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Temporal Distribution of Illinois Precipitation During the Twentieth Century

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ABSTRACT

Temporal fluctuations in precipitation across Illinois during the 20th Century are assessed. Regional precipitation amounts for 15-year periods were analyzed to show how the precipitation has shifted both spatially and temporally in Illinois. The late 19th Century and early 20th Century experienced near average precipitation conditions, followed by predominately dry conditions from 1913 through 1942. For example, during 1928-1942, all of Illinois had below average precipitation. After 30 years with near average precipitation from 1943 to 1972, extremely wet conditions appeared during 1973-2002, with all of the state experiencing above average precipitation. Extremely high and low precipitation values within Illinois during each 15-year period revealed temporal differences with much greater spatial variability during the wetter periods than during near average or dry periods. The state's lowest 15-year values frequently occurred in southern Illinois, whereas the highest values were most common in northern Illinois. Summer rainfall fluctuations reflected those found in annual precipitation, revealing the importance of summer rainfall in determining annual amounts. The results, which reveal sequences of 30-year periods with near average, then dry, then average, and finally wet conditions, should be useful in considering future precipitation conditions for hydrologic and agricultural planning. If the past is a predictor of the future, the 2003-2032 period should have near average precipitation.

INTRODUCTION

Fluctuations in the annual precipitation across Illinois during the 20th Century have relevance in hydrology, agriculture, and engineering design. The historical fluctuations offer perspectives on impacts of past differences on hydrologic conditions, such as runoff and droughts, and on crop yields. The findings also serve as guidance for future climate outcomes. Summer rainfall amounts were also examined because of their importance to agriculture and water resources.

The design and operation of water management and supply systems in Illinois rely on precipitation information. Inputs typically include the average and extreme annual precipitation values. Extremes include heavy rainfall events and prolonged multi-year wet periods and droughts. The time distributions of high and low precipitation occurrences

traditionally have been treated statistically as random events, and no information is available on how periods with prolonged extremes may systematically shift over time.

Recent studies found multi-decadal increases in annual precipitation across the Midwest since the 1940s (Karl and Knight, 1998). Huff and Angel (1990) assessed the temporal distribution of 1- and 2-day heavy rainfall frequencies (2-year events) in Illinois for 1901-1940 and 1941-1980, finding 10 to 20 percent increases over time across most of the state. Angel and Huff (1997) examined the time distributions of 5.1-centimeter (cm) rain days for 1901-1994, finding 20 percent increases since the 1940s.

Multi-year precipitation values for 105 years embracing the 20th Century for each of the nine climate districts in Illinois, plus those districts in adjoining states, were used to assess the temporal behavior of precipitation (see Fig. 1 for the district boundaries). The analysis was based on precipitation values for 15-year periods in each of the climate districts using precipitation data collected during 1898-2002. Precipitation conditions in the seven discrete 15-year periods during the 105-year period of study were analyzed beginning with those in 1898-1912 and ending with those in 1988-2002. The selection of 15-year periods as a basis for grouping the data, was based on past studies of the fluctuations of precipitation and temperature conditions. These revealed that 10- to 15-year periods dominated the cyclical behavior of the state's precipitation (Neill, 1980; Lamb and Changnon, 1982; Easterling et al., 1990). Neill and Hsu (1981) performed a harmonic spectral analysis of historic Midwestern precipitation data for 1901-1980, and found the most significant wavelengths were between 10 and 18 years in length. Thus, 15-year periods capture the short-term cyclical behavior found in the long-term, century scale distribution of precipitation.

Precipitation data assessed were the regional mean values, as determined for the nine climate districts in Illinois and those in adjacent states. The precipitation values in each climate district are an average of the data from the 20 to 25 weather stations in each district. The selection of regional values for study eliminated the large variations sometimes associated with data from one or two individual weather stations that can experience very localized heavy storms or low rainfall lasting a few years (Changnon and Huff, 1980).

Maps based on the average annual precipitation amounts in the climate districts for the individual 15-year periods were developed. Each district's 15-year precipitation value was expressed as a percent of the district's 105-year average. Thus, these percentages measure the departures in each period from the long-term mean. Analysis of the precipitation patterns, based on the percentage of long-term mean values, allowed definition of when, where, and how much precipitation departed from average in each district and for the seven 15-year periods. It should be noted that a 15-year period with any class of precipitation, such as near average, had a few years with precipitation that was not in that class. Analysis showed that in all periods at least 10 of the 15 years had amounts matching the category classified for the 15-year period's total precipitation.

PRECIPITATION DISTRIBUTION

The average annual precipitation across Illinois has a latitudinal distribution (Fig. 1). Amounts are lowest in the northern districts with 86 cm, and highest in extreme southern

districts with 116 cm. Isohyetal lines between the extremes are oriented west-east, becoming closer together in southern Illinois where cold season precipitation is much heavier than in central and northern Illinois (Changnon, 2002).

The annual precipitation pattern for 1898-1912 (Fig. 2a) exhibits north-to- south variations. The predominate above-average areas are located in extreme southern and northern Illinois. Values in Table 1 reveal four Illinois districts had above average values and five with below average values, revealing the near average conditions for the entire state. District values of 100 percent or higher were classified as above average in Table 1, and values lower than 100 were classified as below average. The highest percentage among the nine climate districts was 101 percent in northwestern Illinois, and the lowest was 96 percent in east-central Illinois, as shown in Table 1. The second 15-year period, 1913-1927, had district values exhibiting a north-south distribution and greater differences (Fig. 2b) than occurred in 1898-1912. The highest value was 104% in deep southern Illinois, and 97% in northeastern Illinois was the lowest, thus serving as the state's extreme values (Table 1). Most of Illinois was dry with seven districts experiencing below average precipitation.

The 1928-1942 period included the severe droughts of the 1930s, and the prevailing dryness of the period is revealed in Figure 2c. All Illinois climate districts had values below the long-term average, the only 15-year period with such an extreme frequency of below average occurrences (Table 1). The highest district value was 98% found in the west. The lowest district value was 92% in southeastern Illinois.

Precipitation during the 1943-1957 period formed a different pattern than found in previous periods (Fig. 2d). The lowest percentages were in the west, and the highest was in the south. Considerable spatial variability exists in the period's precipitation pattern, as revealed in the range of the extreme district values (Table 1). The highest was 104% and the lowest was 96%, an 8% difference. Four districts had above average values and five were below average, reflecting the impacts of the severe droughts in western Illinois during the 1950s.

The precipitation pattern for 1958-1972 (Fig. 2e) shows that the northern half of Illinois had values above average. In contrast, the southwest district experienced only 95% of average and precipitation in all of southern Illinois was below average. The highest district departure in this period was 106% in the northwest district. Again, more districts had below average than districts with above average values (Table 1).

The 1973-1987 period represented a shift to widespread wet conditions. All nine climate districts had above average values (Fig. 2f). This period was the opposite of the dry 1928-1942 period. The highest departure was 111% in northeast Illinois, the highest departure found during the 105-year period. The lowest district value was 103% in southwestern Illinois (Table 1). Areas with the greatest positive precipitation departures were in the northern half of the state. Streamflows and floods have also increased significantly in this area over time (Changnon and Kunkel, 1995).

The 1988-2002 period (Fig. 2g) also had all nine districts with above average annual precipitation, continuing the wet trend of 1973-1987. The greatest positive departure was

107% in the northwest district. The state's lowest district value was 102% and it occurred in southern Illinois. The century's last two wet periods, coupled with a dry 1928-1942 period, reveals why investigators have found upward time trends in annual precipitation since the 1930s (Karl and Knight, 1998).

Temporal Fluctuations

One measure of the fluctuations in the annual precipitation conditions over time are displayed on Figure 3. The state's maximum and minimum district values for each of the seven 15-year periods reveal major temporal fluctuations from 1898 to 2002. The statewide average percentage values are 100% or less for the first four periods from 1898 to 1957. Thereafter, the values are above average through 2002. This dry-to-wet sequence is further revealed in Figure 4, which is based on the number of climate districts with above or below average precipitation. The temporal distributions of these values indicates Illinois had four distinct eras: 1) near average for 1898-1912, 2) dry conditions from 1913 to 1942, 3) near average conditions from 1943 to 1972, and 4) above average from 1973 to 2002. Precipitation values for 1901-1995 at 12 Illinois stations scattered around the state showed varying temporal differences (Changnon et al., 1997). Most stations in the northern half of Illinois had increases over time, although two had slight decreases, and most stations in southern Illinois displayed no up or down trends over time. These station-to-station trend differences result from localized shifts and reveal why it is important to use regional mean values for assessing major temporal differences.

The temporal distribution of summer (June-August) rainfall values were examined because of the importance of the season's rainfall to Illinois agriculture and water resources. Summer rainfall is typically the heaviest of that of the four climate seasons. The district summer values were expressed as a percent of their 105-year averages, as done with the annual values, and their distribution based on the 15-year periods is shown in Figure 5. The number of districts with below average amounts dominates from 1898 to 1942, shifting to more districts with above average values from 1958 to 2002. This distribution is very similar to that of the annual values (Fig. 4), illustrating the importance of summer rainfall in determining the annual amounts. The upward trend in summer rainfall agreed with other findings. A study of growing season (May-August) precipitation and corn yields in Illinois during the 1901-1997 period found good yield seasons based on adequate rainfall occurred only 2 to 3 times per decade during 1921-1950, but the frequency shifted to 5 to 6 good yield seasons for the 1971-1997 period (Changnon and Winstanley, 1999).

SUMMARY AND CONCLUSIONS

The 105-year period encompassing the 20th Century sampled a wide range of annual precipitation conditions across Illinois, and three types of conditions occurred. The first 15-year period, 1898-1912, had near-average precipitation, with minor spatial variability across the state. In the next two periods, 1913-1927 and 1928-1942, below average precipitation conditions prevailed, and considerable spatial variability was evident. The fourth and fifth periods, 1943-1957 and 1958-1972, had near- average precipitation conditions. The last two periods encompassing 1973-2002 experienced above average precipitation. Precipitation values in both 1973-1987 and 1988-2002 exhibited greater spatial variability than occurred in any other periods.

The seven-period sequence was as follows: a near-average period followed by two below average periods, two more near-average periods, and two above average periods. It is important that the three types of precipitation periods since 1912 each lasted 30 years. There were too few weather stations operating during 1882-1897 to determine reliable values for the nine Illinois climate districts, but a reliable statewide average could be calculated. It was 101% of the long-term average and hence similar to the amount in 1898-1912 (Fig. 3). When coupled to 1898-1912, this formed a 30-year period of near-average precipitation. This finding, which involves persistence of given levels of precipitation conditions for approximately 30 years, followed by a shift to another regime also lasting about 30 years is useful information for assessing possible future precipitation outcomes. The 30-year wet period ended in 2002, and the past sequences suggest that the next 30 years, 2003-2032, will likely experience near-average precipitation.

The 1898-2002 distribution of precipitation conditions in Illinois also reveals why various recent studies of total precipitation, heavy rainfall events, and streamflow have all detected upward trends beginning during the 1920s and 1930s. During the 1928-1942 period, all of the nine climate districts had below average precipitation, followed by a balance between above and below average conditions during 1943-1972, and then a high frequency (all nine districts) with above average precipitation conditions during 1973-1987 and 1988-2002. The dry, to near average, to above average shifts from 1913 to 2002 reflect the upward trend for heavier Midwestern precipitation conditions found to have begun in the 1920s (Karl and Knight, 1998; Kunkel et al., 1993).

Annual precipitation values, expressed as a percent of the long-term averages, displayed varying extremes over time. Extremely high and low climate district values sampled in the three earliest periods differed by 7% or less, whereas extreme values in the wetter periods differed by 8 to 11%. This illustrates that the temporal shift to greater precipitation was also associated with a shift to greater spatial variability across Illinois.

Locations where the state's extreme district values occurred in each 15-year period revealed regional preferences. In four of the seven periods the state's lowest departures occurred in southern Illinois, with two in central Illinois, and in only one period did the lowest statewide value occur in northern Illinois. The greatest departures above average in the seven periods were also distributed in various parts of Illinois. In three periods the state's highest values were in the northwest, one in the northeast, and three in southern Illinois. The 105-year results reveal that the state's extreme values for a 15-year period seldom occurred in central Illinois.

Comparison of the number of districts with above and below average amounts in each period, based on the annual precipitation and summer rainfall for the seven 15-year periods, revealed strong temporal agreement in all periods. This helps reveal the considerable impact of summer rainfall distribution in Illinois on the state's annual precipitation values.

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Table 1. Annual precipitation conditions during 1898-2002 for the nine climate districts in Illinois.

	Number of districts		Extreme district values, percent	
Period	Above average	Below average	Maximum	Minimum
1898-1912	4	5	101	96
1913-1927	2	7	104	97
1928-1942	0	9	98	92
1943-1957	4	5	104	96
1958-1972	4	5	106	95
1973-1987	9	0	111	103
1988-2002	9	0	107	102

Figure 1. Pattern based on the average annual precipitation (cm) for the 1898-2002 period. The climate districts are outlined by the light lines.

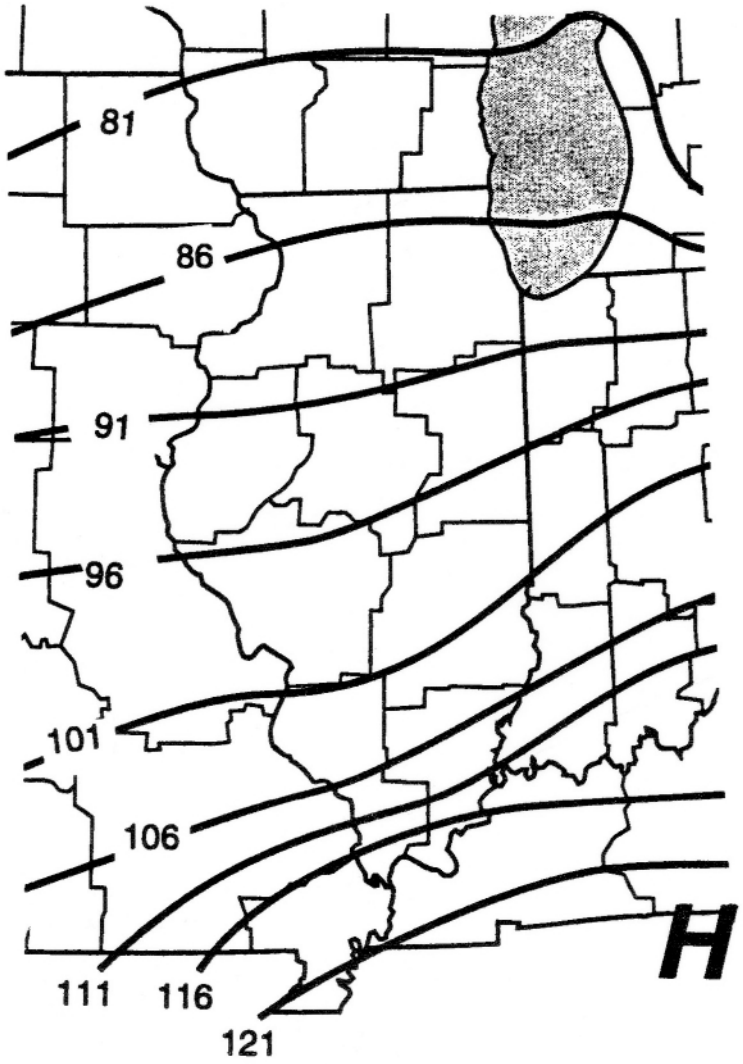

Figure 2. Patterns based on the percent of average annual precipitation in each climate district during the seven 15-year periods between 1898 and 2002.

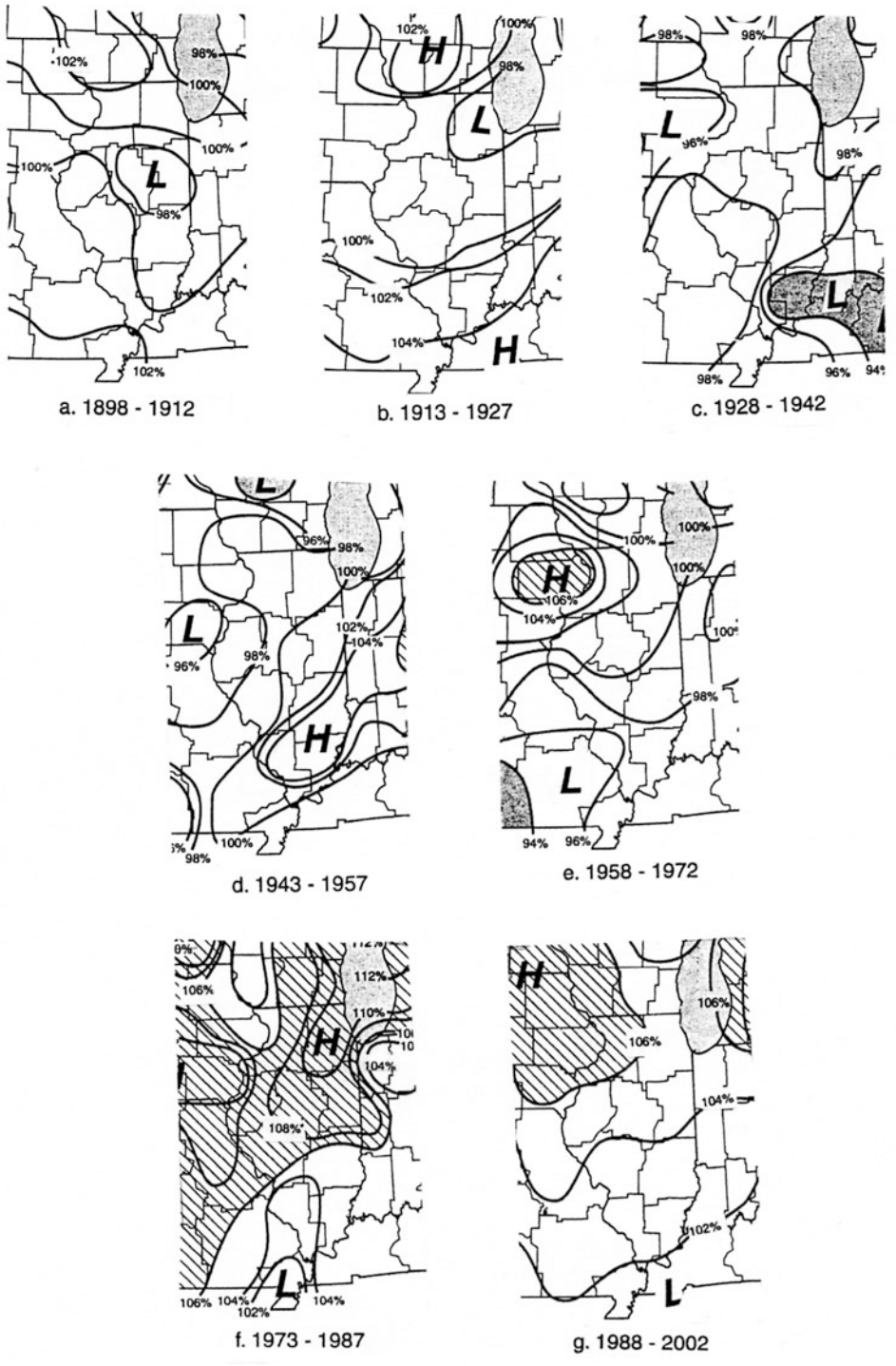

Figure 3. The temporal distribution of the maximum and minimum climate district values in each 15-year period, expressed as a percent of the 105-year district averages, and the statewide average percentage values for Illinois.

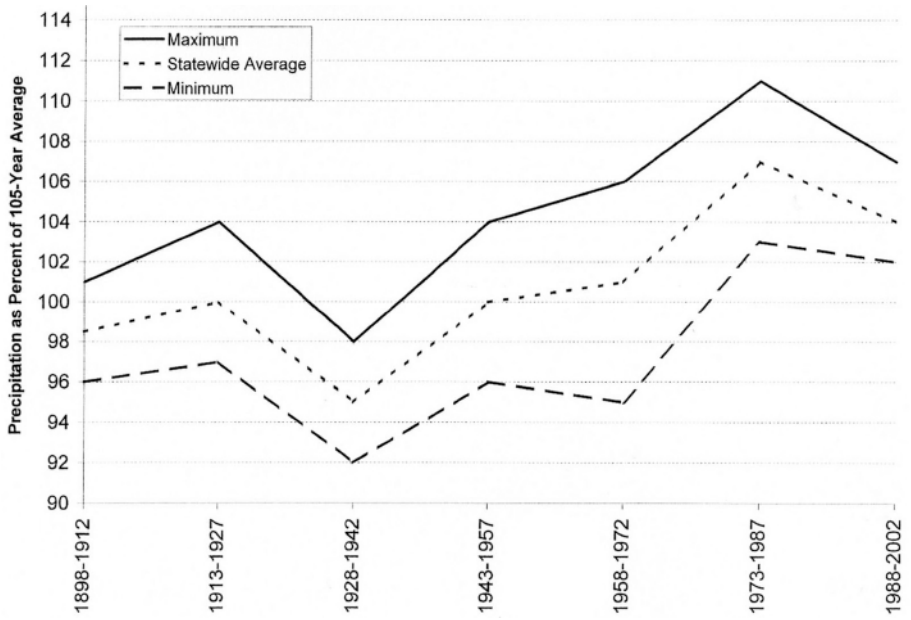

Figure 4. The temporal distribution of the number of Illinois climate districts with above and below average annual precipitation values for each 15-year period, 1898-2002.

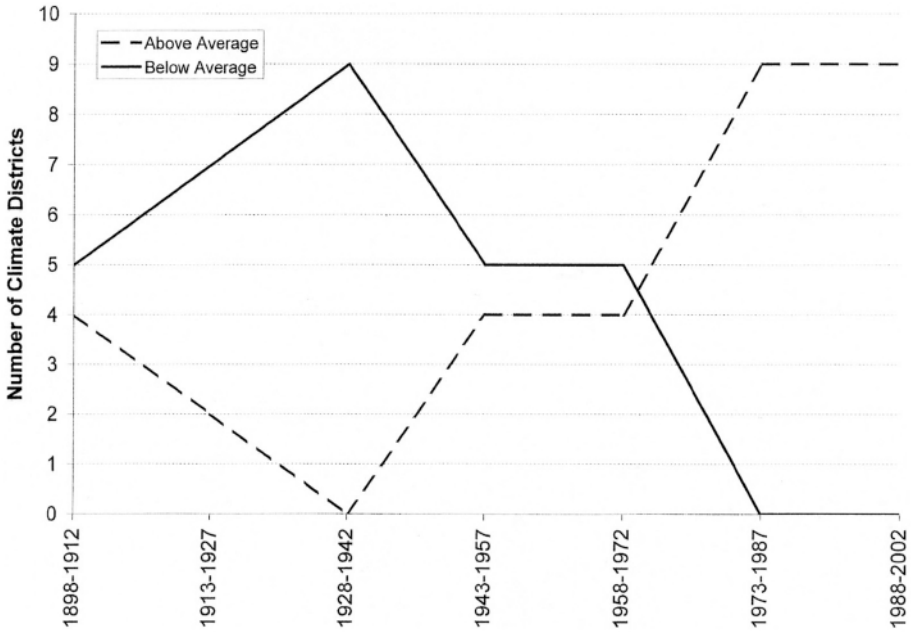

Figure 5. The temporal distribution of the number of Illinois climate districts with above and below average summer rainfall values for each 15-year period, 1898-2002.