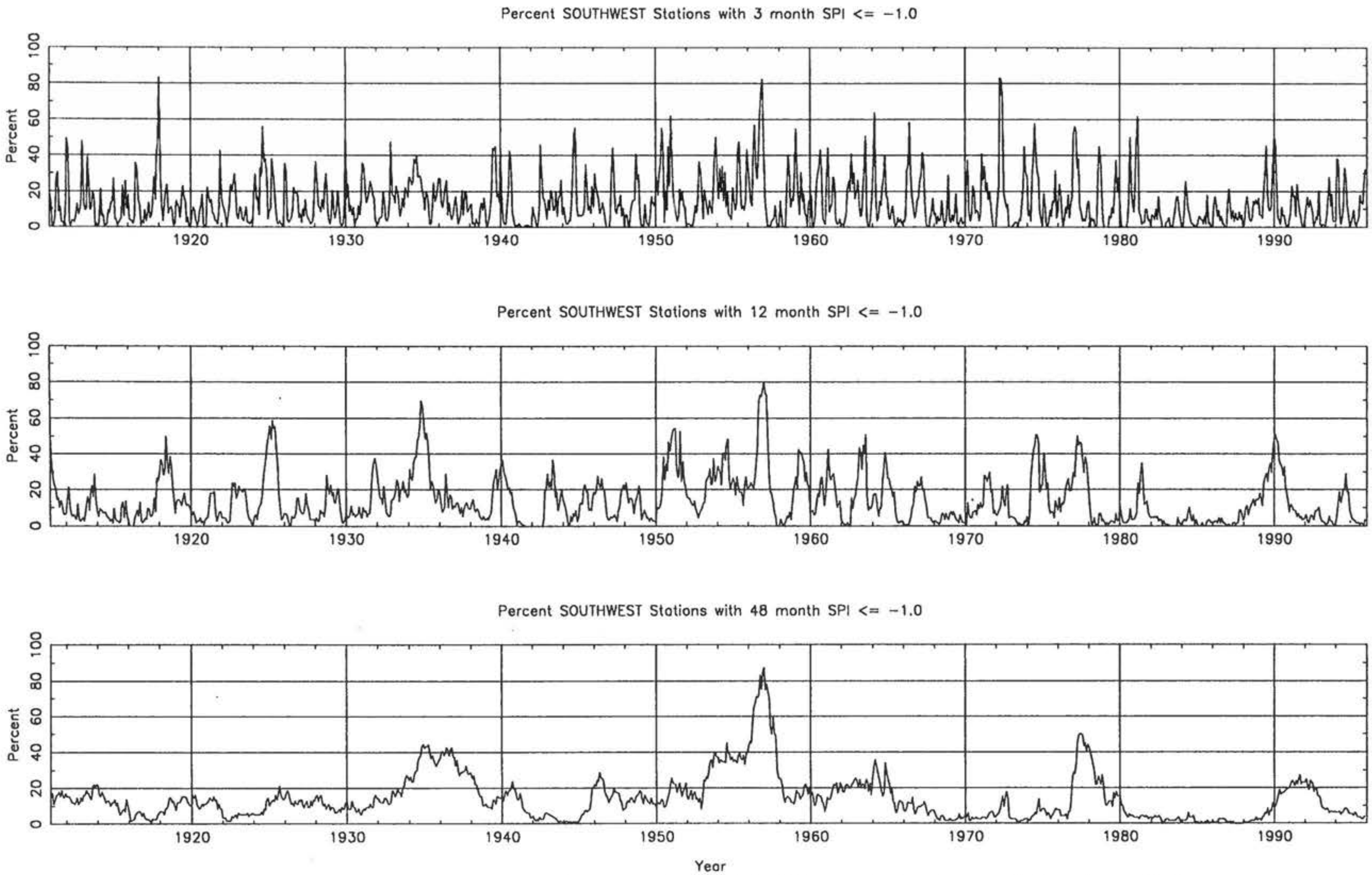


Fig 4.19(D) Time series of percent of all Southwest stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

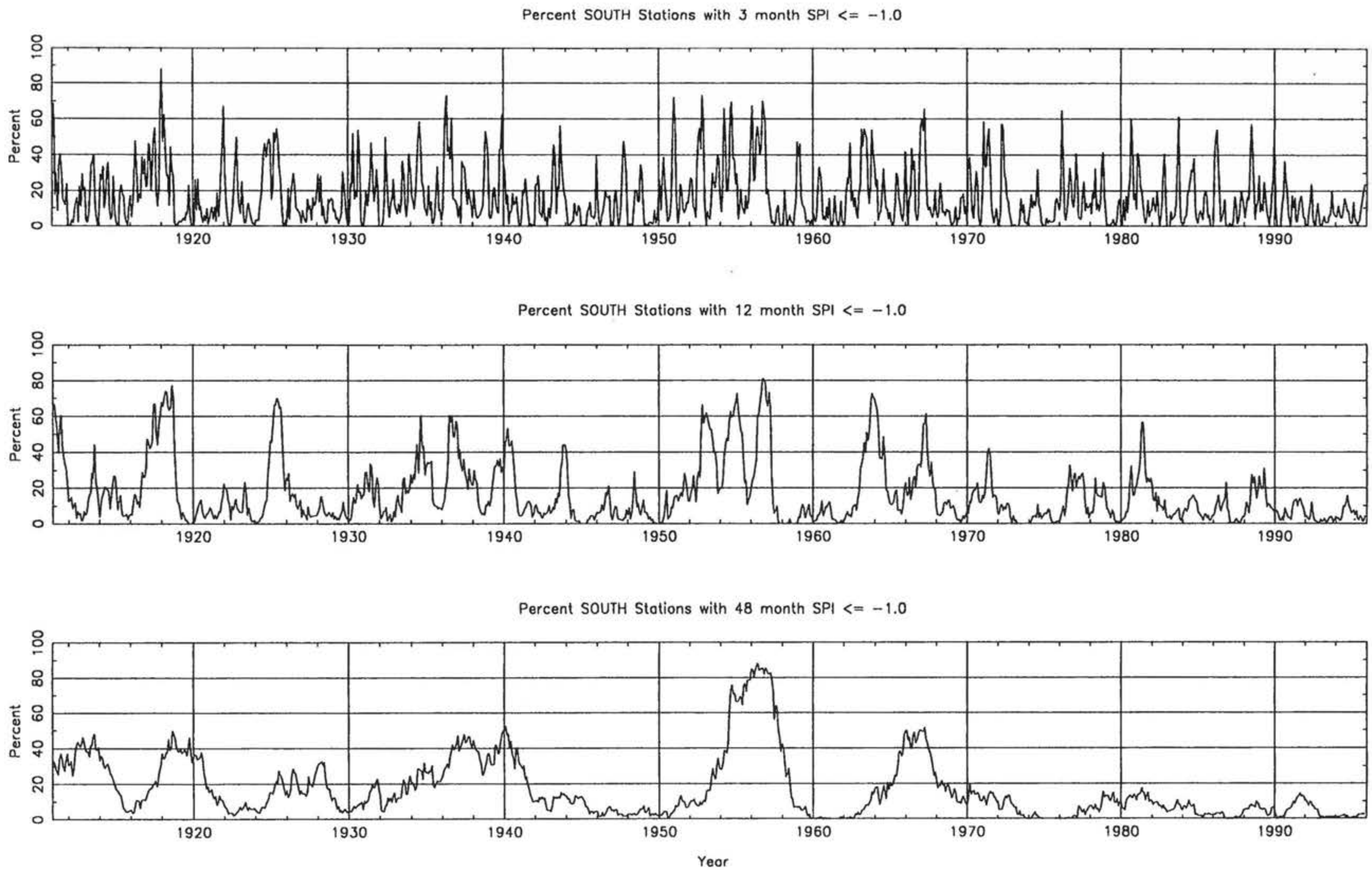


Fig 4.19(E) Time series of percent of all South stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

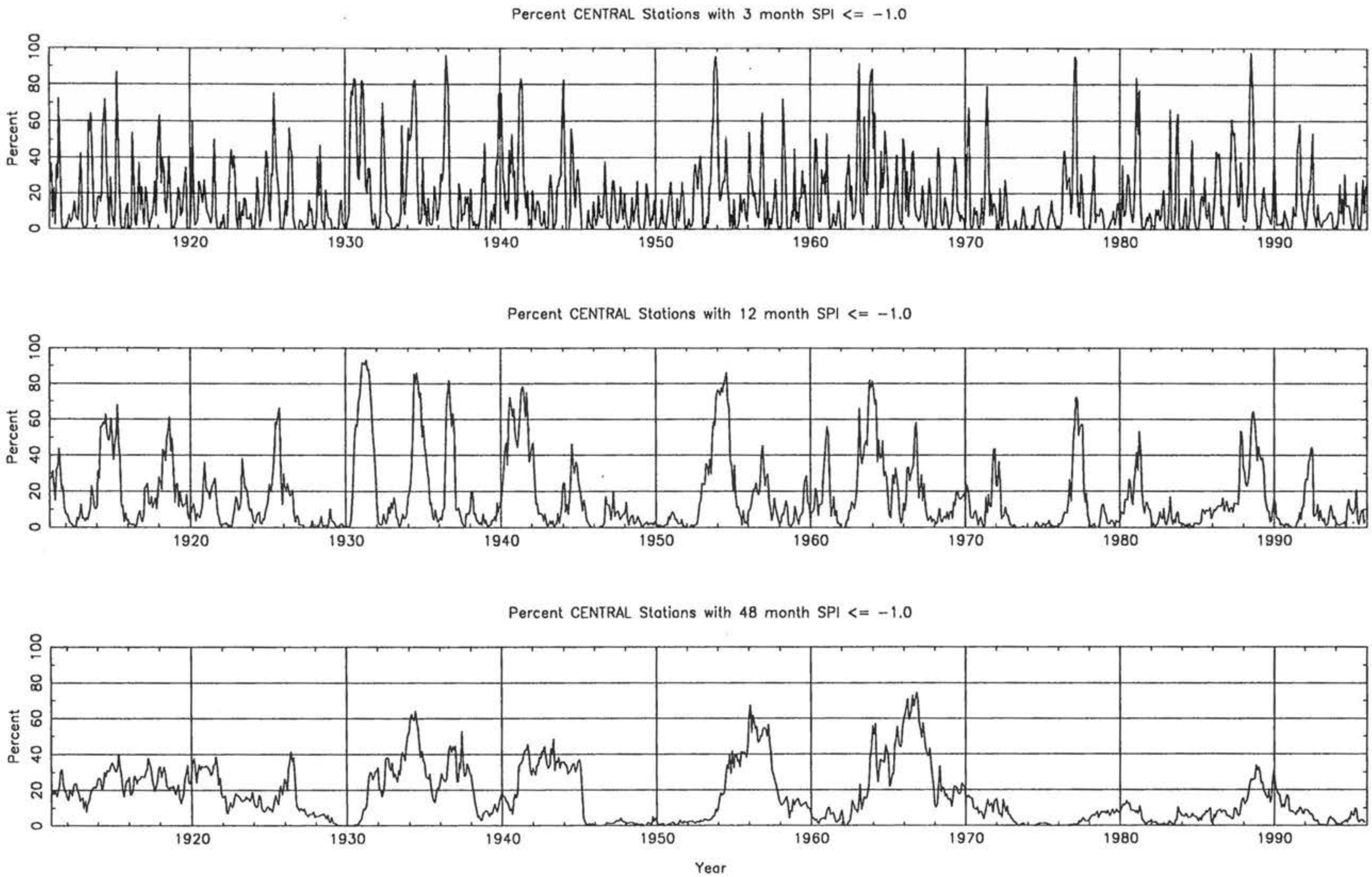


Fig 4.19(F) Time series of percent of all Central stations with SPI $\leq$ -1.0 by time scale for the period January, 1911 through December, 1995.

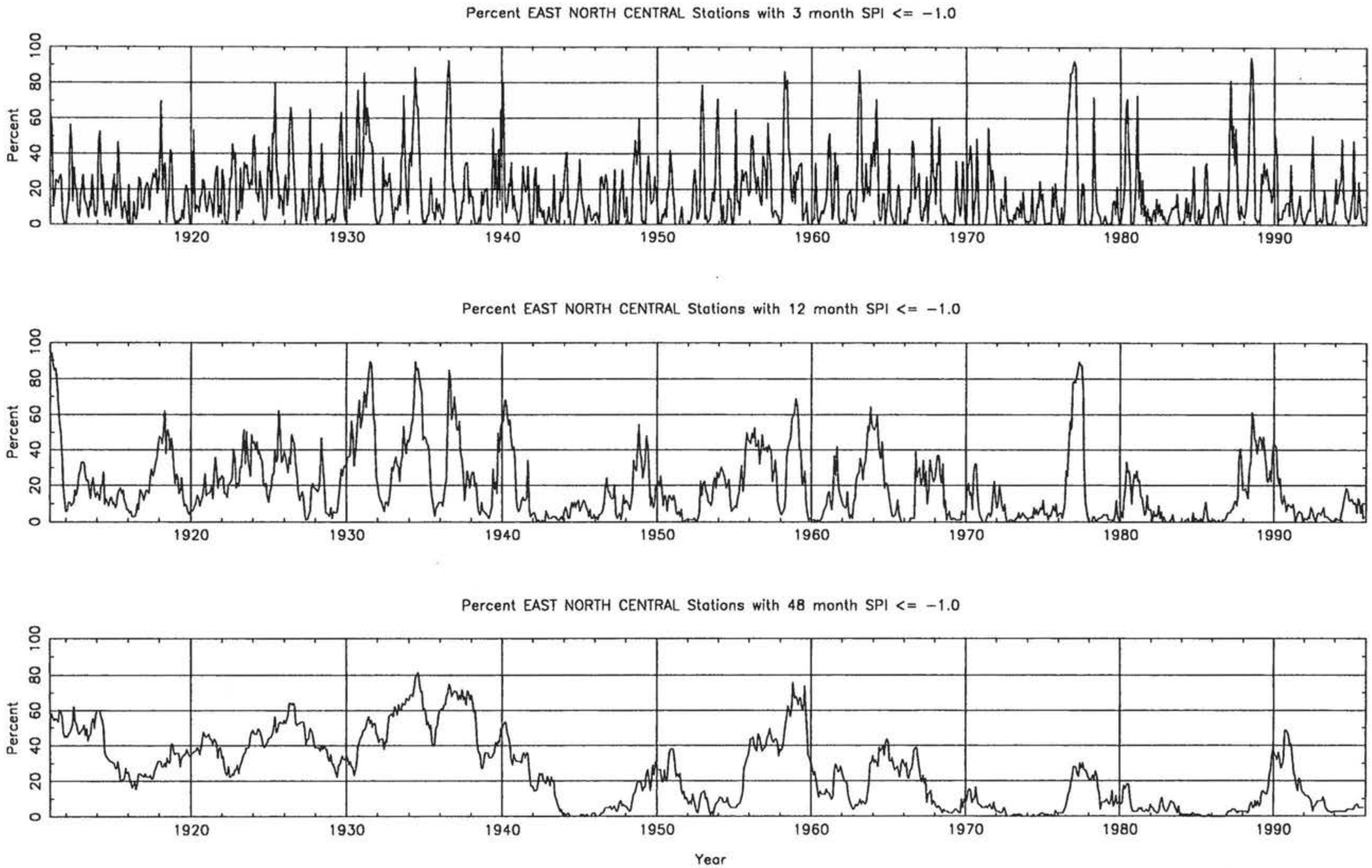


Fig 4.19(G) Time series of percent of all East North Central stations with SPI $\leq$ -1.0 by time scale for the period January, 1911 through December, 1995.

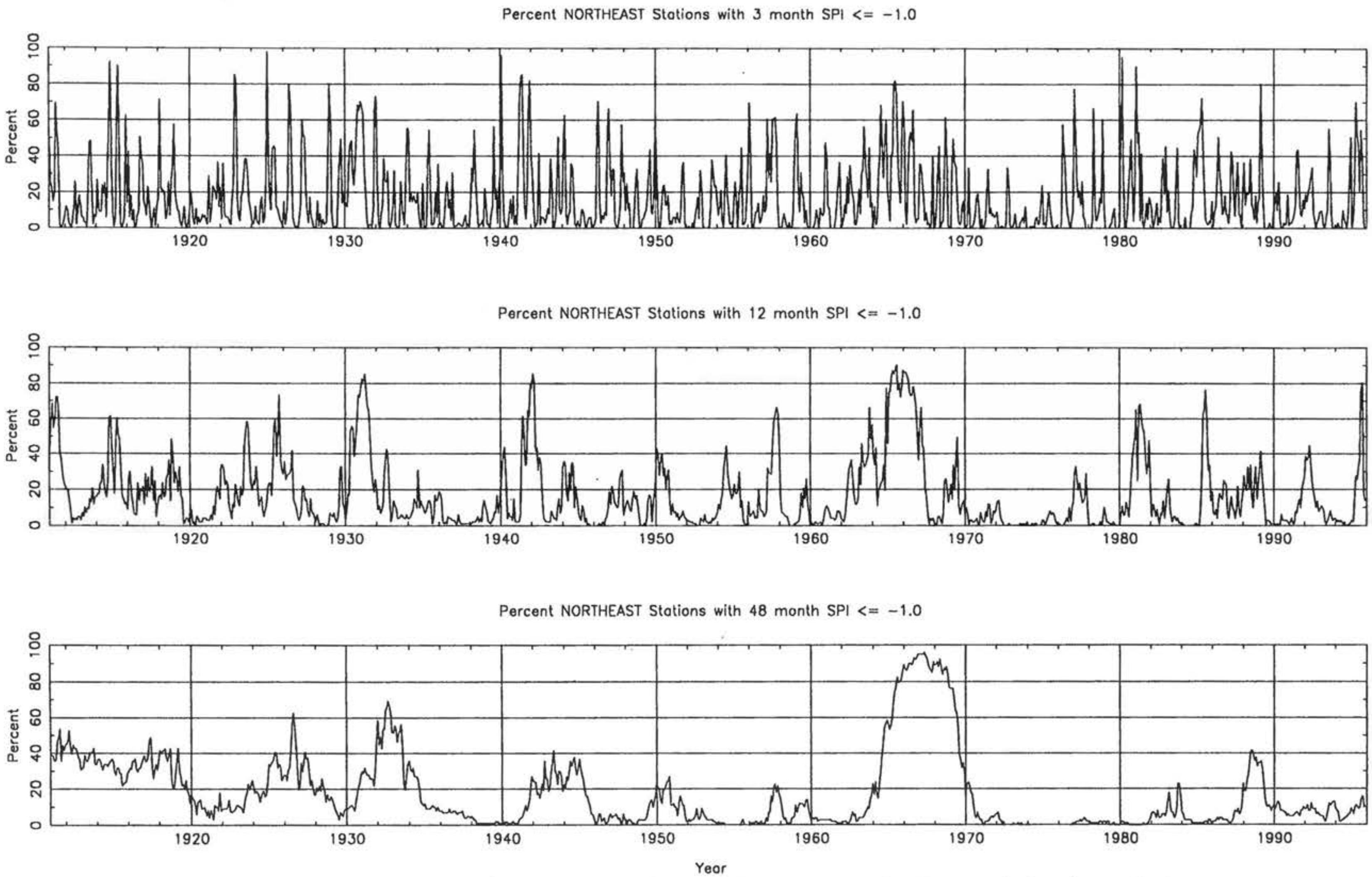


Fig 4.19(H) Time series of percent of all Northeast stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

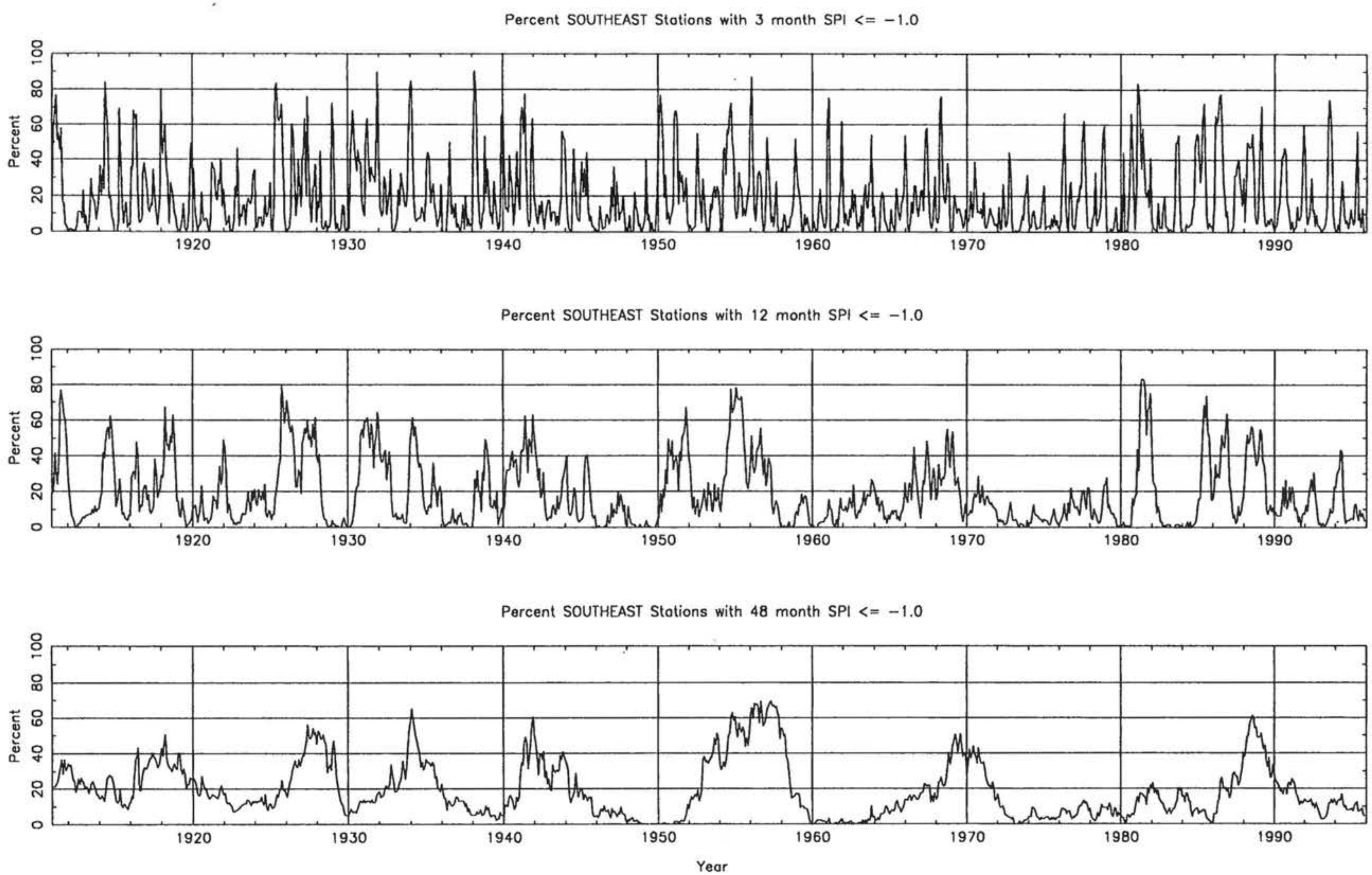


Fig 4.19(I) Time series of percent of all Southeast stations with SPI ≤ -1.0 by time scale for the period January, 1911 through December, 1995.

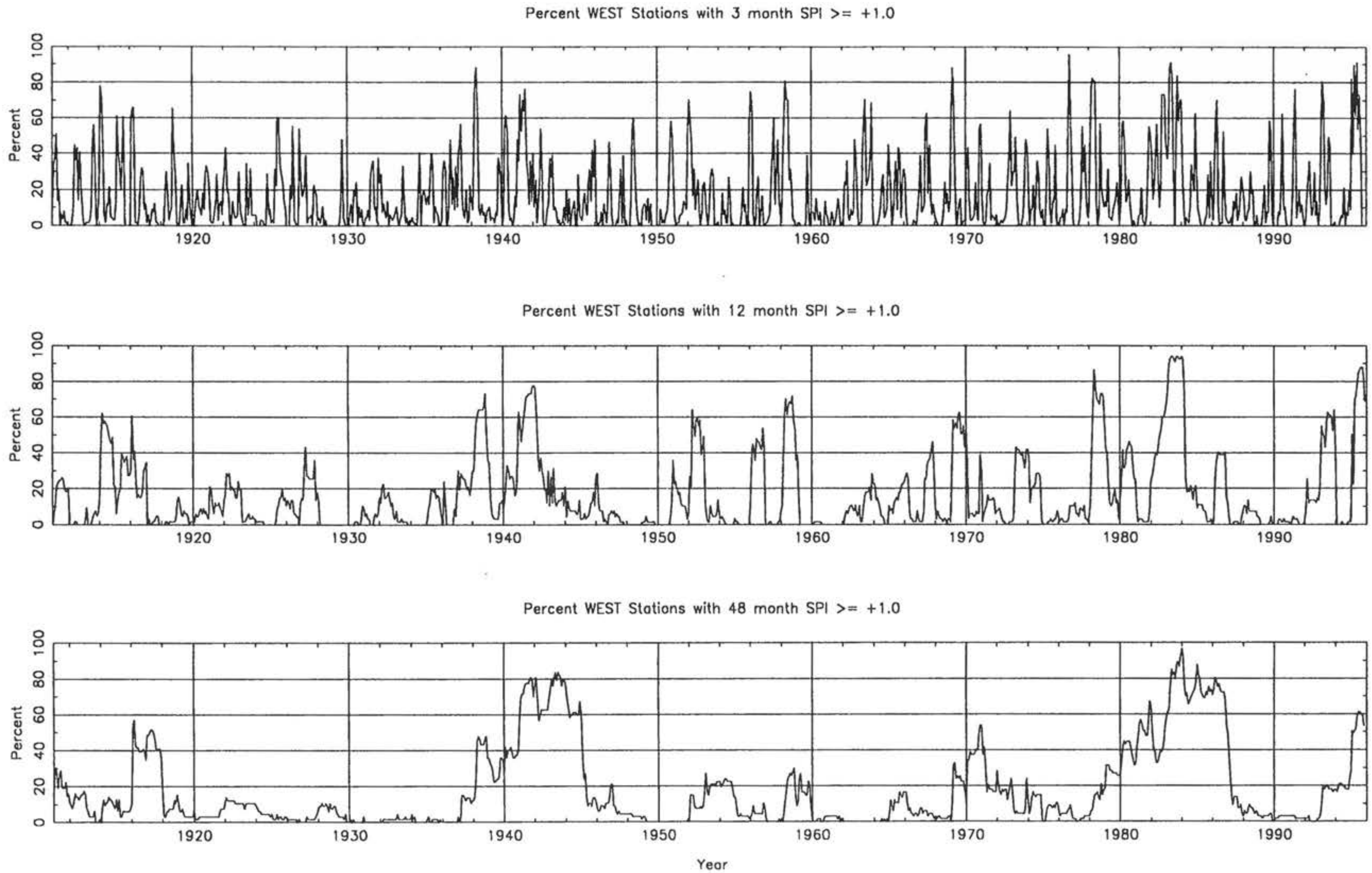


Fig 4.20(A) Time series of percent of all West stations with SPI $\geq$ +1.0 by time scale for the period January, 1911 through December, 1995.

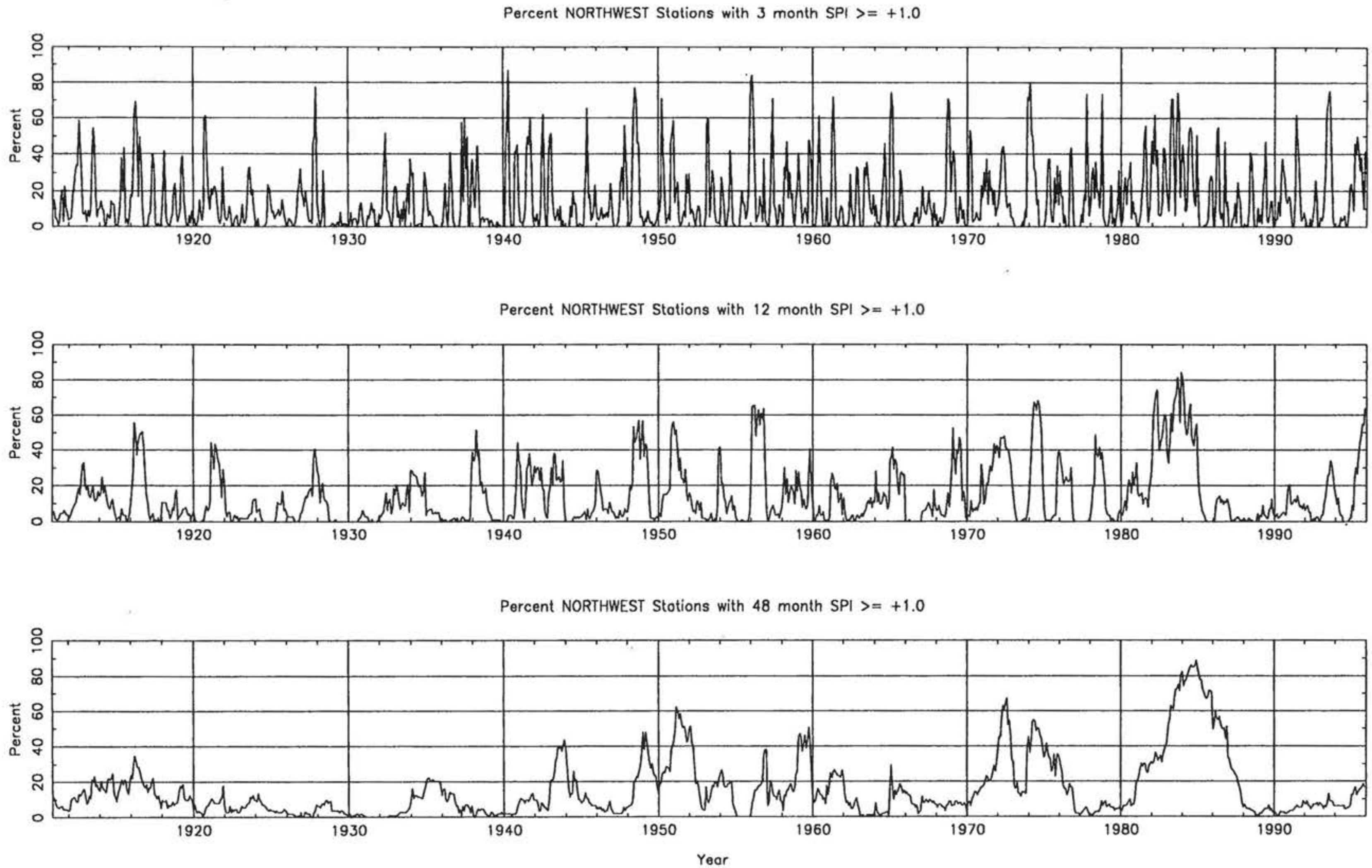


Fig 4.20(B) Time series of percent of all Northwest stations with SPI ≥ +1.0 by time scale for the period January, 1911 through December, 1995.

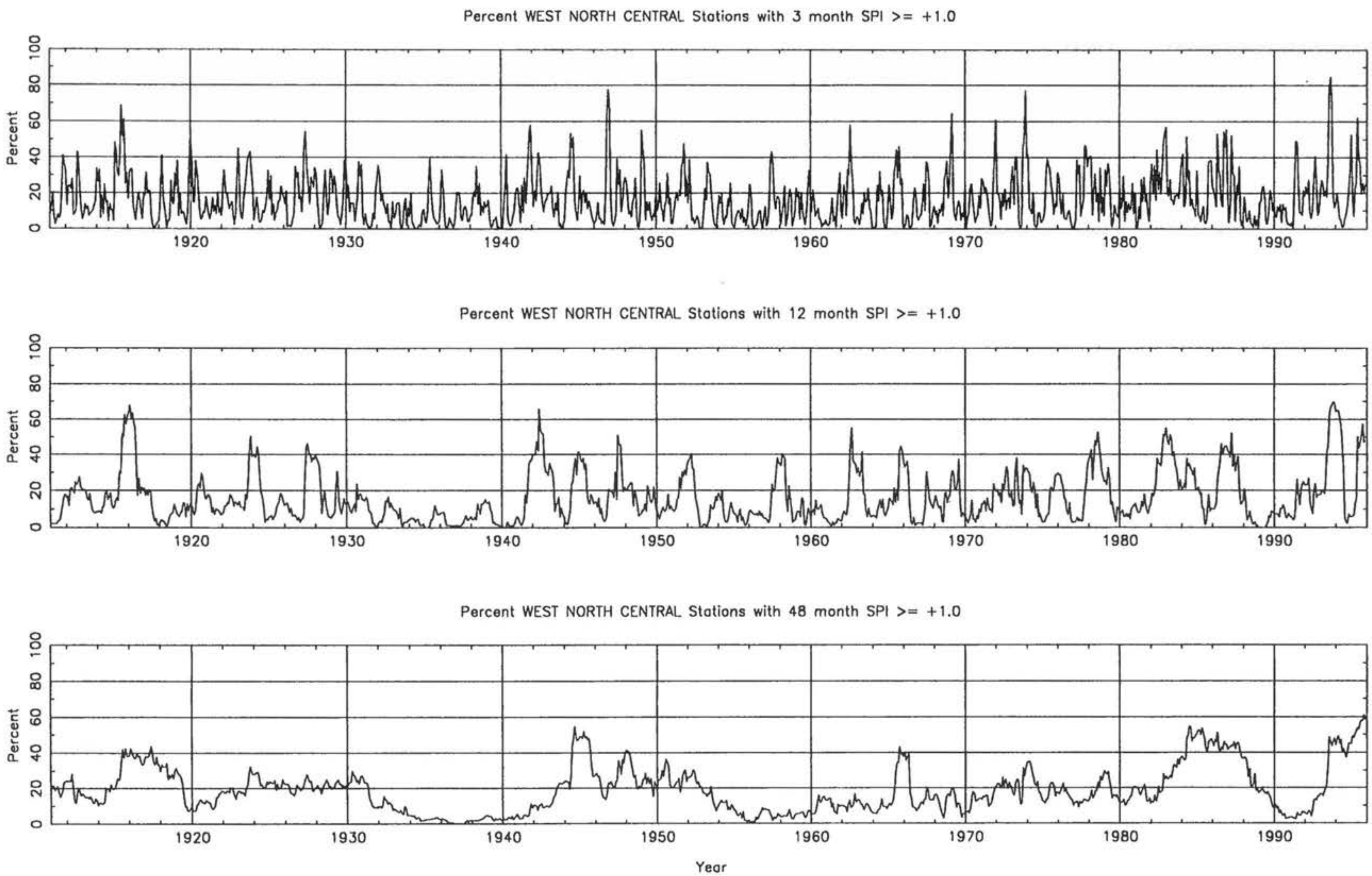


Fig 4.20(C) Time series of percent of all West North Central stations with SPI $\geq +1.0$ by time scale for the period January, 1911 through December, 1995.

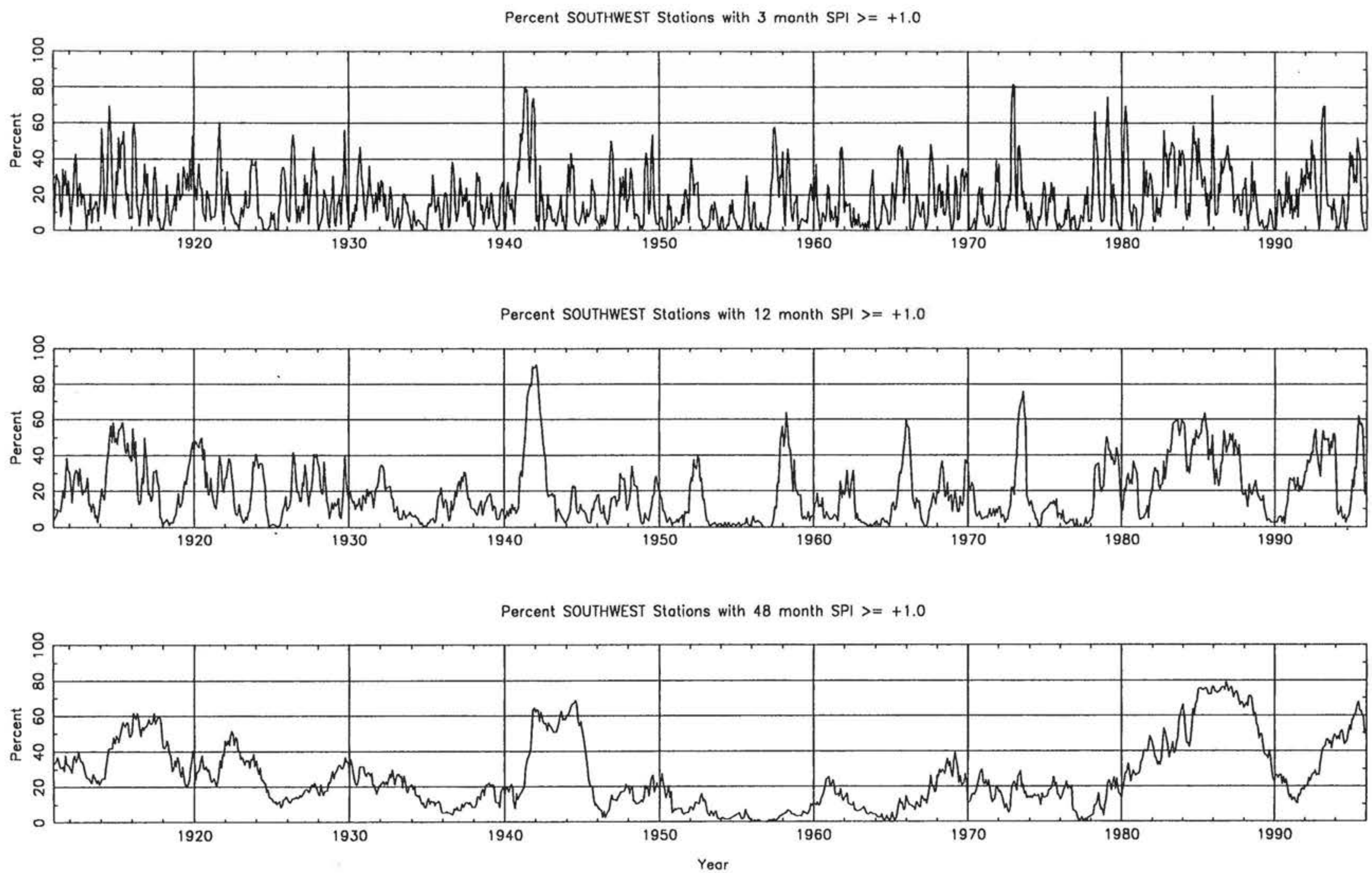


Fig 4.20(D) Time series of percent of all Southwest stations with SPI ≥ +1.0 by time scale for the period January, 1911 through December, 1995.

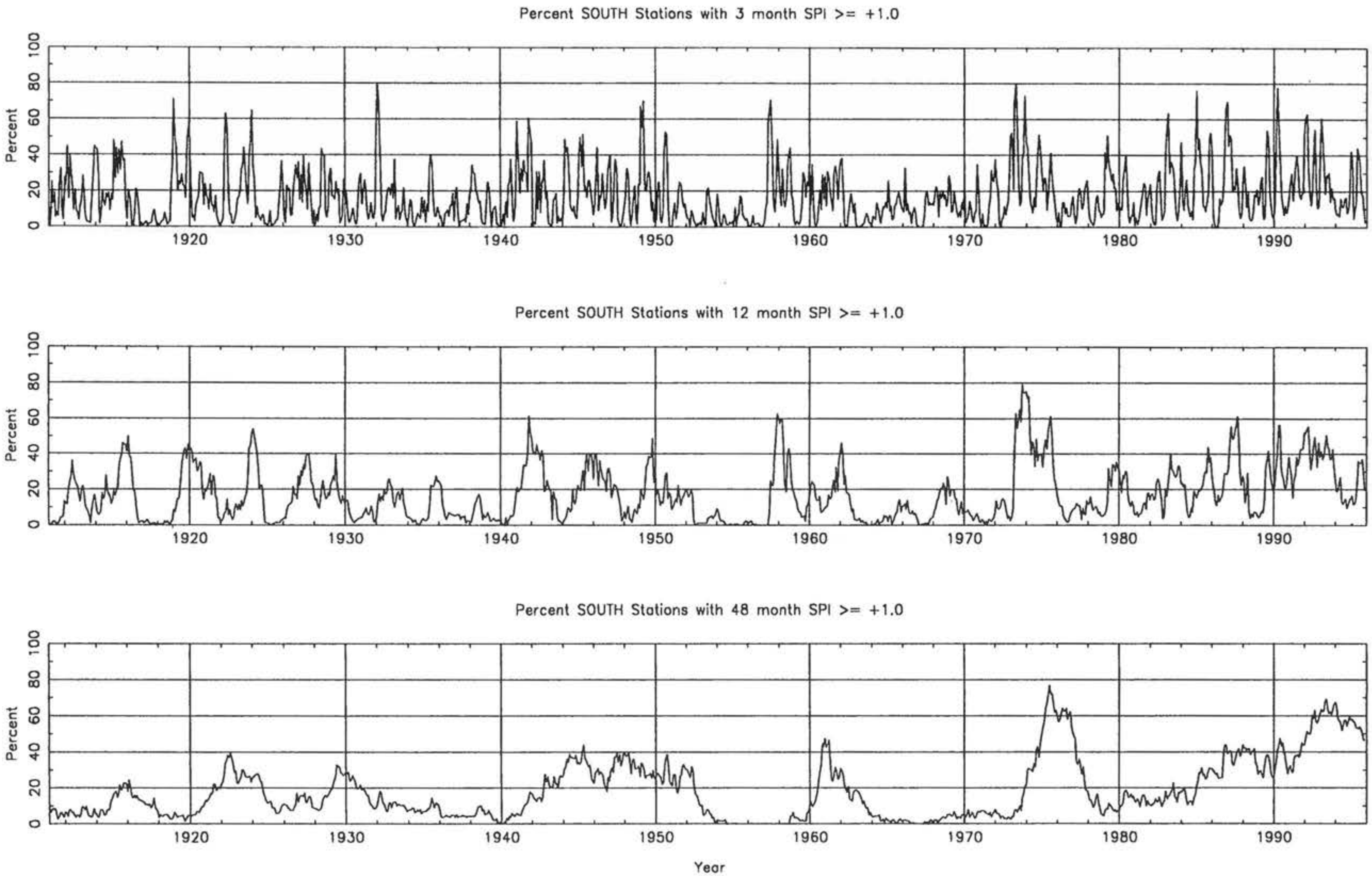


Fig 4.20(E) Time series of percent of all South stations with SPI ≥ +1.0 by time scale for the period January, 1911 through December, 1995.

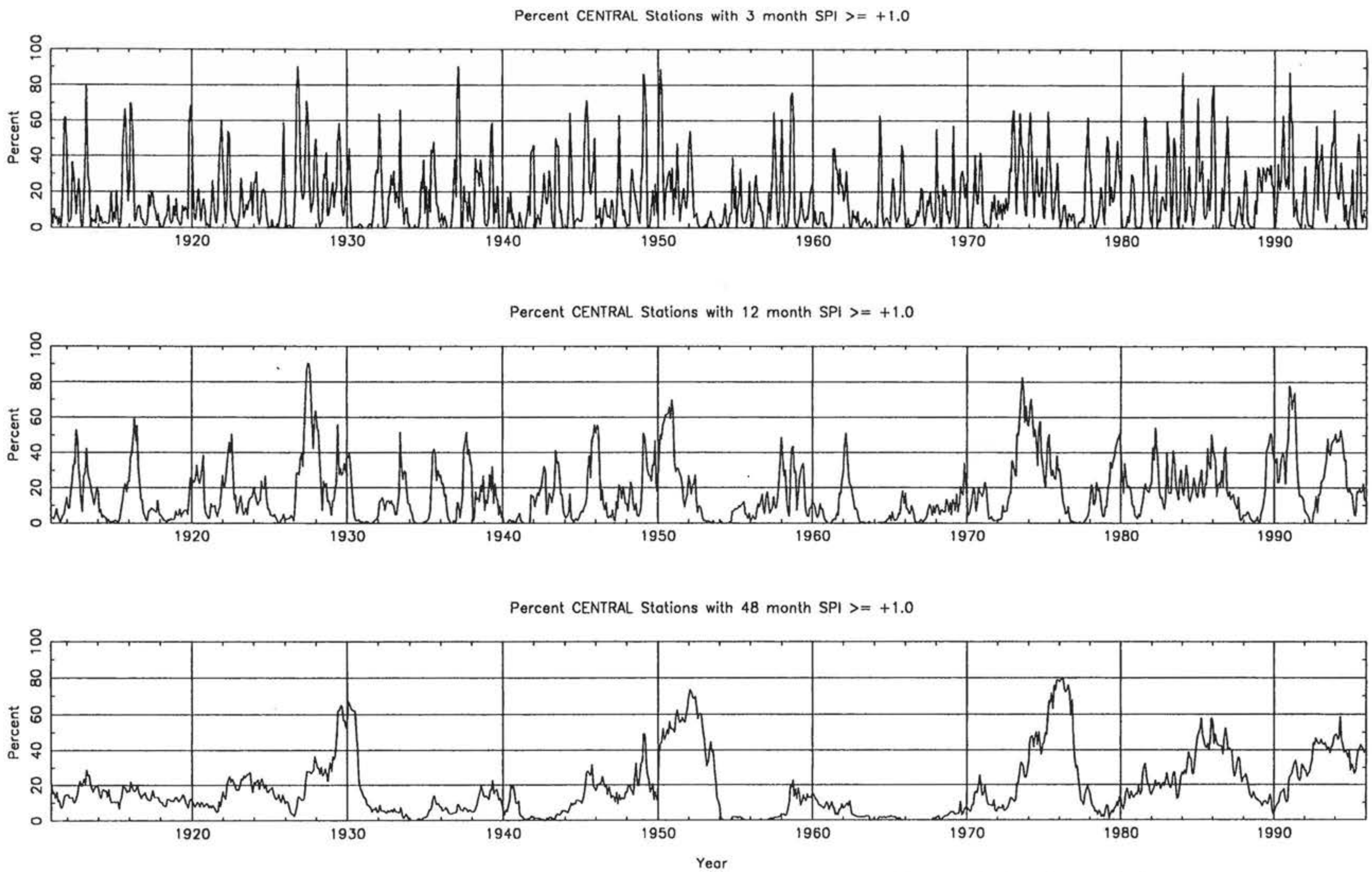


Fig 4.20(F) Time series of percent of all Central stations with SPI ≥ +1.0 by time scale for the period January, 1911 through December, 1995.

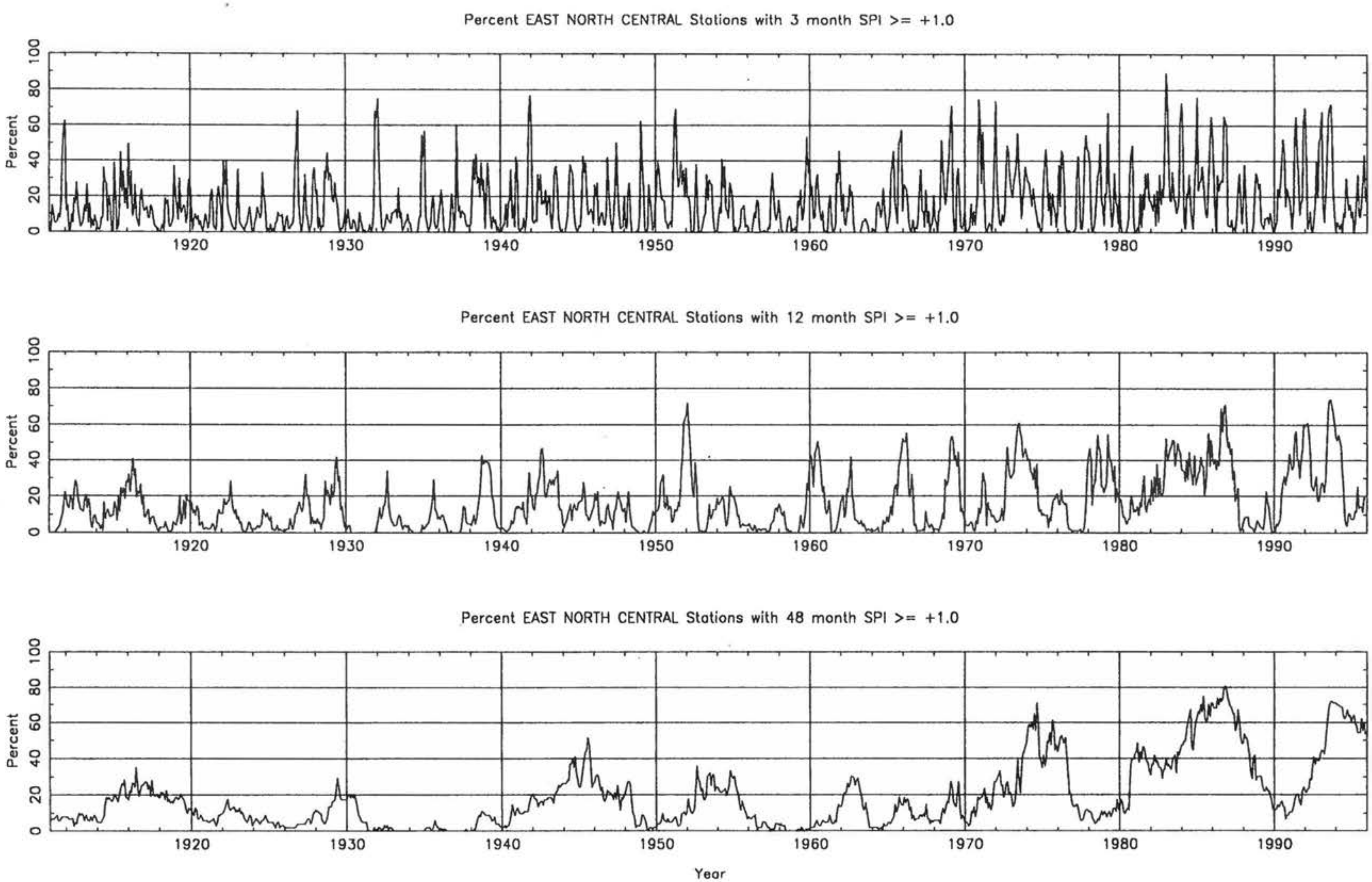


Fig 4.20(G) Time series of percent of all East North Central stations with SPI ≥ +1.0 by time scale for the period January, 1911 through December, 1995.

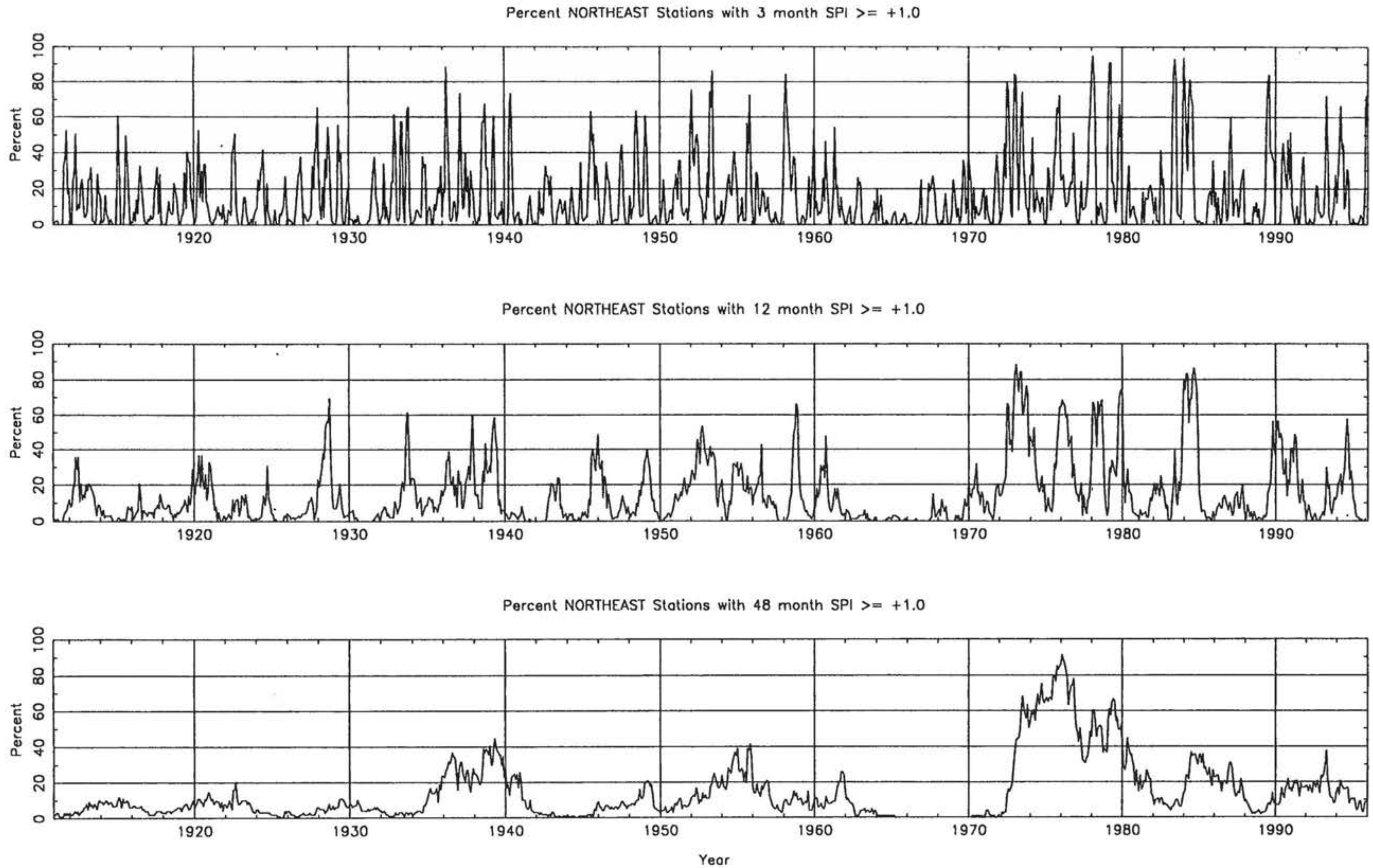


Fig 4.20(H) Time series of percent of all Northeast stations with SPI $\geq +1.0$ by time scale for the period January, 1911 through December, 1995.

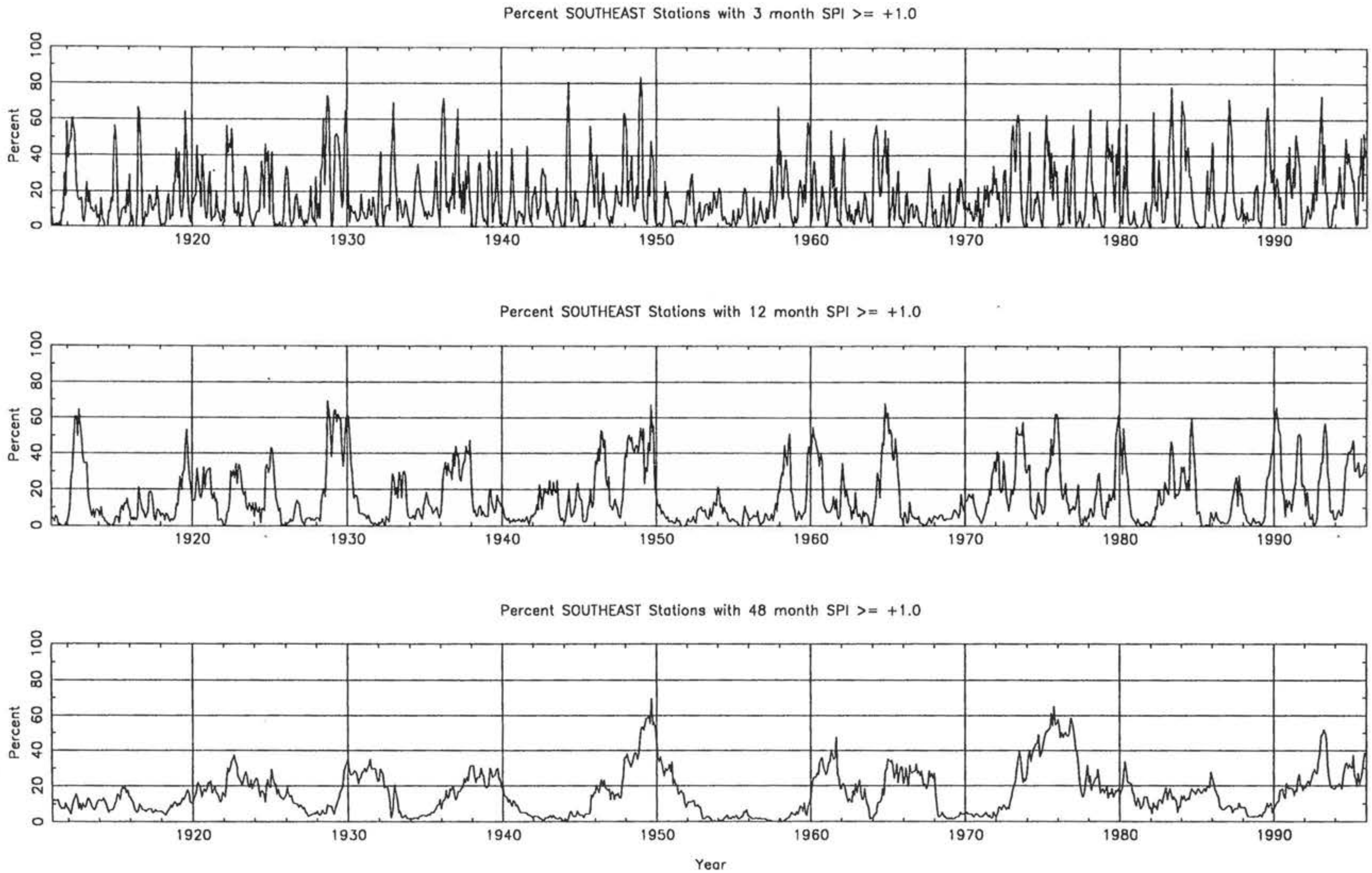


Fig 4.20(I) Time series of percent of all Southeast stations with SPI $\geq +1.0$ by time scale for the period January, 1911 through December, 1995.

Table 4.8: *t* Test for Nonstationarity of Percent USHCN Stations by Region and by Time Scale with SPI ≤ -1.0 or SPI ≥ +1.0 for the Period January, 1911 thru December, 1995

% Stations SPI	Region	time scale (months)	slope (percent/year)	p-value	conclusion
<= -1.0	West	3	-0.051829	0.0488	none
<= -1.0	West	12	-0.078552	0.0022	nonstationary
<= -1.0	West	48	-0.170388	0.0001	nonstationary
>= +1.0	West	3	0.087643	0.0006	nonstationary
>= +1.0	West	12	0.153629	0.0001	nonstationary
>= +1.0	West	48	0.193343	0.0001	nonstationary
<= -1.0	Northwest	3	-0.108695	0.0001	nonstationary
<= -1.0	Northwest	12	-0.172978	0.0001	nonstationary
<= -1.0	Northwest	48	-0.322313	0.0001	nonstationary
>= +1.0	Northwest	3	0.086362	0.0001	nonstationary
>= +1.0	Northwest	12	0.128384	0.0001	nonstationary
>= +1.0	Northwest	48	0.206020	0.0001	nonstationary
<= -1.0	West North Central	3	-0.041316	0.0272	none
<= -1.0	West North Central	12	-0.114142	0.0001	nonstationary
<= -1.0	West North Central	48	-0.237217	0.0001	nonstationary
>= +1.0	West North Central	3	0.038457	0.0277	none
>= +1.0	West North Central	12	0.091212	0.0001	nonstationary
>= +1.0	West North Central	48	0.084149	0.0001	nonstationary
<= -1.0	Southwest	3	-0.013856	0.4300	stationary
<= -1.0	Southwest	12	-0.042541	0.0145	none
<= -1.0	Southwest	48	-0.054911	0.0008	nonstationary
>= +1.0	Southwest	3	0.021340	0.2875	stationary
>= +1.0	Southwest	12	0.060381	0.0056	nonstationary
>= +1.0	Southwest	48	0.066412	0.0067	nonstationary
<= -1.0	South	3	-0.079572	0.0001	nonstationary
<= -1.0	South	12	-0.147779	0.0001	nonstationary
<= -1.0	South	48	-0.243128	0.0001	nonstationary
>= +1.0	South	3	0.061583	0.0016	nonstationary
>= +1.0	South	12	0.128838	0.0001	nonstationary
>= +1.0	South	48	0.276251	0.0001	nonstationary
<= -1.0	Central	3	-0.061851	0.0163	none
<= -1.0	Central	12	-0.115880	0.0001	nonstationary
<= -1.0	Central	48	-0.193774	0.0001	nonstationary
>= +1.0	Central	3	0.057453	0.0150	none
>= +1.0	Central	12	0.099442	0.0001	nonstationary
>= +1.0	Central	48	0.165675	0.0001	nonstationary
<= -1.0	East North Central	3	-0.082329	0.0006	nonstationary
<= -1.0	East North Central	12	-0.230591	0.0001	nonstationary
<= -1.0	East North Central	48	-0.514936	0.0001	nonstationary
>= +1.0	East North Central	3	0.136419	0.0001	nonstationary
>= +1.0	East North Central	12	0.251049	0.0001	nonstationary
>= +1.0	East North Central	48	0.422883	0.0001	nonstationary
<= -1.0	Northeast	3	-0.043223	0.0815	none
<= -1.0	Northeast	12	-0.087782	0.0004	nonstationary
<= -1.0	Northeast	48	-0.218563	0.0001	nonstationary
>= +1.0	Northeast	3	0.090148	0.0003	nonstationary
>= +1.0	Northeast	12	0.170730	0.0001	nonstationary
>= +1.0	Northeast	48	0.240852	0.0001	nonstationary
<= -1.0	Southeast	3	-0.062642	0.0134	none
<= -1.0	Southeast	12	-0.100068	0.0001	nonstationary
<= -1.0	Southeast	48	-0.124313	0.0001	nonstationary
>= +1.0	Southeast	3	0.048466	0.0263	none
>= +1.0	Southeast	12	0.050544	0.0133	none
>= +1.0	Southeast	48	0.094876	0.0001	nonstationary

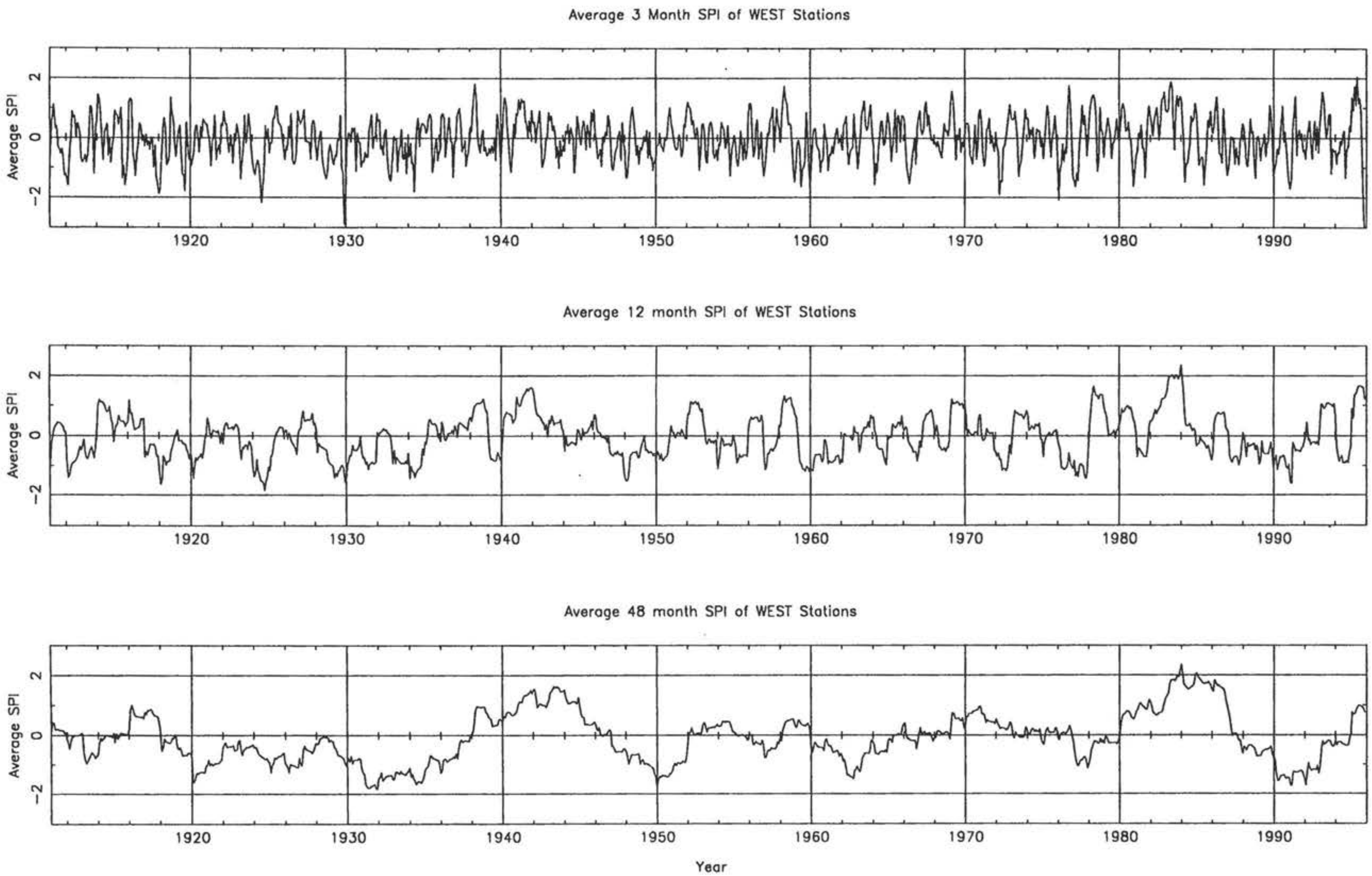


Fig 4.21(A) Time series of average SPI of all West stations by time scale for the period January, 1911 through December, 1995.

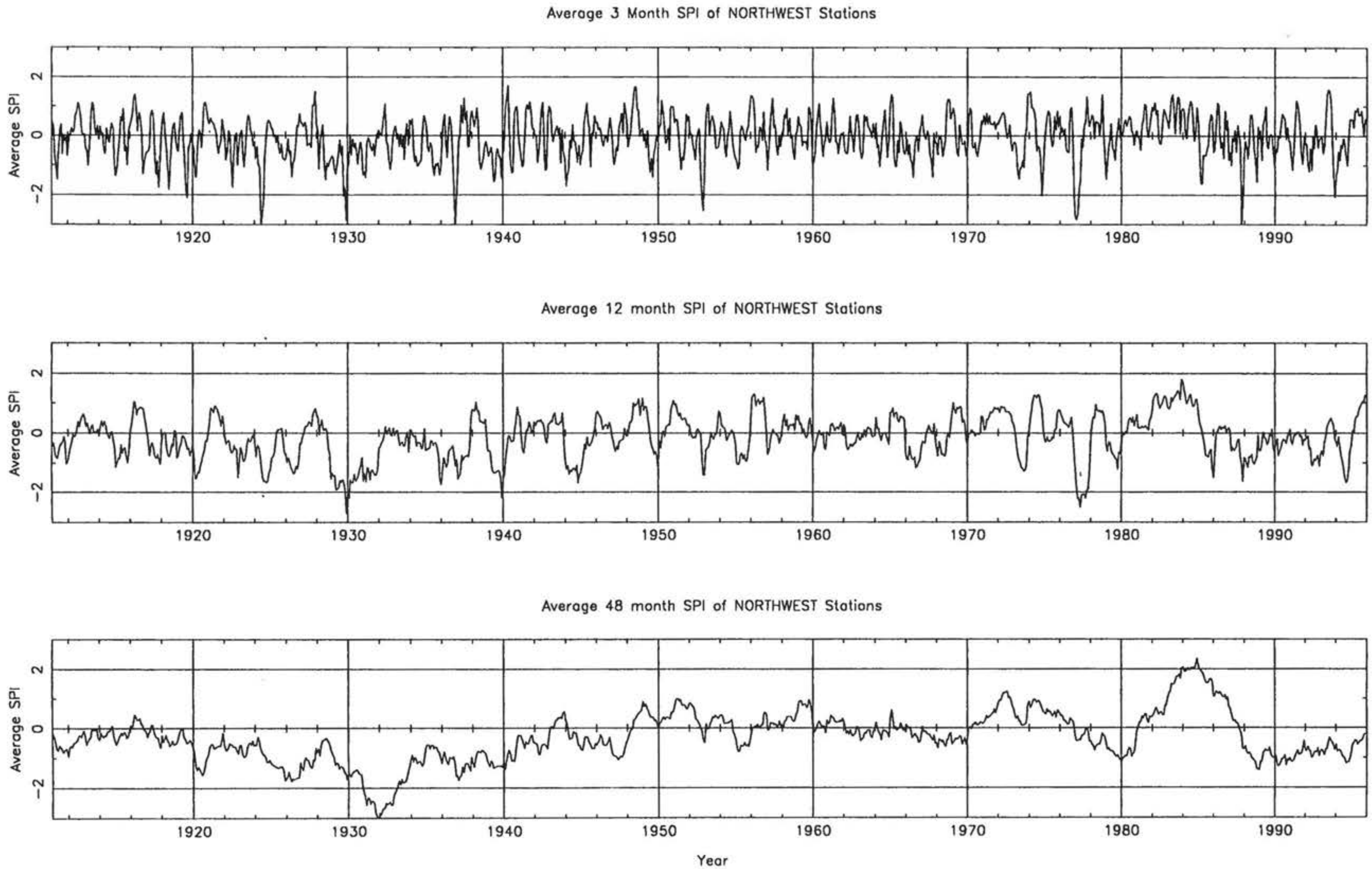


Fig 4.21(B) Time series of average SPI of all Northwest stations by time scale for the period January, 1911 through December, 1995.

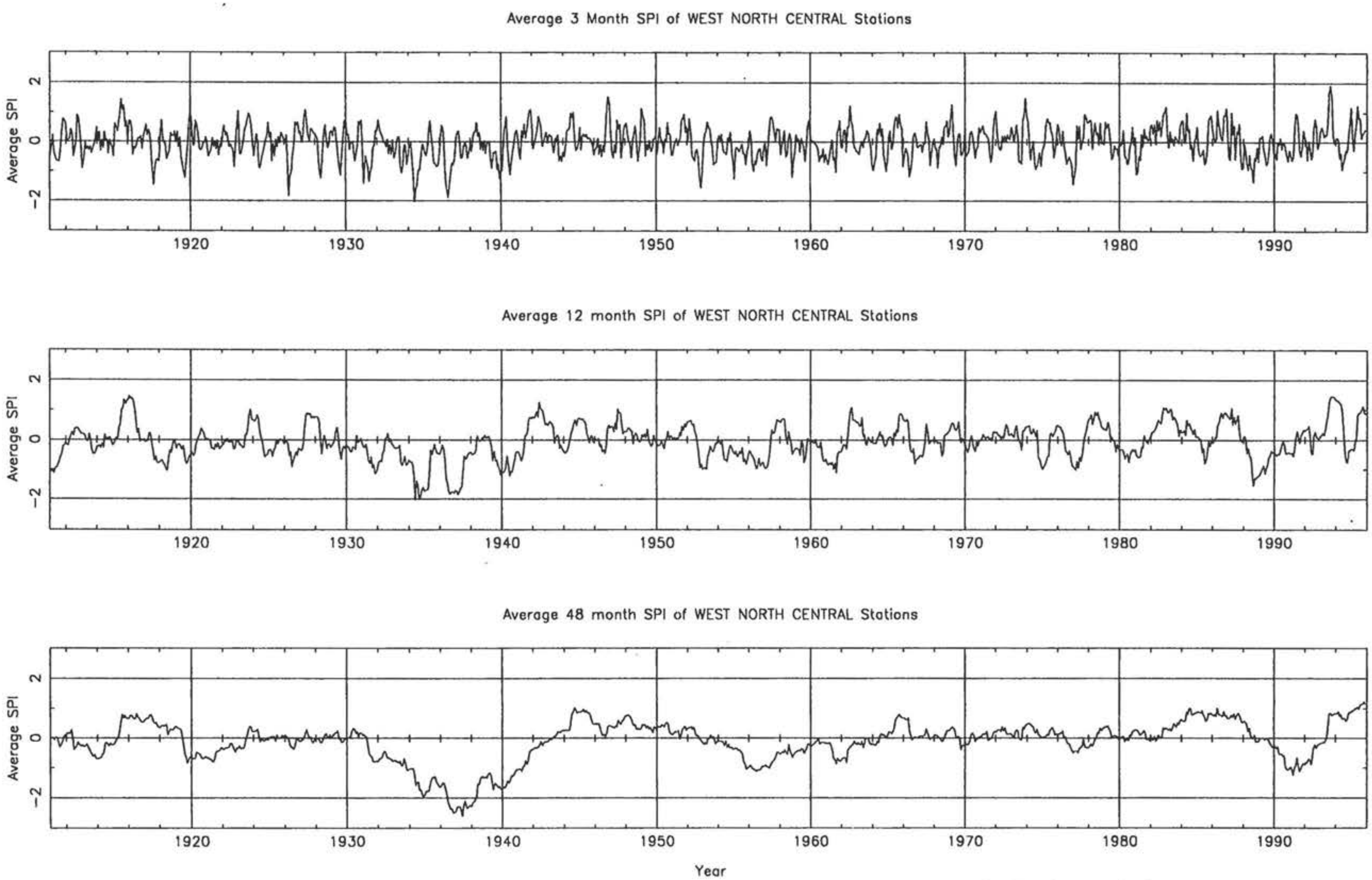


Fig 4.21(C) Time series of average SPI of all West North Central stations by time scale for the period January, 1911 through December, 1995.

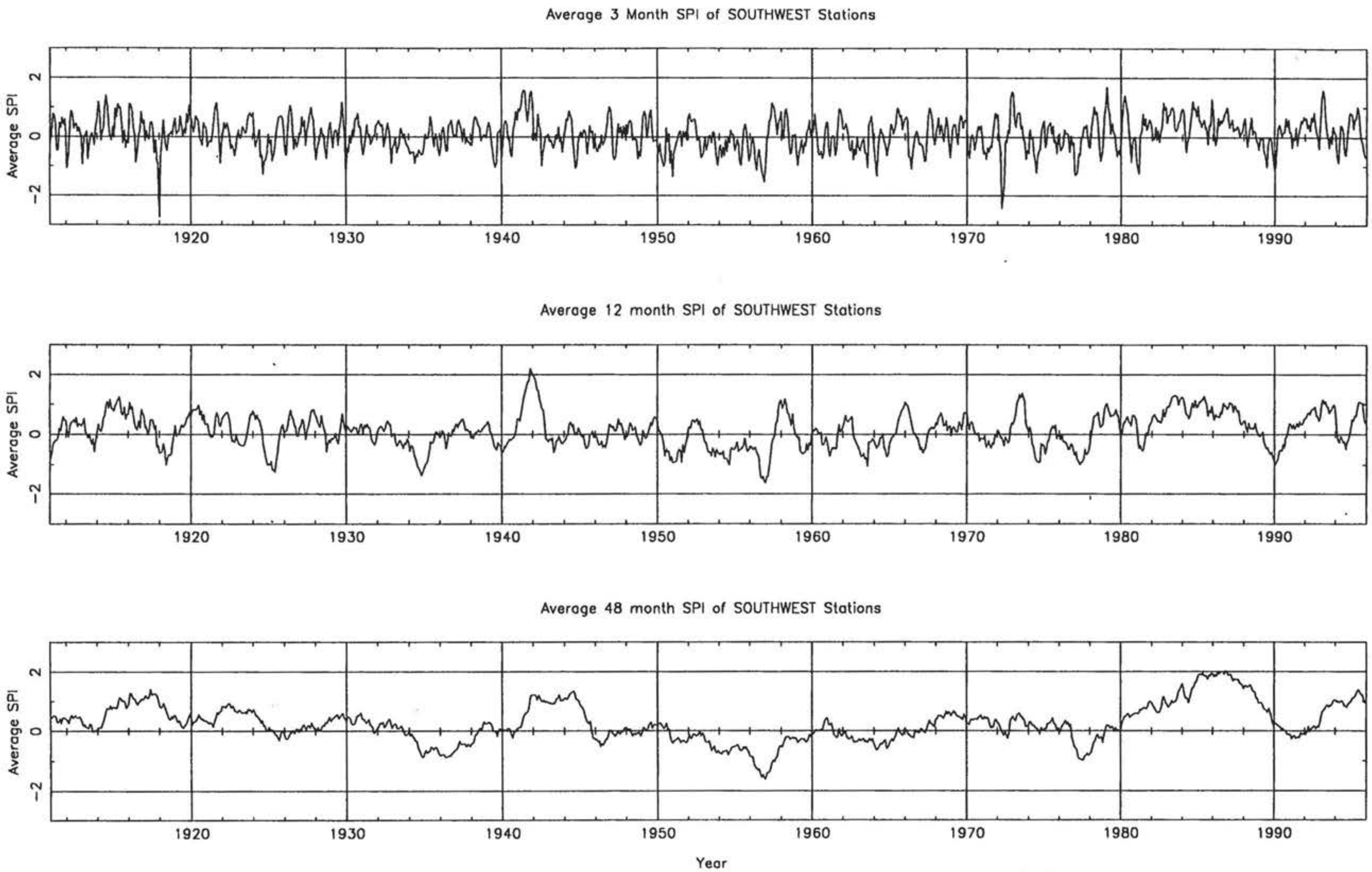


Fig 4.21(D) Time series of average SPI of all Southwest stations by time scale for the period January, 1911 through December, 1995.

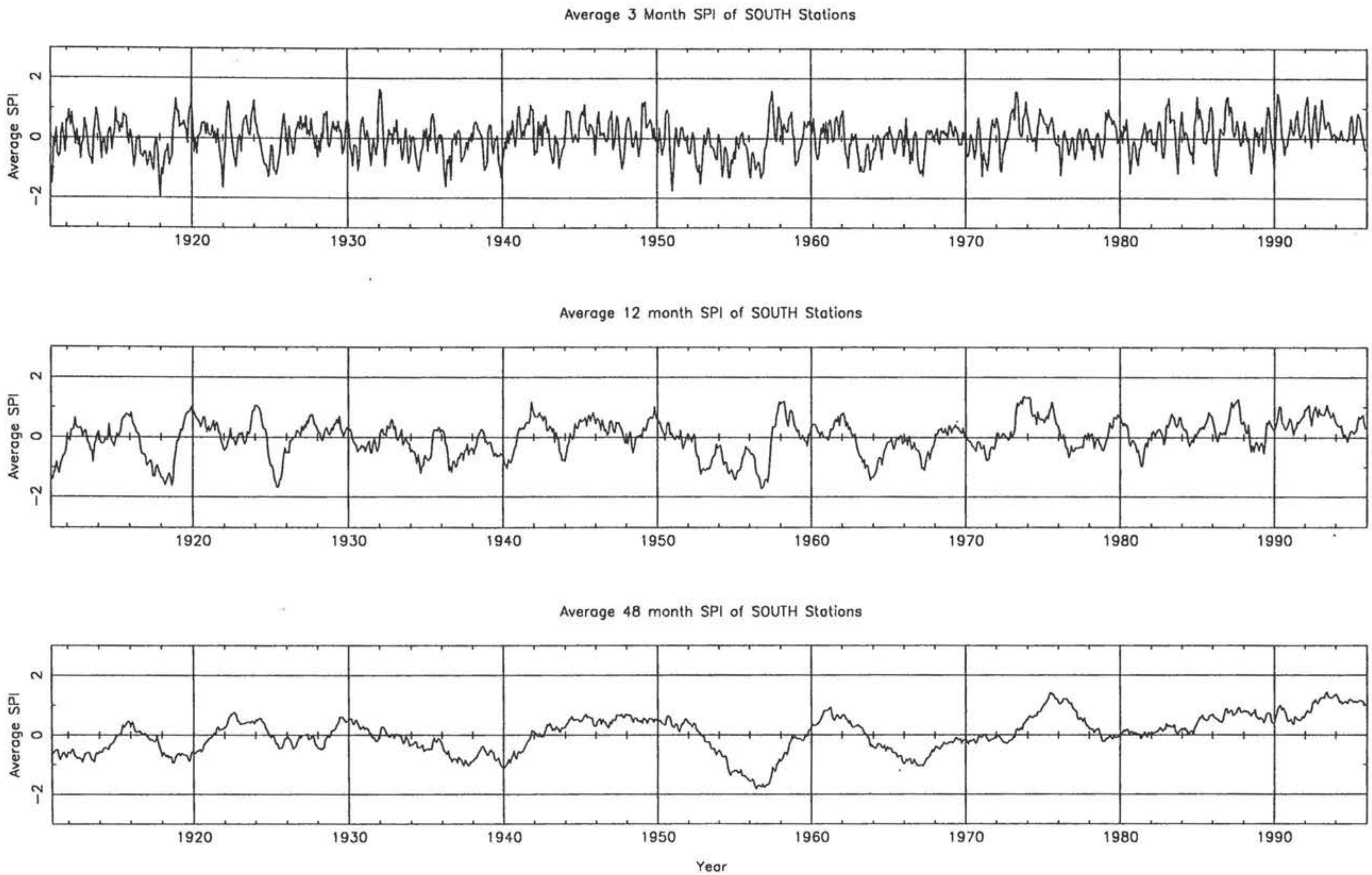


Fig 4.21(E) Time series of average SPI of all South stations by time scale for the period January, 1911 through December, 1995.

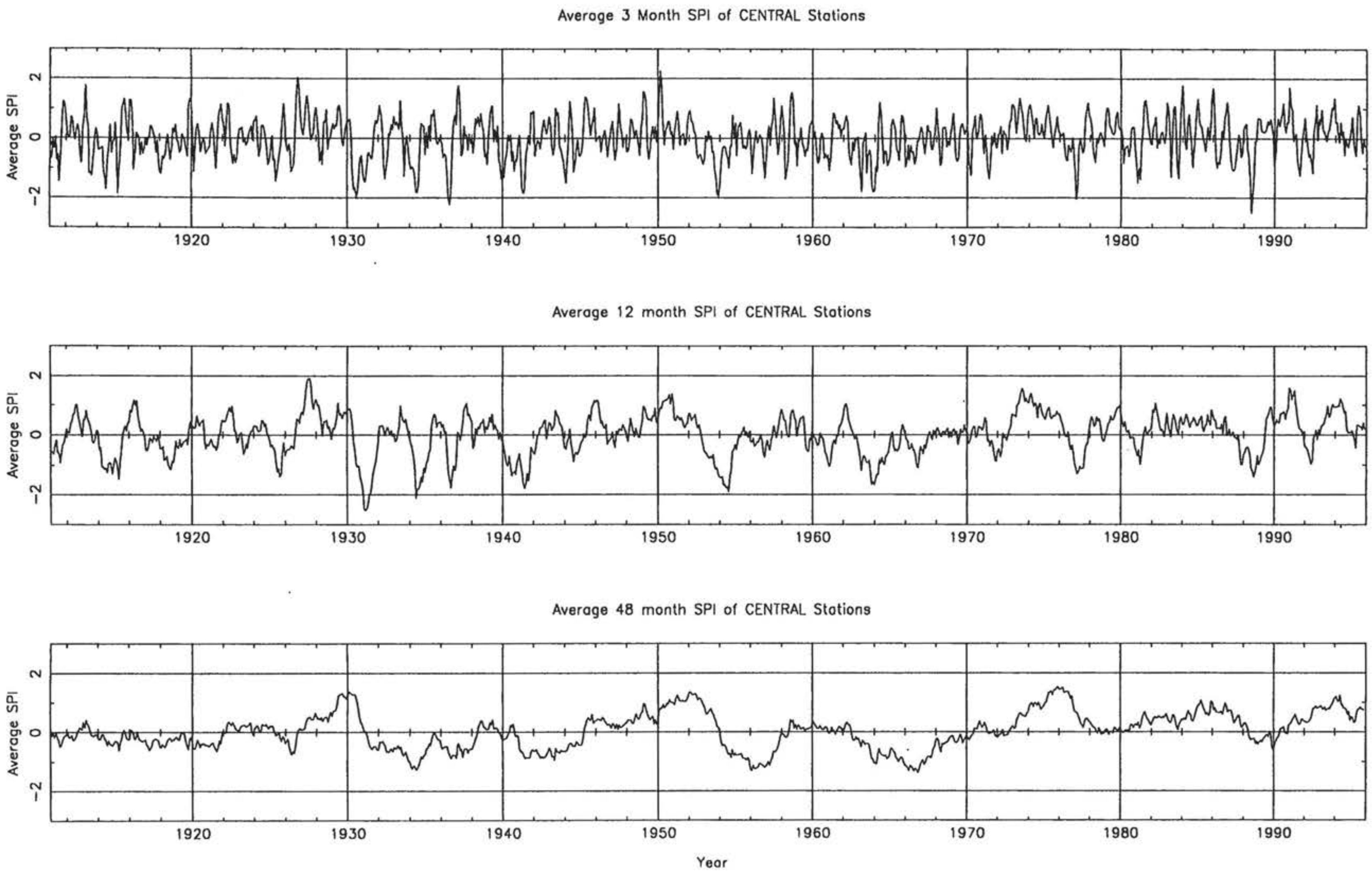


Fig 4.21(F) Time series of average SPI of all Central stations by time scale for the period January, 1911 through December, 1995.

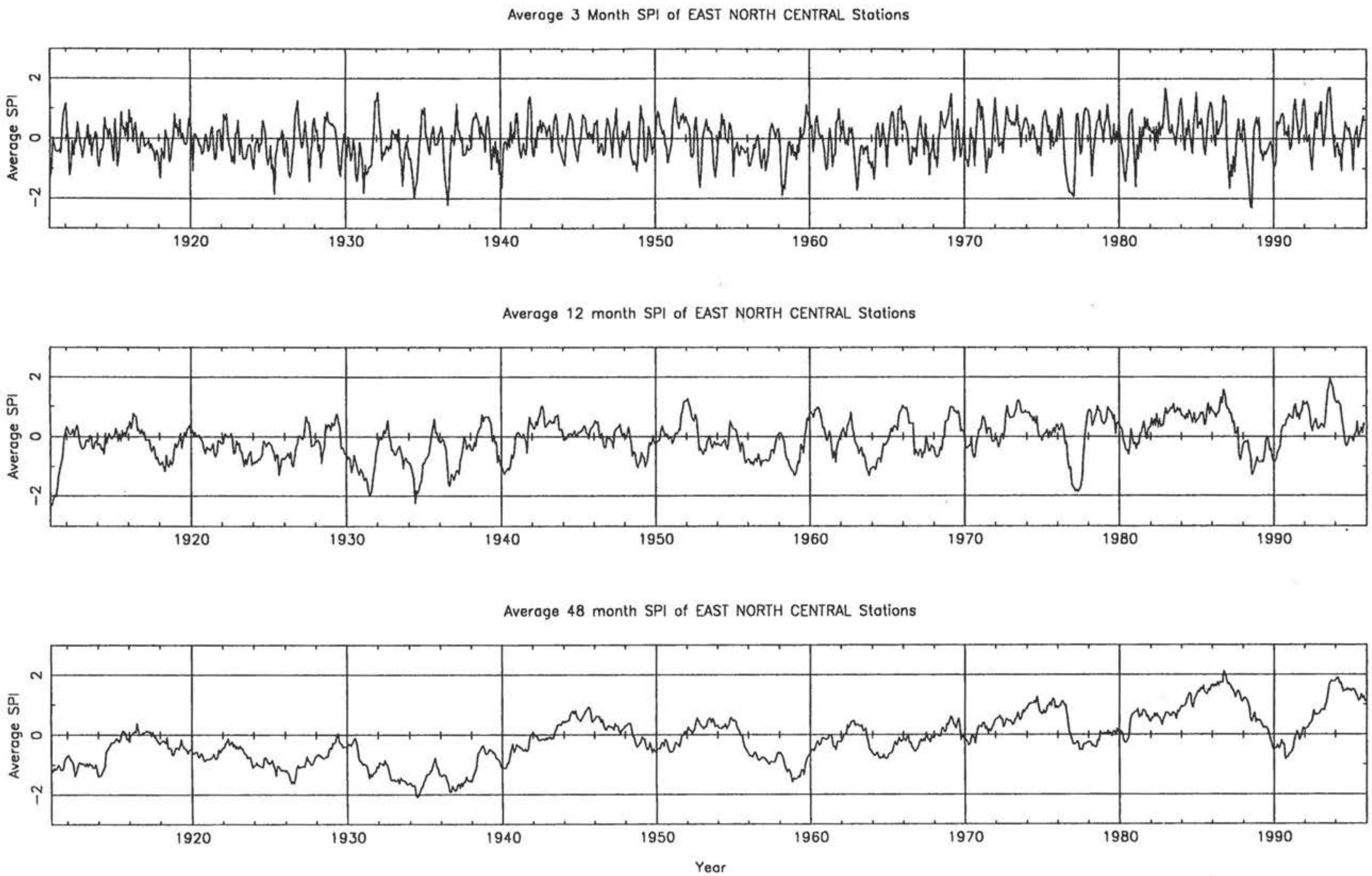


Fig 4.21(G) Time series of average SPI of all East North Central stations by time scale for the period January, 1911 through December, 1995.

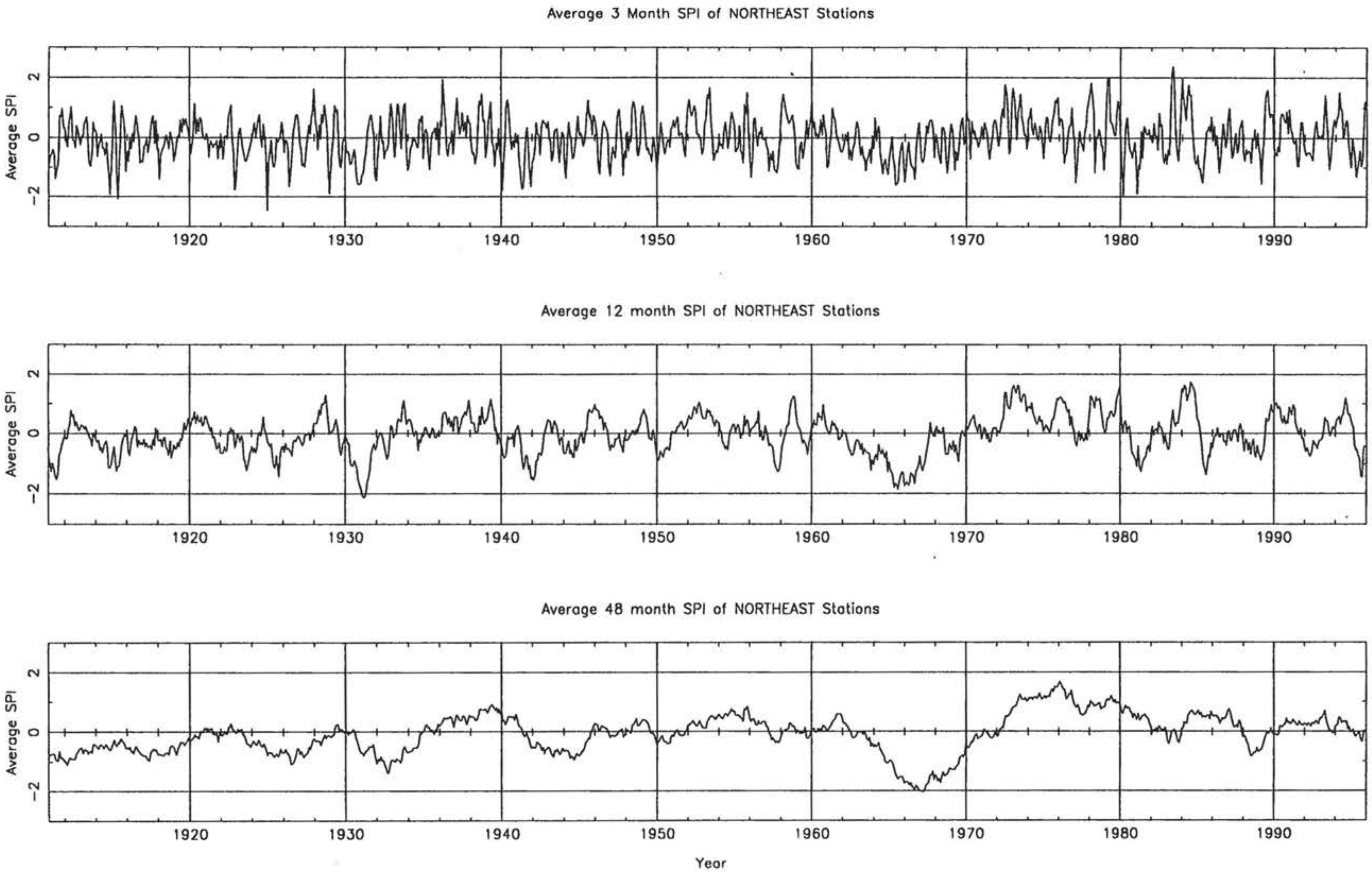


Fig 4.21(H) Time series of average SPI of all Northeast stations by time scale for the period January, 1911 through December, 1995.

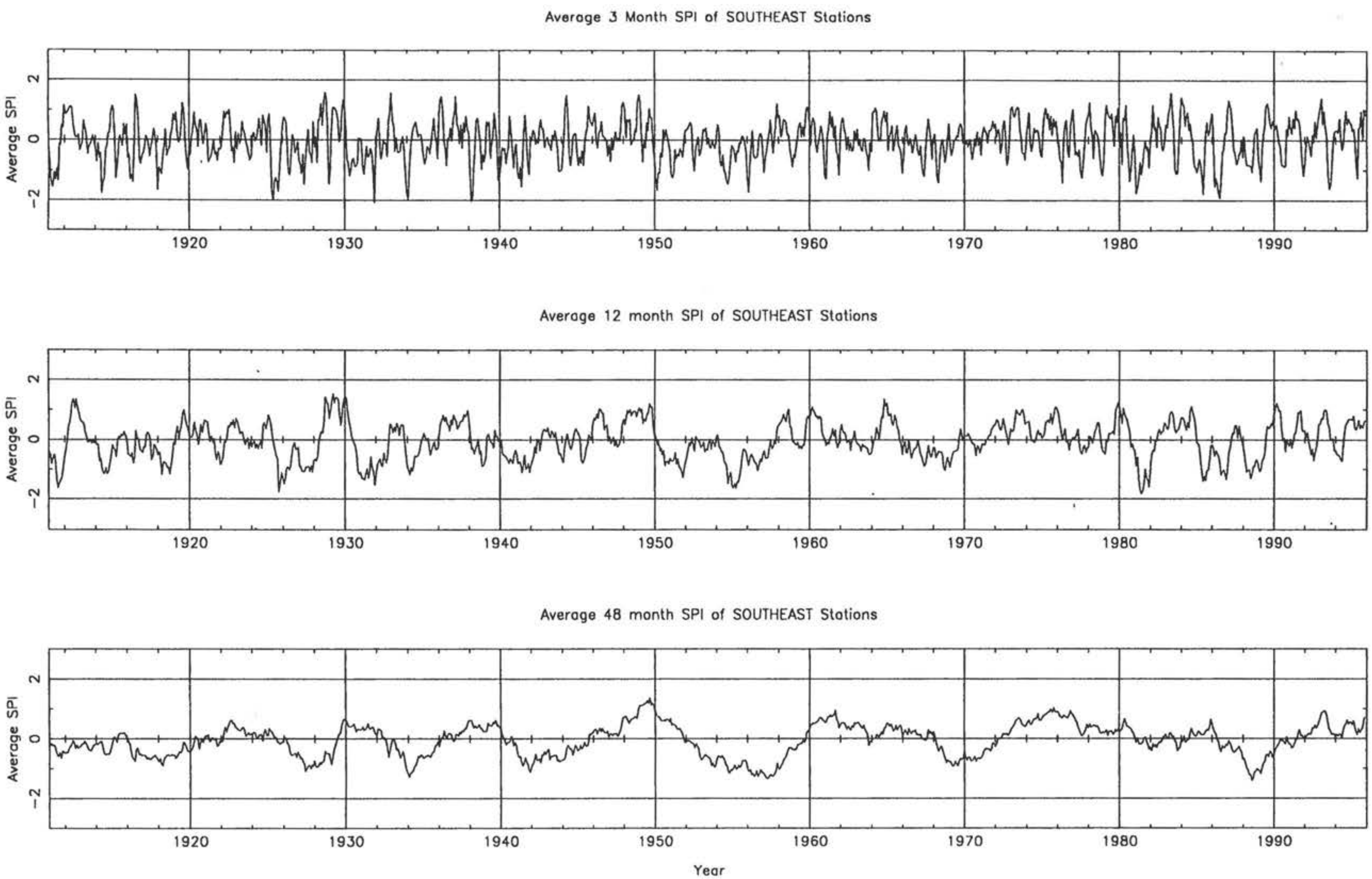


Fig 4.21(I) Time series of average SPI of all Southeast stations by time scale for the period January, 1911 through December, 1995.

Tab 4.9: *t* Test for Nonstationarity of Average SPI of USHCN Stations by Region and by Time Scale for the Period January, 1911 through December, 1995

Region	time scale (months)	slope (units of SPI/year)	p-value	conclusion
West	3	0.002776	0.0030	nonstationary
West	12	0.004340	0.0001	nonstationary
West	48	0.007935	0.0001	nonstationary
Northwest	3	0.004010	0.0001	nonstationary
Northwest	12	0.006128	0.0001	nonstationary
Northwest	48	0.012891	0.0001	nonstationary
West North Central	3	0.001706	0.0129	none
West North Central	12	0.004313	0.0001	nonstationary
West North Central	48	0.007407	0.0001	nonstationary
Southwest	3	0.000829	0.2413	stationary
Southwest	12	0.002325	0.0014	nonstationary
Southwest	48	0.003558	0.0001	nonstationary
South	3	0.003008	0.0001	nonstationary
South	12	0.005890	0.0001	nonstationary
South	48	0.010887	0.0001	nonstationary
Central	3	0.002439	0.0064	nonstationary
Central	12	0.004525	0.0001	nonstationary
Central	48	0.007587	0.0001	nonstationary
East North Central	3	0.004567	0.0001	nonstationary
East North Central	12	0.010291	0.0001	nonstationary
East North Central	48	0.021829	0.0001	nonstationary
Northeast	3	0.002841	0.0013	nonstationary
Northeast	12	0.005322	0.0001	nonstationary
Northeast	48	0.010003	0.0001	nonstationary
Southeast	3	0.002134	0.0142	none
Southeast	12	0.003059	0.0002	nonstationary
Southeast	48	0.004307	0.0001	nonstationary

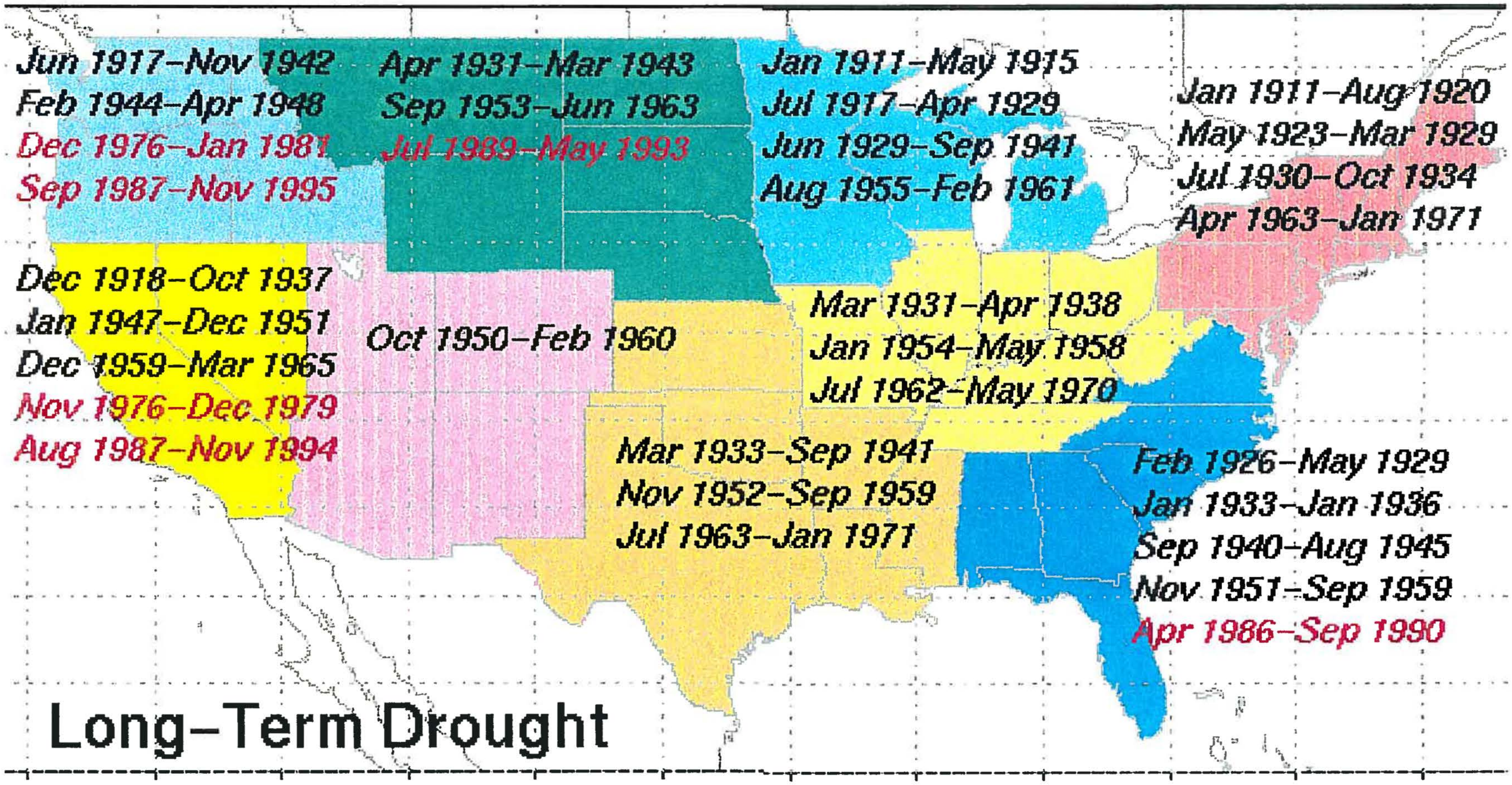


Fig 4.22 (A) Periods of long-term drought by region for the period January, 1911 through December, 1995.

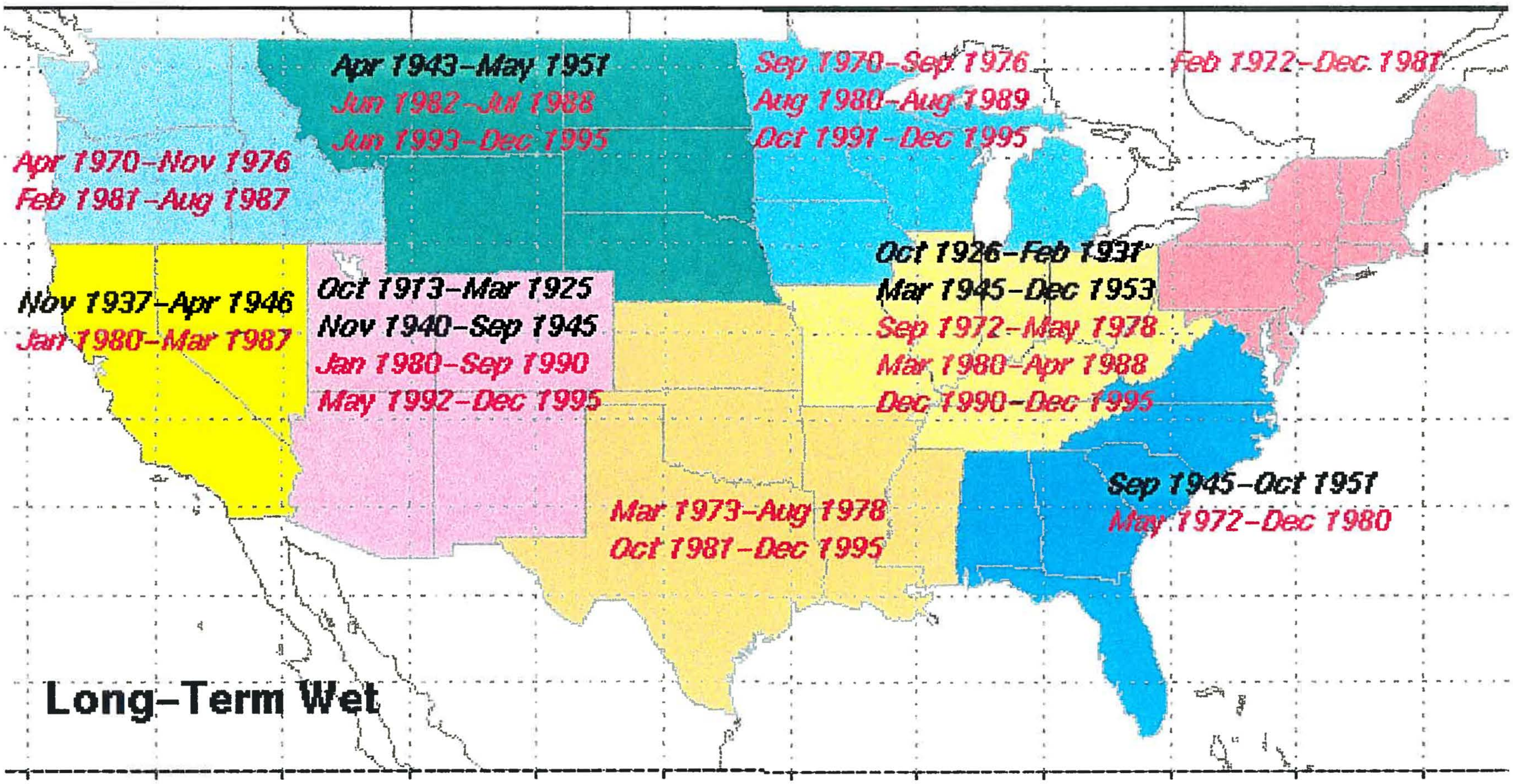


Fig 4.22 (B) Periods of long-term wet by region for the period January, 1911 through December, 1995.

Tab 4.10(A): Summary Statistics for Drought and Wet Periods of USHCN Stations by Region for 3 Month SPI (1911-1995)

Time Scale (SPI)	Region	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
3 months	West	drought duration	5177	4.85	4	37	1	3	6	3	3.21	13.20
3 months	West	wet duration	4274	5.54	5	31	1	3	7	4	3.23	15.99
3 months	Northwest	drought duration	7607	5.91	5	48	1	3	7	4	3.94	15.15
3 months	Northwest	wet duration	6468	5.82	5	40	1	3	7	4	3.38	17.83
3 months	West North Central	drought duration	11317	5.74	5	55	1	3	7	4	3.74	15.23
3 months	West North Central	wet duration	10382	5.71	5	37	1	3	7	4	3.29	16.60
3 months	Southwest	drought duration	6775	5.59	5	41	1	3	7	4	3.69	17.77
3 months	Southwest	wet duration	6825	6.66	5	37	1	4	8	4	3.97	17.64
3 months	South	drought duration	11749	5.83	5	40	1	3	7	4	3.85	16.41
3 months	South	wet duration	11180	6.14	5	35	1	4	8	4	3.53	17.24
3 months	Central	drought duration	10523	5.78	5	30	1	3	7	4	3.71	15.99
3 months	Central	wet duration	10363	5.74	5	30	1	3	7	4	3.16	18.24
3 months	East North Central	drought duration	6573	5.93	5	44	1	3	7	4	3.88	15.98
3 months	East North Central	wet duration	6180	5.82	5	39	1	3	7	4	3.23	17.00
3 months	Northeast	drought duration	10420	5.91	5	40	1	3	7	4	3.87	15.66
3 months	Northeast	wet duration	9215	5.82	5	42	1	4	7	3	3.27	17.71
3 months	Southeast	drought duration	9205	5.87	5	43	1	3	8	5	3.67	15.18
3 months	Southeast	wet duration	8428	5.77	5	28	1	3	7	4	3.18	16.58
3 months	West	drought start	5177	1.98	2	14	1	1	2	1	1.23	
3 months	West	wet start	4274	2.27	2	15	1	1	3	2	1.34	
3 months	Northwest	drought start	7607	2.22	2	16	1	1	3	2	1.32	
3 months	Northwest	wet start	6468	2.36	2	18	1	1	3	2	1.43	
3 months	West North Central	drought start	11317	2.24	2	16	1	1	3	2	1.33	
3 months	West North Central	wet start	10382	2.29	2	13	1	1	3	2	1.33	
3 months	Southwest	drought start	6775	2.29	2	14	1	1	3	2	1.38	
3 months	Southwest	wet start	6825	2.48	2	16	1	1	3	2	1.52	
3 months	South	drought start	11749	2.3	2	17	1	1	3	2	1.41	
3 months	South	wet start	11180	2.34	2	18	1	1	3	2	1.38	
3 months	Central	drought start	10523	2.32	2	21	1	1	3	2	1.37	
3 months	Central	wet start	10363	2.27	2	15	1	1	3	2	1.25	
3 months	East North Central	drought start	6573	2.34	2	12	1	1	3	2	1.38	
3 months	East North Central	wet start	6180	2.35	2	14	1	2	3	1	1.27	
3 months	Northeast	drought start	10420	2.38	2	14	1	1	3	2	1.43	
3 months	Northeast	wet start	9215	2.31	2	14	1	1	3	2	1.31	
3 months	Southeast	drought start	9205	2.22	2	16	1	1	3	2	1.32	
3 months	Southeast	wet start	8428	2.24	2	13	1	1	3	2	1.25	
3 months	West	drought end	5177	2.04	2	13	1	1	3	2	1.29	
3 months	West	wet end	4274	2.18	2	15	1	1	3	2	1.34	
3 months	Northwest	drought end	7607	2.24	2	12	1	1	3	2	1.32	
3 months	Northwest	wet end	6468	2.36	2	14	1	1	3	2	1.39	
3 months	West North Central	drought end	11317	2.25	2	12	1	1	3	2	1.34	
3 months	West North Central	wet end	10382	2.22	2	14	1	1	3	2	1.3	
3 months	Southwest	drought end	6775	2.34	2	18	1	1	3	2	1.46	
3 months	Southwest	wet end	6825	2.47	2	18	1	2	3	1	1.49	
3 months	South	drought end	11749	2.28	2	16	1	1	3	2	1.4	
3 months	South	wet end	11180	2.34	2	14	1	1	3	2	1.39	
3 months	Central	drought end	10523	2.2	2	15	1	1	3	2	1.29	
3 months	Central	wet end	10363	2.28	2	12	1	1	3	2	1.29	
3 months	East North Central	drought end	6573	2.22	2	13	1	1	3	2	1.29	
3 months	East North Central	wet end	6180	2.32	2	13	1	1	3	2	1.31	
3 months	Northeast	drought end	10420	2.35	2	14	1	1	3	2	1.34	
3 months	Northeast	wet end	9215	2.32	2	17	1	1	3	2	1.34	
3 months	Southeast	drought end	9205	2.27	2	13	1	1	3	2	1.36	
3 months	Southeast	wet end	8428	2.24	2	15	1	1	3	2	1.29	

Tab 4.10(B): Summary Statistics for Drought and Wet Periods of USHCN Stations by Region for 6 Month SPI (1911-1995)

Time Scale (SPI)	Region	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
6 months	West	drought duration	3033	8.79	8	62	1	5	11	6	5.92	22.53
6 months	West	wet duration	2671	8.99	8	51	1	6	11	5	5.28	25.59
6 months	Northwest	drought duration	4524	10.59	9	70	1	6	13	7	6.97	25.48
6 months	Northwest	wet duration	3737	9.88	8	66	1	6	12	6	5.96	30.84
6 months	West North Central	drought duration	6849	9.88	8	77	1	6	12	6	6.77	25.17
6 months	West North Central	wet duration	6317	9.47	8	73	1	6	12	6	5.61	27.29
6 months	Southwest	drought duration	3939	10.17	9	72	1	6	13	7	6.64	30.56
6 months	Southwest	wet duration	4030	11.7	10	68	1	7	14	7	6.85	29.87
6 months	South	drought duration	6712	10.5	9	73	1	6	13	7	6.74	28.72
6 months	South	wet duration	6454	10.91	9	73	1	7	13	6	6.25	29.87
6 months	Central	drought duration	6200	10.11	8	68	1	6	13	7	6.33	27.15
6 months	Central	wet duration	6052	10.25	9	47	1	6	13	7	5.7	27.81
6 months	East North Central	drought duration	4162	9.77	8	69	1	6	12	6	6.42	25.24
6 months	East North Central	wet duration	3809	9.66	8	59	1	6	12	6	5.65	27.58
6 months	Northeast	drought duration	5991	10.54	8	80	1	6	13	7	7.28	27.24
6 months	Northeast	wet duration	5414	10.22	9	67	1	6	12	6	5.84	30.14
6 months	Southeast	drought duration	5555	10.04	8	67	1	6	13	7	6.13	25.16
6 months	Southeast	wet duration	5059	9.89	8	45	1	6	12	6	5.28	27.62
6 months	West	drought start	3033	2.93	2	17	1	2	4	2	2.03	
6 months	West	wet start	2671	3.05	3	17	1	2	4	2	2	
6 months	Northwest	drought start	4524	3.15	3	20	1	2	4	2	2	
6 months	Northwest	wet start	3737	3.29	3	20	1	2	4	2	2.09	
6 months	West North Central	drought start	6849	3.06	3	19	1	2	4	2	1.93	
6 months	West North Central	wet start	6317	3.1	3	16	1	2	4	2	1.9	
6 months	Southwest	drought start	3939	3.35	3	19	1	2	4	2	2.14	
6 months	Southwest	wet start	4030	3.53	3	23	1	2	5	3	2.17	
6 months	South	drought start	6712	3.37	3	22	1	2	4	2	2.06	
6 months	South	wet start	6454	3.32	3	20	1	2	4	2	1.96	
6 months	Central	drought start	6200	3.09	3	22	1	2	4	2	1.88	
6 months	Central	wet start	6052	3.21	3	18	1	2	4	2	1.87	
6 months	East North Central	drought start	4162	3.1	3	16	1	2	4	2	1.91	
6 months	East North Central	wet start	3809	3.21	3	19	1	2	4	2	1.91	
6 months	Northeast	drought start	5991	3.42	3	20	1	2	4	2	2.02	
6 months	Northeast	wet start	5414	3.26	3	19	1	2	4	2	1.88	
6 months	Southeast	drought start	5555	3.09	3	20	1	2	4	2	1.89	
6 months	Southeast	wet start	5059	3.13	3	15	1	2	4	2	1.76	
6 months	West	drought end	3033	3.02	3	20	1	2	4	2	2.01	
6 months	West	wet end	2671	2.97	2	15	1	2	4	2	2.01	
6 months	Northwest	drought end	4524	3.12	3	17	1	2	4	2	1.92	
6 months	Northwest	wet end	3737	3.31	3	21	1	2	4	2	2.17	
6 months	West North Central	drought end	6849	3.12	3	21	1	2	4	2	1.91	
6 months	West North Central	wet end	6317	3	3	22	1	2	4	2	1.93	
6 months	Southwest	drought end	3939	3.42	3	18	1	2	4	2	2.14	
6 months	Southwest	wet end	4030	3.5	3	17	1	2	4	2	2.14	
6 months	South	drought end	6712	3.24	3	18	1	2	4	2	1.95	
6 months	South	wet end	6454	3.4	3	18	1	2	4	2	1.97	
6 months	Central	drought end	6200	3.18	3	19	1	2	4	2	1.88	
6 months	Central	wet end	6052	3.2	3	19	1	2	4	2	1.9	
6 months	East North Central	drought end	4162	3.06	3	23	1	2	4	2	1.8	
6 months	East North Central	wet end	3809	3.1	3	18	1	2	4	2	1.96	
6 months	Northeast	drought end	5991	3.32	3	22	1	2	4	2	2.07	
6 months	Northeast	wet end	5414	3.22	3	18	1	2	4	2	1.89	
6 months	Southeast	drought end	5555	3.16	3	21	1	2	4	2	1.93	
6 months	Southeast	wet end	5059	3.14	3	17	1	2	4	2	1.83	

Tab 4.10(C): Summary Statistics for Drought and Wet Periods of USHCN Stations by Region for 12 Month SPI (1911-1995)

Time Scale (SPI)	Region	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
12 months	West	drought duration	1346	21.16	16	126	1	12	25	13	14.47	50.77
12 months	West	wet duration	1078	20.4	15	78	2	13	25	12	10.51	63.40
12 months	Northwest	drought duration	2419	21	16	187	1	12	24	12	16.29	47.65
12 months	Northwest	wet duration	1838	19.33	15	111	1	12	23	11	11.27	62.71
12 months	West North Central	drought duration	3356	20.82	16	263	1	11	26	15	16.19	51.38
12 months	West North Central	wet duration	2994	19.25	16	128	1	12	24	12	10.87	57.58
12 months	Southwest	drought duration	2084	19.13	15	119	1	12	23	11	12.56	57.75
12 months	Southwest	wet duration	2124	22.33	18	145	2	13	26	13	14.51	56.67
12 months	South	drought duration	3446	20.66	17	139	1	12	25	13	13.85	55.94
12 months	South	wet duration	3273	20.98	18	128	1	13	25	12	11.21	58.90
12 months	Central	drought duration	3208	19.38	17	82	2	12	25	13	11.2	52.46
12 months	Central	wet duration	3169	19.69	16	119	2	12	24	12	11.68	53.11
12 months	East North Central	drought duration	1955	20.86	17	254	1	12	25	13	16.7	63.74
12 months	East North Central	wet duration	1824	19.79	16	146	2	12	24	12	12.11	67.60
12 months	Northeast	drought duration	2874	21.18	17	182	2	12	26	14	15.45	56.78
12 months	Northeast	wet duration	2799	20.14	17	155	2	13	25	12	12.05	58.31
12 months	Southeast	drought duration	2999	18.74	15	141	1	11	24	13	12.67	48.60
12 months	Southeast	wet duration	2698	17.81	15	103	2	12	22	10	9.63	51.79
12 months	West	drought start	1346	5.43	4	27	1	2	8	6	4.2	
12 months	West	wet start	1078	5.13	4	28	1	2	7	5	3.99	
12 months	Northwest	drought start	2419	4.89	4	35	1	2	7	5	3.35	
12 months	Northwest	wet start	1838	5.25	4	36	1	3	7	4	3.46	
12 months	West North Central	drought start	3355	4.92	4	33	1	2	7	5	3.63	
12 months	West North Central	wet start	2994	5.11	4	39	1	2	7	5	3.66	
12 months	Southwest	drought start	2084	5.37	4.5	39	1	3	7	4	3.72	
12 months	Southwest	wet start	2124	5.46	5	30	1	3	7	4	3.69	
12 months	South	drought start	3446	5.5	5	37	1	3	7	4	3.67	
12 months	South	wet start	3273	5.29	5	27	1	3	7	4	3.31	
12 months	Central	drought start	3208	5.17	4	27	1	3	7	4	3.31	
12 months	Central	wet start	3169	5.1	4	26	1	3	7	4	3.09	
12 months	East North Central	drought start	1955	5.12	4	30	1	2	7	5	3.65	
12 months	East North Central	wet start	1824	5.03	4	27	1	3	7	4	3.46	
12 months	Northeast	drought start	2874	5.53	5	34	1	3	7	4	3.55	
12 months	Northeast	wet start	2799	5.53	5	27	1	3	7	4	3.3	
12 months	Southeast	drought start	2999	4.73	4	27	1	3	6	3	2.96	
12 months	Southeast	wet start	2698	4.76	4	26	1	3	6	3	2.93	
12 months	West	drought end	1346	5.18	4	32	1	2	8	6	4.01	
12 months	West	wet end	1078	5.05	4	25	1	2	8	6	3.9	
12 months	Northwest	drought end	2419	4.99	4	33	1	3	7	4	3.34	
12 months	Northwest	wet end	1838	5.26	4	37	1	3	7	4	3.56	
12 months	West North Central	drought end	3355	5.02	4	39	1	2	7	5	3.73	
12 months	West North Central	wet end	2994	4.91	4	32	1	2	7	5	3.53	
12 months	Southwest	drought end	2084	5.23	4	33	1	3	7	4	3.63	
12 months	Southwest	wet end	2124	5.51	4	34	1	3	7	4	3.73	
12 months	South	drought end	3446	5.38	4	37	1	3	7	4	3.67	
12 months	South	wet end	3273	5.5	5	34	1	3	7	4	3.69	
12 months	Central	drought end	3208	5.02	4	22	1	3	6	3	3.1	
12 months	Central	wet end	3169	5.07	4	37	1	3	7	4	3.34	
12 months	East North Central	drought end	1955	5.06	4	29	1	3	7	4	3.39	
12 months	East North Central	wet end	1824	5.08	4	25	1	2	7	5	3.46	
12 months	Northeast	drought end	2874	5.59	5	29	1	3	7	4	3.65	
12 months	Northeast	wet end	2799	5.34	4	27	1	3	7	4	3.4	
12 months	Southeast	drought end	2999	4.74	4	25	1	3	6	3	3.08	
12 months	Southeast	wet end	2698	4.75	4	33	1	3	6	3	2.87	

Tab 4.10(D): Summary Statistics for Drought and Wet Periods of USHCN Stations by Region for 24 Month SPI (1911-1995)

Time Scale (SPI)	Region	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
24 months	West	drought duration	715	39.14	34	250	1	23	50	27	26.71	95.58
24 months	West	wet duration	564	37.39	34	144	3	25	44	19	19.96	121.17
24 months	Northwest	drought duration	1269	40.21	31	300	3	19	49	30	33.85	90.83
24 months	Northwest	wet duration	1040	33	28	123	3	22	40	18	18.49	110.83
24 months	West North Central	drought duration	1796	38.41	30	292	2	20	47	27	30.79	96.03
24 months	West North Central	wet duration	1672	34.09	28	220	2	24	39	15	20.58	103.10
24 months	Southwest	drought duration	1096	35.37	28	241	3	21	44	23	24.17	109.82
24 months	Southwest	wet duration	1178	39.94	32	157	5	24	48	24	24.99	102.17
24 months	South	drought duration	1847	36.98	30	160	2	22	48	26	23.47	104.37
24 months	South	wet duration	1842	36.07	31	214	2	24	44	20	19.14	104.66
24 months	Central	drought duration	1792	33.91	28	168	3	21	40	19	20.97	93.92
24 months	Central	wet duration	1657	36.57	32	192	4	24	46	22	19.93	101.57
24 months	East North Central	drought duration	1102	36.67	28	315	2	20	44	24	32.3	95.34
24 months	East North Central	wet duration	990	35.46	29	189	1	23	43	20	21.55	106.12
24 months	Northeast	drought duration	1470	39.99	33	305	3	23	50	27	26.59	111.02
24 months	Northeast	wet duration	1402	37.67	31	156	3	24	43	19	21.91	116.41
24 months	Southeast	drought duration	1626	33.55	28	182	3	18	42	24	22.94	85.94
24 months	Southeast	wet duration	1442	32.34	28	170	3	21	39	18	18.25	96.91
24 months	West	drought start	715	8.07	7	36	1	3	12	9	5.84	
24 months	West	wet start	564	8.68	8	47	1	3	12	9	6.49	
24 months	Northwest	drought start	1269	7.24	6	48	1	4	10	6	4.96	
24 months	Northwest	wet start	1040	7.87	7	44	1	4	11	7	5.16	
24 months	West North Central	drought start	1795	7.22	6	48	1	3	10	7	5.34	
24 months	West North Central	wet start	1672	7.59	7	37	1	3	11	8	5.18	
24 months	Southwest	drought start	1096	8.71	7	70	1	5	11	6	5.86	
24 months	Southwest	wet start	1178	8.37	7	42	1	4	11	7	5.59	
24 months	South	drought start	1847	8.7	7	48	1	5	12	7	5.61	
24 months	South	wet start	1842	8.54	7	60	1	5	11	6	5.4	
24 months	Central	drought start	1792	8.4	7	42	1	5	11	6	5.12	
24 months	Central	wet start	1657	8.61	8	45	1	5	11	6	5.3	
24 months	East North Central	drought start	1102	7.58	6	30	1	4	10	6	5.06	
24 months	East North Central	wet start	990	7.84	7	37	1	4	11	7	4.85	
24 months	Northeast	drought start	1470	9.42	8	63	1	5	12	7	6.47	
24 months	Northeast	wet start	1402	9.53	8	69	1	5	12	7	5.91	
24 months	Southeast	drought start	1626	7.46	6	41	1	4	10	6	4.77	
24 months	Southeast	wet start	1442	8.14	7	54	1	5	10	5	5.01	
24 months	West	drought end	715	8.98	8	47	1	3	12	9	6.92	
24 months	West	wet end	564	9.12	9	37	1	4	13	9	6.03	
24 months	Northwest	drought end	1269	7.46	6	37	1	4	10	6	4.68	
24 months	Northwest	wet end	1040	7.2	6	32	1	3	9.5	6.5	4.79	
24 months	West North Central	drought end	1796	7.69	7	46	1	3	10	7	5.28	
24 months	West North Central	wet end	1672	7.7	7	48	1	3	11	8	5.61	
24 months	Southwest	drought end	1096	8.02	7	59	1	4	11	7	5.64	
24 months	Southwest	wet end	1178	9.11	8	67	1	5	12	7	6.34	
24 months	South	drought end	1847	8.33	7	43	1	4	11	7	5.43	
24 months	South	wet end	1842	8.77	8	44	1	5	12	7	5.65	
24 months	Central	drought end	1792	8.31	7	61	1	5	11	6	5.35	
24 months	Central	wet end	1657	8.85	8	45	1	5	12	7	5.31	
24 months	East North Central	drought end	1102	7.75	7	48	1	4	10	6	5.31	
24 months	East North Central	wet end	990	8.01	7	54	1	4	11	7	5.55	
24 months	Northeast	drought end	1470	9.88	8	49	1	5	13	8	6.3	
24 months	Northeast	wet end	1402	8.97	8	40	1	5	12	7	5.46	
24 months	Southeast	drought end	1626	7.69	6	42	1	4	10	6	4.83	
24 months	Southeast	wet end	1442	7.43	6	48	1	4	10	6	4.69	

Tab 4.10(E): Summary Statistics for Drought and Wet Periods of USHCN Stations by Region for 48 Month SPI (1911-1995)

Time Scale (SPI)	Region	Drought/Wet Duration/Start/End	Total Count	Mean Length (months)	Median Length (months)	Max Length (months)	Min Length (months)	25th Percentile (months)	75th Percentile (months)	IQR (months)	Standard Deviation (months)	Average Period (months)
48 months	West	drought duration	392	70.95	59	323	8	38	86	48	50.81	174.34
48 months	West	wet duration	316	65.36	58	250	13	37	91.5	54.5	35.72	216.27
48 months	Northwest	drought duration	672	70.74	54	382	6	31	90	59	59.78	171.52
48 months	Northwest	wet duration	626	55.05	51	184	3	33	71	38	30.09	184.12
48 months	West North Central	drought duration	953	69.48	53	384	2	30	90	60	57.76	180.88
48 months	West North Central	wet duration	870	62.54	53	271	5	37	83	46	38.92	198.14
48 months	Southwest	drought duration	581	61.88	51	368	4	31	82	51	43.29	207.16
48 months	Southwest	wet duration	581	71.15	59	366	11	43	95	52	43.17	207.16
48 months	South	drought duration	943	67.27	59	353	4	38	86	48	40.8	204.43
48 months	South	wet duration	905	65.49	57	303	5	45	78	33	38.84	213.02
48 months	Central	drought duration	867	62.77	56	246	6	38	78	40	36.12	194.12
48 months	Central	wet duration	838	62.73	56	255	8	41	80	39	33.33	200.84
48 months	East North Central	drought duration	569	64.31	52	324	7	33	73	40	51.7	184.64
48 months	East North Central	wet duration	525	59.91	54	234	3	37	75	38	33.58	200.11
48 months	Northeast	drought duration	680	73.4	63	311	8	45	95	50	43.47	240.00
48 months	Northeast	wet duration	619	76.17	65	290	11	50	97	47	38.7	263.65
48 months	Southeast	drought duration	779	62.09	56	390	2	36	80	44	38.24	179.38
48 months	Southeast	wet duration	726	58.64	52	212	6	37	72	35	32.57	192.48
48 months	West	drought start	392	13.22	12	51	1	5	16.5	11.5	9.47	
48 months	West	wet start	316	12.32	12	72	1	6	14	8	9.05	
48 months	Northwest	drought start	672	11.36	10	72	1	6	15	9	7.42	
48 months	Northwest	wet start	626	10.96	10	64	1	6	13	7	7.57	
48 months	West North Central	drought start	953	11.79	10	77	1	5	15	10	9.1	
48 months	West North Central	wet start	870	11.94	10	74	1	5	15	10	9.01	
48 months	Southwest	drought start	581	13.2	11	73	2	6	17	11	9.66	
48 months	Southwest	wet start	581	13.8	12	63	1	8	18	10	9.06	
48 months	South	drought start	943	15.35	13	92	1	8	20	12	10.62	
48 months	South	wet start	905	15.41	13	77	1	9	20	11	10.18	
48 months	Central	drought start	867	14.18	12	77	2	8	18	10	9.28	
48 months	Central	wet start	838	14.73	12	91	1	8	18	10	9.88	
48 months	East North Central	drought start	569	11.62	10	53	1	6	14	8	8.17	
48 months	East North Central	wet start	525	11.74	10	47	1	6	15	9	7.64	
48 months	Northeast	drought start	680	18.45	15	110	2	10	23	13	13.2	
48 months	Northeast	wet start	619	18.21	15	85	3	10	24	14	11.65	
48 months	Southeast	drought start	779	13.36	11	74	1	7	17	10	9.4	
48 months	Southeast	wet start	726	13.72	11	70	1	7	18	11	9.03	
48 months	West	drought end	392	13.9	12.5	82	1	7	17	10	10.28	
48 months	West	wet end	316	13.71	12	69	1	5	20	15	10.01	
48 months	Northwest	drought end	672	11.01	9	45	1	6	14	8	7.57	
48 months	Northwest	wet end	626	12.02	11	87	1	6	15	9	8.47	
48 months	West North Central	drought end	953	12.05	10	68	1	6	15	9	8.73	
48 months	West North Central	wet end	870	12.68	11	114	1	6	16	10	10.11	
48 months	Southwest	drought end	581	13.67	11	121	1	7	17	10	10.2	
48 months	Southwest	wet end	581	13.41	11	122	1	7	17	10	10.13	
48 months	South	drought end	943	15.58	13	231	2	8	20	12	13	
48 months	South	wet end	905	14.74	13	61	1	9	19	10	8.93	
48 months	Central	drought end	867	13.75	11	66	1	7	17	10	9.31	
48 months	Central	wet end	838	13.96	11	82	1	7	17	10	10.11	
48 months	East North Central	drought end	569	12.23	10	66	1	6	15	9	8.7	
48 months	East North Central	wet end	525	12.31	11	48	1	6	15	9	8.14	
48 months	Northeast	drought end	680	17.87	15	79	1	10	24	14	10.93	
48 months	Northeast	wet end	619	18.24	16	77	2	10	23	13	11.05	
48 months	Southeast	drought end	779	13.71	12	69	1	7	18	11	9.3	
48 months	Southeast	wet end	726	13.19	11	89	1	7	17	10	8.88	

Tab 4.11: *t* Test for Nonstationarity of Avg. 3 Month SPI of all USHCN Stations by Season and Region and Time Scale (1911-1995)

region	month	time scale (months)	slope (units of SPI/year)	p-value	conclusion
West	1	3	0.001913	0.5763	stationary
West	2	3	-0.001460	0.6668	stationary
West	3	3	0.001347	0.7030	stationary
West	4	3	0.001962	0.5671	stationary
West	5	3	0.004224	0.1912	none
West	6	3	-0.000970	0.7491	stationary
West	7	3	0.001307	0.6401	stationary
West	8	3	0.006779	0.0245	none
West	9	3	0.006351	0.0338	none
West	10	3	0.003975	0.2084	stationary
West	11	3	0.005756	0.1196	none
West	12	3	0.002342	0.4788	stationary
Northwest	1	3	0.001573	0.6188	stationary
Northwest	2	3	0.000363	0.9113	stationary
Northwest	3	3	0.002703	0.3955	stationary
Northwest	4	3	0.005137	0.1044	none
Northwest	5	3	0.007432	0.0246	none
Northwest	6	3	0.005882	0.0746	none
Northwest	7	3	0.006988	0.0316	none
Northwest	8	3	0.008411	0.0058	nonstationary
Northwest	9	3	0.004971	0.1012	none
Northwest	10	3	0.000376	0.9168	stationary
Northwest	11	3	0.002029	0.6096	stationary
Northwest	12	3	0.002335	0.4850	stationary
West North Central	1	3	-0.000099	0.9641	stationary
West North Central	2	3	-0.004078	0.0413	none
West North Central	3	3	0.000693	0.6964	stationary
West North Central	4	3	0.001765	0.4248	stationary
West North Central	5	3	0.004944	0.0540	none
West North Central	6	3	0.003141	0.2277	stationary
West North Central	7	3	0.005360	0.0440	none
West North Central	8	3	0.003918	0.1249	none
West North Central	9	3	0.003001	0.2210	stationary
West North Central	10	3	0.000815	0.7331	stationary
West North Central	11	3	0.000702	0.7919	stationary
West North Central	12	3	0.000220	0.9270	stationary
Southwest	1	3	0.003658	0.1538	none
Southwest	2	3	-0.001111	0.6619	stationary
Southwest	3	3	0.000048	0.9849	stationary
Southwest	4	3	-0.001782	0.4701	stationary
Southwest	5	3	0.001500	0.5578	stationary
Southwest	6	3	0.000341	0.8839	stationary
Southwest	7	3	-0.000508	0.8136	stationary
Southwest	8	3	-0.000004	0.9987	stationary
Southwest	9	3	0.000107	0.9608	stationary
Southwest	10	3	0.002188	0.3631	stationary
Southwest	11	3	0.003064	0.2563	stationary
Southwest	12	3	0.002425	0.4133	stationary
South	1	3	0.003544	0.2183	stationary
South	2	3	0.001204	0.6691	stationary
South	3	3	0.002869	0.2884	stationary
South	4	3	0.001126	0.6722	stationary
South	5	3	0.003646	0.1222	none
South	6	3	0.004234	0.0640	none

region	month	time scale (months)	slope (units of SPI/year)	p-value	conclusion
South	7	3	0.006074	0.0056	nonstationary
South	8	3	0.002002	0.4080	stationary
South	9	3	0.001645	0.4443	stationary
South	10	3	0.001682	0.4855	stationary
South	11	3	0.005025	0.0604	none
South	12	3	0.003134	0.3210	stationary
Central	1	3	0.004116	0.2239	stationary
Central	2	3	0.000062	0.9840	stationary
Central	3	3	-0.003950	0.2020	stationary
Central	4	3	0.001214	0.6848	stationary
Central	5	3	0.002709	0.4281	stationary
Central	6	3	0.002465	0.4691	stationary
Central	6	3	0.002465	0.4691	stationary
Central	7	3	0.006527	0.0436	none
Central	8	3	0.003619	0.1830	none
Central	9	3	0.002937	0.2480	stationary
Central	10	3	-0.001183	0.6619	stationary
Central	11	3	0.004070	0.2010	stationary
Central	12	3	0.006500	0.0549	none
East North Central	1	3	0.005895	0.0788	none
East North Central	2	3	-0.000480	0.8716	stationary
East North Central	3	3	0.000968	0.7088	stationary
East North Central	4	3	0.005265	0.0555	none
East North Central	5	3	0.004656	0.1207	none
East North Central	6	3	0.001963	0.4896	stationary
East North Central	7	3	0.004082	0.1333	none
East North Central	8	3	0.008746	0.0006	nonstationary
East North Central	9	3	0.007966	0.0017	nonstationary
East North Central	10	3	0.005593	0.0308	none
East North Central	11	3	0.003821	0.2043	stationary
East North Central	12	3	0.006008	0.0574	none
Northeast	1	3	0.005810	0.0674	none
Northeast	2	3	0.000936	0.7500	stationary
Northeast	3	3	-0.001287	0.6441	stationary
Northeast	4	3	0.000765	0.8073	stationary
Northeast	5	3	0.003754	0.2810	stationary
Northeast	6	3	0.002506	0.4128	stationary
Northeast	7	3	0.001195	0.6745	stationary
Northeast	8	3	0.000050	0.9842	stationary
Northeast	9	3	0.001362	0.5782	stationary
Northeast	10	3	0.002358	0.3765	stationary
Northeast	11	3	0.007405	0.0121	none
Northeast	12	3	0.008237	0.0171	none
Southeast	1	3	0.005511	0.0997	none
Southeast	2	3	0.001777	0.6054	stationary
Southeast	3	3	0.005695	0.0857	none
Southeast	4	3	0.002300	0.4803	stationary
Southeast	5	3	0.003528	0.2851	stationary
Southeast	6	3	0.000990	0.7288	stationary
Southeast	7	3	-0.000850	0.7651	stationary
Southeast	8	3	-0.002434	0.3528	stationary
Southeast	9	3	-0.002459	0.3117	stationary
Southeast	10	3	0.001514	0.5496	stationary
Southeast	11	3	0.005112	0.0873	none
Southeast	12	3	0.004854	0.1432	none

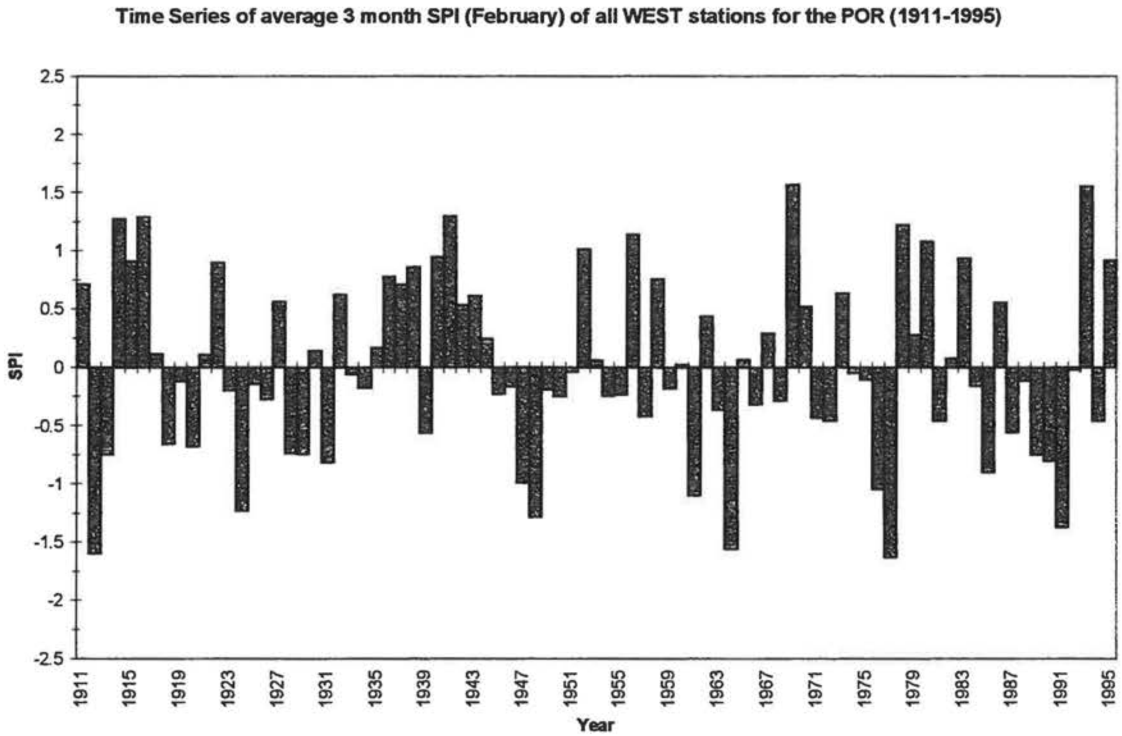


Fig 4.23(A) Time series of average 3 month SPI for February (winter) of all West stations for the period January, 1911 through December, 1995.

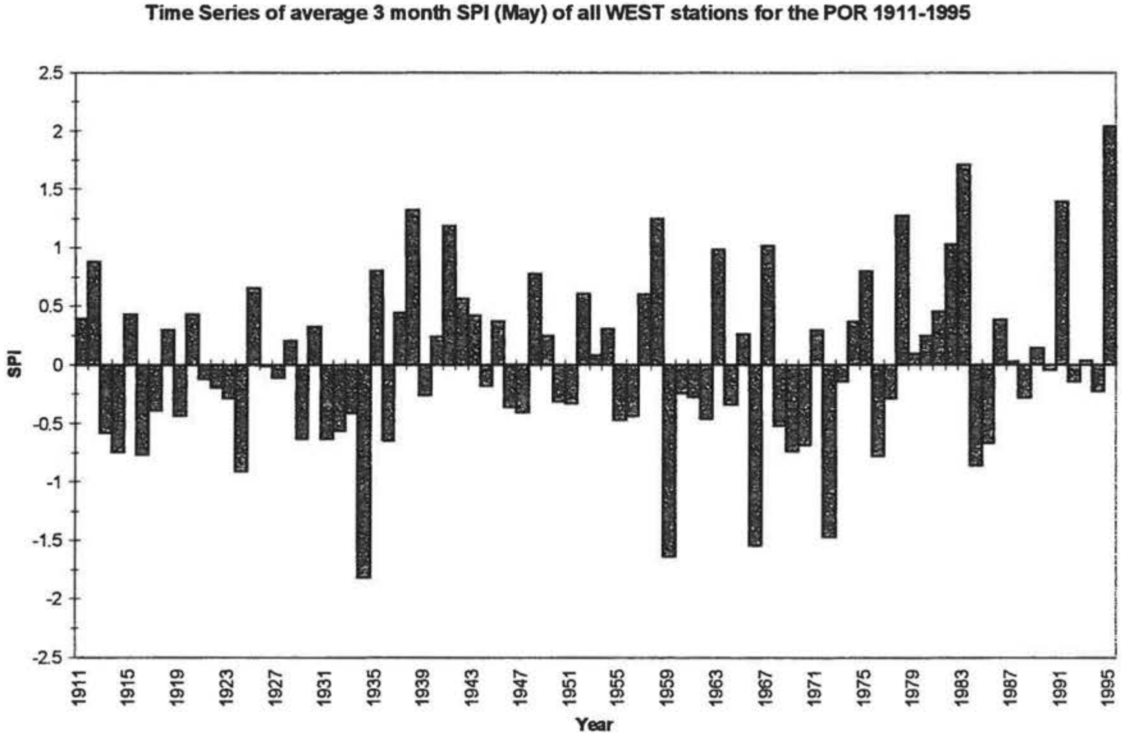


Fig 4.23(B) Time series of average 3 month SPI for May (spring) of all West stations for the period January, 1911 through December, 1995.

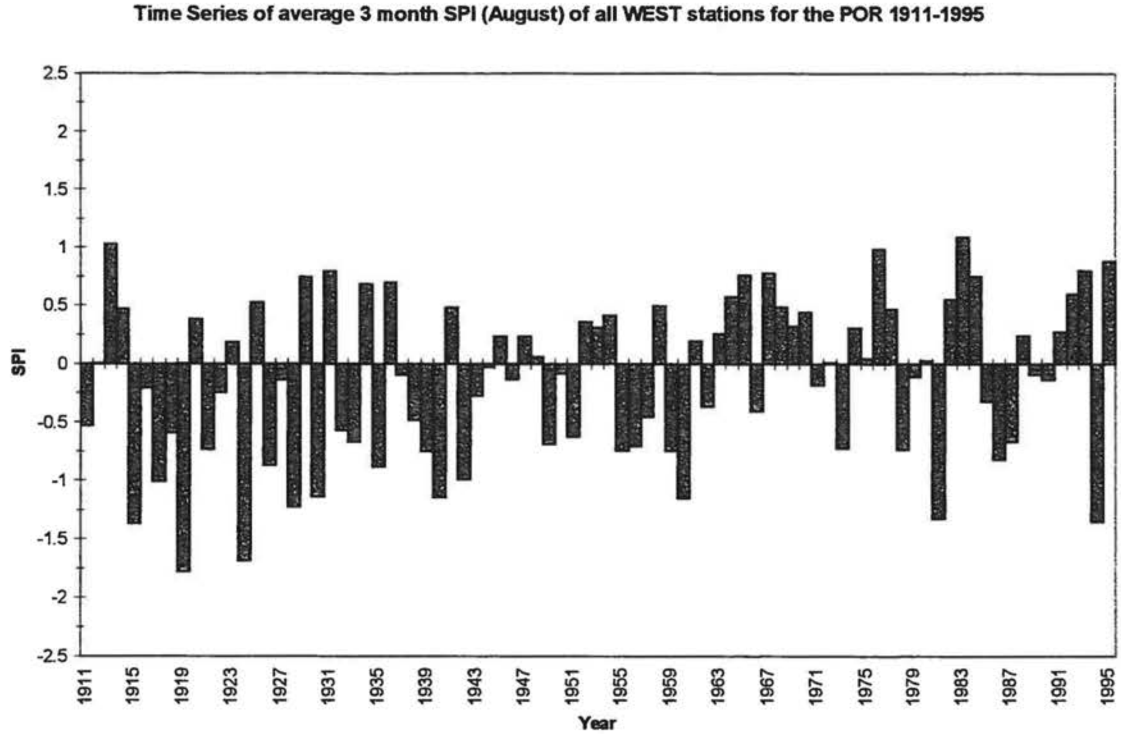


Fig 4.23(C) Time series of average 3 month SPI for August (summer) of all West stations for the period January, 1911 through December, 1995.

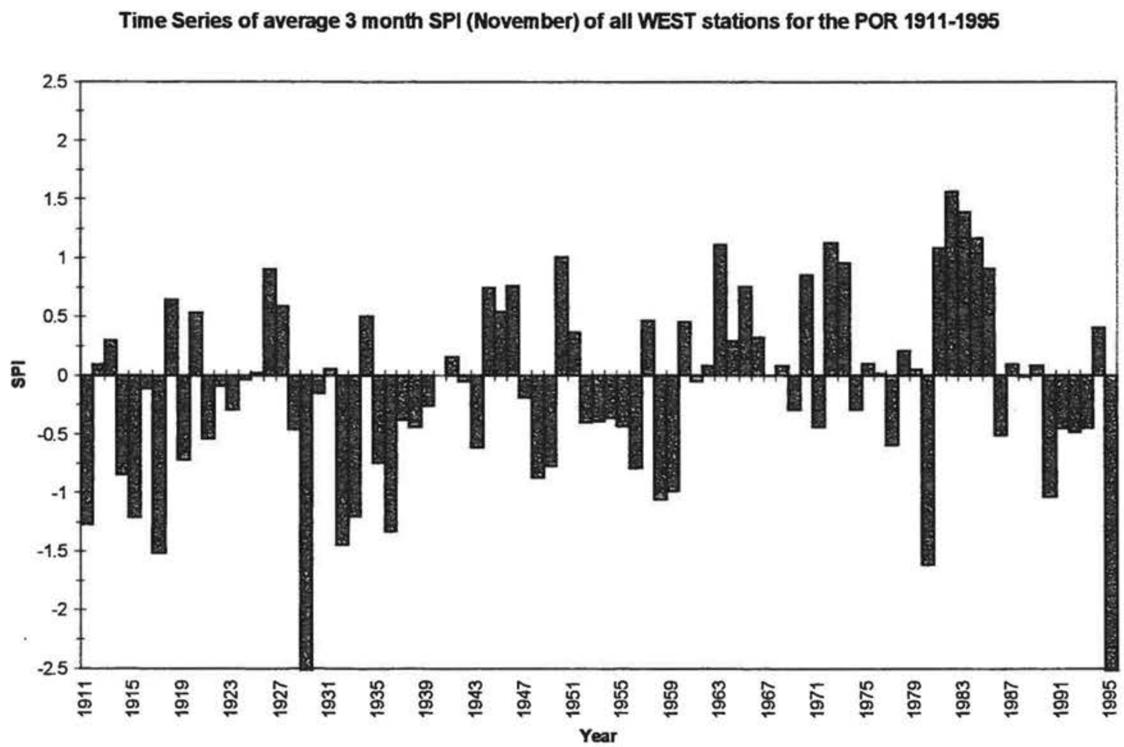


Fig 4.23(D) Time series of average 3 month SPI for November (autumn) of all West stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Feb) of all NORTHWEST stations for the POR 1911-1995

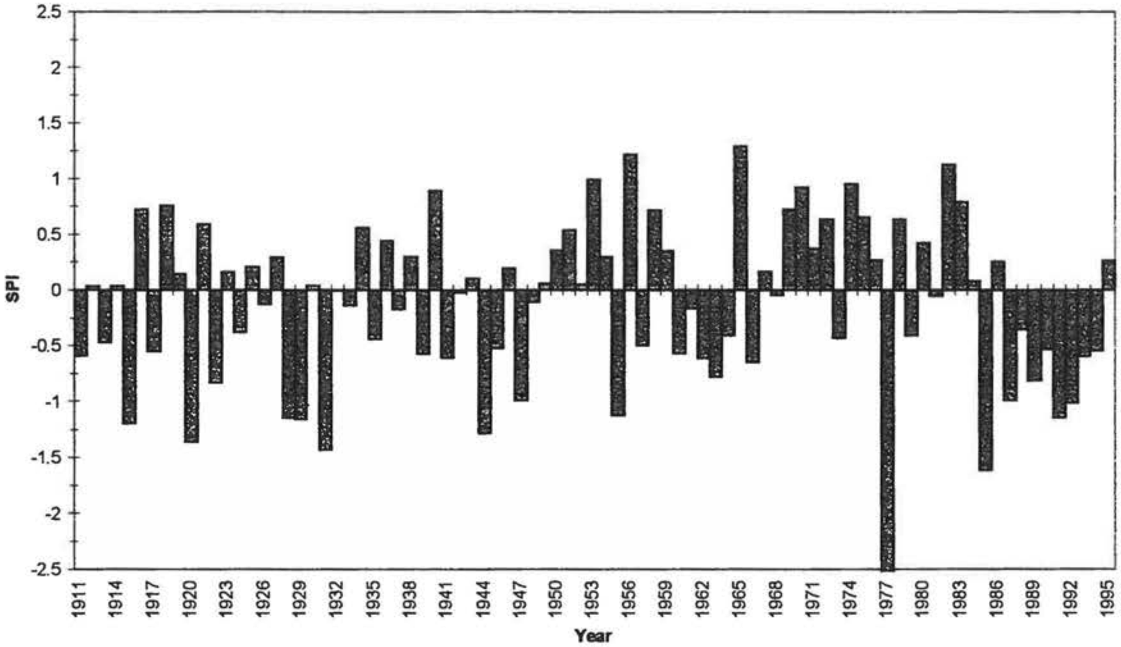


Fig 4.24(A) Time series of average 3 month SPI for February (winter) of all Northwest stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (May) of all NORTHWEST stations for the POR 1911-1995

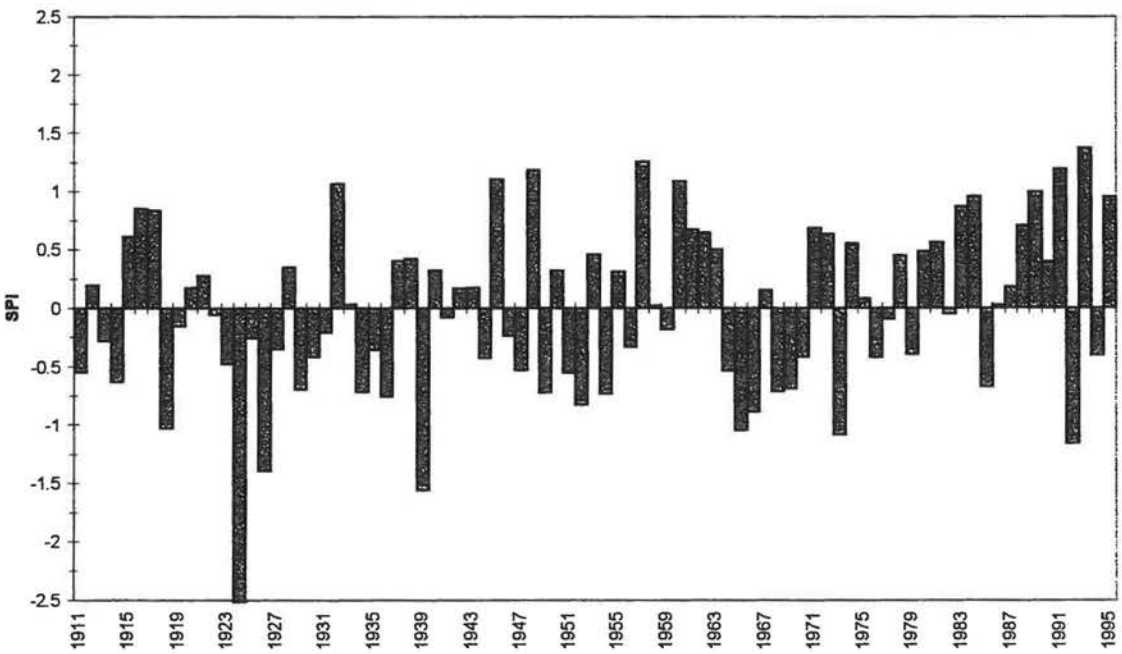


Fig 4.24(B) Time series of average 3 month SPI for May (spring) of all Northwest stations for the period January, 1911 through December, 1995.

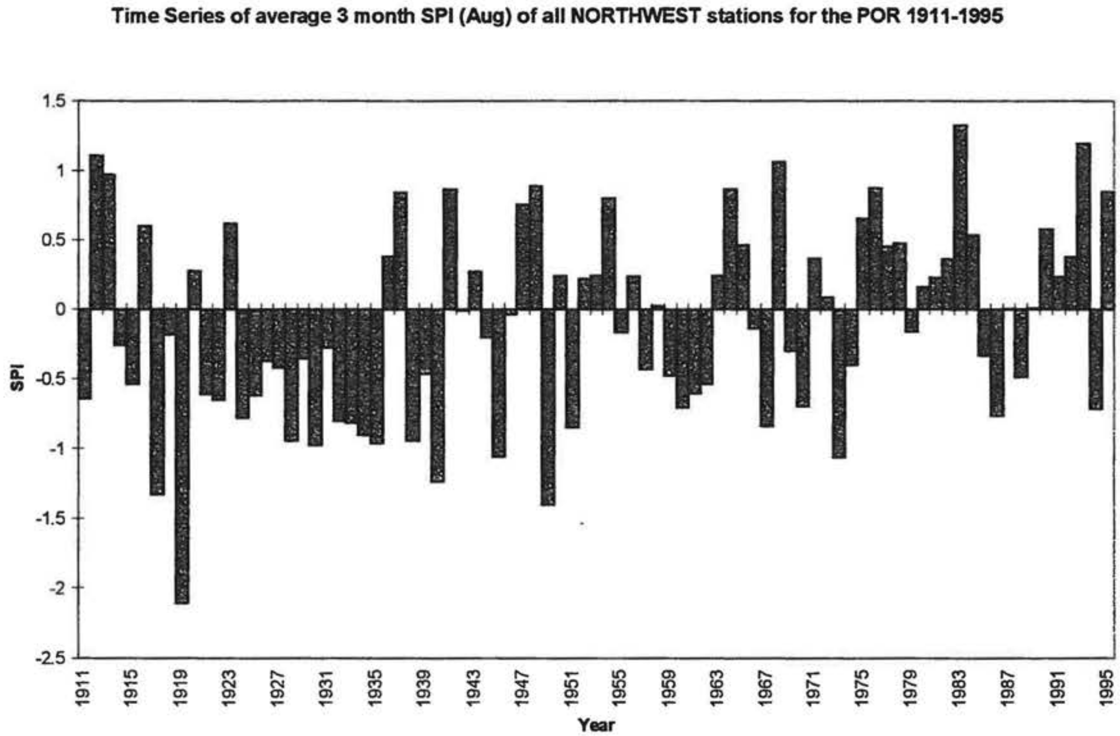


Fig 4.24(C) Time series of average 3 month SPI for August (summer) of all Northwest stations for the period January, 1911 through December, 1995.

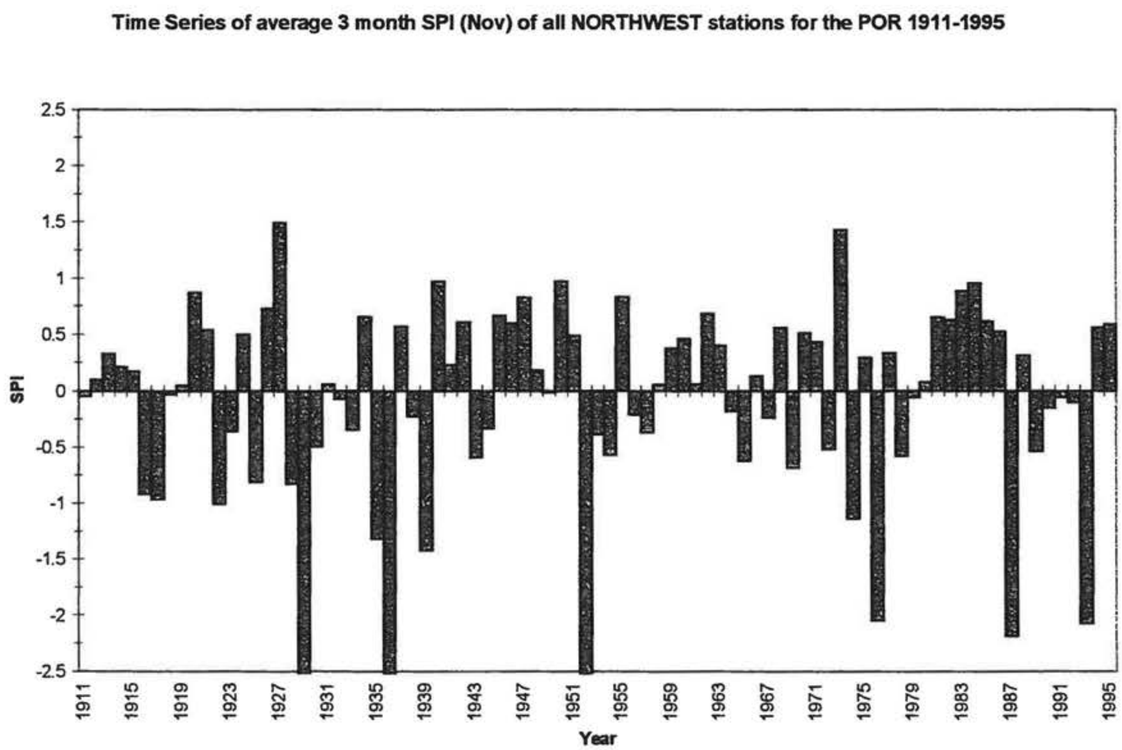


Fig 4.24(D) Time series of average 3 month SPI for November (autumn) of all Northwest stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Feb) of all W. N. CEN. stations for the POR 1911-1995

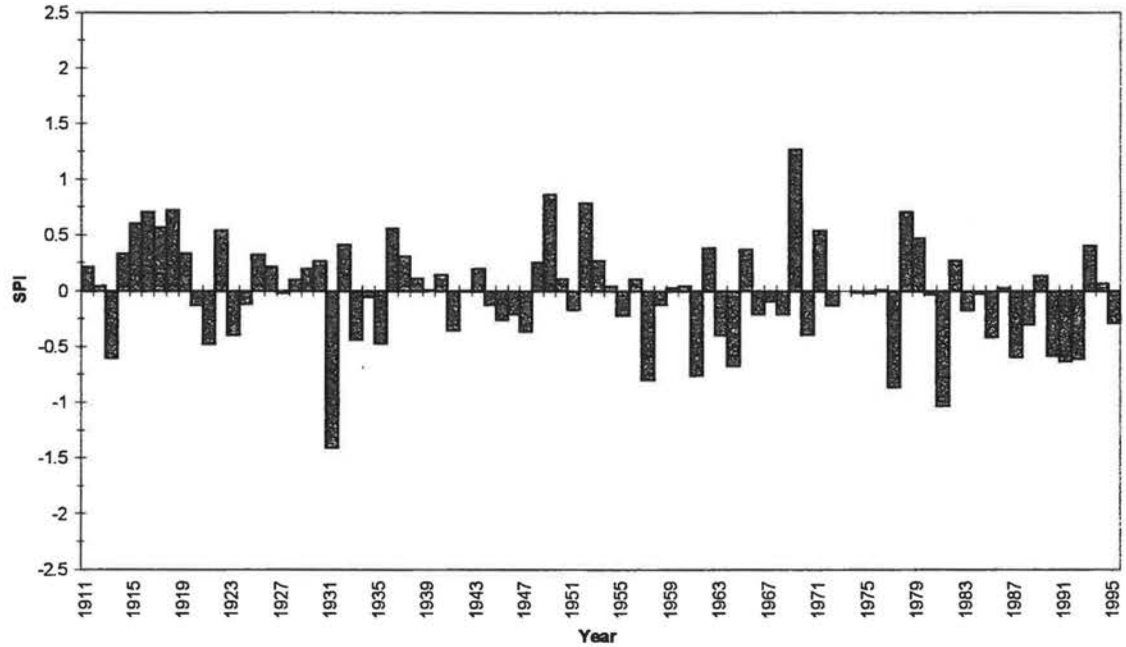


Fig 4.25(A) Time series of average 3 month SPI for February (winter) of all West North Central stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (May) of all W. N. CEN. stations for the POR (1911-1995)

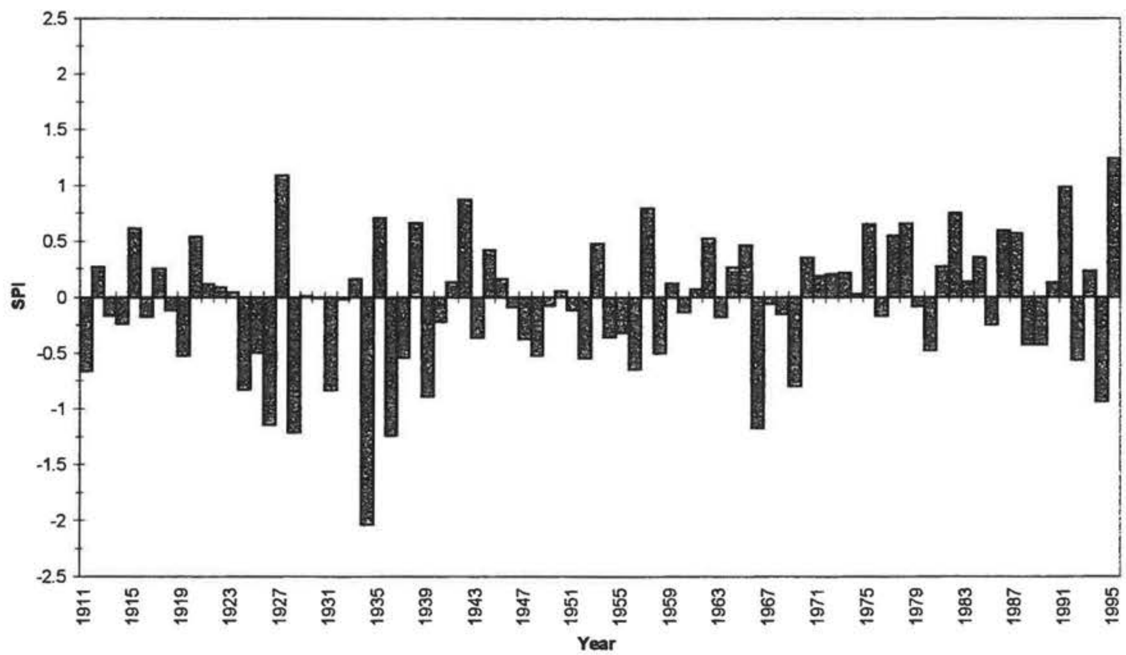


Fig 4.25(B) Time series of average 3 month SPI for May (spring) of all West North Central stations for the period January, 1911 through December, 1995.

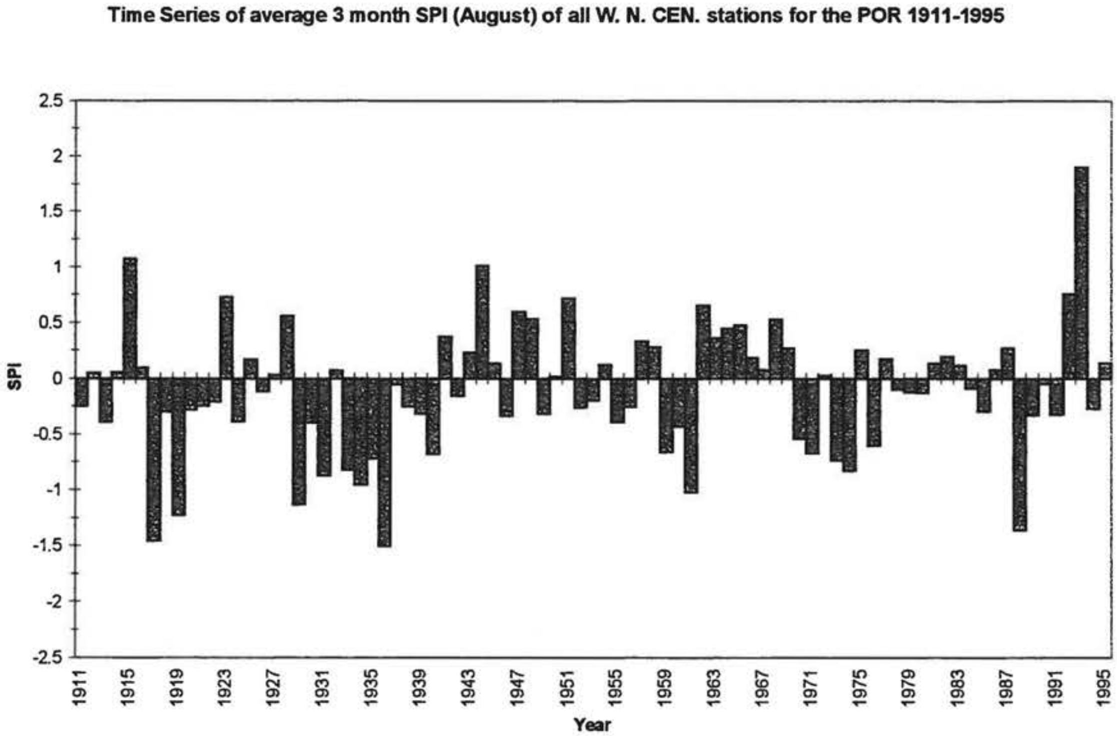


Fig 4.25(C) Time series of average 3 month SPI for August (summer) of all West North Central stations for the period January, 1911 through December, 1995.

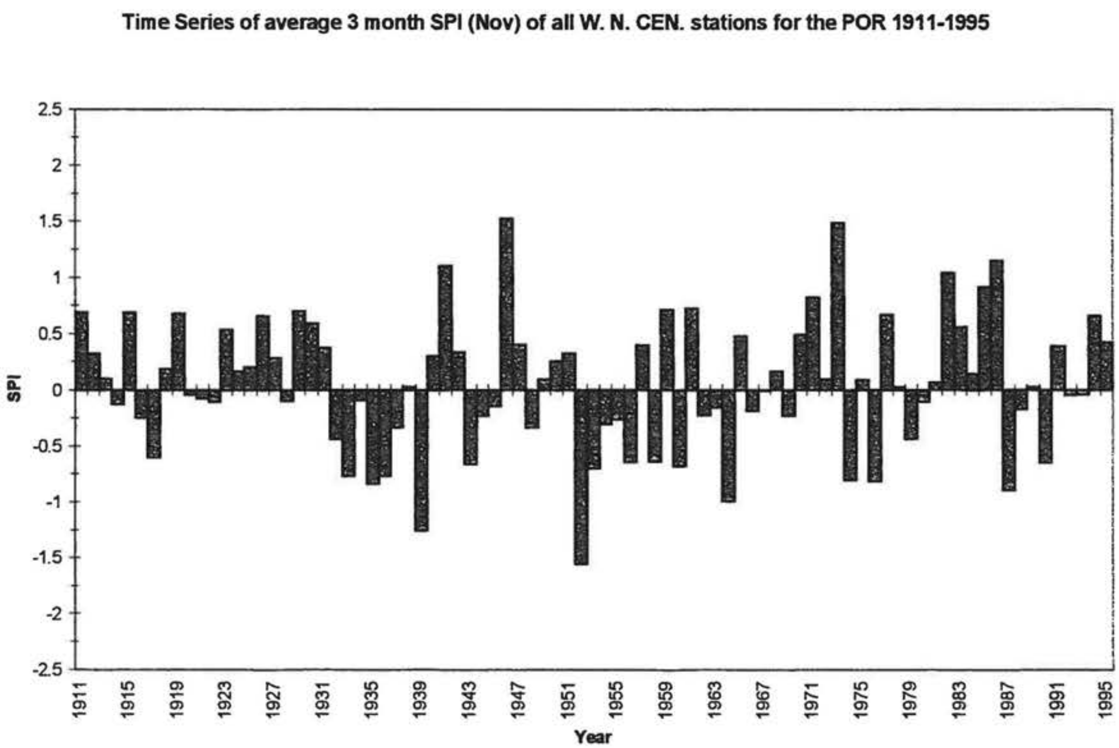


Fig 4.25(D) Time series of avg. 3 month SPI for November (autumn) of all West North Central stations for the period January, 1911 through December, 1995.

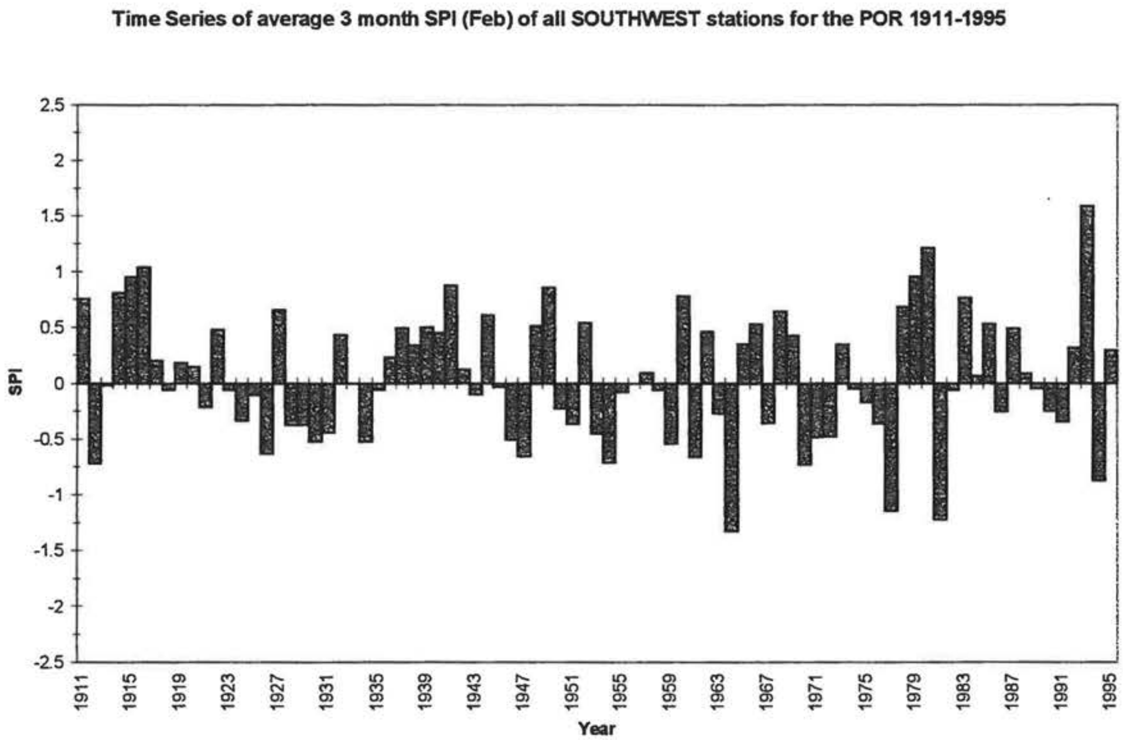


Fig 4.26(A) Time series of average 3 month SPI for February (winter) of all Southwest stations for the period January, 1911 through December, 1995.

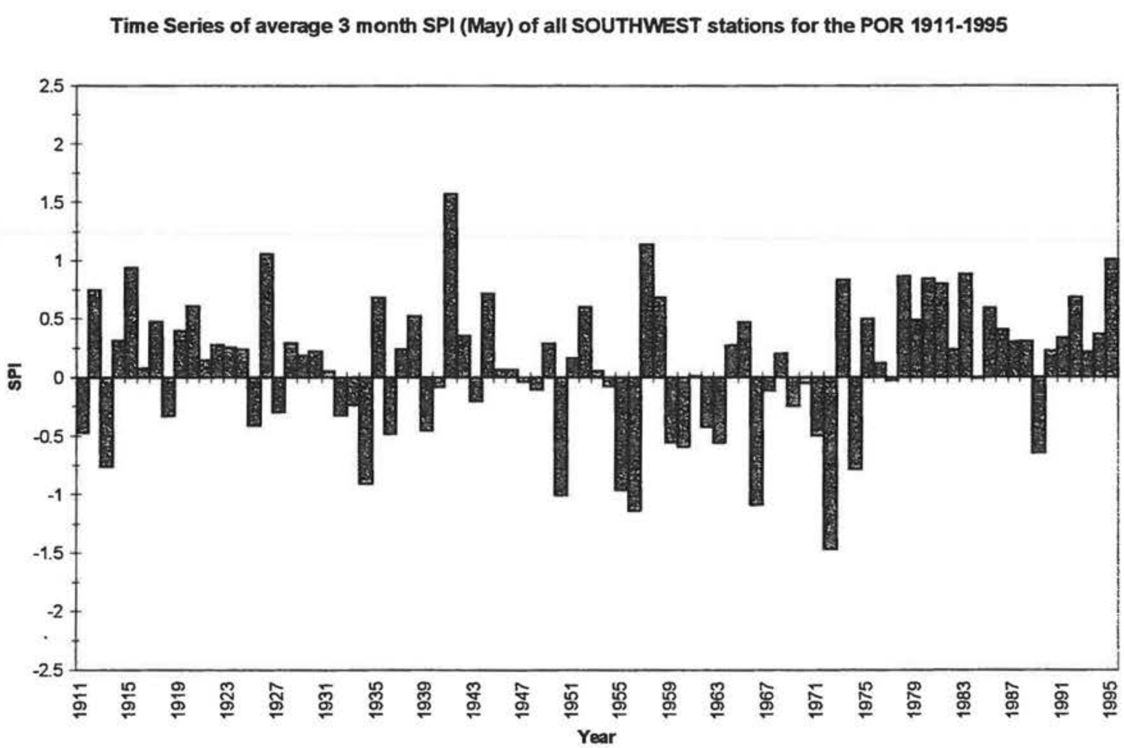


Fig 4.26(B) Time series of average 3 month SPI for May (spring) of all Southwest stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Aug) of all SOUTHWEST stations for the POR 1911-1995

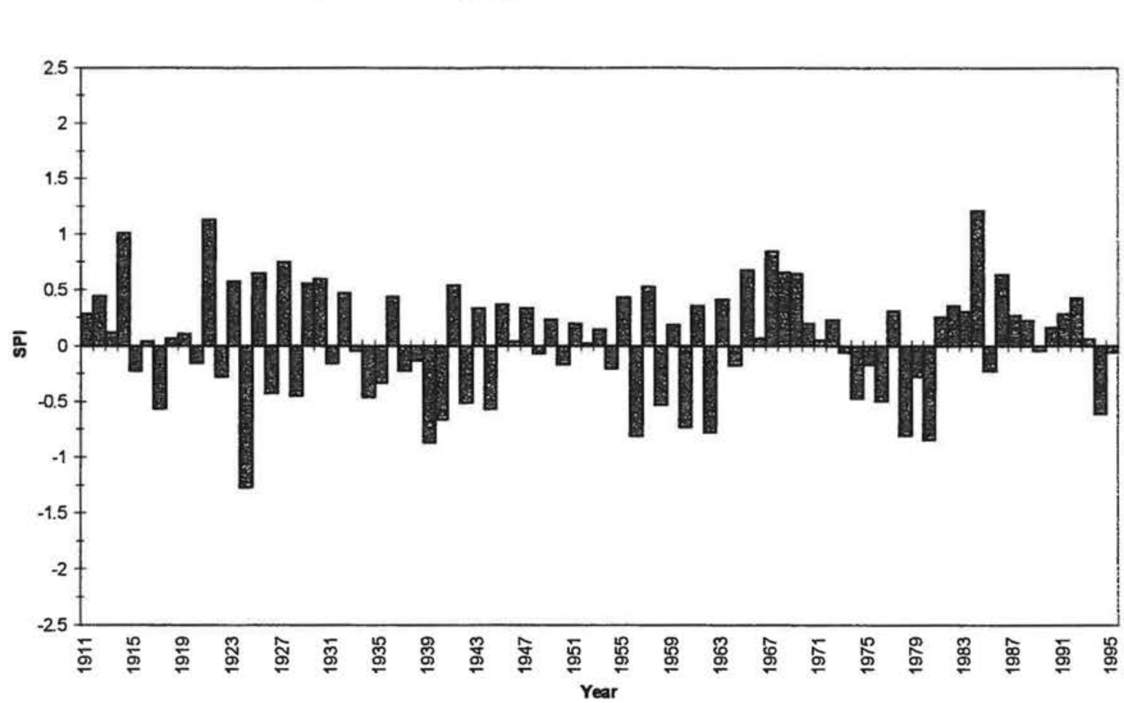


Fig 4.26(C) Time series of average 3 month SPI for August (summer) of all Southwest stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Nov) of all SOUTHWEST stations for the POR 1911-1995

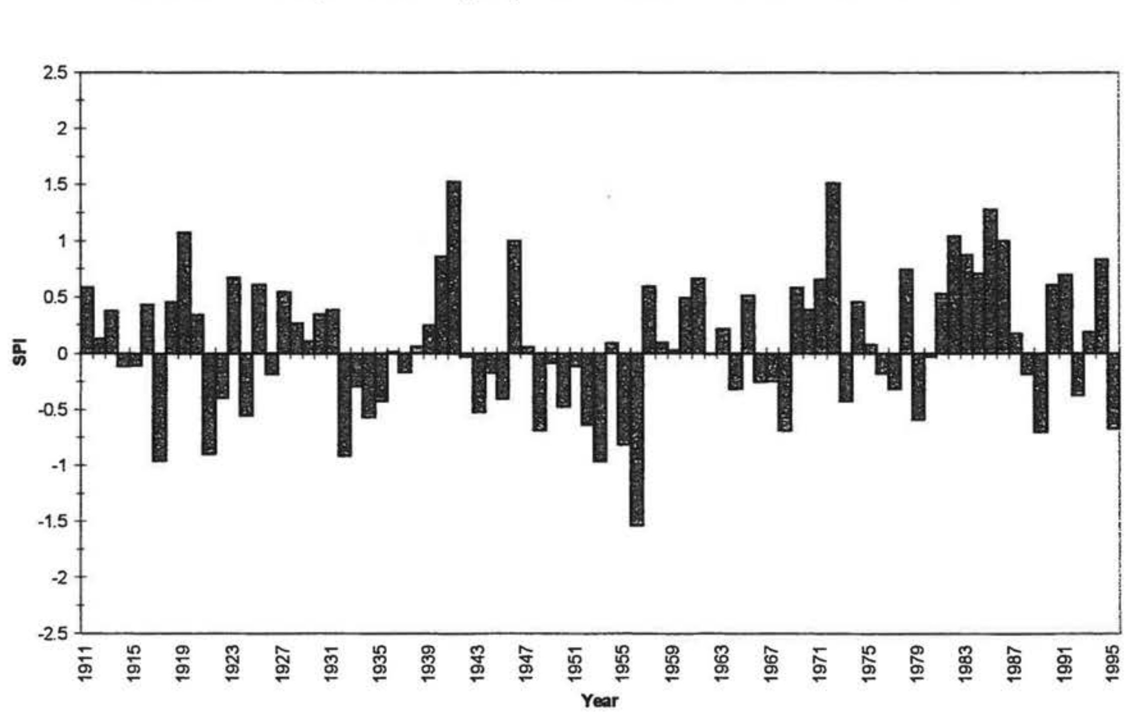


Fig 4.26(D) Time series of average 3 month SPI for November (winter) of all Southwest stations for the period January, 1911 through December, 1995.

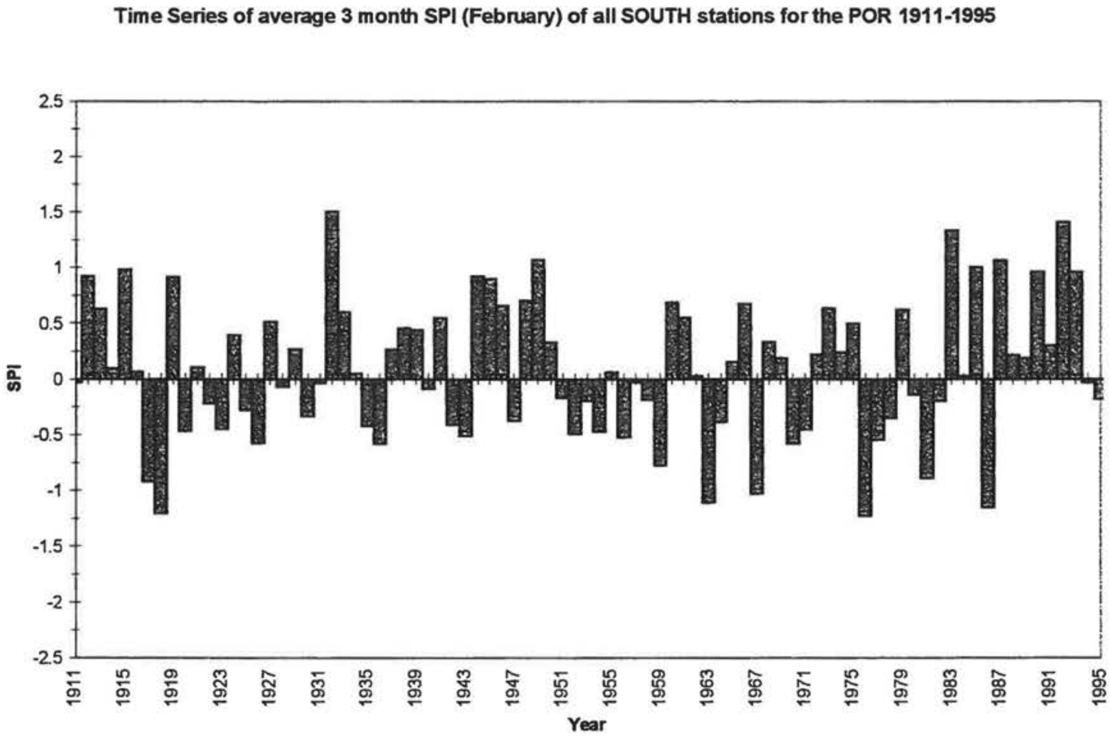


Fig 4.27(A) Time series of average 3 month SPI for February (winter) of all South stations for the period January, 1911 through December, 1995.

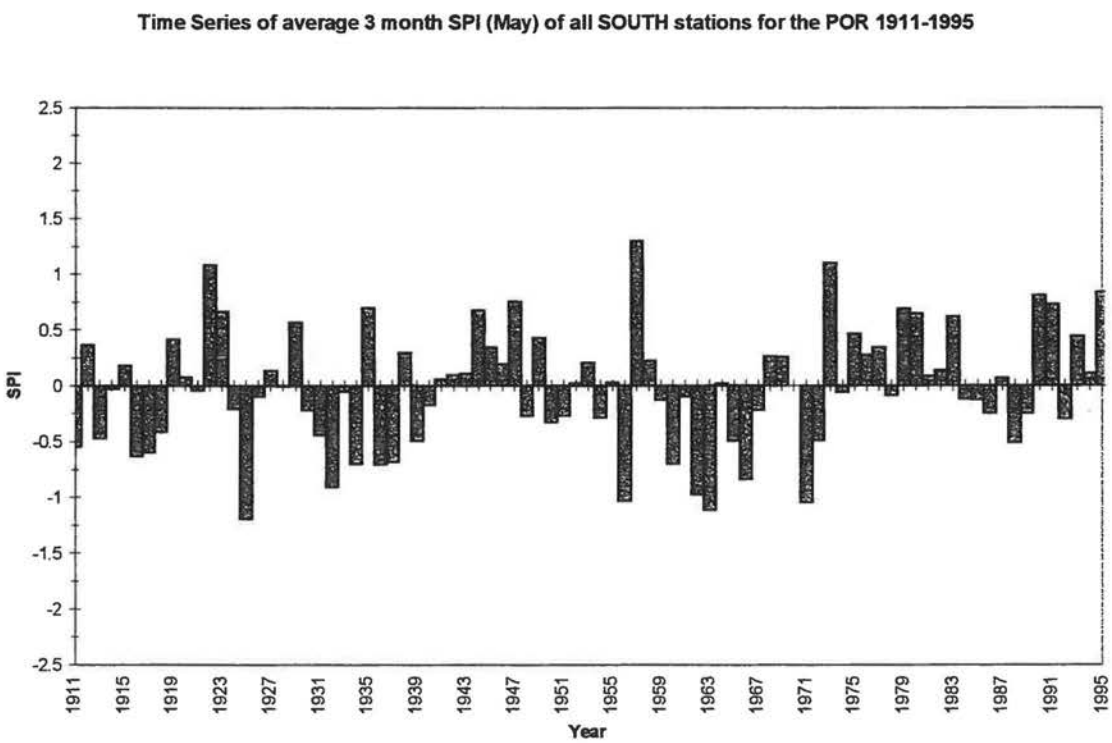


Fig 4.27(B) Time series of average 3 month SPI for May (spring) of all South stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (August) of all SOUTH stations for the POR 1911-1995

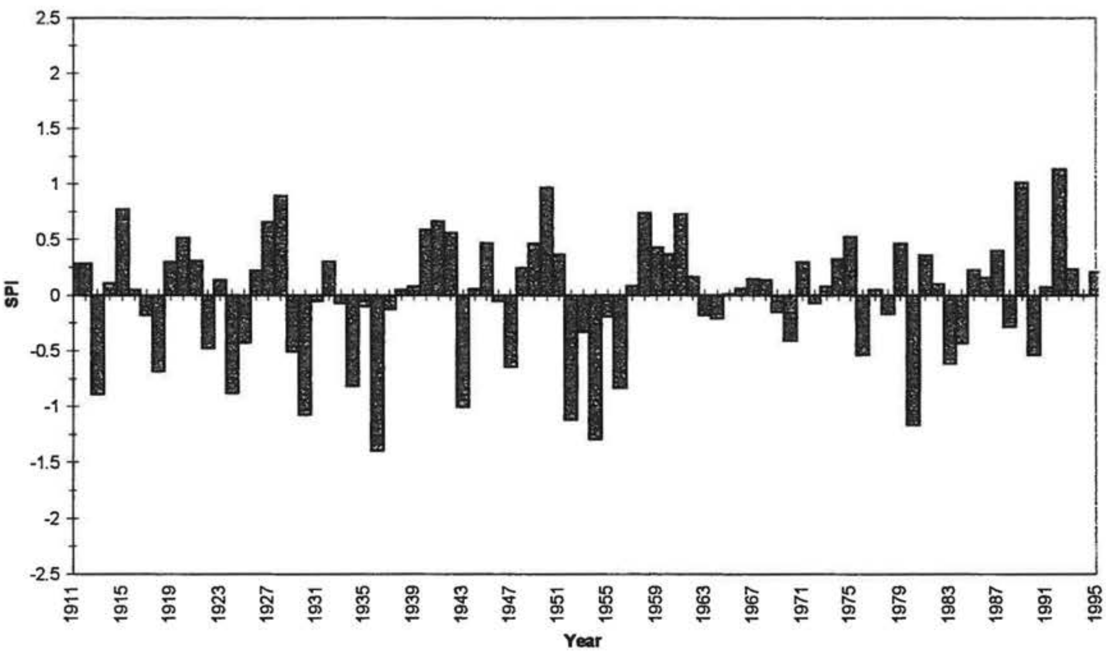


Fig 4.27(C) Time series of average 3 month SPI for August (summer) of all South stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (November) of all SOUTH stations for the POR 1911-1995

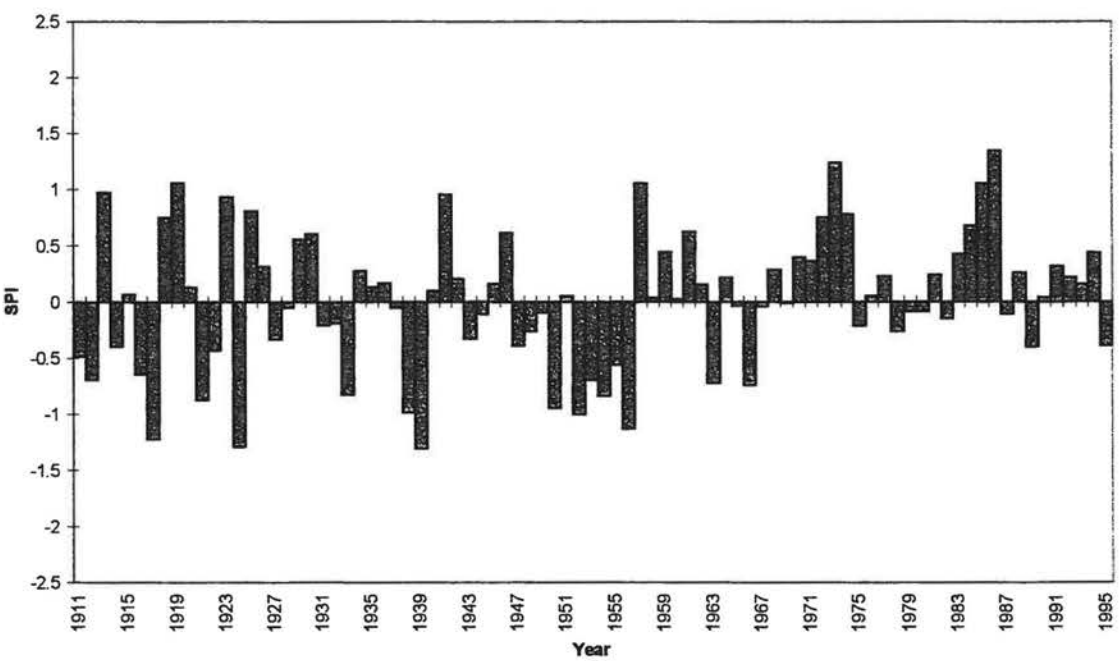


Fig 4.27(D) Time series of average 3 month SPI for November (autumn) of all South stations for the period January, 1911 through December, 1995.

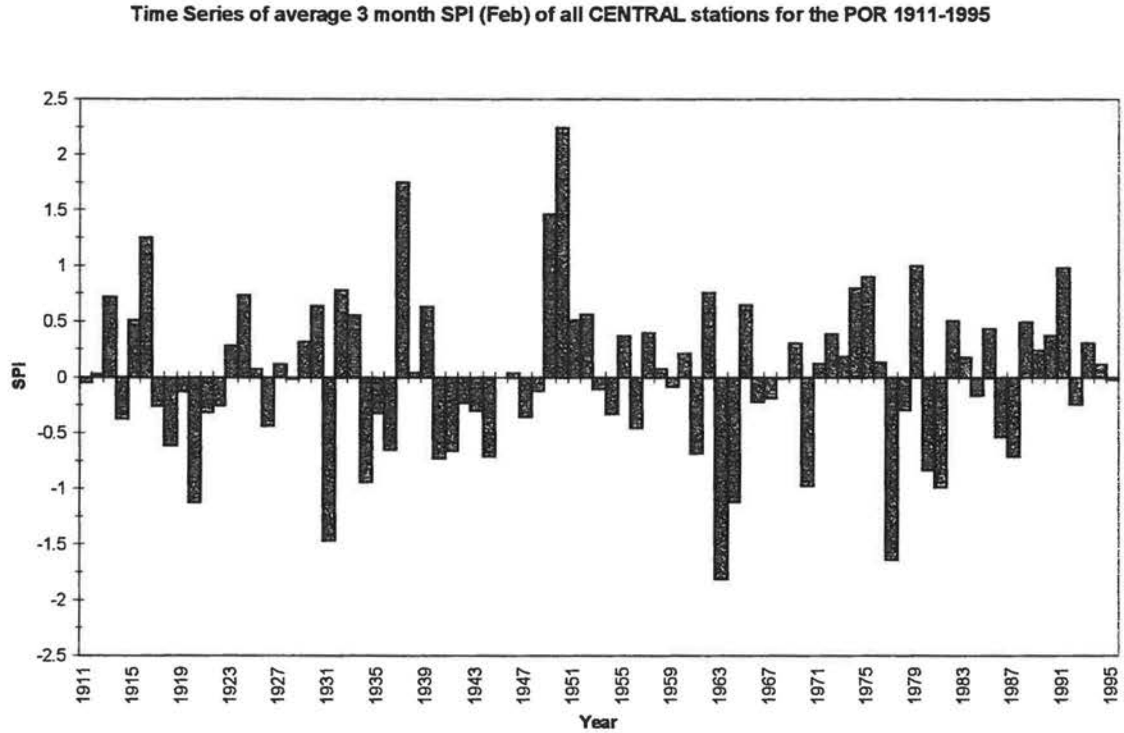


Fig 4.28(A) Time series of average 3 month SPI for February (winter) of all Central stations for the period January, 1911 through December, 1995.

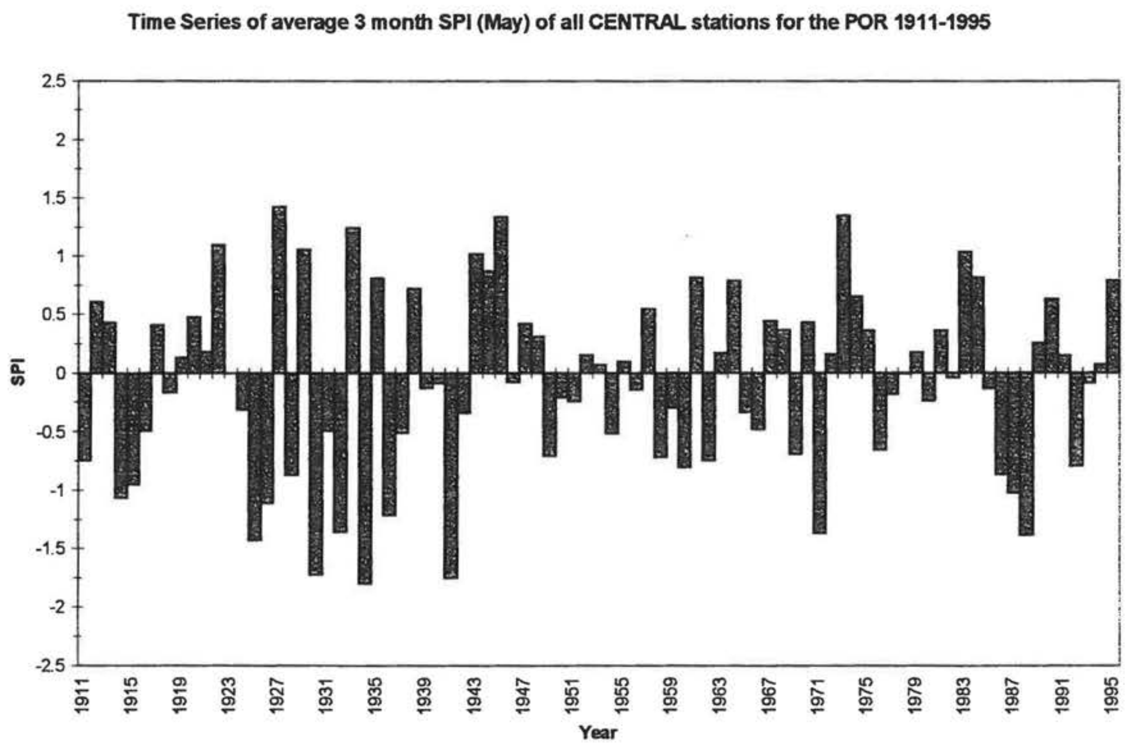


Fig 4.28(B) Time series of average 3 month SPI for May (spring) of all Central stations for the period January, 1911 through December, 1995.

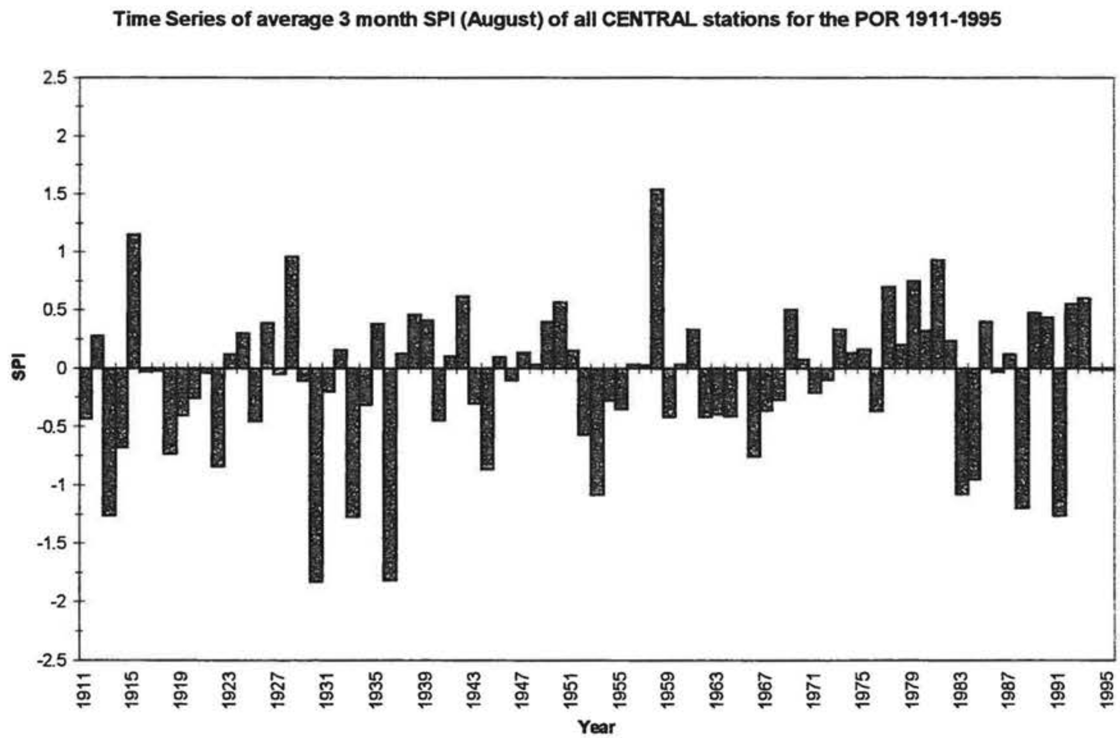


Fig 4.28(C) Time series of average 3 month SPI for August (summer) of all Central stations for the period January, 1911 through December, 1995.

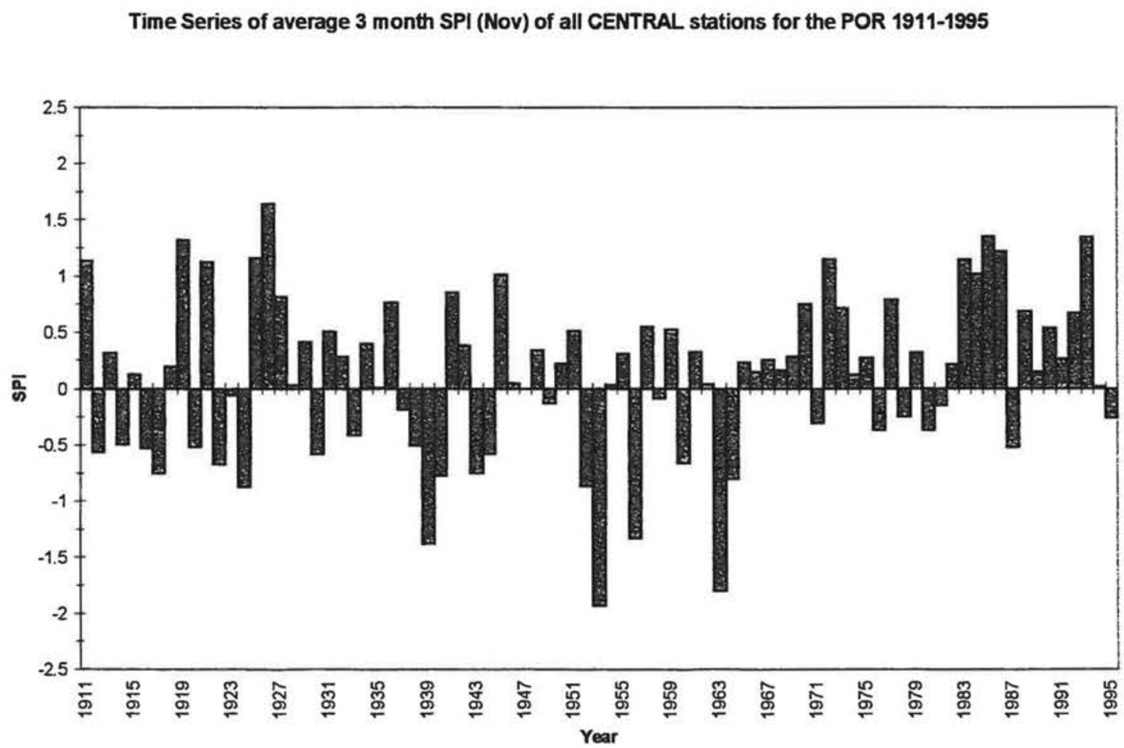


Fig 4.28(D) Time series of average 3 month SPI for November (autumn) of all Central stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Feb) of all E. N. CEN. stations for the POR 1911-1995

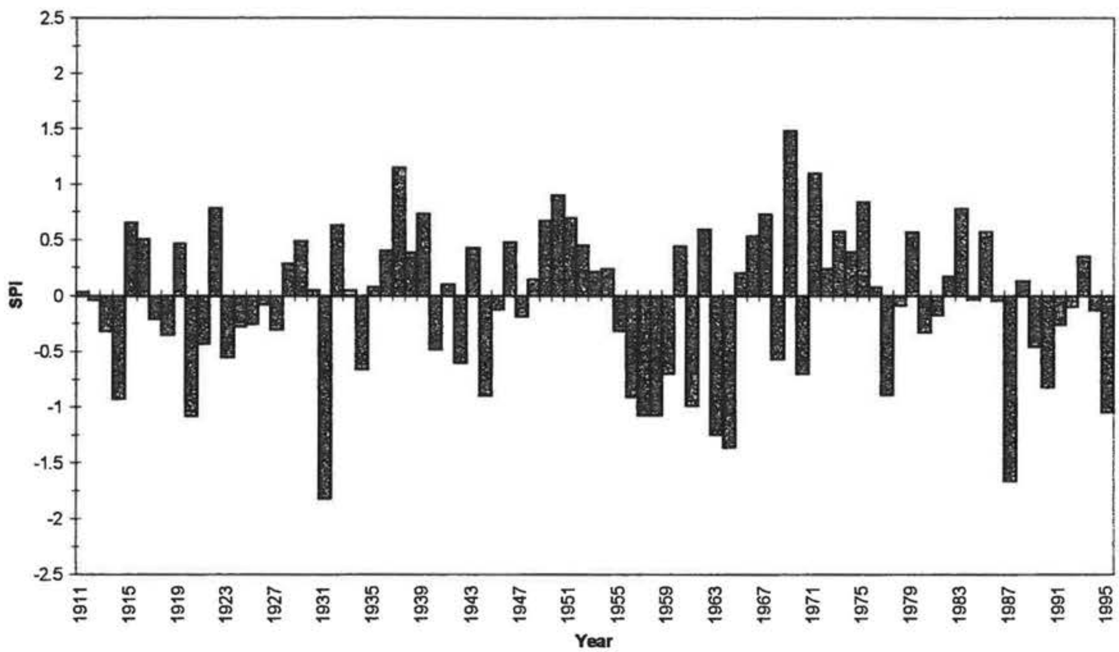


Fig 4.29(A) Time series of average 3 month SPI for February (winter) of all East North Central stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (May) of all E. N. CEN. stations for the POR 1911-1995

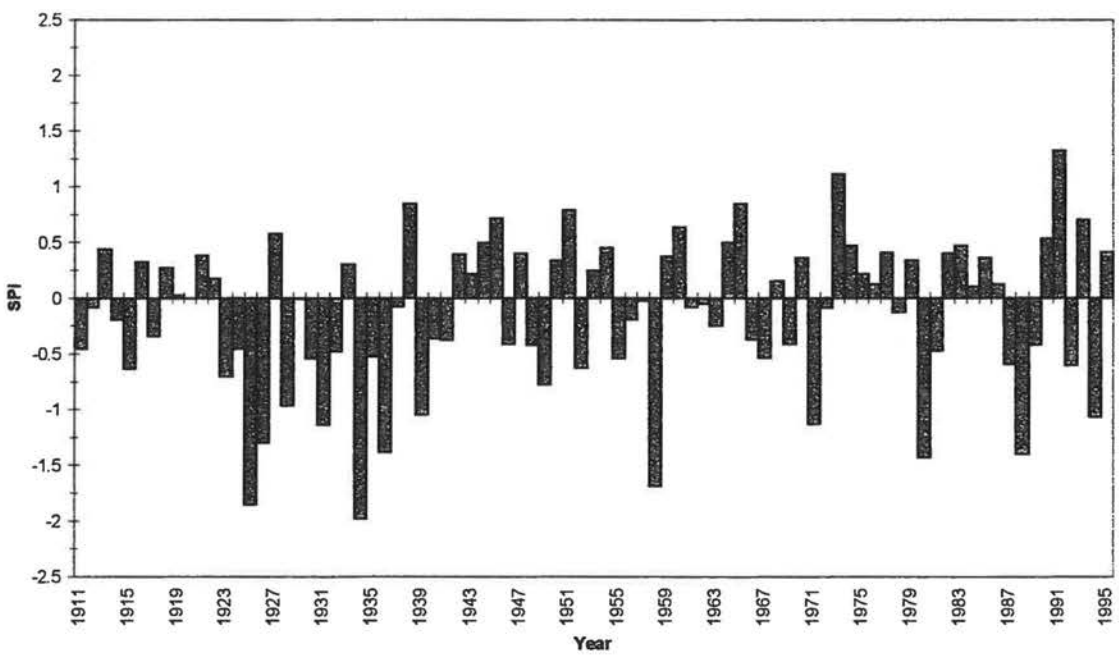


Fig 4.29(B) Time series of average 3 month SPI for May (spring) of all East North Central stations for the period January, 1911 through December, 1995.

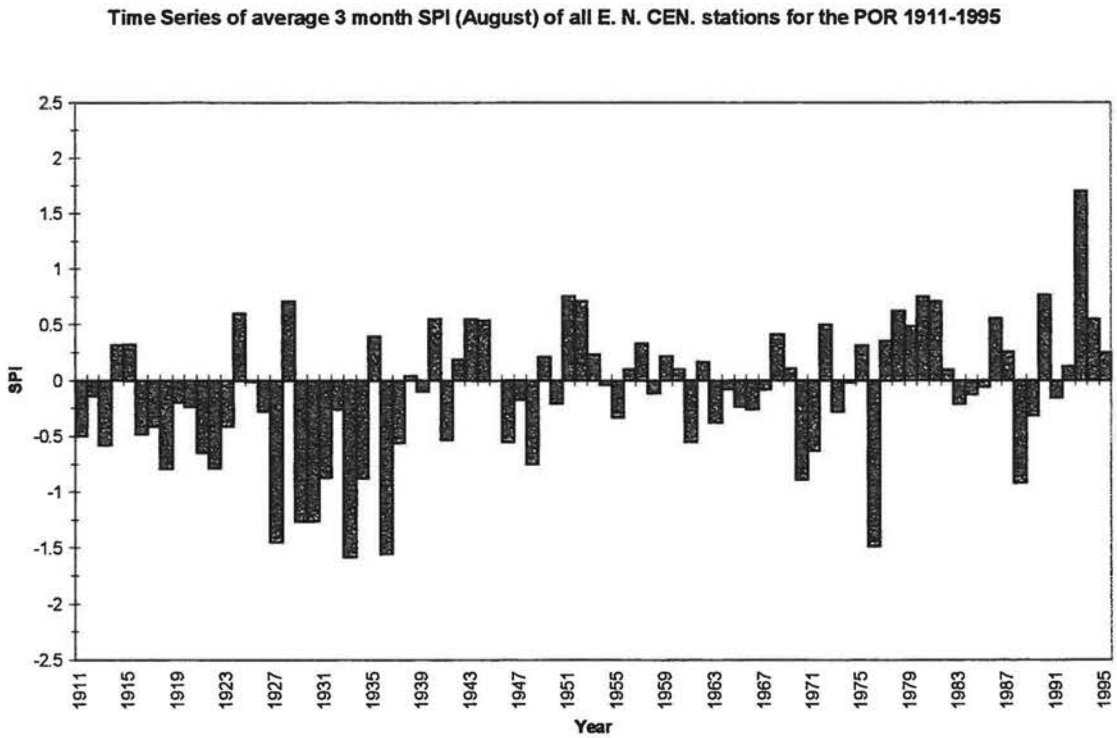


Fig 4.29(C) Time series of average 3 month SPI for August (summer) of all East North Central stations for the period January, 1911 through December, 1995.

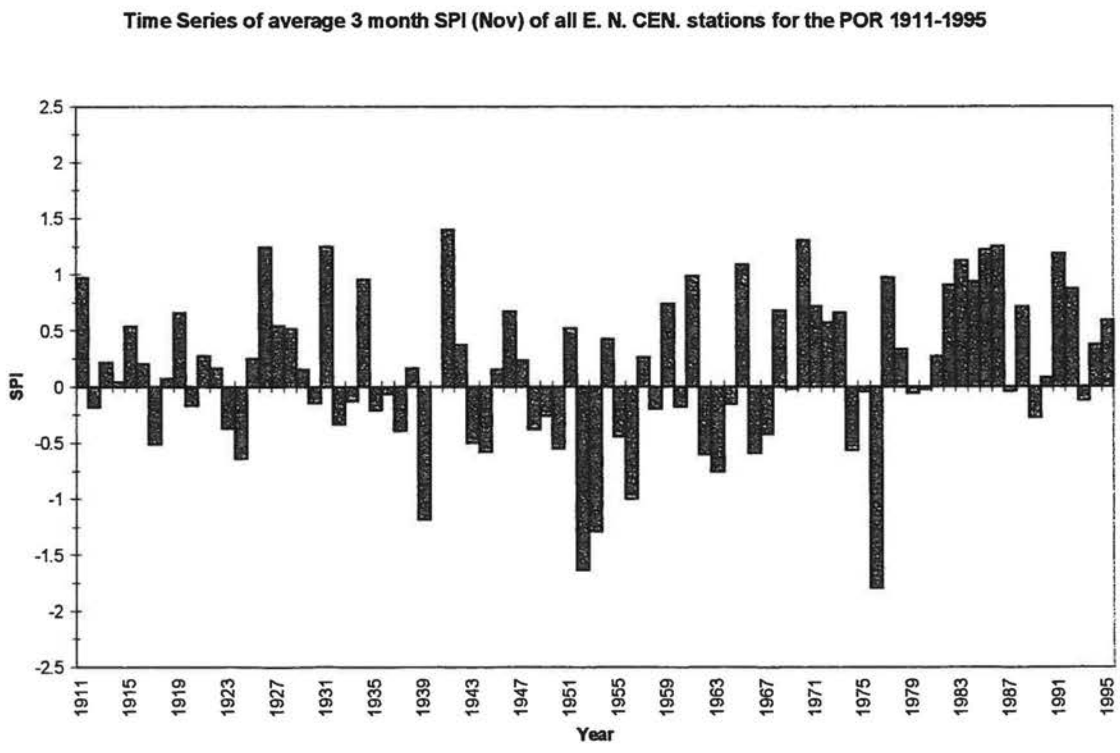


Fig 4.29(D) Time series of avg. 3 month SPI for November (autumn) of all East North Central stations for the period January, 1911 through December, 1995.

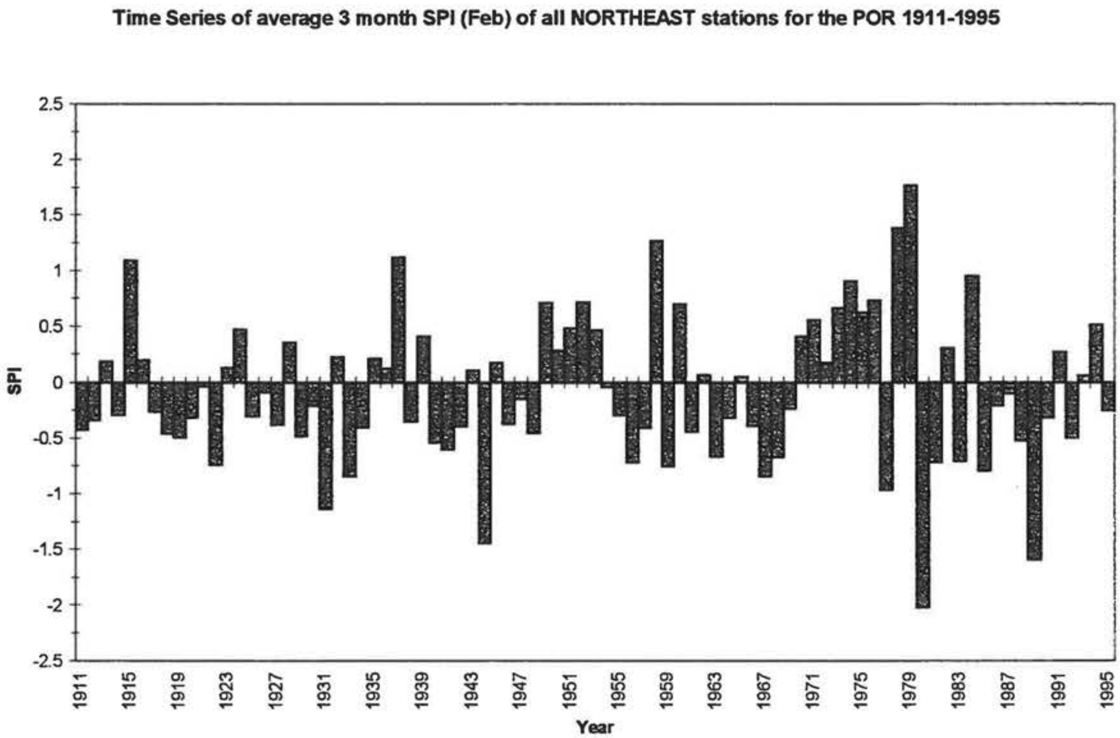


Fig 4.30(A) Time series of average 3 month SPI for February (winter) of all Northeast stations for the period January, 1911 through December, 1995.

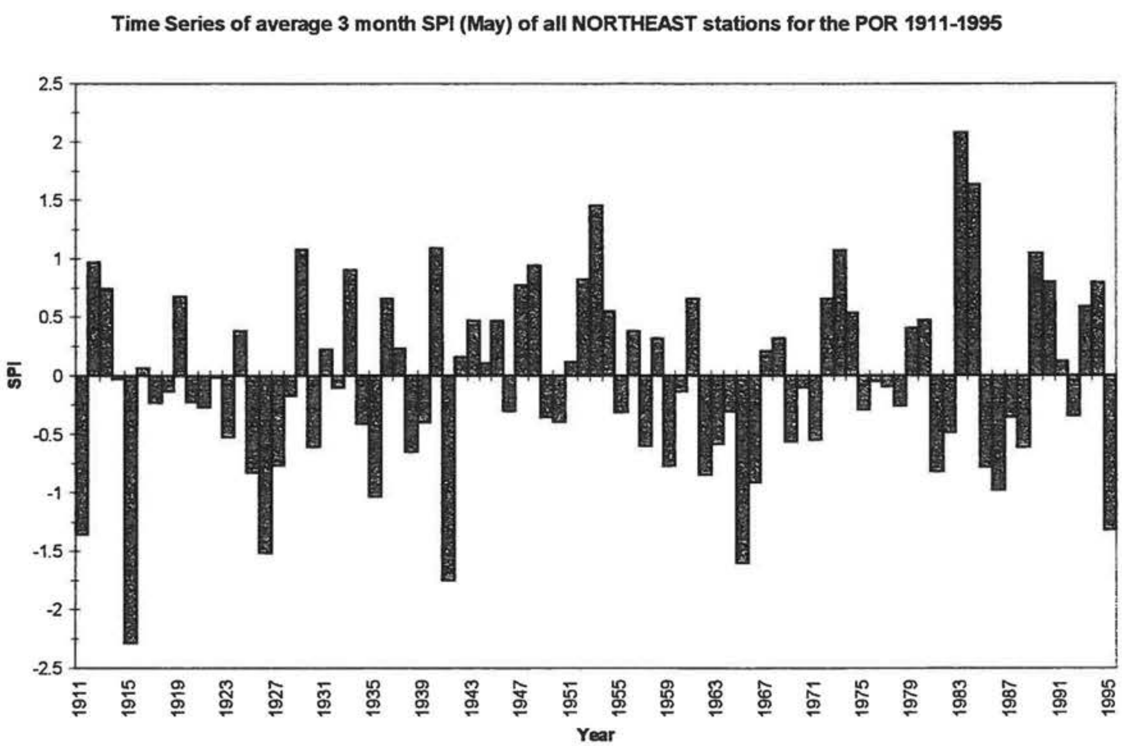


Fig 4.30(B) Time series of average 3 month SPI for May (spring) of all Northeast stations for the period January, 1911 through December, 1995.

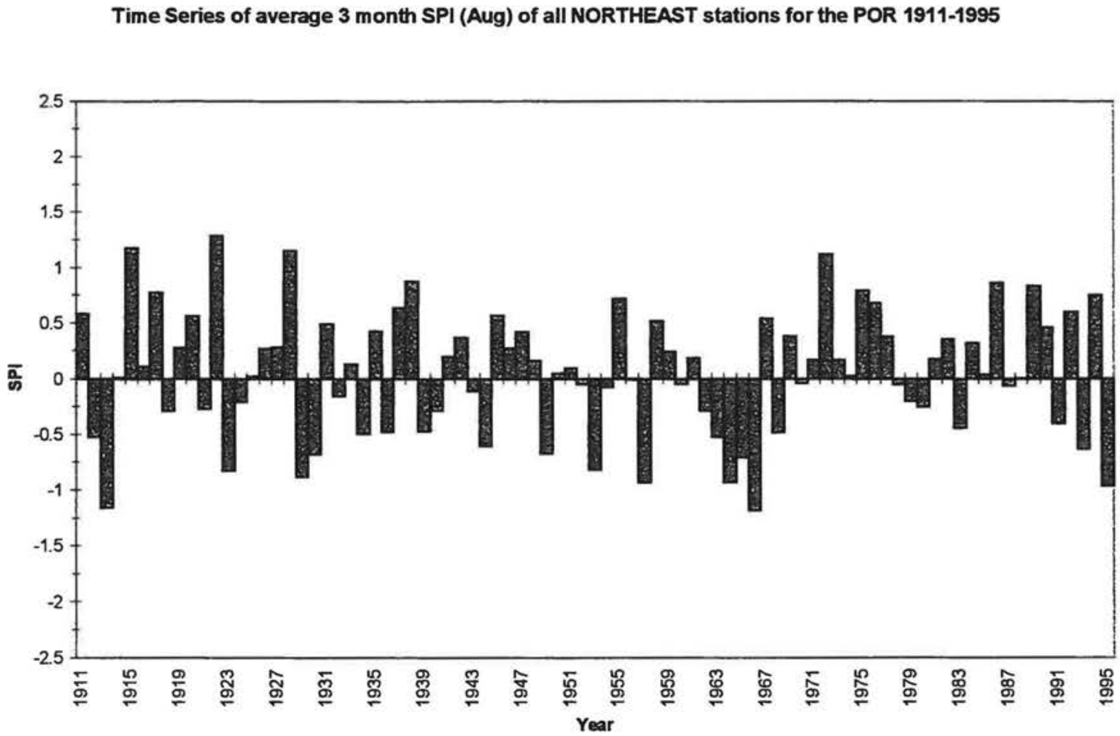


Fig 4.30(C) Time series of average 3 month SPI for August (summer) of all Northeast stations for the period January, 1911 through December, 1995.

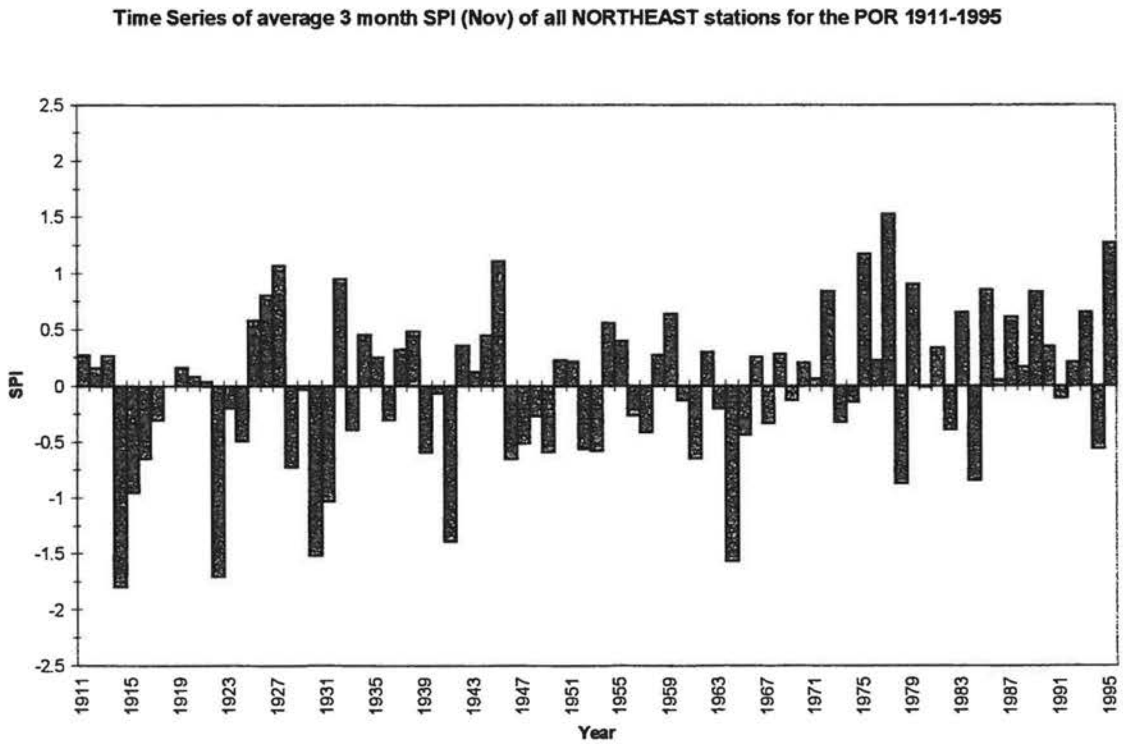


Fig 4.30(D) Time series of average 3 month SPI for November (autumn) of all Northeast stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (Feb) of all SOUTHEAST stations for the POR 1911-1995

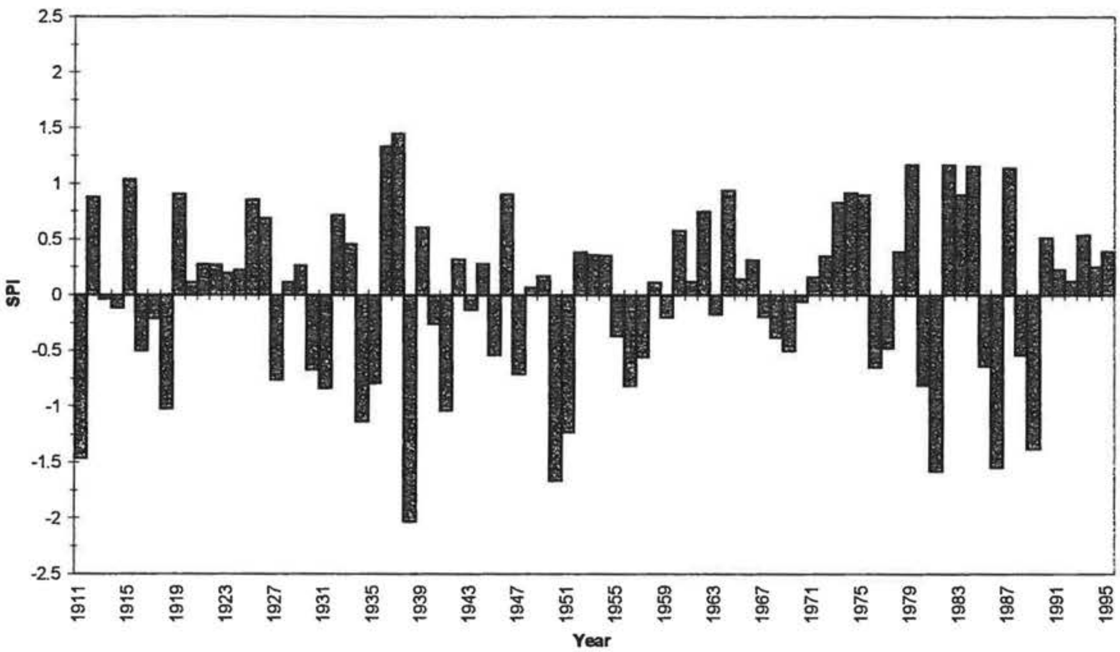


Fig 4.31(A) Time series of average 3 month SPI for February (winter) of all Southeast stations for the period January, 1911 through December, 1995.

Time Series of average 3 month SPI (May) of all SOUTHEAST stations for the POR 1911-1995

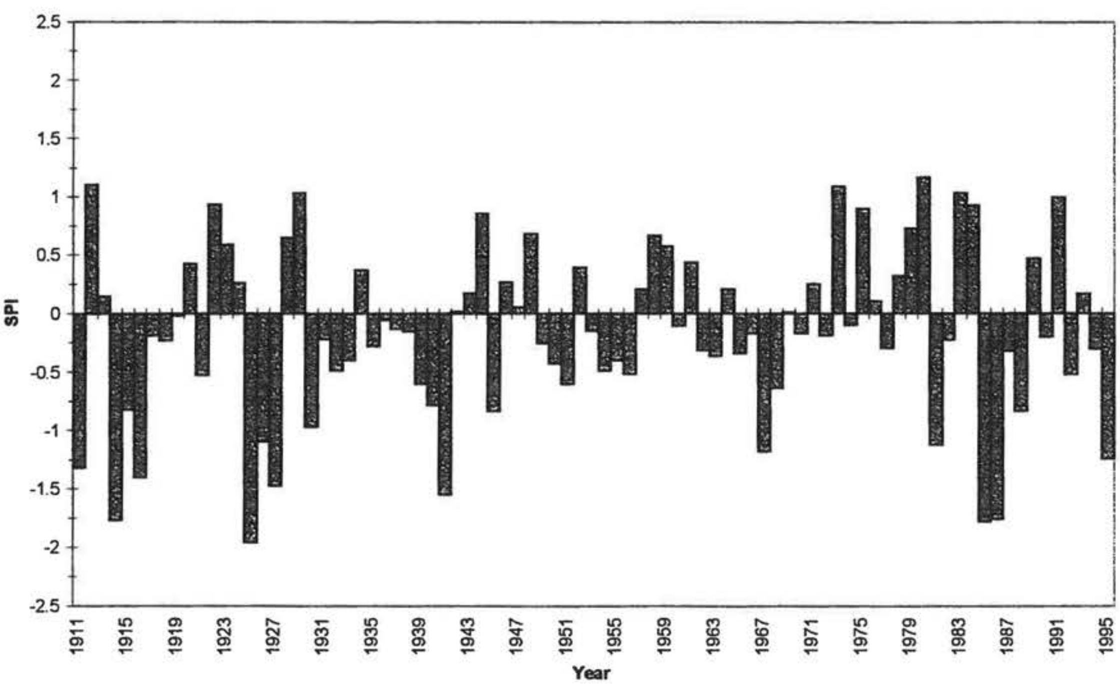


Fig 4.31(B) Time series of average 3 month SPI for May (spring) of all Southeast stations for the period January, 1911 through December, 1995.

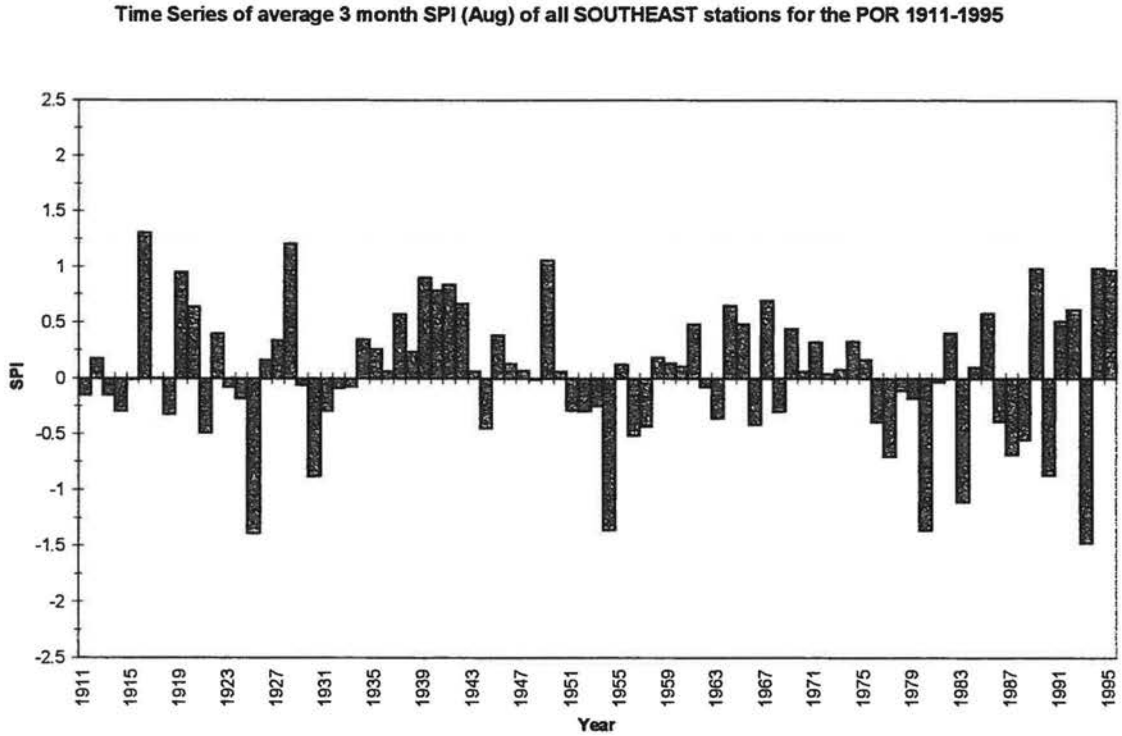


Fig 4.31(C) Time series of average 3 month SPI for August (summer) of all Southeast stations for the period January, 1911 through December, 1995.

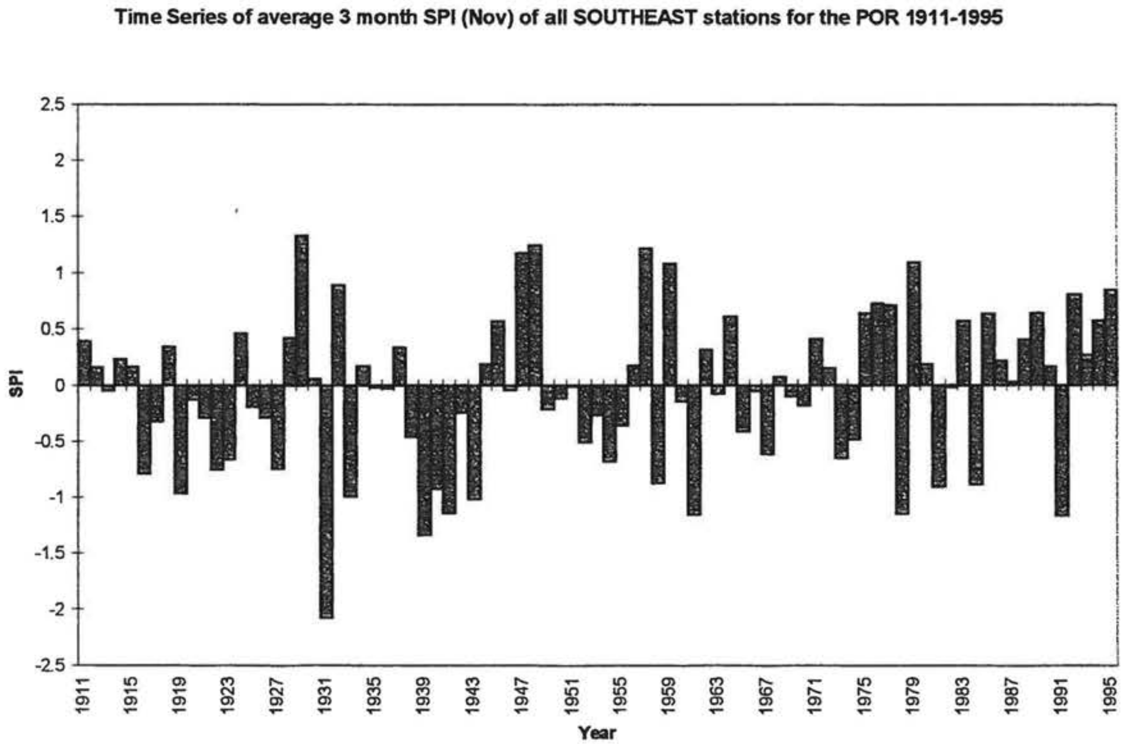


Fig 4.31(D) Time series of average 3 month SPI for November (autumn) of all Southeast stations for the period January, 1911 through December, 1995.

5.0 SUGGESTIONS FOR FURTHER STUDY

Certainly intriguing is the long-term anomalously wet conditions that much of the Mississippi and Ohio Valleys have experienced between 1970 and 1995. Data was analyzed through November of 1996 and there is no evidence of this long-term trend reversing as of this writing. Investigations into the global atmospheric and oceanic circulation and temperature anomalies of this period may shed some light on this current long-term phenomenon.

For example, Kushnir (1994) found prevailing warm sea surface temperature anomalies in the North Atlantic Ocean from about 1930 on into the 1960s along with a cyclonic sea level pressure anomaly in the North Atlantic that persisted from 1930 to 1970 except for a short break around 1950. These anomalies correspond with the long-term droughts of the 1930s, 1950s, and 1960s that affected large portions of the eastern one-half of the United States. Around 1970, Kushnir (1994) found that an anticyclonic sea level pressure anomaly had developed in the North Atlantic corresponding with cooler North Atlantic sea surface temperatures. Gray (1993) attributes this cooling to a weakening of the net northward Atlantic thermohaline circulation that he infers to have started around 1968. Further investigation into this phenomenon is necessary. For example, the Bermuda-Azores high pressure belt is normally well developed during the summer. Are cold sea surface temperature anomalies in the North Atlantic maintaining the strength of this high pressure belt longer into the autumn? As a result, has there been an increased moisture transport in the autumn out of the Gulf of Mexico and into the Mississippi and Ohio Valleys between 1970 and 1995? But again, intense and widespread short-term droughts still occurred during this period. Hence, did these short-term droughts occur during short breaks in these long-term anomalies? How do these anomalies in the Atlantic correspond with anomalous positioning of the midlatitude storm track? Will these long-term anomalies reverse? If so, will the eastern United States again experience the widespread and long-term droughts that occurred between 1930 and 1970? With increased population and a subsequent increased water demand, is the United States prepared to effectively mitigate future widespread long-term drought such as those that occurred between 1930 and 1970?

Similar investigations for wet anomalies in the western United States would be just as valuable. For example, Cayan (1996) found years with anomalously low winter precipitation in the western United to be associated with 700 millibar pressure anomalies that resembled the PNA pattern (anomalously low pressure in the central North Pacific and anomalously high pressure over the Pacific Northwest). Other investigations could include correlating the SPI at a given time scale for a given region to such phenomena as El Niño, La Niña, the quasi-biennial oscillation, the North Atlantic oscillation, etc. Also, would a principal component analysis performed on the SPI produce different homogeneous drought regions than determined by Karl and Koscielny (1982)? How would the regions differ spatially as the time scale changes? Or at the short-term time scales, how would the regions differ as the season changes? These are just a few suggestions on how the SPI can be used for research purposes.

6.0 CONCLUSIONS

The contiguous United States was never entirely in drought at any time scale during this period. Additionally, the contiguous United States was never entirely experiencing anomalously wet conditions either. Conversely, the contiguous United States was never completely without drought or anomalously wet conditions at any time scale during the period of record.

The contiguous United States as a whole has become wetter over the period January, 1911 through December, 1995. Additionally, all nine major regions studied for the United States have also become wetter over the period. As a result, there has been a lower frequency of both short- and long-term droughts and a higher frequency of both short-and long-term wet periods during the last 25 years of the period of record. On the other hand, the short-term droughts of the last 25 years of the period do compare in intensity and areal coverage to short-term droughts of the first 60 years of the period. Likewise, short-term wet periods between 1911 and 1970 compare in intensity and areal coverage to short-term wet periods of the last 25 years of the period of record. However, for the country as a whole, the areal coverage and intensity of long-term wet periods that occurred between 1970 and 1995 are unmatched by the long-term wet periods that occurred between 1911 and 1970. Also, for the country as a whole, the areal coverage and intensity of long-term droughts between 1911 and 1970 are unmatched by the long-term droughts of the last 25 years of the period of record.

Additionally, for the country as a whole, the average duration and frequency of short-term wet periods have increased at a magnitude opposite to the decreasing average duration and frequency of short-term droughts over this period of record. Furthermore, the percentages of stations experiencing drought at all time scales have decreased at rates nearly opposite to the increasing percentages of stations experiencing anomalously wet conditions at all time scales.

Regionally, the most dramatic increase in the frequency of long-term wet anomalies over the last 25 years of the period has occurred in regions along the Mississippi and Ohio river valleys. Despite the occurrence of a few intense short-term droughts, these major regions have all experienced long-term wet periods in the 1970s, the 1980s, and again in the early 1990s.

The autumn has had the most consistent seasonal wet anomalies over the last 25 years of the period for these regions along the Mississippi and Ohio river valleys. Additionally, these anomalously wet autumn periods correspond well with the long-term wet periods these regions have experienced during the last 25 years of the period of record.

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