Iowa weather patterns
associated with the El-Nino/southern oscillation

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Iowa has experienced extremes of temperature and precipitation in recent years. From climatological data for Iowa, it is known that the summers of 1983 and 1988 were accompanied with above normal air temperatures. Soybean production is especially prone to outbreaks of two-spotted spider mite (TSSM) during periods of low precipitation or high air temperature. The Iowa Cooperation Extension Service (Entomology) reported there are some years with serious spider mite outbreaks that are related to drought conditions. For example, central Iowa experienced severe drought in 1954 and 1955 and TSSM were common on corn and soybean. Similar problems happened in 1975, 1976, 1983 and 1988.

Thompson (1988) noted 1901, 1916, 1934, 1936, 1947, 1974 and 1983 to be the years with low corn yields, and these were known as severe drought years. For soybeans, 1927 and 1947 were two of the lowest yielding years. These events were associated with relatively dry summers.

Since drought frequently occurs in Iowa with serious effects, it is important to know whether the drought years follow some pattern. If patterns of drought could be predicted more precisely, more timely information about the possibility of the TSSM outbreaks and the prediction of crops yields could be provided to Iowa producers. However, it is not easy to study climate variability because it is influenced by many factors.

One factor that may significantly influence climate variability is the El-Nino cycle. Thompson (1989) stated that since 1973, El-Nino events were related to the variability of corn yields in the Midwest. Handler and Handler (1983) said that when El-Nino conditions cause the sea surface temperatures in the Tropical Pacific to be warmer than normal, the corn yields in the United States have a higher probability of being above average.

For the above reasons, this research was initiated to quantify relationship between El-Nino, Iowa's weather and it's predictability.

LITERATURE REVIEW

The influence of weather factors on agriculture production is well known. Planting time, irrigation scheduling, plant disease, insect migration and outbreak, and crop yields are some factors that in general depend on weather. Therefore, understanding weather patterns is important in agriculture.

Weather Patterns

In general Iowa annual air temperatures trended upward during the period from 1900 until the early 40's and then downward through the late 60's. The 70's and 80's have been somewhat above normal but no trends were evident. Considering summer seasons (June, July and August), 15 consecutive years starting with 1930 and the recent years 1983 and 1988 have experienced temperatures warmer than normal. The years 1934 and 1936 were extremely warm. (Carlson, 1990).

Before 1956 Iowa heat-stress (accumulation of temperatures exceeding 30 C) showed considerable interannual variability, with frequent annual highs and lows. Heat-stress was low from 1956 through the early 70's, but in the past 12 years, 4 years have had high heat-stress values that reduced Iowa crop yields (Carlson, 1990).

Scientists have many different opinions concerning climate change and variability. The greenhouse effect, the ozone hole, the lunar cycle, and El-Nino are several possibilities that can help explain these changes in climate (Trenberth, 1990, Rassmusson and Hall, 1983, Currie, 1988). However, the El-Nino cycle is one believed to be a dominant factor among the several that affect global weather patterns.

What is El-Nino?

In general, the term El-Nino refers to the occurrence of unusually warm sea-surface temperatures near the coast of South America along the coast of Equador and Peru (Luther et.al., 1983). Philander (1983) added that the warm current tends to occur in January through March which marks the end of the local fishing season. In addition the name El-Nino means the "child" because this event tends to occur near the Christmas time.

Each time a major El-Nino occurs, the barometric pressure over the southeast Pacific falls, and the pressure in the area of Indonesia and Northern Australia rises. About the time that El-Nino ends, the situation changes in the opposite direction. From that explanation, it is clear that El-Nino is related to a large scale changes in the atmospheric circulation over the first discovered by Sir Gilbert Walker. He tried to develop methods to forecast monsoon rainfall over India in 1920. A "seesaw" pattern of atmospheric pressure between the eastern and western tropical Pacific was identified and named "The Southern Oscillation" (Rasmusson and Hall, 1983).

Recently, the term El-Nino refers to those interannual events when, not only the coastal zone of South America is covered by that anomalously warm sea surface waters, but when much the equatorial tropical Pacific ocean is abnormally warm. This happens at an irregular interval of years (Philander, 1983). Major events have been recently termed ENSO (El-Nino Southern Oscillation), illustrating the linkage between El-Nino and the southern oscillation.

El-Nino and southern oscillation index

It was explained earlier that the southern oscillation was named by Sir Gilbert Walker for the pattern of atmospheric pressure between the eastern and western tropical Pacific. However, during that time investigators were unable to explain the physical process responsible for the anomalous conditions associated with the southern oscillation itself.

Late in 1960's Bjerknes (1969) determined that the southern oscillation is closely linked with the interannual sea-surface temperature variations in the eastern and central

Pacific ocean, which is related to El-Nino. Furthermore, it was demonstrated by Berlage (1966) in Kousky et.al. (1984) that the El-Nino phenomenon is closely linked to the southern oscillation for there is a remarkable similarity between the sea-level pressure curve for Darwin, Australia and the sea surface temperature curve for Puerto Chicama, Peru.

To observe the time changes of this oscillation, which has now been linked to ocean-atmosphere fluctuations responsible for year-to-year world climate variability, climatologists developed an index by using the difference in atmospheric pressure between two stations at opposite ends of the "seesaw". For example, between Tahiti, French Polynesia and Darwin, Australia. This index was named the Southern Oscillation Index (SOI). It is an index of the sign and the size of atmospheric pressure anomalies at any one time, and exhibits an irregular periodicity between 2 to 10 years (Rasmusson and Hall, 1983; Troup, 1965).

According to Walker's description and convention, the SOI is positive when atmospheric air pressure is high over the Pacific and lower over the Indian Ocean (Troup, 1965). Kousky et. al. (1984) added that the positive phase refers to the situation when both the low pressure system in Indonesia and the high pressure system in the subtropical East Pacific are stronger than normal, in another words, when sea level pressure of Tahiti, French Polynesia is higher than normal and Darwin, Australia is lower than normal.

The opposite condition is termed the negative phase of the SOI. This means that both the low pressure system in Indonesia and the high pressure system in the East Pacific subtropical are weaker than normal, i.e., when sea level pressure of Tahiti, French Polynesia is lower than normal and Darwin, Australia is higher than normal.

Rasmusson and Carpenter (1982) called the time when the SOI changes sign from positive to negative and when sea surface temperatures over central and eastern equatorial Pacific become anomously warm year 0 of a warm event. Bradley et. al. (1987) said that large negative values of the SOI correspond to warm events and large positive values of the SOI to cold events. Quinn (1974) mentioned that 25 to 30 years of weather records clearly show that low SOI indices are associated with El-Nino type activity and high SOI indices are with anti El-Nino (or La-Nina) conditions. Warming along the Peruvian Cost usually follows the sea-surface temperature warming in the central Pacific by about six months (Rasmusson and Carpenter, 1983).

Some experts use different stations for measuring the index. Kousky et. al. (1984) used Buenos Aires, Argentina and Sydney, Australia. Berlage used only the pressure at Jakarta, Indonesia to measure the index (Troup, 1965). However, Chen (1982) in Trenberth (1984) concluded that the combination of Tahiti, French Polynesia (18 S, 150 W) minus Darwin, Australia (12 S, 131 E) atmospheric pressure is the most effective in computing the percentage variance on the SOI.

Most of these indexes are computed by taking either a monthly mean atmospheric pressure difference or a difference in atmospheric pressure deviations from normal between two stations which represent the two centers of action (Kousky et. al., 1984).

The impacts of El-Nino Southern Oscillation (ENSO)

Philander (1983) wrote that the ENSO involves far more weather impacts than just different atmospheric pressure between the South East Pacific high pressure zone and the North Australian-Indonesian low pressure zone. It is now related to interannual climate variability on a global scale via teleconnections (Kousky et. al., 1984). Over the tropical Pacific Ocean, the ENSO is related to considerable rainfall fluctuation, sea surface temperature anomalies and the intensity of the trade winds (Mc Bride and Nicholls, 1983). It has recently been associated with droughts over India (Kiladis and Diaz, 1989), with winter precipitation in the southeastern United States and with fluctuations of the average temperature of the Northern Hemisphere (Ropelewski and Halpert, 1986).

Other areas of the world with southern oscillation impacts are drought in Indonesia (Berlage, 1957 in Quinn et. al., 1978), extensive winter drought in Australia during the negative phase of the SOI (Streten, 1983 in Kousky et. al., 1984) and abnormally wet conditions in Southern Brazil. According to Allan et. al. (1990), ENSO influences rainfall patterns over northern and eastern Australia and greatly affects the rainfall in eastern China (Wang and Li, 1990).

Thompson (1989) stated that during El-Ninos, the United States Corn Belt experienced cool and wet springs and early summers. He also found that the five droughts in the United States Corn Belt since 1973 were all in years following El-Nino events. Handler and Handler (1983) concluded from Iowa research that for 49 El-Nino years, as specified by the Quinn index, 36 years showed corn yields at or above trend. However, Ropelewski and Halpert (1987) stated that El-Nino and midlatitude precipitation are linked for all major land masses of the Southern Hemisphere, but in the Northern Hemisphere the linkage is not consistent.

<u>The predictability of the SOI</u>

The impact of climatic anomalies can be minimized by improving a better physical understanding of the anomalies.

Although not periodic, the SOI frequently follows a certain sequence of events (Kousky et. al., 1984). Experts have different opinions about the period of time for the SOI, but Trenberth (1984) stated that the SOI is not regular. It has a preferred period between about 2 and 10 years.

It has been previously stated that the SOI relates to El-Nino. However, sometimes it is difficult to classify El-Nino years since no two are exactly alike in terms of onset, duration, areal extent, thermal departure or degree of devastation (Quinn et. al., 1978). He categorized El-Nino events as strong, moderate, weak and very weak depending upon the intensity of the activity and the time of year when it occurred.

Kiladis and Diaz (1989) stated that in order to qualify one time as a warm event, the sea-surface temperature anomaly has to be positive for at least three consecutive seasons. In addition one of the seasons must be at least 0.5 degree C above the mean. The seasonal SOI has to remain -1.0 for the same duration of time. Based upon the standard SOI, which has been extended back to the year 1882, and a sea-surface temperature anomaly index for the eastern equatorial Pacific, Table 1 lists the year 0's of the warm and cold events (Kiladis and Diaz, 1989).

Table 1. List of year 0s of warm and cold events (1877 - 1988)

Warm events (year 0)

1877	1880	1884	1891	1896	1899	1902	1904	1911	1913
1918	1923	1925	1930	1932	1939	1951	1953	1957	1963
1965	1969	1972	1976	1982	1986				

Cold events (year 0)

1886	1889	1892	1898	1903	1906	1908	1916	1920	1924
1928	1931	1938	1942	1949	1954	1964	1970	1973	1975
1988									

MATERIALS AND METHODS

Source of Data

This study focuses on one important component of drought, that being precipitation. However, annual and seasonal air temperatures and various stress indices are included in some analysis to provide additional information.

To study those factors, monthly precipitation totals for the period from 1890 until 1989 were compiled for three districts in Iowa, i.e. northwest (district 1), central (district 5) and southeast (district 9). These 3 districts were chosen to traverse the expected annual precipitation pattern across the state of Iowa. In addition, monthly temperatures and stress indices covering the period from 1900 until 1989 for Ames were assembled. All data are provided by NOAA (1900-1989) and have been described by Carlson (1990).

Data describing the normalized monthly SOI from 1935 until 1989 were provided by Dr. Kevin E. Trenberth (National Center for Atmospheric Research, Boulder Colorado).

Methods of Analyses

T Test

The T tests were calculated for seasonal district precipitation to compare separately the warm/cold events (year 0's from Table 1.), years before the events (year -1's) and years after the events (year +1's) with years having no influence from El-Nino.

The t statistic for testing the equality of means, X1 and X2, from two independent samples with n_1 and n_2 observations is

$$t=(\overline{X_1}-\overline{X_2})/(s^2(1/n_1+1/n_2))^{0.5} \qquad (1)$$

where

s^2 = the pooled variance

$$s^2=[(n_1-1)s_1^2+(n_2-1)s_2^2]/(n_1+n_2-2) \qquad (2)$$

s_1^2 and s_2^2 = the sample variances of the two groups.

The tests were done by following these procedures :

1. The monthly precipitation was composited by using the standard seasons : December, January and February (DJF) for winter; March, April and May (MAM) for spring; June, July, and August (JJA) for summer; and September, October and November (SON) for fall.

2. By using PROC T TEST in SAS (Statistical Analysis System), the tests were done to compare every season in year 0's, year -1's and year +1's to the seasons in the rest of the years.

Percentile rank analysis

The analysis below follows that used by Ropelewski and Halpert (1986). The first step of this analysis was to rank the data for each individual month, to normalize the rank by the total number of years of data and to express this ratio as a percentage. PROC RANK (GROUPS = 100) in SAS was used for this purpose after which the results were subjected to the following analysis:

1. Based on the events identified by Rasmusson and Carpenter (1983), see Table 1., El-Nino year composite ranks were formed for two-year periods starting with July before the events, designated as July (-1) through June after the events, June (+1).

2. Means of each month in that period were calculated, and the results were plotted to identify a single "season" within the El-Nino years which shows an apparent response.

3. Time series of the percentiles were plotted for the appropriate "season" defined in the previous step and then were used to examine the consistency of the response associated with warm and cold events.

4. Contingency tables and the χ^2 test were used to determine the significance of the responses. The test criterion was

$$\chi^2 = (r_2 n_1 - r_1 n_2)^2 / r_1 r_2 (n_1 + n_2) \tag{3}$$

for a ratio $r_1 : r_2$ with observed numbers n_1 and n_2 and (row-1)(column-1) degrees of freedom (Steel and Torrie, 1980). A sample calculation is given in the Appendix.

Spectral analysis

Spectral analysis is a method to identify periodicities (harmonics) and to analyze the relationship between one or more sets of concurrent time series. If a relationship between the series exists, this analysis will explain whether the relationship is associated with high or low frequency oscillations (Wang and Li, 1990).

To understand this analysis there are some terms that need to be explained. These terms are defined as follows:

Periodogram This shows the relative size of the harmonic components which are used to indicate possible periodicities (Essenwanger, 1986). The normalized periodogram, obtained by dividing each harmonic by the variance of the data in the time series, is called the spectral density or the power spectrum. The power spectrum allows identification of significant and important periodicities which appear as peaks in the spectrum.

$$I_k^x = (n/2)\,(a_k^{x2} + b_k^{x2}) \qquad (4)$$

here

I_k^x = periodogram of x

a_k^x = cosine transform of x

b_k^x = sine transform of x

$$a_k^x = (2/n) \sum_{t=1}^{n} X_t \cos\omega_k t \qquad (5)$$

$$b_k^x = (2/n)\sum_{t=1}^{n} x_t \sin\omega_k t \tag{6}$$

$$\omega_k = 2\pi k/n \tag{7}$$

where

n = number of observations

k = harmonics

π = radian

<u>Co-spectrum</u> This spectrum measures the extent to which there are oscillations with the same phase in the two series (or with opposite sign). Peaks in the co-spectrum will indicate the correlated parts of the time series (Bloomfield, 1976).

$$C_k = (1/4\pi)\sum_{j=-p}^{p} W_j R(I_{k+j}^{xy}) \tag{8}$$

where

$R(I_{k+j}^{x})$ = real part of periodogram

W_j = smoothing weight

$$R(I_k^{xy})=(n/2)\,(a_k^x a_k^y+b_k^x b_k^y) \tag{9}$$

<u>Coherency spectrum</u> This spectrum measures the correlation between the two series at each frequency. It has affinity with the commonly used correlation coefficient (r value) used in regression analysis that varies from 0 to 1, except that the coherence is a function of the harmonic.

$$K_k=A_k^2/\,(F_k^x * F_k^y) \tag{10}$$

where

A_k = amplitude

F_k^x = spectral density estimate of x or y

$$F_k^x=(1/4\pi)\sum_{j=-p}^{p} W_j I_{k+j}^x \tag{11}$$

$$A_k=(C_k^2+Q_k^2)^{0.5} \tag{12}$$

where

Q_k = quadrature-spectrum estimate

C_k = cospectral density estimate (see eq.8)

$$Q_k = (1/4\pi)\sum_{j=-p}^{p} w_j (n/2)(a_k^x b_k^y - b_k^x a_k^x) \tag{13}$$

Phase spectrum This spectrum measures the phase difference between the two series. It will indicate whether one series leads or lags the other (Jenkins and Watts, 1969)

$$\Phi_k = \arctan(Q_k, C_k) \tag{14}$$

where

Q_k = quadrature spectrum estimate (see eq.13)

C_k = cospectral density estimate (see eq.8)

In this study seasonal precipitation data from central Iowa (district 5) and the seasonal SOI index from 1935 until 1989 were used. All computations were done by using PROC SPECTRA (COEF P S CROSS K PH) in SAS.

Caution must be used in the spectrum because the peaks in the spectrum may be caused by chance. Therefore, it is necessary to test the statistical significance of the peaks. The power spectrum can be related to the χ^2 test, where the test criteria is:

$$F_k^x / F_k^x(E) = \chi^2 / N_f \qquad (15)$$

where:

F_k = the spectral density (see eq. 11)

$F_k(E)$ = the expected value of the power spectrum

$$F_k^x(E) = \left(\sum_1^m F_k^x\right) / m \qquad (16)$$

m = number of employed lags

N_f = number of degrees of freedom which is

$$N_f = 2N / (m - 0.5) \qquad (17)$$

N = number of data points of the original data

A significant criteria for the coherence is the expectancy

$$eK_k = [1 - \alpha^1 / (N_f - 1)]^{0.5} \qquad (18)$$

where:

α = the probability level of significance

N_f = number of degrees of freedom (see eq. 17) like the test before

$$K_k/\epsilon K_k=\chi^2/N_f \tag{19}$$

where

K_k = the coherence (see eq. 10)

ϵK_k = the expected coherence (see eq.18)

RESULTS AND DISCUSSION

T Test

The results of the t test are shown in Tables 2 and 3.

Table 2. Mean precipitation (cm) differences for seasons of warm event year 0's, year -1's and year +1's compared to years without El-Nino influence

District	Winter	Spring	Summer	Fall
		Year -1's		
Northwest	-0.04	-2.41	-0.45	0.09
Central	-0.37	-2.55	-3.58*	-3.15*
Southeast	0.37	-3.34	-3.86*	-4.97*
		Year 0's		
Northwest	0.51	0.61	1.27	-0.97
Central	-1.60	2.00	1.65	-2.22
Southeast	-1.04	0.53	2.25	-3.03
		Year +1's		
Northwest	2.05	0.06	1.61	-0.09
Central	-0.91	1.09	3.20	0.76
Southeast	0.88	-0.25	-0.57	-1.52

* difference significant at the 5% level

Table 3. Mean precipitation (cm) differences in seasons of cold event year 0's year -1's and year +1's compared to years without anti El-Nino (La-Nina) influence

District	Winter	Spring	Summer	Fall
		Year -1's		
Northwest	0.94	0.07	2.90	0.17
Central	0.70	-0.70	3.30	-0.33
Southeast	0.73	-2.38	2.56	-1.54
		Year 0's		
Northwest	0.59	3.38	-0.26	1.78
Central	0.90	0.71	1.28	-0.49
Southeast	0.09	2.03	1.69	-1.92
		Year +1's		
Northwest	0.32	-2.10	-3.52	-3.82*
Centra	0.76	-1.48	-1.41	-3.77*
Southeast	0.89	-0.36	2.16	-5.03*

*difference significant at the 5% level

From Tables 2 and 3, it can be seen that only a few significant differences were noted. Most seasons in year -1's of warm events had precipitation less than the years without El Nino influences, especially for summer and fall in the central and southeast districts. For all districts during the warm events (year 0's) spring and summer tended to have more precipitation, while winter and fall tended to have less. No specific pattern was found for the seasons within year +1's.

For cold event summers in year -1's, precipitation received was above that of years without any cold event influence. Spring and fall seasons tended to have less precipitation except for the northwest district. During year 0's precipitation had a tendency to be above average except for fall seasons in central and southeast districts and summer season in the northwest district. In year +1's precipitation tended to be below the average of seasons within the years without cold event effect except for winter seasons. In general, the warm event effects reveal stronger patterns than the cold events in Iowa based on this statistical criteria.

Percentile Rank Analysis

In this section El-Nino effects were studied using graphical analysis. Based on the warm events as identified by Rasmusson and Carpenter (1983) given in Table 1. El-Nino composite ranks of Iowa precipitation and temperature were formed for a two-year period starting with July before the event, July (-), through June after the event year, June (+). The results, Figure 1 through Figure 4 , show how the monthly ranks depart from the median value, i.e., greater or less than the 50th percentile.

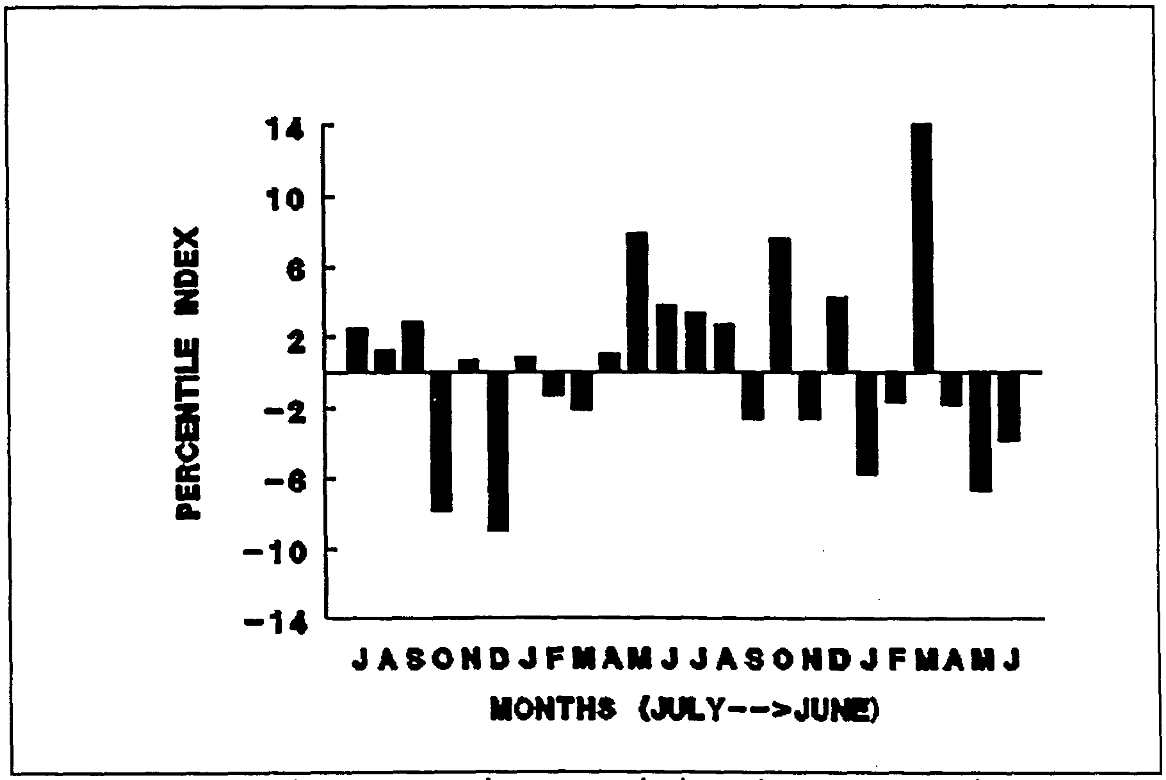

Figure 1. El-Nino composite precipitation percentiles for northwest Iowa

For northwest Iowa (Figure 1), the mean percentile rank revealed three time periods containing consecutive months with near median or, above or below, sequences. From October (-) until March (0) monthly precipitation tended below the median except for November and January. April (0) through August (0) averaged above the median. The (+) years beginning with January (+) through June (+) reveal a sequence of months averaging below the median except for March.

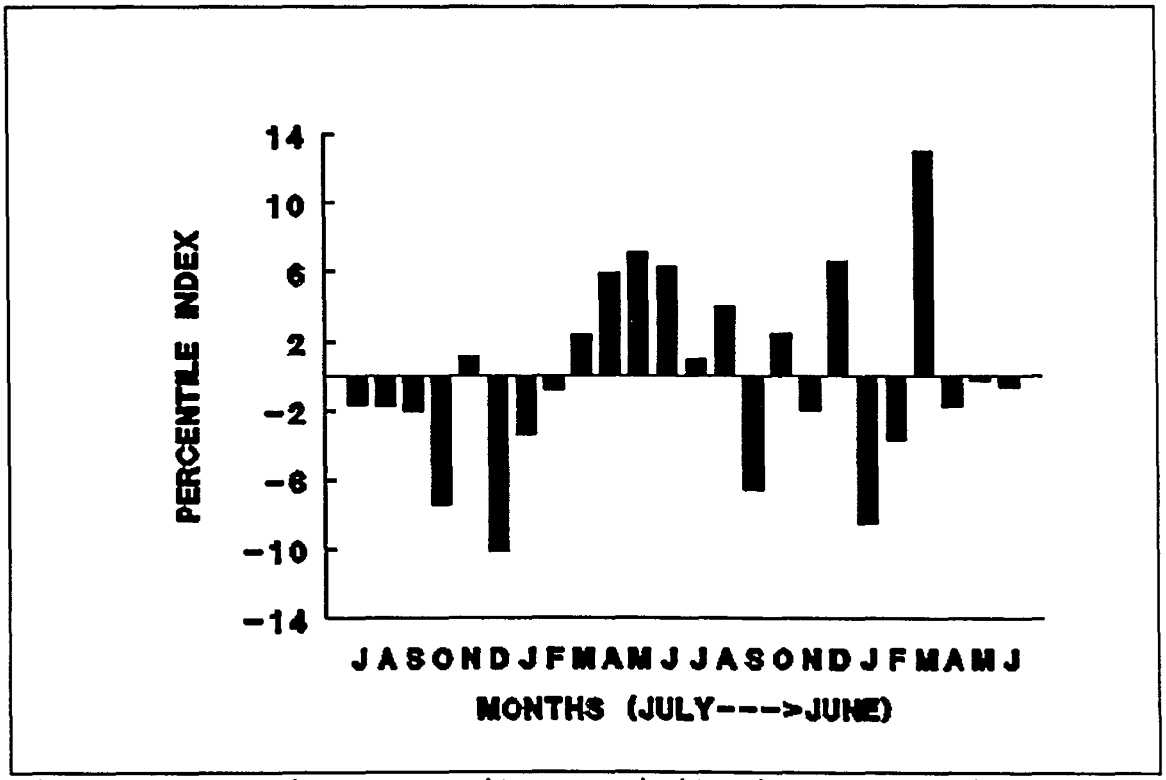

Figure 2. El-Nino composite precipitation percentiles for central Iowa

Monthly precipitation percentile ranks in the central district (Figure 2) tended below the median from July (-) until February (0). March (0) through August (0) averaged above the median. Similar to northwest Iowa, the (+) months from January (+) until June (+) averaged below the median except for March.

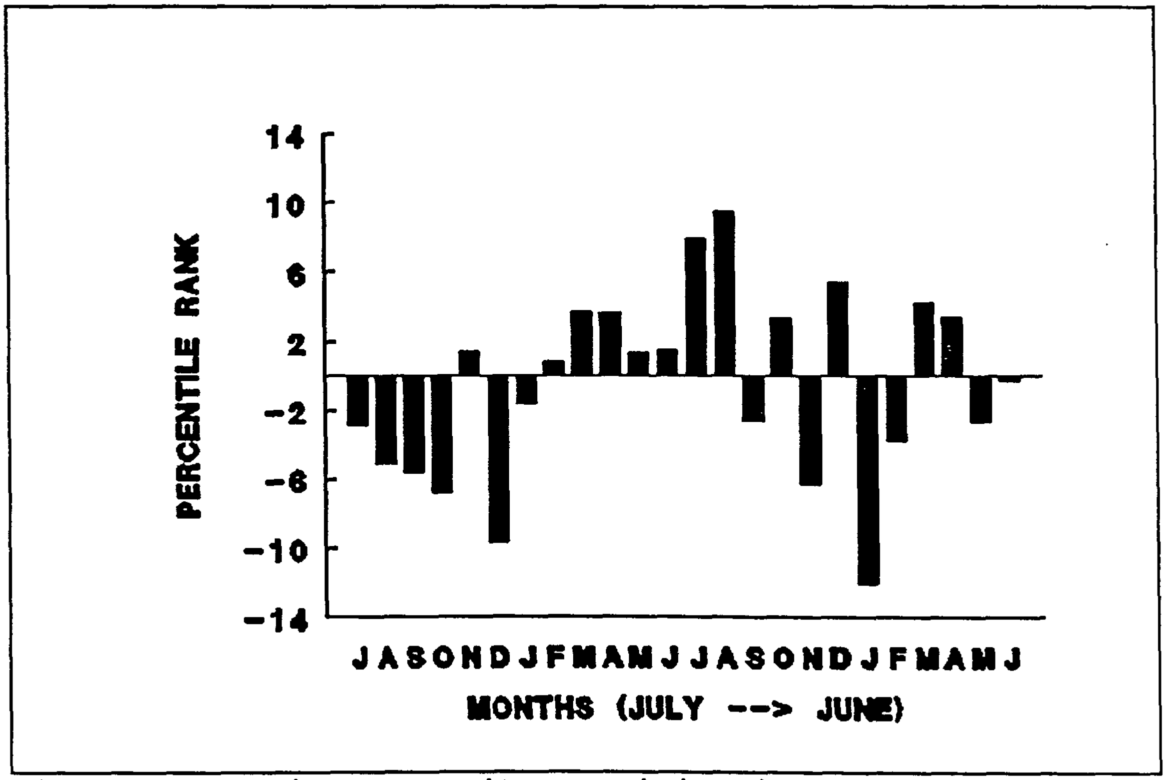

Figure 3. El-Nino composite precipitation percentiles for southeast Iowa

Southeast Iowa (Figure 3) had a pattern similar to the central part. From July (-) until January (0), monthly precipitation tended below the median. February (0) through August (0) averaged above the median. For the (+) years monthly precipitation from January (+) until June (+) tended to be below the median, but unlike the other two districts, March and April were the exception to this sequence in southeast Iowa.

From these districts in general, there were three time periods in Iowa that gave responses related to El-Nino. Monthly precipitation tended below the median in the (-) years, above the median during the (0) years and below the median in the (+) years.

The below median monthly precipitation in the (-) years is of significance because this time period includes the time Iowa soil moisture supplies are recharged. The above median monthly precipitation in the (0) years also is significant for agricultural production because this period includes the major portion for corn and soybean vegetative and reproductive development. In addition, these wet conditions would seem to be detrimental for two-spotted spider mite development.

For northwest Iowa, the time period with below median sequences, October (-) until March (0), were shorter and less consistent compared with the other two districts, July (-) to Jan (0). According to Rasmusson and Carpenter (1982), the period from August (-) to October (-) is the "antecedent" period and November (-) to January (0) is the "onset" period of the El-Nino events during which the sea surface temperature (SST) anomalies are set up. The influence of these periods were strong enough for the southern part of Iowa, but not for the northern part. The "peak" stage of the El-Nino events is from March (0) to May (0). At this time the SST anomalies are largest along the Peru coast. September (0) marks the end of the sharp anomalies along that coast. During this time Iowa precipitation averaged above median.

An exception to the sequence of dry months in the (+) years is March (+) for the northwest and central districts and March (+) and April (+) for the southeast district. These high or above median percentile ranks occur when the SOI started being positive and was returning to normal conditions. According to Philander (1983), it was often after the peak along the coast that both sea level and SST have a second maximum in January until March after which it rapidly decreases. This condition may explain the exception of the above-median March and April precipitation.

The same procedure was used for monthly temperatures. In this analysis, the Ames, Iowa weather station was used to represent the temperature conditions in central Iowa. These results are shown in Figure 4.

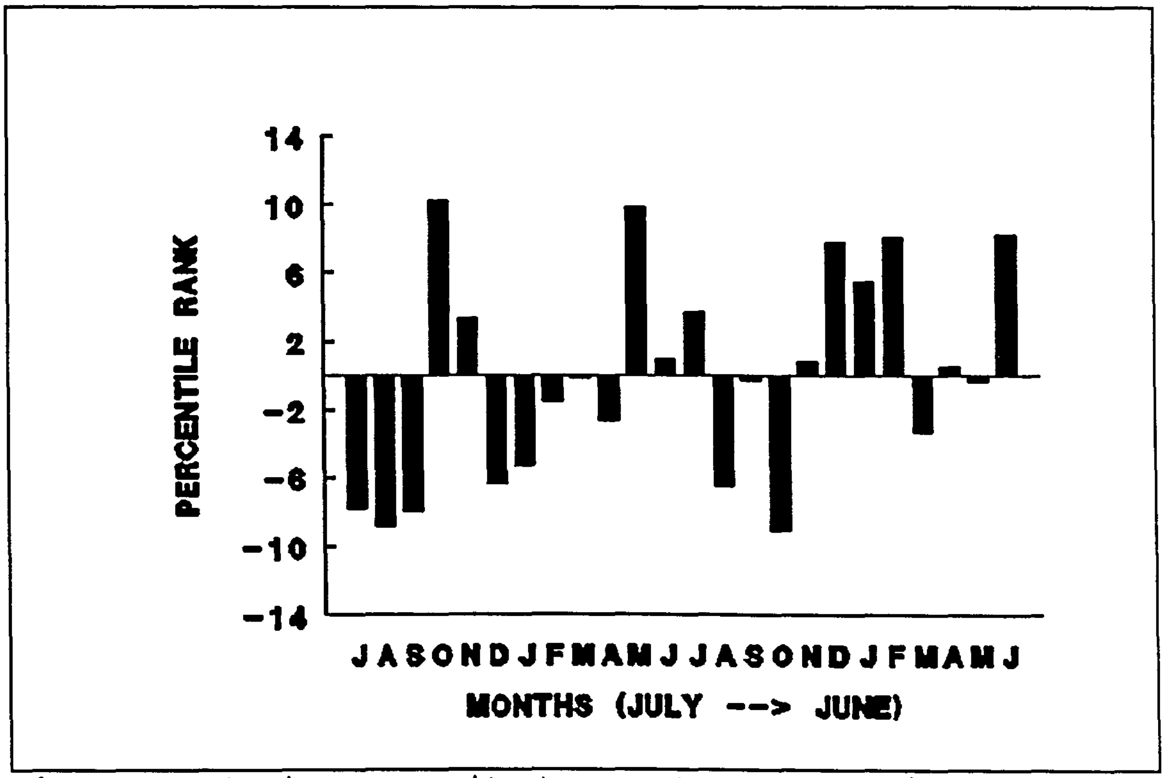

Figure 4. El-Nino composite temperature percentiles for Ames, Iowa.

The percentile composite for Ames, Iowa temperatures (Figure 4) shows that from July (-) until April (0) monthly temperatures tended below median with the exceptions being October (-) and November (-). For the (+) years, November (0) through February (+) averaged above median.

In Figures 5 through 22, time series of the percentile ranks averaged for all months within the time periods identified in the previous analysis were plotted to examine the consistency of response related to El-Nino events.

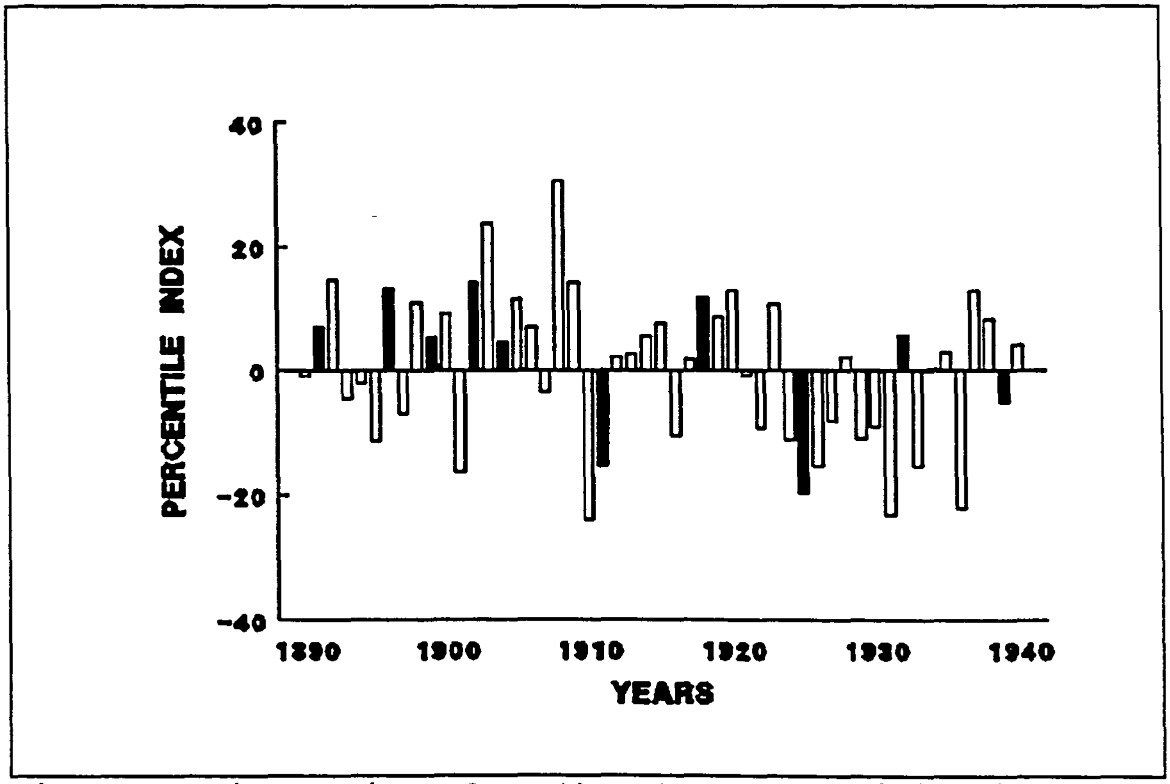

Figure 5. Time series of northwest Iowa precipitation for the April(0) until August (0) season 1890-1940. The El-Nino years are represented by dark bars

A χ^2 test (see eq.3 and Appendix) was used to test the hypothesis that the probability of above median precipitation during El-Nino events is not equal to the probability of below median precipitation during El-Nino events. The data (1890-1989) presented in Figures 5-6, and subsequent figures is split so that El-Nino and non El-Nino could be visually identified by solid and open bars.

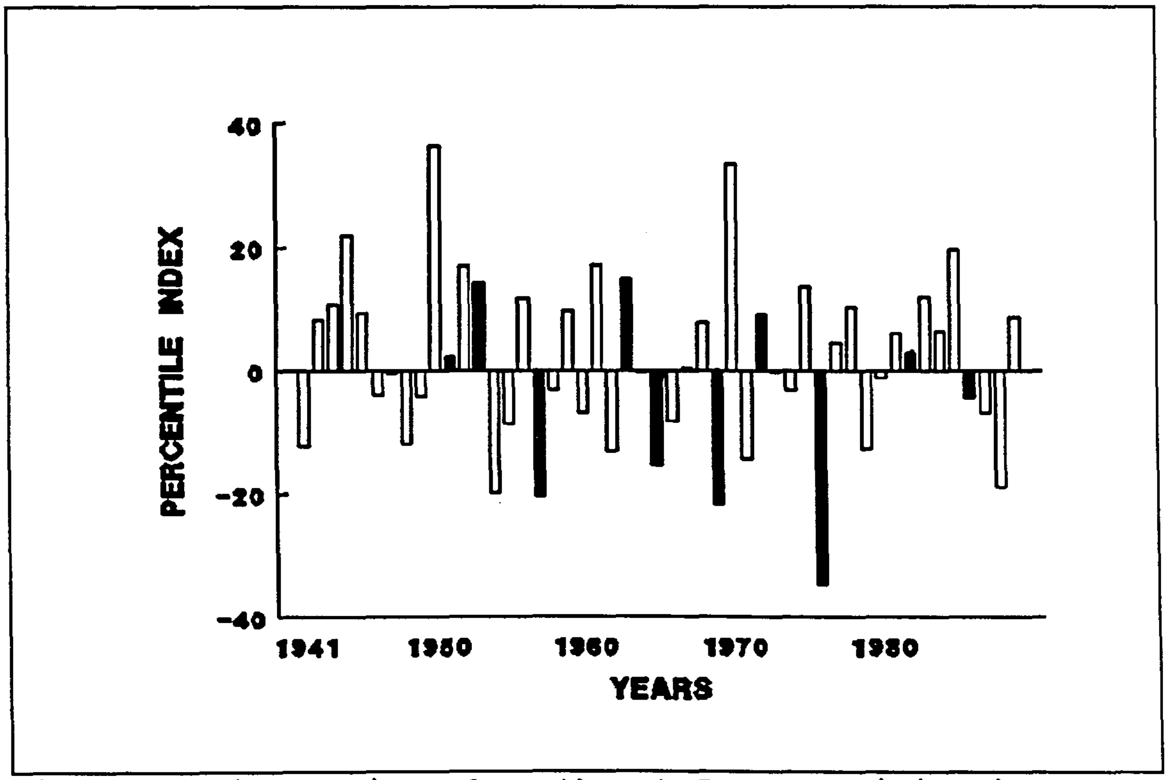

Figure 6. Time series of Northwest Iowa precipitation for the April (0) until August (0) season 1941-1989. The El-Nino years are represented by dark bars

For northwest Iowa (Figures 5 and 6), precipitation during the time period from April (0) through August (0) indicated 14 out of 23 events (61%) averaging above the median. Here, $\chi^2 = 0.57$, where $\chi^2_{(.05)}$ with 1 degree of freedom = 3.84. The data do not support the hypothesis that there was a significant difference.

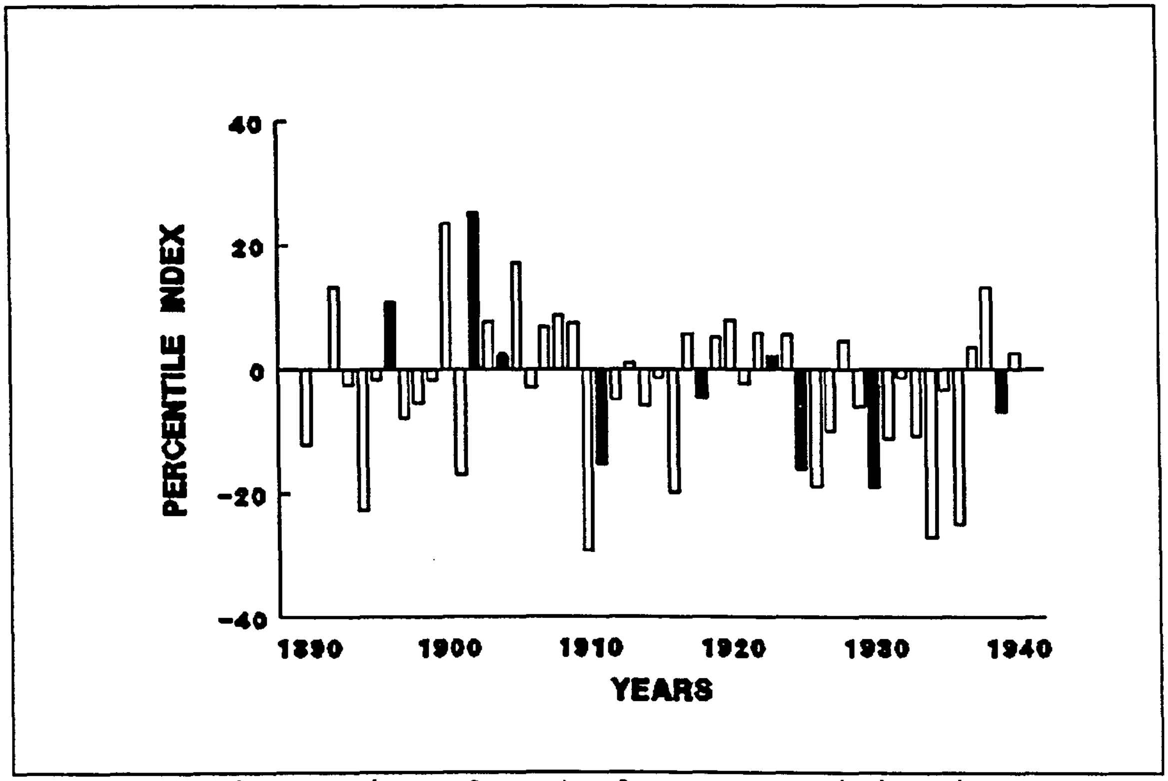

Figure 7. Time series of central Iowa precipitation for the March (0) until August (0) season 1890-1940. The El-Nino years are represented by dark bars

The time series of the March (0) to August (0) precipitation percentile ranks over central Iowa (Figures 7 and 8) indicated 15 out of 23 El-Nino events (65%) were above the median. The χ^2 test gave result 1.378, which was not significant.

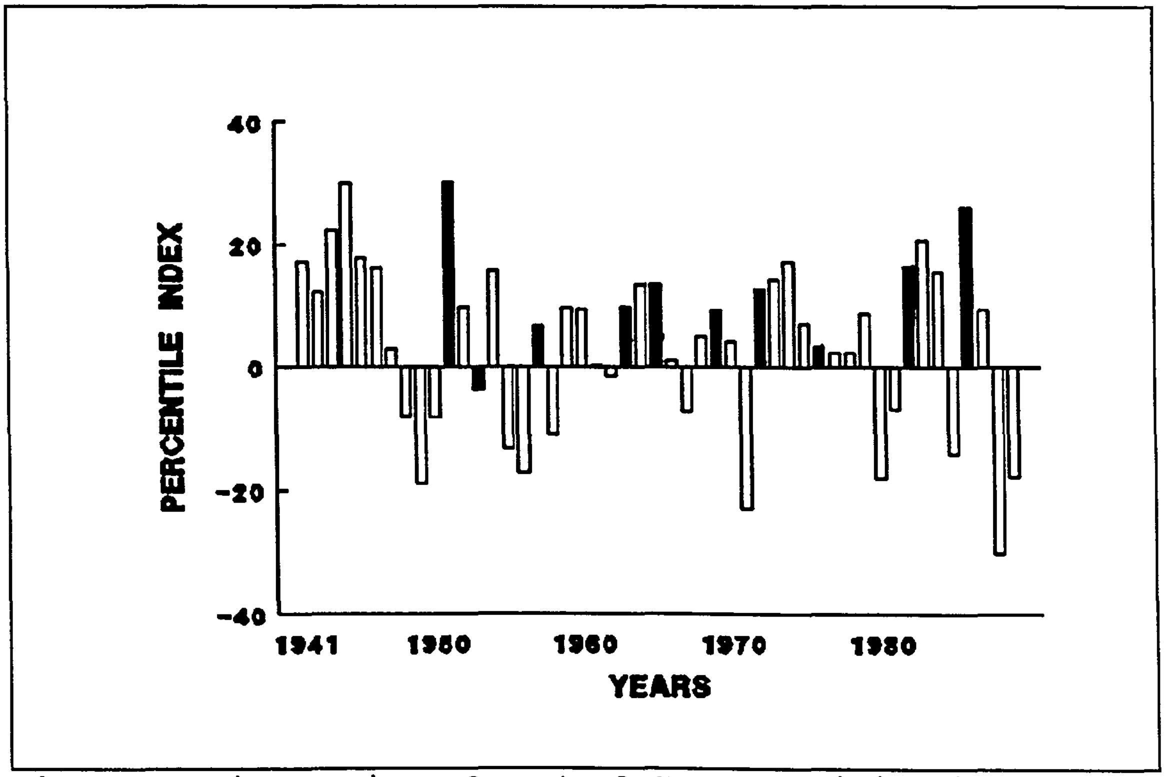

Figure 8. Time series of central Iowa precipitation for the March (0) until August (0) season 1941-1989. The El-Nino years are represented by dark bars

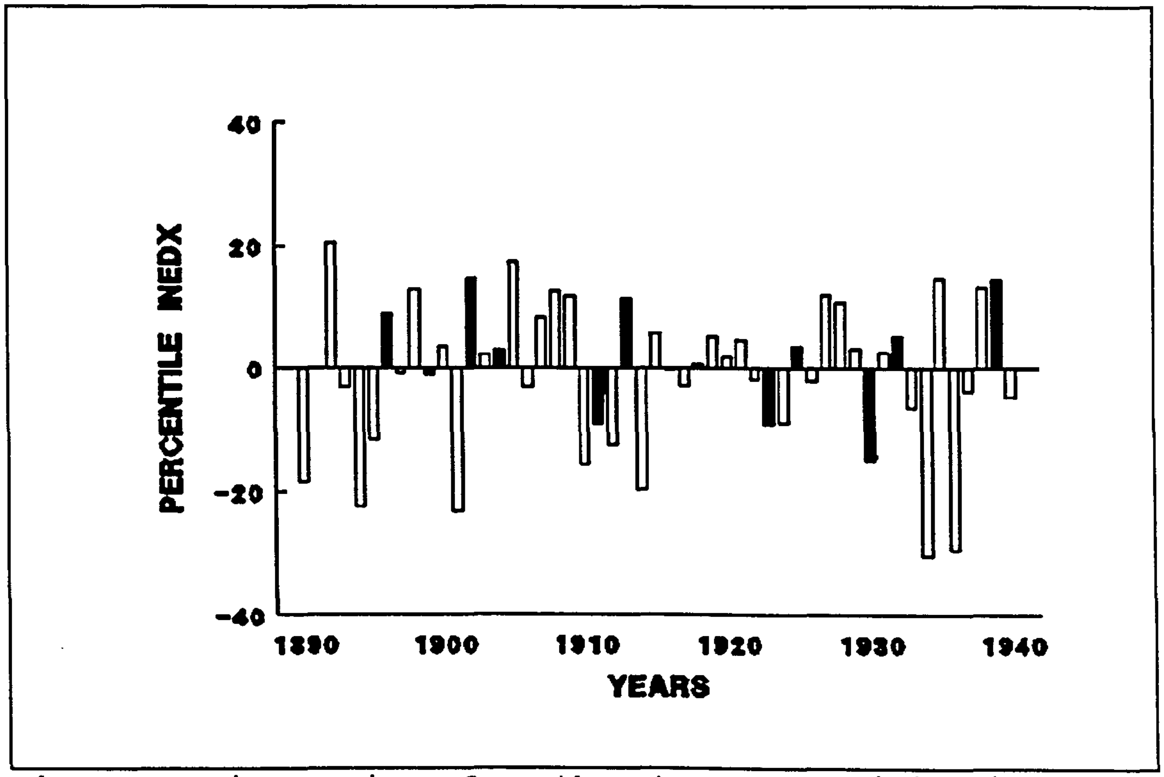

Figure 9. Time series of southeast Iowa precipitation for February (0) until August (0) season 1890-1940. The El-Nino years are represented by dark bars

The time series of the February (0) to August (0) precipitation percentile ranks over southeastern Iowa (Figures 9 and 10) expressed the strongest consistency with El-Nino events when compared to the other two districts. This time period indicated above the median precipitation for 17 out of

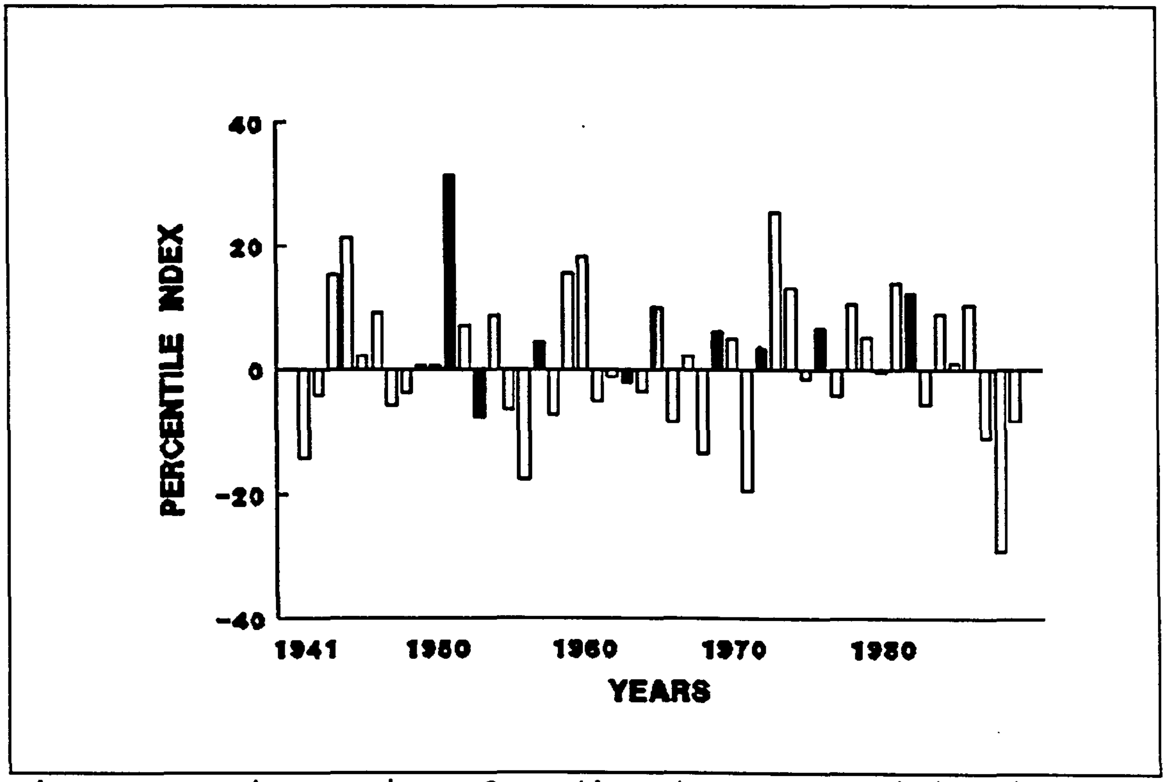

Figure 10. Time series of southeast Iowa precipitation for the February (0) until August (0) season 1941-1989. The El-Nino years are represented by dark bars

23 El-Nino events (74%). The result from the χ^2 test is 4.038 and significant at the 5% level.

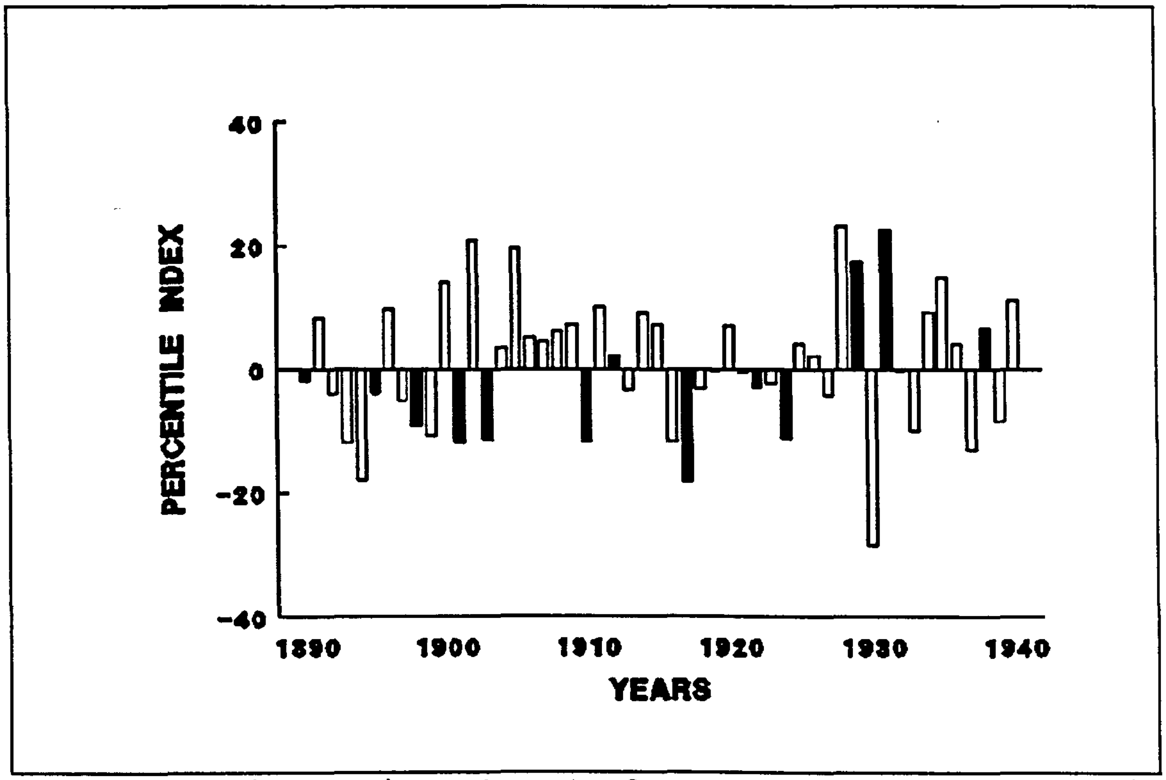

Figure 11. Time series of central Iowa for the July(-) until February (0) season 1890-1940. The year -1's are represented by dark bars

Similar analyses were performed for the dry time period, July (-) through February (0), for the central and southeastern regions and from January (+) until June (+) for the northwestern region. The results are shown in Figures 11 through 16.

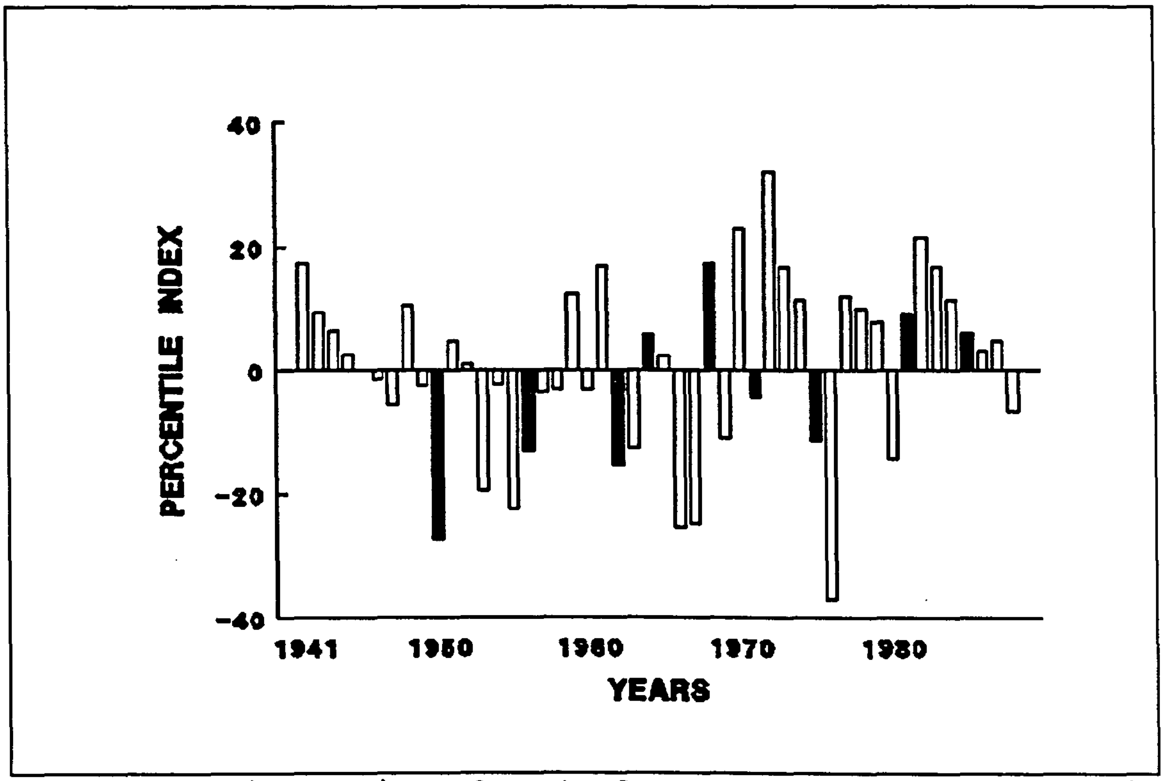

Figure 12. Time series of central Iowa for the July (-) until February (0) season 1941-1989. The year -1's are represented by dark bars

The time series of the dry months from July (-) to February (0) in central Iowa (Figures 11 and 12) showed below median precipitation for 15 out 23 El-Nino events (69%). The χ^2 test = 4.202 showed the result to be significant at the 5% level.

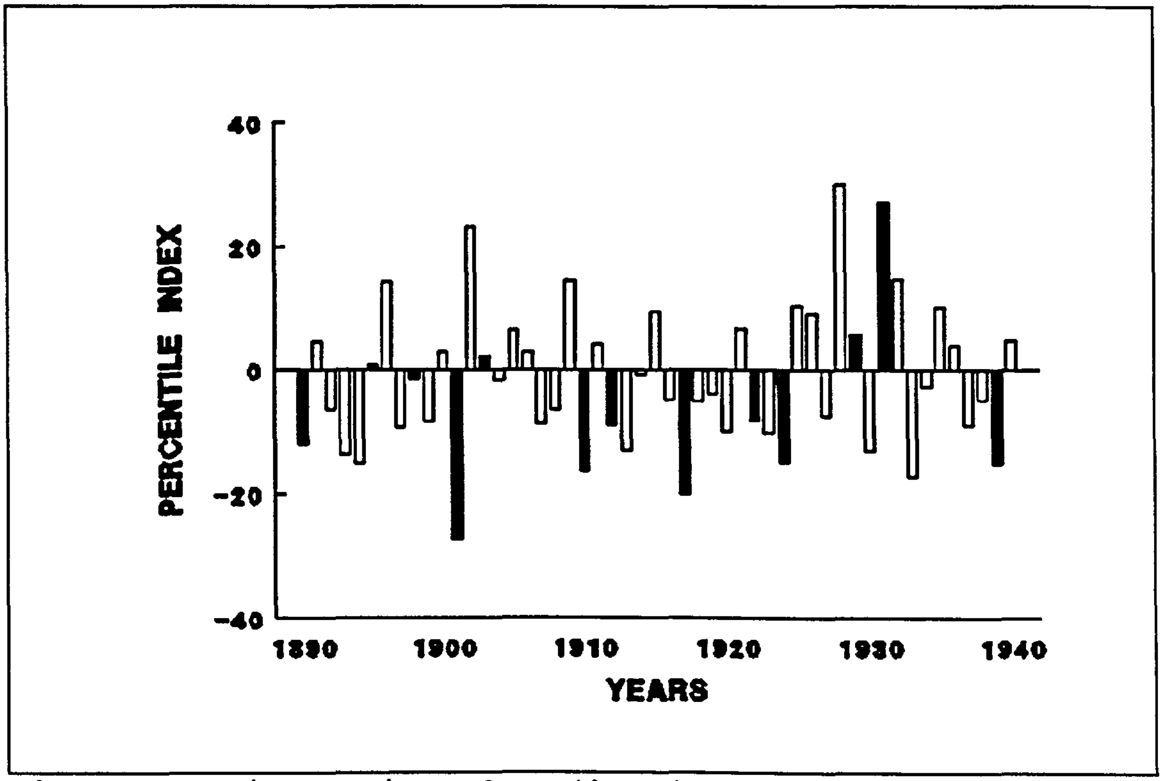

Figure 13. Time series of southeast Iowa for the July (-) until January (0) season 1890-1940. The year -1's are represented by dark bars

For southeast Iowa (Figures 13 and 14) the time period from July (-) to January (0) showed 16 out of 23 events (70%) having below median precipitation. This was not much different than central Iowa. The result from the χ^2 test, 5.14, is also significant for 5% level.

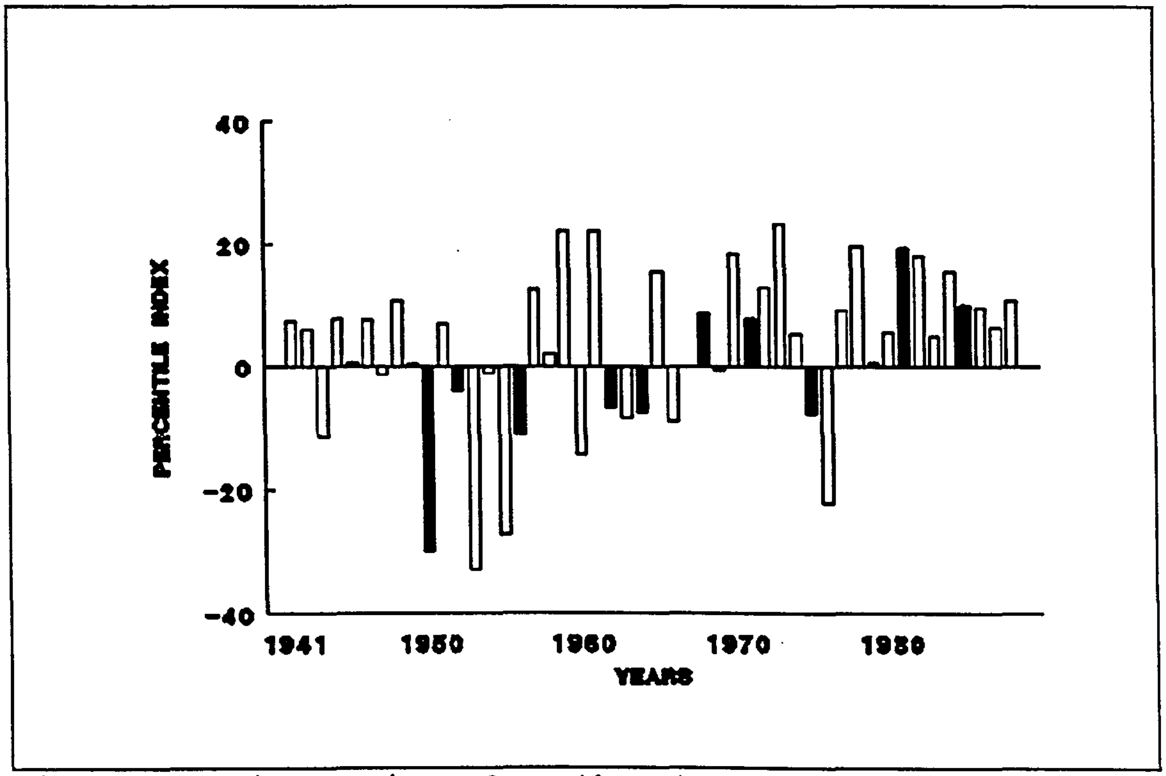

Figure 14. Time series of southeast Iowa for the July (-) until January (0) season 1941-1989. The year -1's are represented by dark bars

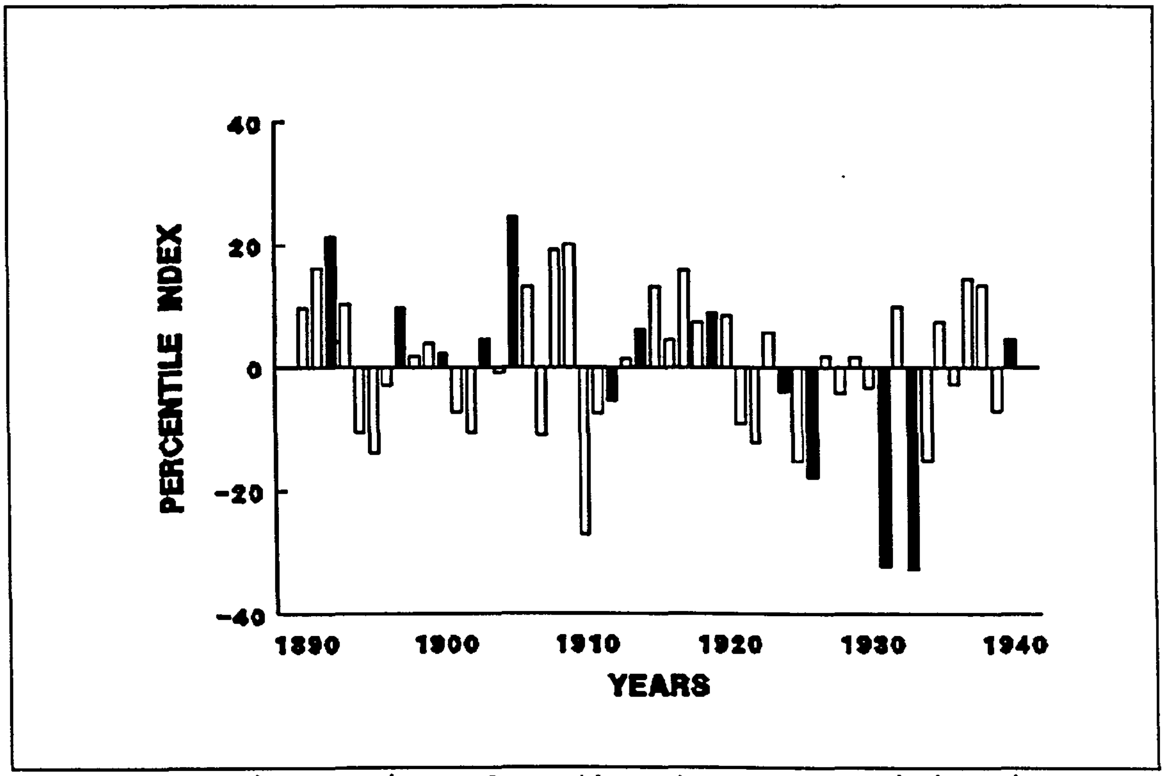

Figure 15. Time series of northwest Iowa precipitation for the January (+) until June (+) season 1890-1940. The year +1's are represented by dark bars

The time series of the January (+) to June (+) precipitation percentiles rank over the northwestern Iowa (Figures 15 and 16) had about the same chance of being either above the median or below the median value. Eleven to 12 out of 23 El-Nino events were above the median value.

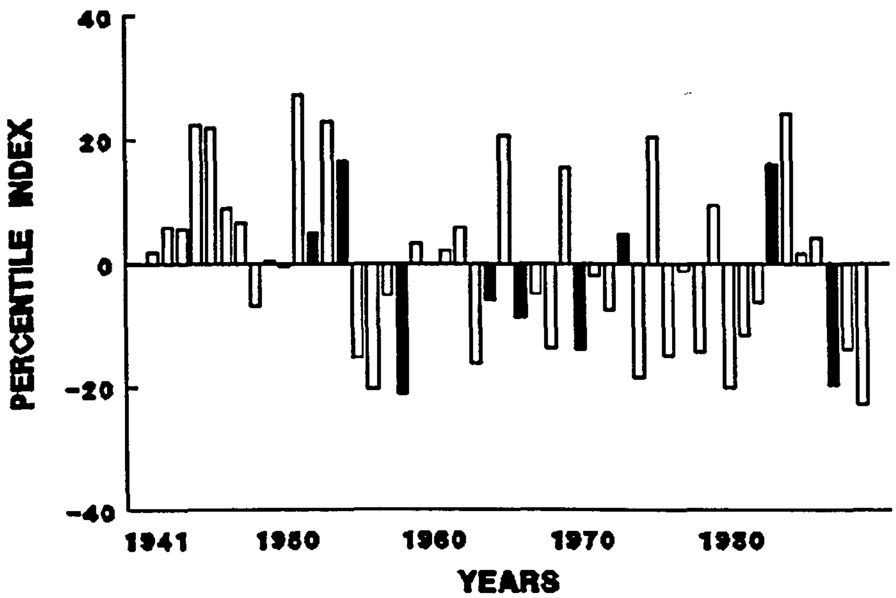

Figure 16. Time series of northwest Iowa precipitation for the January (+) until June (+) season 1941-1989. The year +1's are represented by dark bars

The mean percentile rank for temperatures (see Figure 4) revealed that December (-) until April (0) monthly temperatures for Ames, Iowa tended below the median value and November (0) until February (+) above the median value. In Figures 17 and 18 the time series for winter seasons was chosen to examine the consistency of the response to El-Nino events. This season includes both above mentioned time periods. Even though the analysis did not indicate any response for summer seasons, similar analysis were performed for the Ames monthly summer temperatures and monthly heat stress indices, i.e., sum of maximum air temperatures above 30 C. The intent was to achieve an understanding between El-Nino events and those factors in Iowa. The results are shown in Figures 19-22.

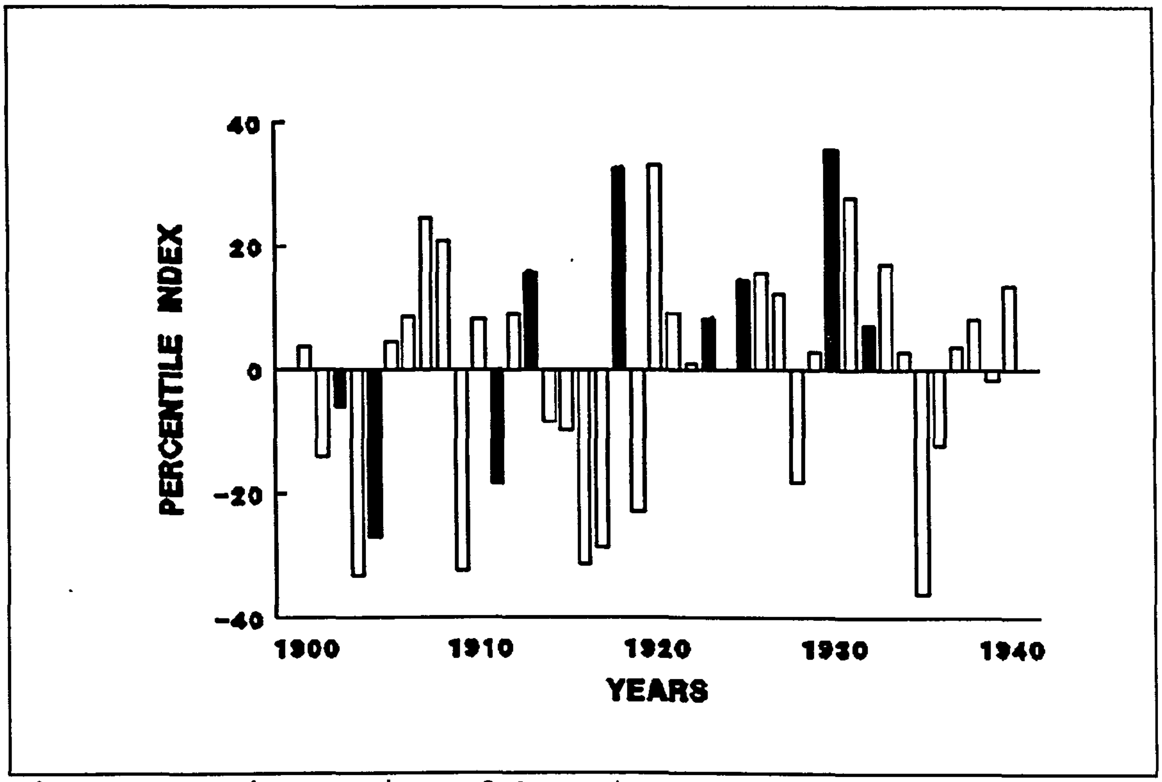

Figure 17. Time series of Ames temperatures for the winter season 1900-1940. El-Nino years are represented by dark bars

Winter season temperatures during year -1's (Figures 17 and 18) had about the same chances of being above or below the median value with 10 out of 20 El-Nino years fitting this category. The winter temperatures during EL-Nino years tended above the median value with 13 out of 20 El-Nino years. However, the χ^2 test = 0.6 showed this to be not significant.

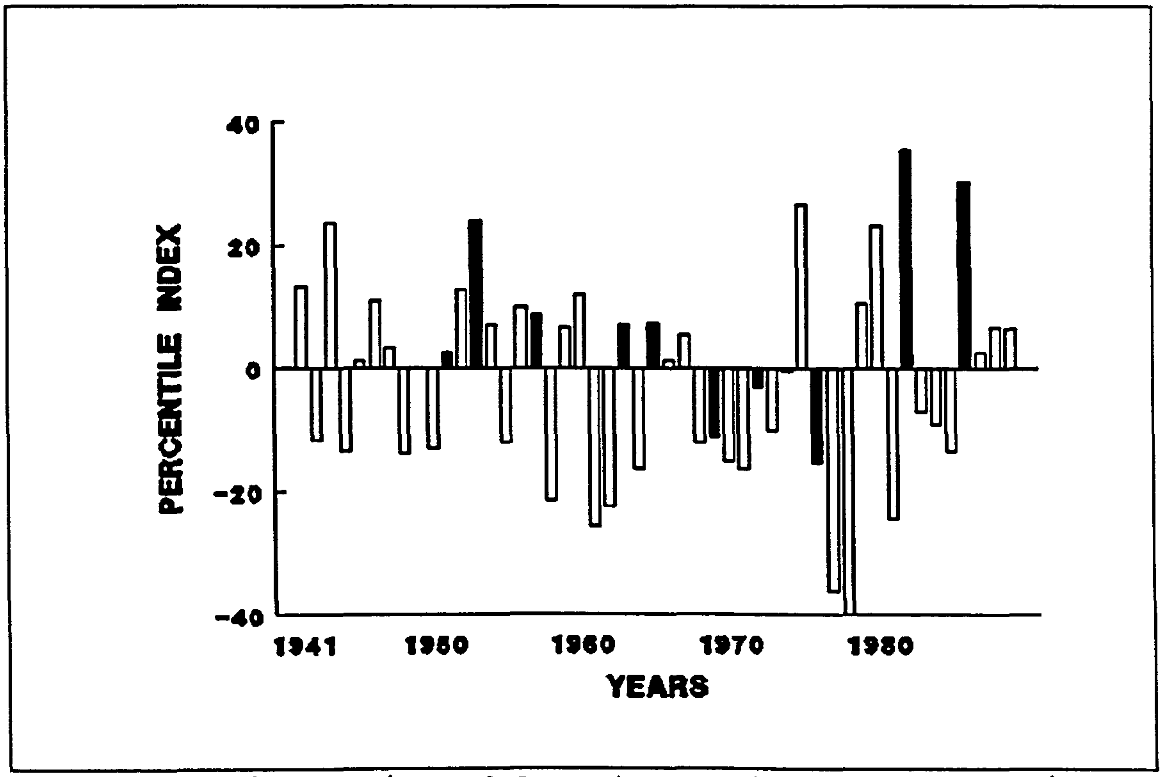

Figure 18. Time series of Ames temperatures for the winter season 1941-1989. El-Nino years are represented by dark bars

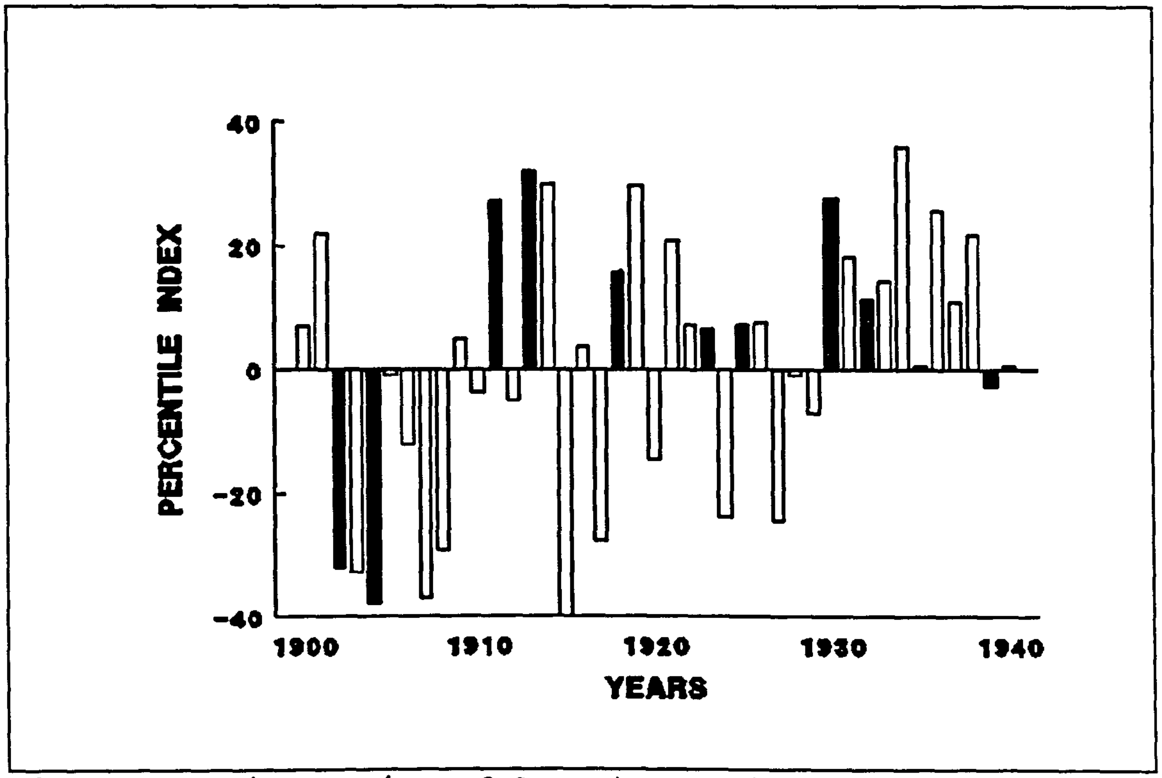

Figure 19. Time series of Ames temperatures for the summer season 1900-1940. El-Nino years are represented by dark bars

Summer season temperatures during El-Nino years (Figures 19 and 20) had about the same chance of being above or below the median value with 11 to 10 out of 20 El-Nino events fitting this category.

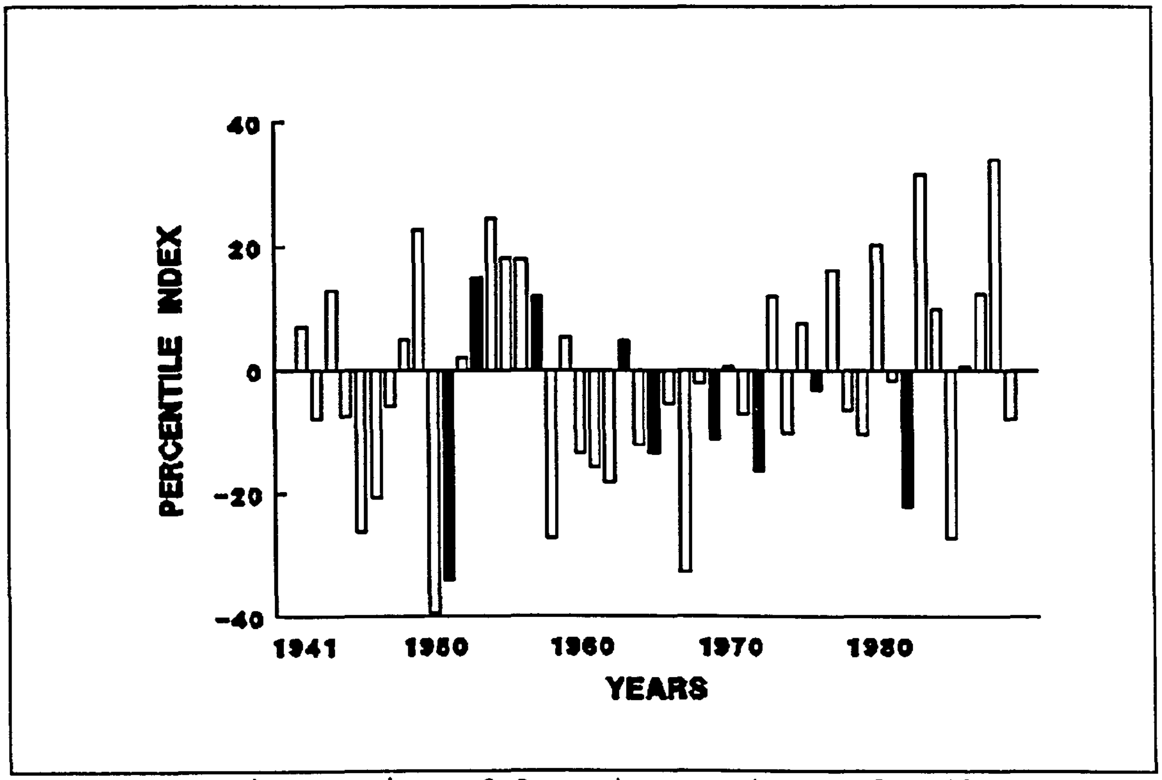

Figure 20. Time series of Ames temperatures for the summer season 1941-1989. El-Nino years are represented by dark bars

The temperatures in years before El-Nino tended to be below the median value for 13 out of 20 events (65%). Similarly, years following El-Nino events were above the median value. Almost the same pattern was found with heat stress (Figures 21 and 22).

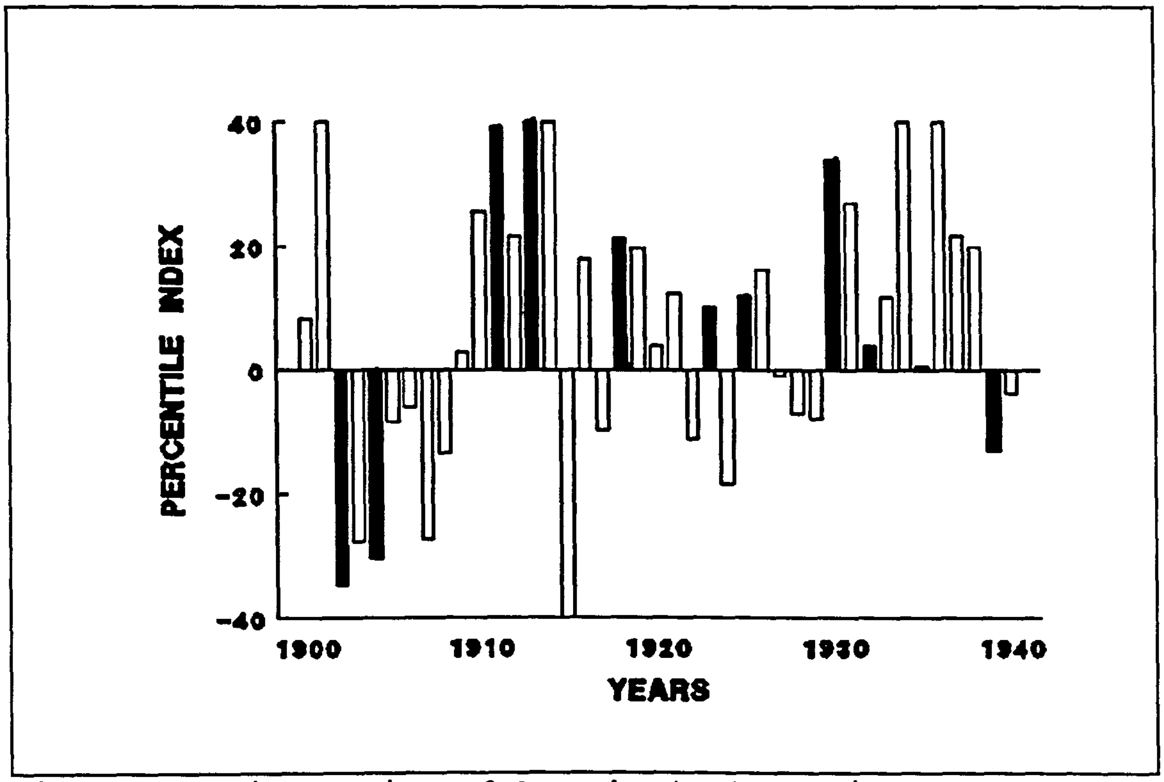

Figure 21. Time series of Ames heat stress index for summer season 1900-1940. El-Nino years are represented by dark bars

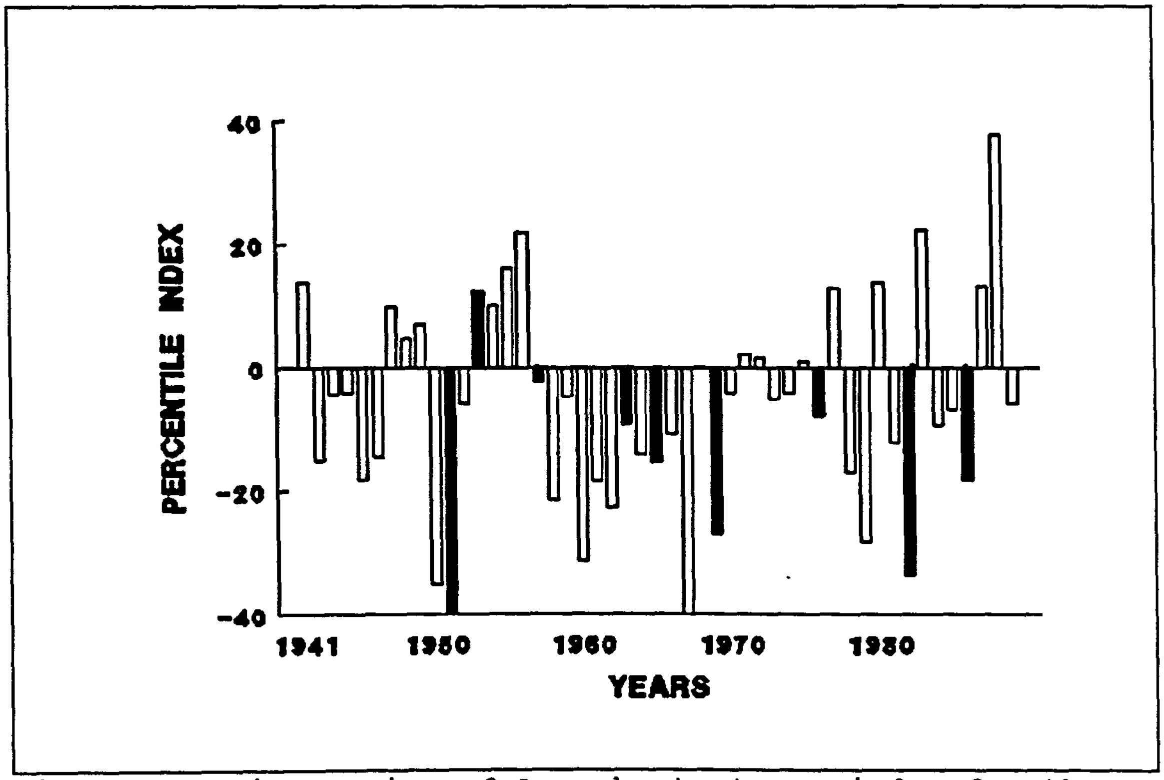

Figure 22. Time series of Ames heat stress index for the summer season 1941-1989. El-Nino years are represented by dark bars

It is of interest to note that for both summer temperatures and heat stress during the period from 1900 through 1940 (Figures 19 and 21) the El-Nino years were consistently above the median. The opposite is true for the period from 1941 through 1989 (Figures 20 and 22). The reason for this behaviour is unknown.

Spectral Analysis

In general, the previous analysis suggested that above normal precipitation was associated with El-Nino events. This section studies to what extent the precipitation fluctuation in Iowa is related to the southern oscillation index (SOI), which is closely related to El-Nino. For this purpose, only central Iowa precipitation data were used. Figures 23 and 24 show standardized central Iowa annual precipitation or temperature fluctuations compared to the SOI.

In this analysis, data are standardized by subtracting the mean and by dividing by the standard deviation of each data set. The analyses were limited to the time period beginning in 1935 because of SOI data availability.

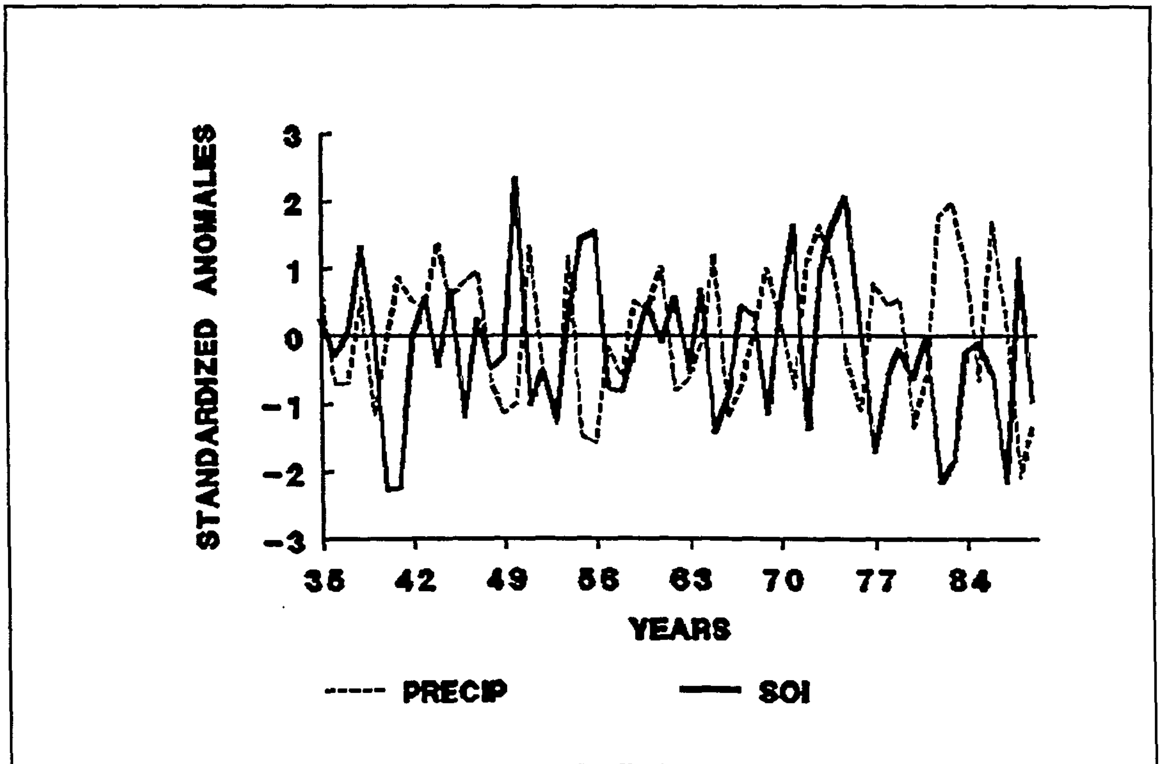

Figure 23. Time series of standardized annual precipitation in central Iowa and the southern oscillation index from 1935 until 1989

As can be seen from Figure 23, an exact relationship cannot be discerned from these two time series. This fact could be the explanation of the results from the previous analysis which showed that El Nino in some degree did affect Iowa climate, but not in a high degree of consistency. The pattern is even more inconsistent for the temperature (Figure 24).

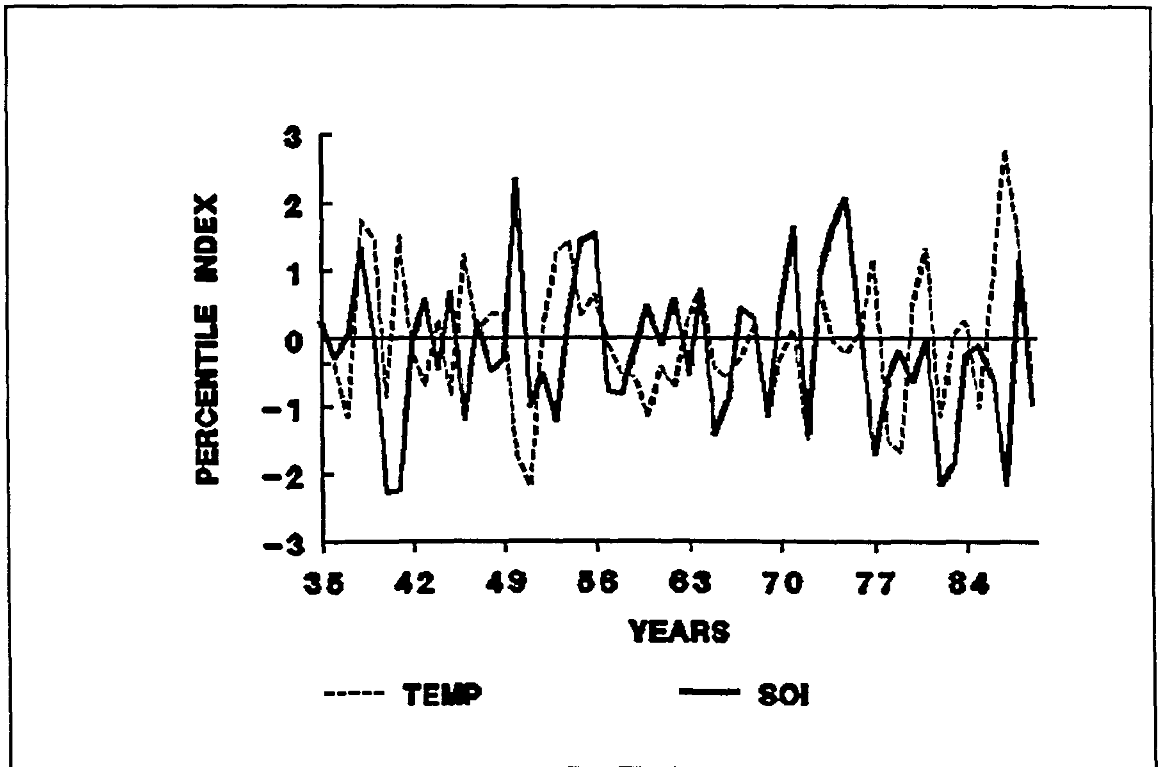

Figure 24. Time series of standardized annual temperature in central Iowa and the southern oscillation index from 1935 until 1989

The spectral densities of these two weather variables, i.e., central Iowa precipitation and the SOI are shown individually in Figures 25 and 26. Peaks in these spectrums indicate possible periodicities for each time series.

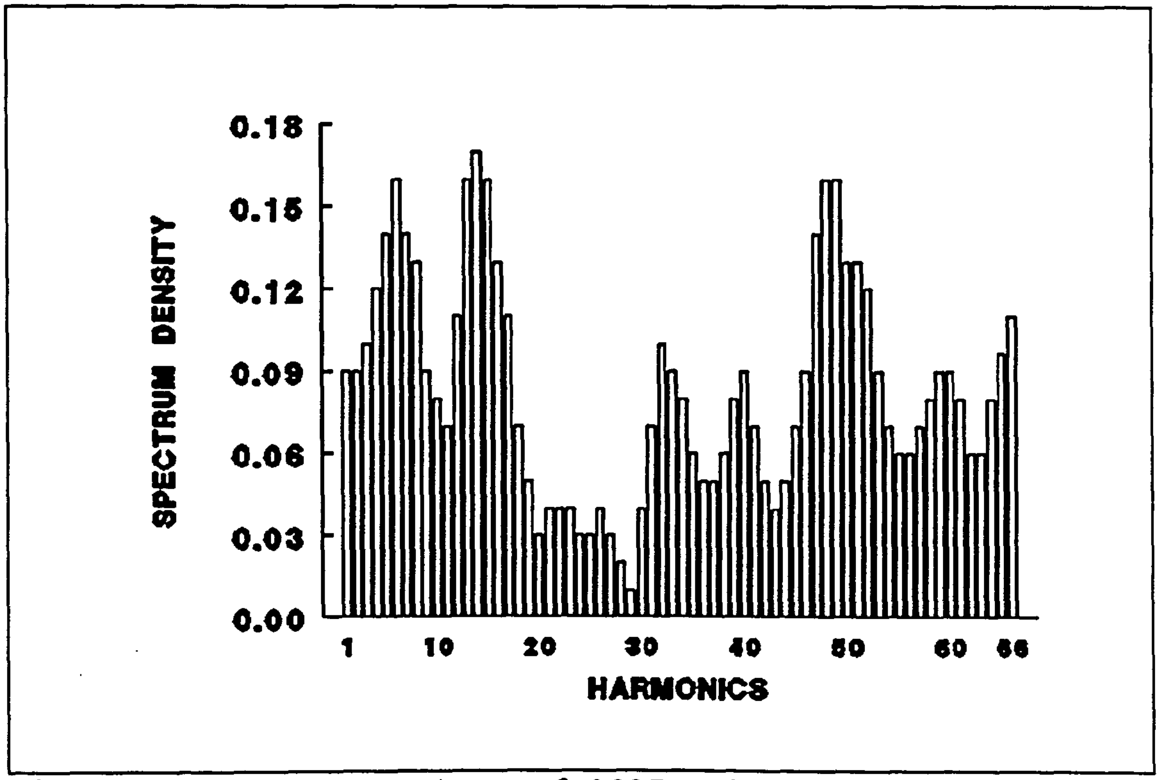

Figure 25. Power spectrum of 1935 - 1989 standardized seasonal precipitation in central Iowa

For seasonal precipitation (Figure 25), the power spectrum reveals peaks at harmonics 5, 14 and 49. This suggests periodicities of 11 years, 4 or 5 years and 1 year. By using the χ^2 test, spectral densities exceeding 0.16 are significant at the 5% level.

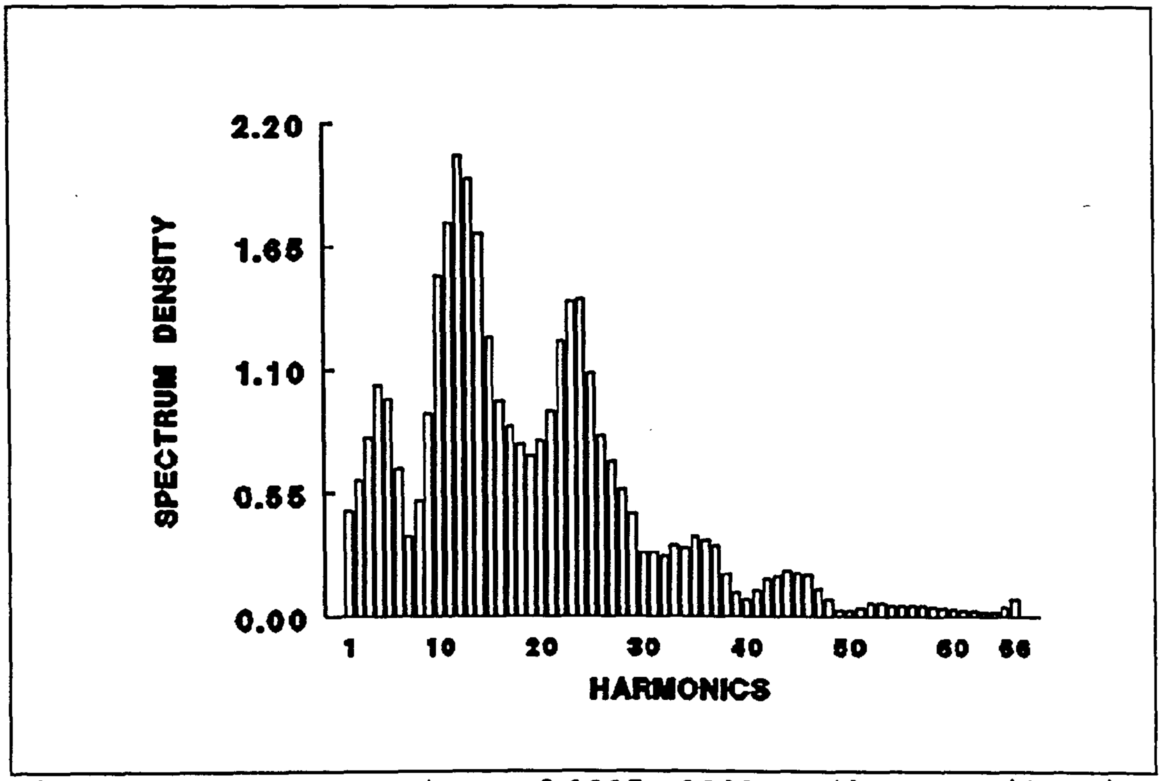

Figure 26. Power spectrum of 1935 -1989 southern oscillation index

For the SOI (Figure 26), the power spectrum showed peaks at harmonics centered near 13 and 24. This suggests two possible periodicities of about 5 and 2 years. The spectral densities exceeding 0.79 are significant at the 5% level.

This spectrum agrees with Rasmusson, Wang and Ropelewski (1990), who noted that El-Nino possibly is forced by two cycles, one with a 2-year period and the other with a 4 to 5-year period. These two combinations apparently produce a highly irregular rhythm of El-Nino.

Figure 27 illustrates the cospectrum of central Iowa seasonal precipitation and the SOI. This spectrum indicates fluctuation magnitude within the same phase, either with the same sign or opposite sign. Thus, peaks in this spectrum show the correlated part at a specific harmonic. Also, this figure illustrates the coherence spectrum, a measure of the intensity of association between these two series.

The cospectrum analysis in Figure 27 shows a peak (-0.27) at harmonic 13. This result gives an indication that these two series have the same phase yet with opposite sign (negative contribution) in the frequency near 5 years. The coherence for this frequency is 0.65 and significant at the 5% level. This is related to the previous spectrum (Figures 25 and 26), which showed that both series exhibit possible periodicities near 5 years. The phase spectrum is illustrated in Figure 28.

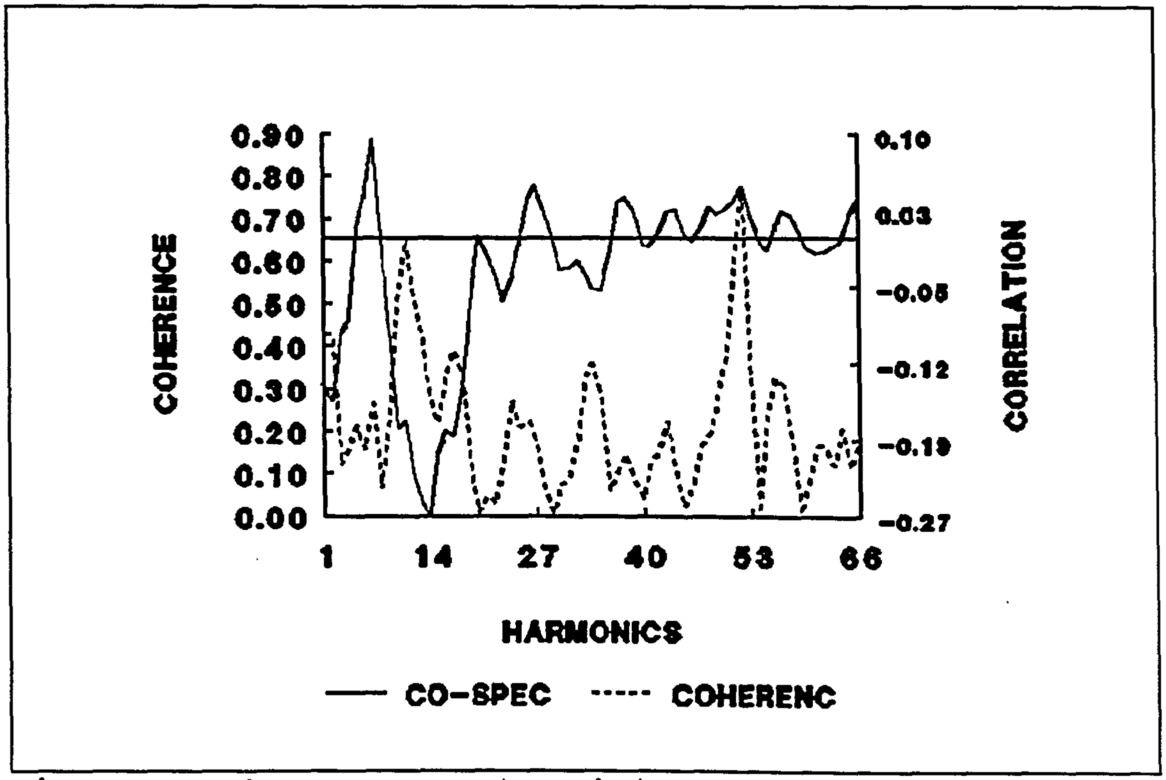

Figure 27. The cross-spectrum between central Iowa seasonal precipitation and the SOI from 1935 until 1989

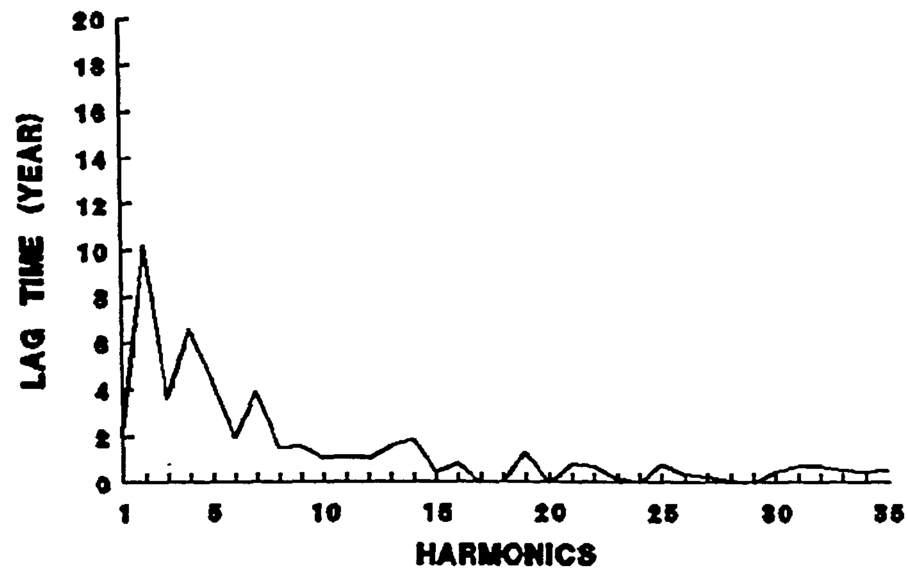

Figure 28. Phase spectrum of central Iowa seasonal precipitation and the SOI from 1935 until 1989. Positive lag time indicated that the SOI leads the precipitation.

This spectrum indicates that at harmonic 13, where the series exhibits the high coherence (see Figure 27), the variation of SOI generally preceded the precipitation variation by about 1.1 year. This implies that about 1.1 years after the SOI changed from positive to negative, central Iowa precipitation would change from negative to positive.

CONCLUSIONS

From this analysis, it can be concluded that there is some indication of an El-Nino-related signal in Iowa. However, this study indicates that the response is not highly consistent over time.

While studying El-Nino effects on precipitation in North America, Ropelewski and Halpert (1986) concluded that the Great Basin and Gulf of Mexican regions are the only areas in North America that showed a consistent El-Nino-related response. The High Plains region gave some indication about the signal, but the response was not consistent. The sensitivity of regional precipitation to the exact location and strength of El-Nino related Pacific-North America or other circulation patterns might be the reason for the lack of a consistent pattern for El-Nino effects at higher latitudes.

Van Loon and Maden (1981) wrote that the relation between the Southern Oscillation and the Northern Hemisphere had positive correlations in the tropical and subtropical parts of western Pacific and negative correlations over the western Atlantic. No stable relations were found outside of those regions. The Southern Oscillation was sometimes strong enough to influence the northern part, but sometimes it was relatively weak. It is also possible that no important physical link between the southern oscillation and the North

Atlantic exists. For Iowa the lack of consistent response does not necessary show lack of evidence of EL-Nino influence on Iowa's climate. It is possible that the magnitude of El-Nino-related precipitation response was large, but had different sign from one period to another period. According to Van Loon and Madden (1981), the pressure anomalies in the Northern Hemisphere may sometimes be in-phase with the SOI and sometimes out-of-phase with it.

As the results from the spectrum analysis suggested, it may be easier to find a weather pattern related to EL-Nino if the data were analyzed over some short period of time, i.e., 5 years, since the magnitude and extent of El-Nino itself may vary from episode to episode.

Horel and Wallace (1981) noted that the influence of variations in the Equatorial Pacific on North American climate is clear only during the winter season which falls within warm events and only over the northwestern and southeastern parts of the continent. It is reasonable then that Iowa's geographical position in central North America may explain why the response was not highly consistent. Furthermore, Philander (1983) stated that the tropical Pacific predictors account for less than half the variance of wintertime mean surface temperature over North America. This means not all ENSO events are associated with a severe winter in that area. There was a severe winter during the 1976-1977 ENSO event, but not during the 1972-1973 event, and there was an exceptionally cold winter in 1978-1979 when there were no ENSO events.

One problem in studying El-Nino was the difficulty relative to classification of each El-Nino event. Since no two events are exactly alike, the classification is highly subjective (Quinn e. al., 1978). Some similar atmospheric changes can occur even when no El-Nino is present. During 1979 and 1980, there were changes in wind, sea level and rainfall west of the dateline in the Pacific, which is similar to the observation during El-Nino events, however, there was no such indication over the central and eastern Pacific (Philander, 1983).

The 1982 and 1983 event was one of the strongest that has ever been recorded. This event was in unusual fashion since the positive sea surface temperature anomalies appeared first in the central Pacific during the Southern Hemisphere winter rather then near the coast of South America during the Southern Hemisphere summer (Kousky et. al., 1984).

It was mentioned before that El-Nino is considered as an important factor for ocean-atmosphere fluctuations and related to year-to-year variability of world climate. However, more study is needed to gain a better understanding about El-Nino and its influence on Iowa's climate.

SUMMARY

This study indicated that about 60 to 70 % of the time, precipitation in Iowa has a tendency to be above median value during the El-Nino years especially in spring and summer, and below median value in summer and fall of the years before the El-Nino. For the years following El-Nino, the precipitation has the same chance of being above or below the median value.

The spectrum analysis showed that Iowa precipitation had possible periodicities of 11 and 4 to 5 years while the Southern Oscillation Index had periodicities of 5 and 2 years. These two series had the same phase with opposite sign at the frequency of 5 years. The coherency of this frequency was 0.65.

The phase spectrum implied that in general 1.1 years after the Southern Oscillation Index changed from positive to negative, Iowa precipitation would change from negative to positive.

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It is really a blessing that my paper was done. Thank you God!

APPENDIX

USING CHI-SQUARE TO TEST THE PERCENTILE RANK

To test a null hypothesis that the probability of above median precipitation during El-Nino events is the same as the probability of below median precipitation, a chi-square test was used (Steel and Torrie, 1980). The criterion is:

$$\chi^2 = (r_2 n_1 - r_1 n_2)^2 / r_1 r_2 (n_1 + n_2) \tag{3}$$

for a ratio r_1 : r_2 with observed numbers n_1 and n_2 . For example, for southeast Iowa the precipitation during the time period from February (0) to August (0) revealed that 17 out of 23 El-Nino events were above the median. Total years with above median precipitation were 53 out of a 100-year data set (1890-1989). The 2 x 2 contingency table is as follows:

	above the median	below the median	total
El-Nino events	17	6	23
Non El-Nino	36	41	77
Total	53	47	100

The ratio of total above median and below median is 53 : 47 and observed numbers of above median and below median are 17 and 6, respectively. Applying the test criterion given by eq.3, we obtain

$$\chi^2=(47x17-53x6)^2/53x47x23$$

$$= 4.038$$

The chi-square table shows that for 5 % significant level with 1 degree of freedom is 3.84. This result implies that the probability of above median precipitation in southeast Iowa during the El-Nino events was not the same as the probability of being below median. The same procedure was used for another regions.