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Variability in Illinois Summer Precipitation: An Analysis of Nine Selected Stations

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ABSTRACT

Summer precipitation totals from nine weather stations distributed across Illinois were examined for the period 1948-1993 to determine recent temporal and spatial variability characteristics. Two descriptors of temporal variability, the coefficient of variation and the frequency that stations experienced summer precipitation totals outside one standard deviation (either high or low), increased since 1970 at eight of the nine stations. The two northern Illinois stations exhibited the greatest increases in variability during the later period. When considering summer precipitation totals from all nine stations, 50 percent of all extreme summer precipitation totals (a station experiencing one of its five wettest or driest summers) were found to have occurred since 1980. The long-term change in the temporal variability of summer precipitation that occurred in the 1970s appears to be related to changes in the global ocean/climate system. Spatial variability in Illinois' summer precipitation amounts, which appears to be related to Illinois' large latitudinal extent and the convective nature of summer precipitation, indicated that a statewide average often produces erroneous results.

INTRODUCTION

Based on precipitation data averaged across Illinois, the summer (June, July, and August) of 1988 was extremely dry, while during the summer of 1993 record amounts of rain fell (NCDC, 1994). However, not all weather stations in Illinois reported record events in either 1988 or 1993. A report by Changnon and Huff (1980) indicated that there were spatial and temporal differences across Illinois when considering July and August precipitation totals from 1895 to 1975. Huff and Angel (1989) identified that long-term trends associated with large precipitation events increased in the northern half of Illinois, while those in southern Illinois remained the same or have decreased. In another study, Changnon, D. (1994) identified that precipitation values analyzed from individual stations, rather than regional or statewide precipitation averages, provided more useful information when describing spatial and temporal variability in precipitation over a region.

In this study, the questions posed were: 1) Is the variability in summer precipitation, over time, consistent across the state?, 2) What extent of the state experiences a similar summer precipitation extreme?, and 3) What are the potential causes for the observed variability? The authors examined summer precipitation amounts over a span of 46 (1948-1993) years to determine the temporal and spatial variability characteristics. This short period was chosen so that a cyclone frequency data set, currently being developed, could be examined in an effort to explain the variability in summer precipitation. Results described in this paper are based on the 1948-1993 period and could differ when examining other periods.

DATA AND METHODS

Illinois, with its large latitudinal extent, is divided into nine climatic divisions. A cooperative weather station in each division was carefully selected to encompass the north-to-south climate differences across the state (Figure 1). These stations were identified by Huff and Angel (1989) as having high-quality, digitized, long-term daily precipitation records.

Monthly precipitation totals for the nine stations were acquired from the Illinois State Water Survey Midwestern Climate Information Service (MICIS) database. More than 99% of the monthly data was available for the nine stations. For months when data were missing, values from a nearby weather station in the same climatic division were substituted.

Precipitation values for the summer months of June, July, and August were added for each year. Each station's 46-year summer mean, standard deviation, and coefficient of variation were determined. The period was then divided into two equal 23-year samples and similar descriptive information determined for each.

The five wettest and driest summers at each station were determined to investigate the variations in extremes. The mean and standard deviation were calculated for the five wettest and the five driest summers at each station. These ten extreme years were chosen to examine the variability associated with the extreme summers in the 46-year period. A time series showing the frequency of stations experiencing extremes was developed. Comparisons of extreme summers from the first and second half of the period were completed. Finally, years when more than half of the nine selected stations experienced a singular summer precipitation extreme, either wet or dry, were examined.

RESULTS

Spatial and temporal variability of summer precipitation

The small ranges in mean annual summer precipitation values, standard deviations, and coefficients of variation for the nine selected stations indicate that there is little spatial variability across Illinois (Table 1). Based on the data presented, the group of stations appear to have similar summer precipitation climatologies. Interestingly, Illinois' long-term mean annual precipitation increases from north-to-south and can be explained by large-scale climate controls including: frequency and location of storm tracks, differences in air masses colliding over the state, nearness to the Gulf of Mexico, and latitude. However, because the polar jet stream generally moves north into Canada during the summer, precipitation is predominantly derived from convection within the warm, humid air mass that exists over Illinois (Trewartha and Horn, 1980). This is reflected by a lack of a long-term mean summer precipitation pattern across Illinois.

The study period was divided into two equal length periods, 1948-1970 and 1971-1993, to determine whether the temporal variability had changed (Table 2). Except at Urbana and Fairfield the differences in mean summer precipitation totals at the nine stations were less than one inch. Six of the nine stations reported an increase in precipitation, with Urbana increasing 2.74 inches, while Fairfield experienced the greatest decline, decreasing 1.12 inches. The changes in the standard deviation and coefficient of variation values indicate that the variability from the earlier to later period changed. At five of the nine stations the differences in the standard deviations were greater than those for the mean, indicating significant changes in the variability. Dixon, Joliet, and Peoria experienced the greatest changes in variability, with coefficient of variation values increasing more than 0.15. Anna, located in southern Illinois, experienced the only decrease in variability. This pattern of increased variability in the north to decreased variability in the south indicated that there can be significant spatial differences in variability across Illinois.

Variability associated with extreme summer precipitation

For each station, years with summer precipitation values outside (plus or minus) one standard deviation were identified and categorized by the two 23-year periods in Table 3. All but Effingham experienced more summers outside one standard deviation during the later period. Dixon and Joliet experienced the greatest increase in number of summers outside one standard deviation, going from three to nine and two to ten, respectively. The overall increase in summer variability was associated with fairly consistent increases in the number of summer precipitation totals above one standard deviation (6 of 9) and below (7 of 9).

The 46 summer precipitation totals were ranked for each station. The mean and standard deviation were calculated for the five wettest (highest in the ranked list) summers and the five driest (lowest) summers. In any year, a wet summer at a station represents one of the five wettest summers in the 46-year period, while a dry summer represents one of the five driest summers (Table 4). Based on the student t-test, the difference in means from the average wettest to the average driest summer was significant at the 1% level for all stations. The difference in the amount of summer precipitation from an average wet to an average dry summer was determined by subtracting the mean driest summer from the mean wettest summer; these figures ranged from 11.54 to 15.04 inches for the nine stations.

The two 23-year periods were analyzed to further investigate whether the variability associated with extreme summers had changed. A sample of 90 extreme summers existed, based on nine stations, each with five wet and five dry summers. Identifying how these 90 extremes were distributed over the 46-year period would indicate variability changes.

Nineteen wet events were reported in the first period, with 26 wet events in the second period. Similarly, 15 dry summers were identified in the first period, while 30 dry summers were identified in the second period. When wet and dry summers are combined, 34 extreme summers occurred in the earlier period, while 56 occurred during the later period (Figure 2). Based on the nine selected stations, on average 1.5 stations per year experienced an extreme during the earlier period, whereas the average for the later period was 2.4 stations. Clearly, the recent period had more dry and wet summers than the early period. Furthermore, for the last 13 summers (1981-1993) the average annual number of stations experiencing an extreme is 3.5, compared to 1.4 for the earlier 33 summers (1948-1980).

Based on the earlier stated criteria, summers were classified as anomalous when more than half the stations experienced a similar extreme. Anomalous summers with wet extremes were 1958, 1981, and 1993, while the anomalous summers with dry extremes were 1984, 1988, and 1991. Five of six anomalous years have occurred since 1980, indicating that variability has increased during the second half of the study period. Also, these results suggest that it is rare to experience one extreme statewide, because only six years in this sample were considered anomalous and there was no year in which all nine stations experienced a similar extreme.

Some of the recent anomalous extreme precipitation summers had great spatial variation. For example, when averaging data from the nine stations across Illinois, 1988 was considered an extremely dry summer with precipitation values ranging from 3.04 inches at Peoria to 8.83 inches at Anna. However, when comparing these values to the departures from average, not all locations experienced a similar decrease in summer precipitation (Table 5). So while Peoria was 8.44 inches below its summer average rainfall (more than 1.5 standard deviations below), Anna was only 2.6 inches below its summer average (less than one standard deviation below).

Table 6 shows the precipitation distribution for 1993, an anomalous wet summer in Illinois. Spatial variation similar to 1988 existed during the summer of 1993. The values ranged from 23.91 inches at Urbana to 10.41 inches at Fairfield. While Urbana was 11.47 inches above its average summer rainfall (more than two standard deviations above), Fairfield was 0.77 inches under its summer average (less than one standard deviation below).

These tables show there are important spatial differences in summer precipitation amounts across Illinois. These north-to-south variations may be explained by the large latitudinal variation that exists in Illinois and the convective nature of summer precipitation. These variations indicate that averaging summer precipitation values across Illinois will provide erroneous values in some years.

Possible explanations for the observed temporal variability

A number of recent studies have tried to link, through teleconnections, some observed climate pattern to potential causes. A paper by Trenberth (1990) identified that the mean values for three indices, the Southern Oscillation Index, the Pacific/North American Index, and equatorial sea-surface temperatures in the Pacific Ocean, significantly changed in the mid 1970s. A paper by Kerr (1992) explained that the mean state for a composite of 40 environmental variables changed in 1976. These papers, as well as Changnon, D. et al. (1990), indicated that the mean state of climate elements shift not only interannually but also over longer periods such as decades.

To determine whether the teleconnection between processes occurring over the Pacific Ocean and climate patterns experienced in North America is real, one must examine the atmospheric general circulation patterns associated with both. Future research will examine the cyclone frequency characteristics over North America and try to link the results from this paper to processes associated with the Pacific Ocean. The authors expect to identify a change in North American cyclone frequency over the last 20 years in association with the temporal variability identified in this study.

Some climate studies have examined potential global climate change associated with increases in carbon dioxide and other trace gases. Many of these studies have indicated that as surface temperatures increase in the mid-latitudes, the variability in various climate elements such as temperature and precipitation will be greater than in cooler periods (Ausubel, 1991; Changnon and Wendland, 1994). This hypothesis was used as a possible explanation for the 1993 heavy precipitation and flooding in the Midwest (NOAA, 1994). However, there is great uncertainty in the scientific community as to whether the climate has began to change in response to increases in greenhouse gases.

CONCLUSIONS

At nine selected stations across Illinois, summer precipitation totals averaged over a 46-year period from 1948-1993 did not exhibit much spatial variability. However, when that period was broken into two 23-year periods greater variability was identified in extreme summer precipitation totals during the later period from 1971-1993.

Coefficients of variation computed for both periods showed that since 1970 the variability has increased at eight of nine stations. Dixon, Joliet and Peoria in northern Illinois exhibited the greatest increases in variability, while Anna's variability decreased. A temporal analysis of summer precipitation extremes identified that 56 of 90 (62%) extremes occurred in the second half of the period (1971-1993). Furthermore, in the recent 13 years, 1981-1993, 45 of 90 (50%) extremes occurred.

More anomalous (five or more stations experiencing the same extreme) dry or wet extreme summers were experienced in the second period of the sample. Most (five of six) occurred since 1980, and three of the six anomalous years have been recorded since 1987.

As identified in previous research, these temporal changes in the summer precipitation variability over Illinois which occurred during the 1970s could be linked to long-term changes in the global ocean/climate system. Another possible explanation could be related to increases in mean temperature due to increases in carbon dioxide and other trace gases. It has been hypothesized that as surface temperatures warm, climate elements such as temperature and precipitation will become more variable.

When considering years with anomalous summer precipitation extremes, 1988 and 1993, significant spatial differences across Illinois were identified. These spatial differences may be explained by Illinois' large latitudinal extent and the convective nature of summer precipitation. This indicates that using a statewide summer precipitation average may provide an incorrect assessment of the true precipitation pattern across Illinois.

REFERENCES

Ausubel, J.H., 1991: A second look at the impacts of climate change. Am. Sci., 79, May-June, 210-221.

Changnon, D., T.B. McKee, and N.J. Doesken, 1990: Hydroclimatic variability in the Rocky Mountain Region. Climatology Report No. 90-3, Colorado State University, Ft. Collins, CO., 225 pp.

Changnon, D., 1994: Regional and temporal variations in precipitation in South Carolina, International Journal of Climatology, 14, 165-177.

Changnon, S.A. and F.A. Huff, 1980: Review of Illinois summer precipitation conditions. Illinois State Water Survey. Bulletin 64. Urbana, IL, 160 pp.

Changnon, S.A. and W.M. Wendland, 1994: What is and is not known about climate change in Illinois: The scientific perspective. Misc. Publication 156. Illinois State Water Survey. Champaign, IL, 66 pp.

Huff, F. A. and J. R. Angel, 1989: Frequency distributions and hydroclimatic characteristics of heavy rainstorms in Illinois. Illinois State Water Survey. Bulletin 70. Champaign, IL, 177 pp.

Kerr, R.A., 1992: Unmasking a shifty climate system. Science, 255, March 20, 1992, 1508-1510.

National Climatic Data Center, 1994: National Climatological Data. Asheville, NC.

National Oceanic and Atmospheric Administration, 1994: National disaster survey report: The great flood of 1993. Office of Hydrology, National Weather Service, Department of Commerce, Washington D.C., February, 1994, 281 pp.

Trenberth, K.E., 1990: Recent observed interdecadal climate changes in the Northern Hemisphere. Bull. Am. Met. Soc., 71, 988.

Trewartha, G.T. and L.H. Horn, 1980: An Introduction to Climate. McGraw-Hill, New York, 415 pp.

Table 1. Mean, standard deviation, and coefficient of variation for the nine stations. Stations are listed by location from north-to-south.

Station	Mean	Standard Deviation	Coeff. of Var.
Dixon	12.10	3.93	0.32
Joliet	11.52	4.34	0.38
LaHarpe	12.53	3.97	0.32
Peoria	11.48	4.28	0.37
Urbana	12.44	4.05	0.33
Carlinville	10.95	3.54	0.32
Effingham	11.20	3.48	0.31
Fairfield	11.18	3.62	0.32
Anna	11.43	3.88	0.34

Table 2. Mean, standard deviation, and coefficient of variation for two periods, 1948-1970 and 1971-1993.

	1948-1970			**1971-1993**		
Station	Mean	St. Dev.	C.O.V.	Mean	St. Dev.	C.O.V.
Dixon	11.99	2.76	0.23	12.20	4.82	0.40
Joliet	11.12	3.12	0.28	11.91	5.25	0.44
LaHarpe	12.83	3.66	0.29	12.22	4.23	0.35
Peoria	11.09	3.10	0.28	11.88	5.17	0.44
Urbana	11.07	3.07	0.28	13.81	4.42	0.32
Carlinville	10.89	3.06	0.28	11.02	3.96	0.36
Effingham	11.06	3.20	0.29	11.34	3.73	0.33
Fairfield	11.74	3.40	0.29	10.62	3.74	0.35
Anna	11.84	4.24	0.36	11.02	3.43	0.31

Table 3. The number of summers in each period that experienced precipitation outside one standard deviation from the 46-year mean.

	1948-1970			**1971-1993**		
Station	Wet	Dry	Total	Wet	Dry	Total
Dixon	2	1	3	5	4	9
Joliet	2	0	2	5	5	10
LaHarpe	4	2	6	3	4	7
Peoria	2	3	5	4	4	8
Urbana	1	5	6	6	2	8
Carlinville	2	2	4	5	3	8
Effingham	2	4	6	4	2	6
Fairfield	3	3	6	2	5	7
Anna	3	1	4	2	5	7

Table 4. The average and standard deviation of the top five wettest and driest summers at each location.

Station	Wet Mean	Std. Dev.	Dry Mean	Std. Dev.
Dixon	19.68	1.50	5.47	1.39
Joliet	20.62	1.92	5.58	1.28
LaHarpe	20.16	1.57	6.67	0.94
Peoria	20.00	2.48	5.48	1.30
Urbana	20.00	2.09	5.77	0.81
Carlinville	17.81	1.38	5.41	0.68
Effingham	17.06	1.45	5.52	1.39
Fairfield	18.45	2.09	5.77	0.79
Anna	19.94	3.16	6.30	0.45

Table 5. 1988 summer precipitation amounts, departures from average, and number of standard deviations from the mean.

Station	Summer Precipitation	Departures from Average	Number of Standard Deviations from Mean
Dixon	3.55 inches	-8.55 inches	>2σ
Joliet	6.38 inches	-5.14 inches	>1σ
LaHarpe	6.79 inches	-5.74 inches	>1σ
Peoria	3.04 inches	-8.44 inches	>1.5σ
Urbana	5.24 inches	-7.20 inches	>1.5σ
Carlinville	8.13 inches	-2.82 inches	<1σ
Effingham	4.90 inches	-6.30 inches	>1.5σ
Fairfield	6.78 inches	-4.40 inches	>1σ
Anna	8.83 inches	-2.60 inches	<1σ

Table 6. 1993 summer precipitation amounts, departures from average, and number of standard deviations from the mean.

Station	Summer Precipitation	Departures from Average	Number of Standard Deviations from Mean
Dixon	22.10 inches	+10.00 inches	>2σ
Joliet	22.87 inches	+11.35 inches	>2σ
LaHarpe	22.36 inches	+9.83 inches	>2σ
Peoria	23.23 inches	+11.75 inches	>2σ
Urbana	23.91 inches	+11.47 inches	>2σ
Carlinville	17.19 inches	+6.24 inches	>1.5σ
Effingham	16.83 inches	+5.63 inches	>1.5σ
Fairfield	10.41 inches	-0.77 inches	<1σ
Anna	11.13 inches	-0.30 inches	<1σ

Figure 1. Location of nine long-term weather stations used in the study. The regions outlined are climate divisions.

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Figure 2. Time series of extreme wet and dry summers based on data from the nine stations.

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