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Computed Normal Range of Iowa Statewide July Precipitation[1]

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Iowa summer rainfall distributions are examined to identify small-scale anomalies. Examination of extremely wet and dry summer months shows that large rain amounts fall mainly in small, cellular areas for both extremely wet and dry months. These configurations result from individual rainfall events. Analysis of the distribution of mean July rainfall across the state reveals significant anomalous wet and dry regions that contrast with the background, east-west rainfall gradient. Because of the skewed nature of summer rainfall distributions, the median value is used to represent a more realistic expected rainfall amount for any given year. Some parts of the state have a more variable distribution and are more sentitive to the expected annual swing of one standard deviation. On the basis of statistical probabilities, these areas can expect summers of more severe moisture deficiencies to occur more often than in the rest of the state.

INDEX DESCRIPTORS: Iowa rainfall, Natural rain distributions, small-scale rain perturbations.

The variability of annual precipitation in Iowa during a recent 95 year period was discussed in a recent paper (Vaughan, Berning and White, 1987). One objective of that paper was to compare the medium range (95-year) precipitation pattern at four widely separated sites within the state for their similarity. Clearly the variability between sites, as observed in the 95-year record, suggested that local or random rain episodes were a major factor in the distribution of summer precipitation. If this interpretation of these four sites is correct, the conclusion would be that an extended range, 30 to 90 days, precipitation forecast might have a limited value to any specific site during the growing season. In short, the natural variability between sites results from small-scale precipitation episodes.

The present paper presents a more in-depth examination of precipitation patterns across the entire state based on 51 years (1934-1984) of July rain records from each of Iowa's 99 counties. In an attempt to document the cause and effect relationship resulting in extremely dry and wet summer months in Iowa, six charts depicting the national general circulation were drawn. These consisted of national monthly pressure fields and were accompanied by appropriate Iowa precipitation maps.

SCOPE OF THE STUDY

Two objectives have been pursued in this work: (a) a critical comparison of national general circulation moisture flux trajectories associated with extremely dry and wet examples of the summer months of June, July, and August, based on an 80-year sample composed of 25 select uniformly distributed sites and (b) an intercomparison of 51 years of July rainfall as observed in each of the 99 Iowa counties.

In the first phase of this study involving the six extreme cases, nearly every Iowa site was used in the analysis. In the previous 95-year study (Vaughan, Berning and White, 1987), the history of the site location and continuity of observers was deemed important. In the second phase of this study, far less attention was paid to the location and past history of the sites within each county because of the large number of sites, the length of their records, and difficulty in maintaining single-site continuity. Because of the size and length of the data set, which consists of 51 years and 99 counties, some nearby stations were used in a few situations to provide a full complement of data.

A comprehensive study on drought in the United States from 1895 to 1981 by Karl and Koscielny (1982) described large-scale drought patterns and their apparent movement. Because of the large land mass surveyed, such studies require considerable data smoothing, which in turn leaves many small-scale drought patterns unidentified. By dealing with only the most critical growing season month, July, our study was designed to delineate both amount and territorial coverage during both dry and wet extremes. In addition, with a detailed examination of county by county precipitation, it became evident that small areas within the state were more sensitive with regard to overall precipitation distribution. This leads us to question what is statistically normal. During the past decade (1980-1989), a number of dry events have been observed across Iowa. In each instance, some portions of the state received adequate or above-normal rain during the growing season, although most of the attention is drawn to the portion of the state with deficit rainfall (Jensen et al., 1990).

ANALYSIS AND INTERPRETATION

a.) Examination of Extremely Dry and Wet Summer Months

Before attempting a detailed study of variability of statewide rainfall, we thought it advisable to examine specific extremely dry and wet situations. In general, Iowa has an enviable record of volunteer climatological stations with regard to both numbers of sites and longevity of rainfall records. Nevertheless, there are spatiotemporal deficiencies which make an unbiased comprehensive study difficult. The extreme dry and wet months were chosen from an 80-year period (1900-1979) using 25 uniformly distributed sites based on the National Weather Service statewide climatological network. By selecting and using nearly evenly spaced sites, biases from single sites were reduced. Secondly, the selection of these 25 sites was based on a nearly unbroken record with single site continuity. The greatest number of sites showing a collective maximum or minimum rainfall for June, July, and August were designated as the extreme wet and dry months respectively. Surface isobaric charts covering the continental United States were drawn to augment the six extreme precipitation patterns. The orientation and isobaric spacing of these charts were intended to identify air mass sources and potential moisture flow into the central United States.

The designations of wet and dry months according to this procedure do not necessarily identify the most extreme representations of monthly precipitation patterns for June, July, and August. The ranking of the National Weather Service (NWS) comprehensive extreme summer dry and wet months as opposed to the extremes determined through our select method shows good agreement in most instances. The comparative rankings are as follows: for the dry months, June 1933 was ranked the driest June, July 1936 was ranked the driest July, and August 1976 came in as the fourth driest August on record. For the wet months, June 1947 was listed as the wettest June, July 1915 ranked as the second wettest July, and August 1979 was ranked as the ninth wettest August.

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Table 1. Percent area coverage of the state in class intervals for the six extreme months.

Rainfall in cm	Fig. 1	Fig. 2	Fig. 3	Fig. 4	Fig. 5	Fig. 6
0.0-0.9	17.2	47.5	6.2	0.0	0.0	0.0
1.0-4.9	53.1	51.2	66.9	0.0	0.0	10.2
5.0-9.9	23.0	1.3	26.2	0.0	1.9	16.3
10.0-14.9	5.1	0.0	0.7	6.1	23.4	23.5
15.0-19.9	1.6	0.0	0.0	12.8	27.7	20.2
20.0-24.9	0.0	0.0	0.0	24.0	18.5	18.9
25.0-29.9	0.0	0.0	0.0	30.2	18.1	6.1
30.0-34.9	0.0	0.0	0.0	19.3	7.0	2.6
35.0-39.9	0.0	0.0	0.0	6.6	3.3	2.0
40.0-44.9	0.0	0.0	0.0	1.0	0.1	0.2
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The three dry months chosen for this study were June 1933, July 1936, and August 1976. Both June 1933 and August 1976 show significant variability in rain accumulation across the state. Both include areas with rainfall exceeding the 80-year monthly mean value. Specifically, the June 1933 maximum was 17.0 cm, which covered a small part of southeast Iowa (Figure I). July 1936 represents the only extreme drought condition where no part of the state enjoyed normal or near normal rainfall (Figure 2). The maximum July rainfall was 7.0 cm in the northeastern part of the state. In August 1976 four small areas of near-normal rainfall values, 10.0 cm, were observed in the southeastern half of the state. The minimum amount, between 1.0 and 2.0 cm, covered most of the western and central portion of the state (Figure 3). When equal areas of rainfall accumulation are integrated and expressed as percentage coverage of the state, these three dry months show considerable similarity in distribution of area rainfall, (Table 1). Note that two of the three dry months, June 1933 and August 1976, show a very similar rainfall area relationship, whereas July 1936, the all-time driest month, had an almost 50 percent area in the minimum rain category (Table 1).

The three wettest months chosen for this study were June 1947, July 1915, and August 1979. The June 1947 rainfall was the most uniform of the three wet months (Figure 4). The minimum rainfall, 12.9 cm, was found in the northwestern part of the state. The

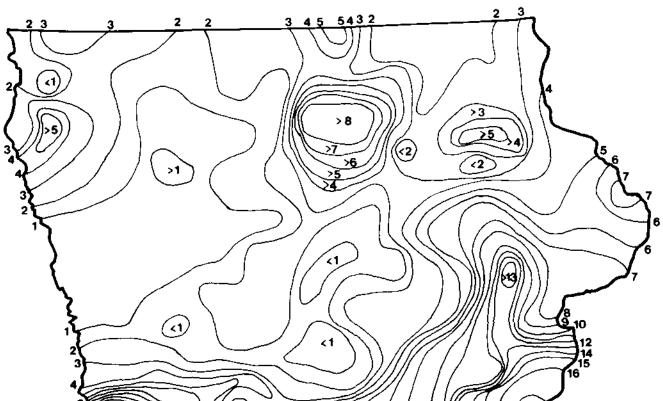

Fig. 1. Isohyet contours are shown in the state of Iowa for the extremely dry month of June 1933. Isohyets are drawn every centimeter. The three areas that received significant rainfall are the extreme southwest, southeast and north-central part of the state. A large part of the western half of the state received less than 1 cm of precipitation. The greatest amount was 13 cm near east central Iowa.

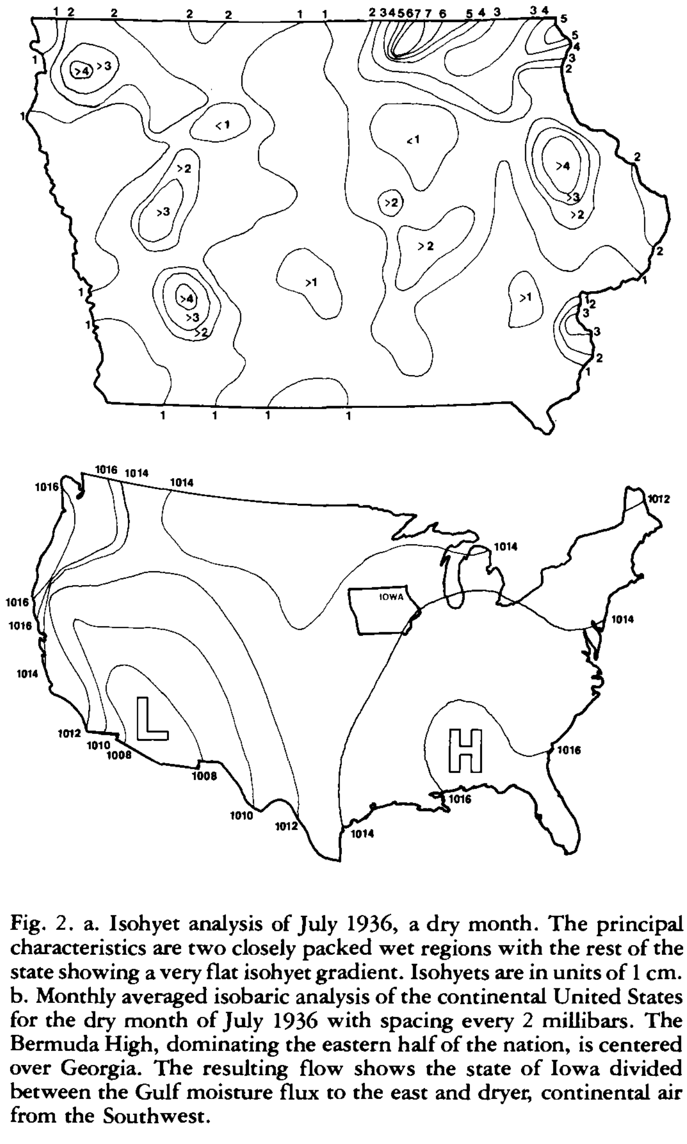

Fig. 2. a. Isohyet analysis of July 1936, a dry month. The principal characteristics are two closely packed wet regions with the rest of the state showing a very flat isohyet gradient. Isohyets are in units of 1 cm. b. Monthly averaged isobaric analysis of the continental United States for the dry month of July 1936 with spacing every 2 millibars. The Bermuda High, dominating the eastern half of the nation, is centered over Georgia. The resulting flow shows the state of Iowa divided between the Gulf moisture flux to the east and dryer, continental air from the Southwest.

maximum rain was centered in both northeastern and central Iowa, each with 39 cm. The distribution was rather uniform considering the extreme excess precipitation. The northwestern portion of the state was the only place where rainfall was reported near normal. The July 1915 rain distribution showed the characteristic variability more frequently observed in dry summers, with a minimum of 9.3 cm in north central Iowa. The maximum July rain of 40.2 cm is observed in a small closed region in southwestern Iowa (Figure 5). August 1979 showed the greatest variabiilty with a minimum of 1.8 cm or approximately one-quarter the normal August rain and a maximum of 41.1 cm in the north central part of the state, which was four times normal (Figure 6). Clearly the summer rainfall for each of the six cases is influenced by small-scale sources of precipitation such as regional thunderstorms (Table 1). What is not clear, because of the limited number of hourly recording sites across the state, is whether the wet months received more rain events or whether the individual thunderstorms covered a greater area. Rain in trace (0.1 mm) or greater amounts was observed somewhere within the state, on a daily basis, for all of the extremely wet and dry months with the exception of July 1936. During this exceptionally dry month, there were five days in which no station in the state reported any rain. However, at least trace

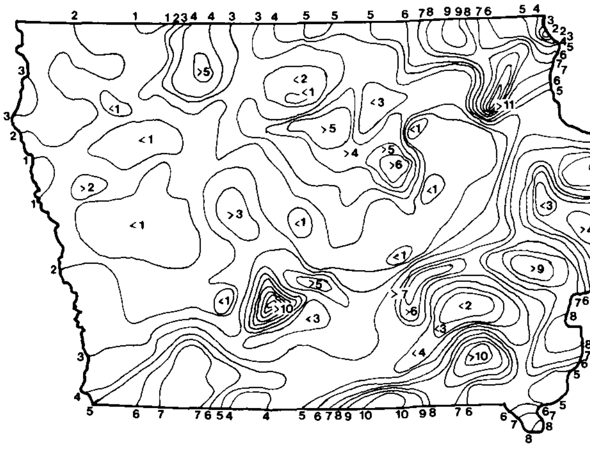

Fig. 3. Isohyet analysis of August 1976, a dry month. Several areas of tight gradients are in the southweastern half of the state with maximum rainfall amounts near 10 cm. The remainder of the state has a flatter isohyet surface. Isohyets are in units of 1 cm.

amounts were reported at all stations sometime during the month. White and Vaughan (1982) described regional precipitation events as observed by surveillance weather radar in central Iowa during one dry and one normal summer. It was found that the number of events tended to be similar, but the echo area coverage and magnitude increased during wet periods.

Supporting isobaric analysis of dry and wet extremes during June, July, and August was intended to identify and document the moisture trajectory patterns. Six mean monthly isobaric charts were prepared to correspond to the selected dry and wet months. Intuitively, a forecaster looks at the position of the almost ever-present Bermuda High and a frequent summertime thermal low in the southwestern United States. If the Bermuda High moves too far west, it tends to cut off moisture flow to the Midwest. If, on the other hand, it moves too far east, the isobaric spacing or pressure gradient tends to decrease, and the northward flow of moisture is diminished. If the southwest thermal low deepens at the same time, the flow of hot dry air from central Mexico dominates the Midwest. This pattern

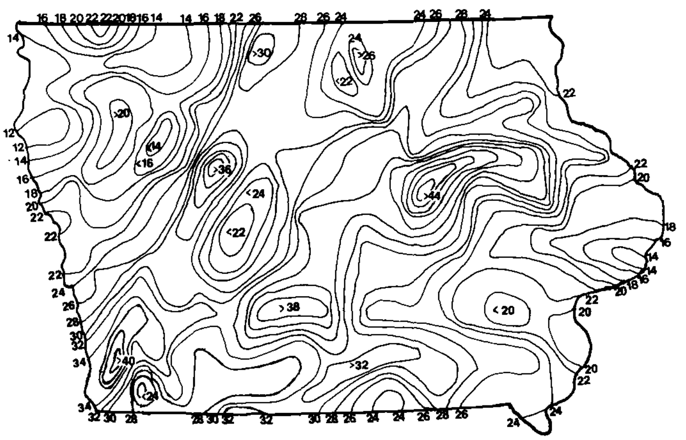

Fig. 4. Isohyet analysis of June 1947, a wet month. Except for the area in the northwestern part of the state with 20 cm., the spacing of isohyets is similar to that of dry months. The contours show mainly gradual spacing between areas of maximum and minimum precipitation amounts. Isohyets are given for even numbered contours in units of 1 cm.

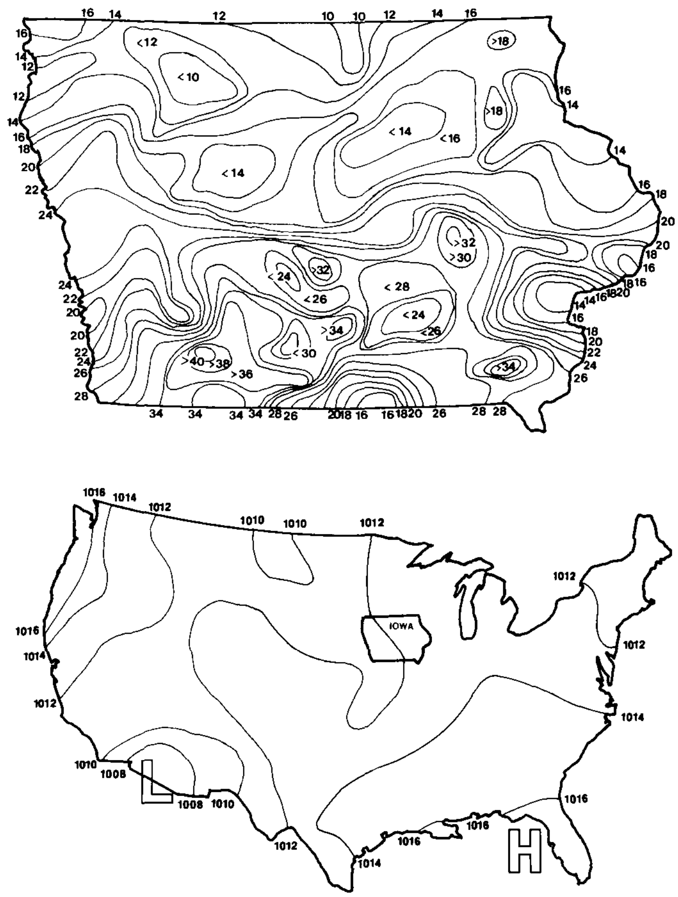

Fig. 5. a. Isohyet analysis of July 1915, a wet month. The greatest amount of rain fell over the southern half of the state with a small area of more than 40 cm in the southwest. Only a small part of the state, in extreme northern Iowa, received less than 10 cm of rain. This large coverage of high precipitation amounts resulted in July 1915 being the wettest of the wet months. Isohyets are given for even numbered contours in units of 1 cm. b. Monthly averaged isobaric analysis of the continental United States for the wet month of July 1915 with spacing every 2 millibars. The Bermuda High is shown centered off the west coast of Florida. The resulting flow pattern seems to steer Gulf moisture to the southeast of Iowa and the arid continental air mass, from the thermal low in the southwest, far to the southwest. The resulting configuration suggests a smooth contour over Iowa and the Midwest.

cuts off moisture from the Gulf of Mexico, and in turn, results in higher air temperatures with appreciably lower dew points.

The two most extreme monthly precipitation distributions July 1915 (a wet month) and July 1936 (a dry month), both show the isobaric analysis to support forecast criterion (Figures 2b and 5b). The similarity of the total area rain amounts and quantized distribution (Table 1) suggests similar sizes and magnitudes of the precipitation episodes for the two less extreme dry months of June 1933 and August 1976 (Figures 1 and 3). The isobaric analysis of these two months shows far less definitive structure. For the two less extreme wet months, June 1947 and August 1979, the same poorly defined isobaric structure was observed. Indeed, several of the average monthly isobaric charts had such weak pressure gradients that they could not be identified as wet or dry without their labels. For illustration purposes, only the isobaric analysis for the two most extreme months were used in this paper.

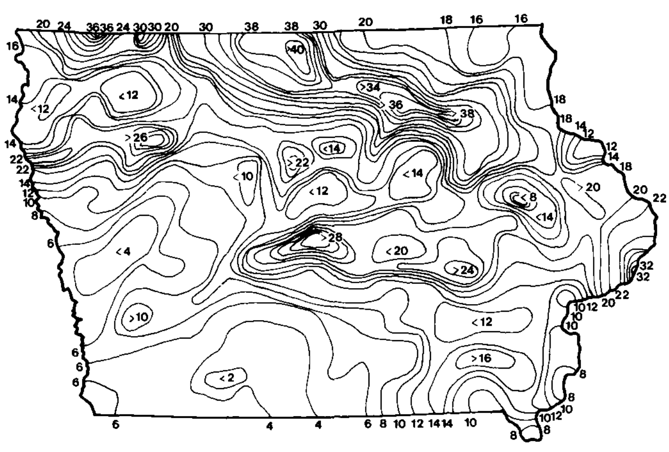

Fig. 6. Isohyet analysis of August 1979, a wet month. The greatest amount of precipitation fell in the northern two-thirds of the state. The driest region, southwest Iowa, had less than 2 cm. The spacing of isohyet contours is much more congested than the other extreme months, especially in areas of large precipitation amounts. Isohyets are given for even contours in units of 1 cm.

b.) Skewness of Rain Distribution

Continental rainfall spectra, defined here as total amounts per rain event, may be divided into a wintertime spectra from stratiform precipitation and summertime spectra from cumuloform rains. The former tend to approach a normal distribution when summed over a number of years. Summer convective rains, on the other hand, are of a skewed distribution. This is because there is a finite lower limit in the rain distribution, which is zero, where the upper limit is without bounds, which results in the distribution's tendency to be skewed to the right. Thus, in a summertime data set, the long term computed mean is larger than the median computed from the same data.

The significance of this depends on the degree of continentality of a particular region. A comparison of the mean and median July rain across Iowa clearly shows the median to be less than the mean in 90 percent of the state. The magnitude of this difference reaches 2 cm in the southwestern counties. Use of the mean, Figure 8, and minus one standard deviation of the mean, Figure 9, provides a somewhat optimistic estimate of the magnitudes of July rainfall. This can most clearly be seen in the southwestern counties, Figures 8 and 10, where the average differences between methods of measure are approximately 1.51 centimeters.

c.) Intercomparison of July Precipitation Across the State

From the previous section, it is clear that the summer rain distribution, whether in a dry or wet month, shows small clusters of near-normal or above-normal rains. This apparent random pattern of rain suggests that the summer rain regime is composed of large numbers of separate, and possibly unrelated, rain episodes. Jensen et al. (1990) followed the history of each outbreak of rain across the southern two-thirds of Iowa and the northern two thirds of Missouri during the summer of 1983. These results clearly show areas of concentrated precipitation in single rain events whereas the major portion of the two states received only minor rainfall amounts.

In an attempt to delineate the spatial variability of regional rainfall, 51 years (1934-1984) of July rain records were tabulated for each of the 99 counties of Iowa. Three parameters were computed: the mean rainfall, the standard deviation, and the median rainfall. A cursory examination of the mean distribution shows the western half of the state as having two or more cm less rainfall than the eastern half, with an "S" shaped North-South 10 cm isohyet providing the dividing line (Figure 8). Two unexplained features of the map are the dry tongue extending into the central portion of the state from the south-southwest and two small dry pockets in east-central Iowa. These two dry pockets, along with three moist areas, two in the north-central and one in the east-central portion of the state, represent seeming anomalies that cannot be explained by either topography or large masses of water (reservoirs).

During any given July, the county-wide rainfall may swing between plus or minus one standard deviation, assuming a long-term normal distribution of July rains. The mean minus one standard deviation, plotted in figure 9, shows a more uniform distribution dividing the state from northwest to southeast by the 4 cm isohyet. This distribution is not as smooth in the southwest quadrant of Iowa, which may be explained by the greater continentality in that portion of the state (Figure 8). Such areas experience larger swings in summer rain amounts, resulting in larger standard deviations (Figure 9).

These seeming anomalies clearly indicate that Iowa does not have a uniform July rain gradient from east to west. The small dry pocket centered in Jackson County along the Mississippi River probably represents the most troubling question about the cause of such anomalies. Generally, the moisture flux into the mid-continent follows a trajectory northward along the Mississippi River valley. The three counties surrounding Jackson, although less pronounced in their deficiencies, report a lower rainfall than the next tier of surrounding counties. From this clear gradient, it seems certain that there is no site bias in Jackson County.

In Johnson County, just two counties southwest of Jackson, is found one of the wettest spots in the state. Again, there seems to be supporting evidence for surrounding counties that this is not an exposure or instrument error. Two other contrasting areas, Benton, a dry county in the east central part of the state, and Blackhawk, a wet county just to the northwest, have somewhat closer spacing with clear supporting gradients in at least some of the surrounding counties. The drier western counties do not seem to hold any unexplained anomalies with a reasonable gradient of increased rainfall as you move east (Figure 8). As stated previously, the southwestern counties tend to show a more continental climate in that they have a larger standard deviation, which becomes evident when the mean minus one standard deviation is plotted, as in Figure 9.

The mean and median rainfall maps (Figures 8 and 10) both show the eastern half of the state as having a more favorable distribution of July rains. The distribution of wetter areas on the median map (Figure 10) shows a somewhat larger coverage with slightly higher values, whereas the lower end of the distribution shows a slightly

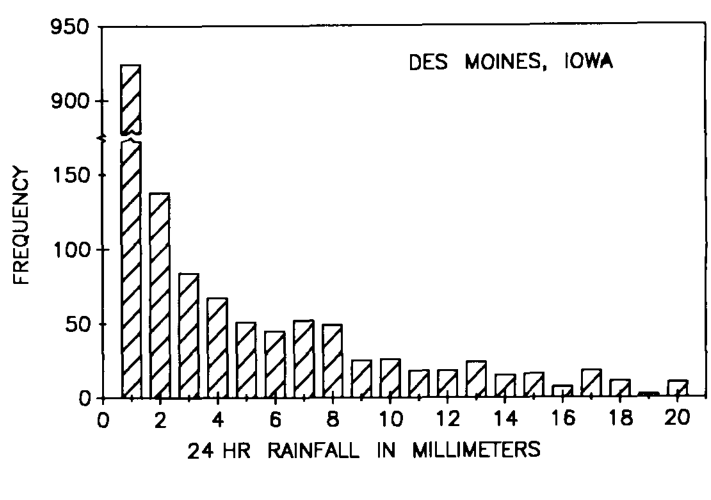

Fig. 7. Histogram of 10 years of 24-hour rainfall at Des Moines, Iowa (1971-1980).

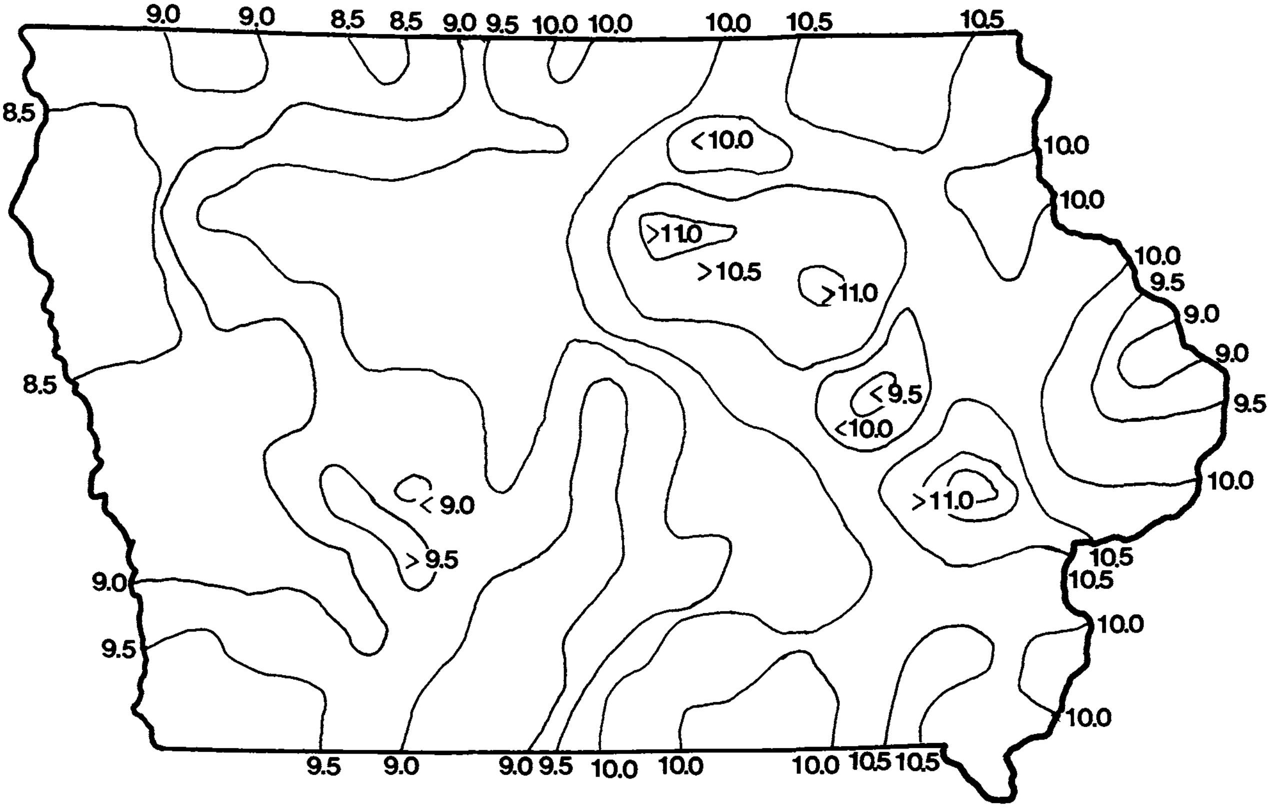

Fig. 8. Mean monthly July rainfall for 1934-1984.

lower limit. The southwestern portion of the state takes on a somewhat different configuration when the two maps are compared. If we take the nine southwestern counties in a three by three configuration, bordering on Nebraska and Missouri, we find the computed difference between the nine mean and median rainfall values to be 1.6 cm; this is an average difference of 20 percent between mean and median values for the area.

The importance of making a clear distinction between mean and median rain totals becomes obvious when the natural "swing" or oscillation of year-to-year annual and monthly rainfall totals is taken into consideration. The yearly oscillation of July Iowa rain, based on the previously mentioned 80 year sample of 25 stations uniformly distributed across the state, is plus or minus 60 percent of the computed mean rainfall. This same statistic was repeated by summing the 99-county mean and standard deviation values based on 51 years of data. During any July, on average, the mean rainfall will appear somewhere between 1.10 and 4.80 cm. Because of the skewed nature of rainfall distributions, more than half of the observed monthly rainfall amounts will be on the low side. Figure 9 shows the state precipitation pattern when one standard deviation is subtracted from the mean. If this amount is put in terms of the less-skewed median rainfall distribution, it is clear that those portions of the state with the most continental climate receive less than satisfactory July rain.

From the previous paragraph, it is clear that some method of estimating rain episode area coverage would be beneficial. Figure 7 provides an estimate of yearly, single-site rainfall in 24-hour increments. This distribution varies little on both a seasonal and regional basis. During drier than normal summers, rainfall of normal or near-normal amounts are seldom received over any significant portion of the state (Table 1). With the exception of a very few well-developed cold front passages where a warm, southerly air flow has provided an abundance of moisture, there is little evidence of single large-scale rain events during the summer months. Such events do occur in the spring and frequently are accompanied by severe weather. In a previous paper (White and Vaughan, 1982) radar measurements of single rain episodes were summarized. The mean echo diameter during any given minute of rain was estimated to be between 25 and 36 km^2. Integrating these echoes through the life of the episode shows an average coverage between 100 and 160 km^2 based on two summers of central Iowa weather radar analysis. The maximum values in columns 1, 2 and 3, respectively, of Table 1 during extremely dry years generally cover an insignificant portion of the state. Because this concept of single-episode and monthly statewide distribution is so important, attempts to reconstruct quantitative area coverage of monthly rains were made (Figures 1-6). It is clear from both the dry and wet extreme area maps that even during the wet months significant portions of the state cannot be identified as being in highly contoured areas of rain cells. Note, however, that these areas of maximum values do not necessarily occur as singular wet regions. The last three columns of Table 1 show a similar situation for the extremely wet years. An extremely small portion of the state received the maximum rain amount during any summer month.

RESULTS AND CONCLUSIONS

Comparison of the six extreme rainfall maps gives some insight into how the dry (Figures 1-3) and wet (Figures 4-6) months differ both in area and magnitude with regard to the complexity of their rain episodes. A cursory review of the six extreme precipitation maps shows that a portion of all cases have a simple, broad uncluttered isohyet pattern. This is best exemplified by the July 1936 dry situation, but, even the August 1979 wet case shows 30 percent of the state with a relatively uniform pattern. With the exception of July

1915, a wet month (Figure 5), these uniform pattern areas are below the mean rainfall for that portion of the state. The remaining area of each of these maps provides some insight into the magnitude and area coverage of the cellular structure stemming from convective precipitation cells. These precipitation clusters tend to retain similar area coverage while the magnitude increases by as much as a factor of two.

The two national pressure field maps, linked to July 1936 and July 1915 extreme precipitation charts, do indicate the air mass sources but lack the structural detail common in pressure gradients one sees in a daily analysis. Applying the geostrophic equation to these two maps (Figures 2b and 5b) does not result in the degree of computed transport of either dry or moist air one would expect. The geostrophic balance is given by the following equation:

$$V_g = (-pf)^{-1}(dP/dn)$$

where p is the density of air, f represents the Coriolis parameter, and the (dP/dn) term represents the change in air pressure with respect to a change in distance. The geostrophic wind equation provides a measure of flow between adjacent isobars and is driven by their spacing and latitude. Possibly the limited structure observed in these two charts results from excessive smoothing encountered in a 30 day average chart.

The two 51 year precipitation charts (Figures 8 and 10), although highly smoothed by the number of observations employed, show small active areas, whereas the rest of the state is similar in appearance to the six monthly charts previously discussed. The median map (Figure 10) does seem to show more definitive structure, particularly in the eastern half of the state. Here again, the simpler isohyets are observed in the more continental, lower rainfall, portion of the state.

Examination of the mean and median rainfall maps (Figures 8 and 10) shows five similar wetter-than-anticipated areas. Two of these exceed 11 cm. The median map has one additional wet area in Butler and Webster counties. The seven wet areas identified on the median map represent a more absolute value because they encompass 51 ascending July rainfall values. These numerical values are essentially the midpoints of the 51-year record.

When the final, July 51 year, portion of this study was initiated, a smooth east-west precipitation gradient was expected. In part, this was because of the gentle geographic gradient of the state. Clearly, this has not been the case. Part of the complexity involves the transition zone between the more continental southwestern air masses in the west and the maritime tropical air masses in the eastern portion of the state. The "swing" between these two air masses causes the statewide rain distribution to be far more complicated than had been anticipated. Greater insight into the statewide rainfall distribution could be obtained by analyzing the other summer months of June and August. Because of the difficulty involved in tabulating the early years of the data set, it would be very time consuming to add additional months to the study. Much of the early data was not available in National Weather Service publications and must be researched on a station-by-station basis from weather archives at the State Climatologist's office.

It is clear that the short-term rainfall variability between sites results from small scale precipitation episodes, but the anomalous, 51-year long term wet and dry regions were not easily explained. It remains to be seen whether these regions are the result of random events or are caused by orographic or unknown factors. Although a hot dry July doesn't make a drought, in the true sense, it could result in considerable hardship to the agricultural community. The World Meteorological Organization has outlined some 150 drought definitions. Clearly, agricultural and hydrologic drought criteria are quite different. In estimating the seasonal moisture supply, some considera-

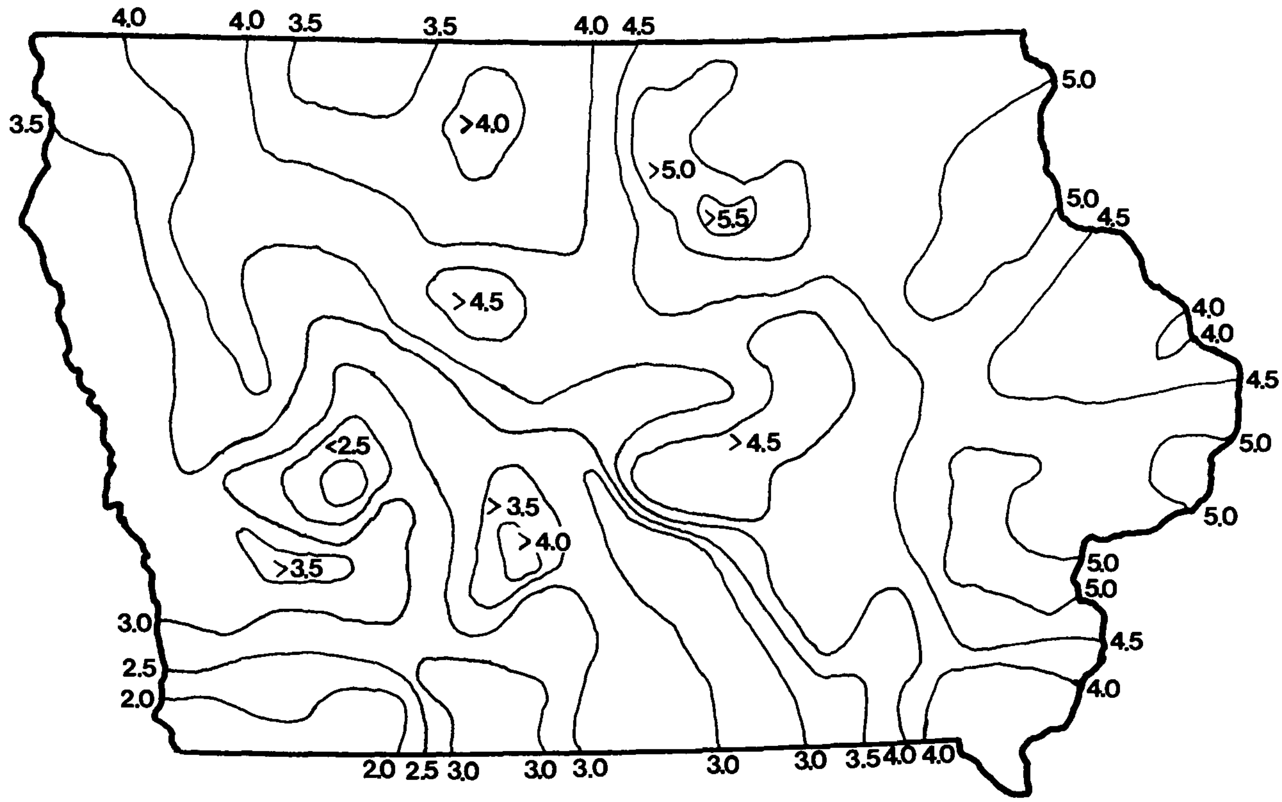

Fig. 9. Mean minus one standard deviation of July rainfall for 1934-1984.

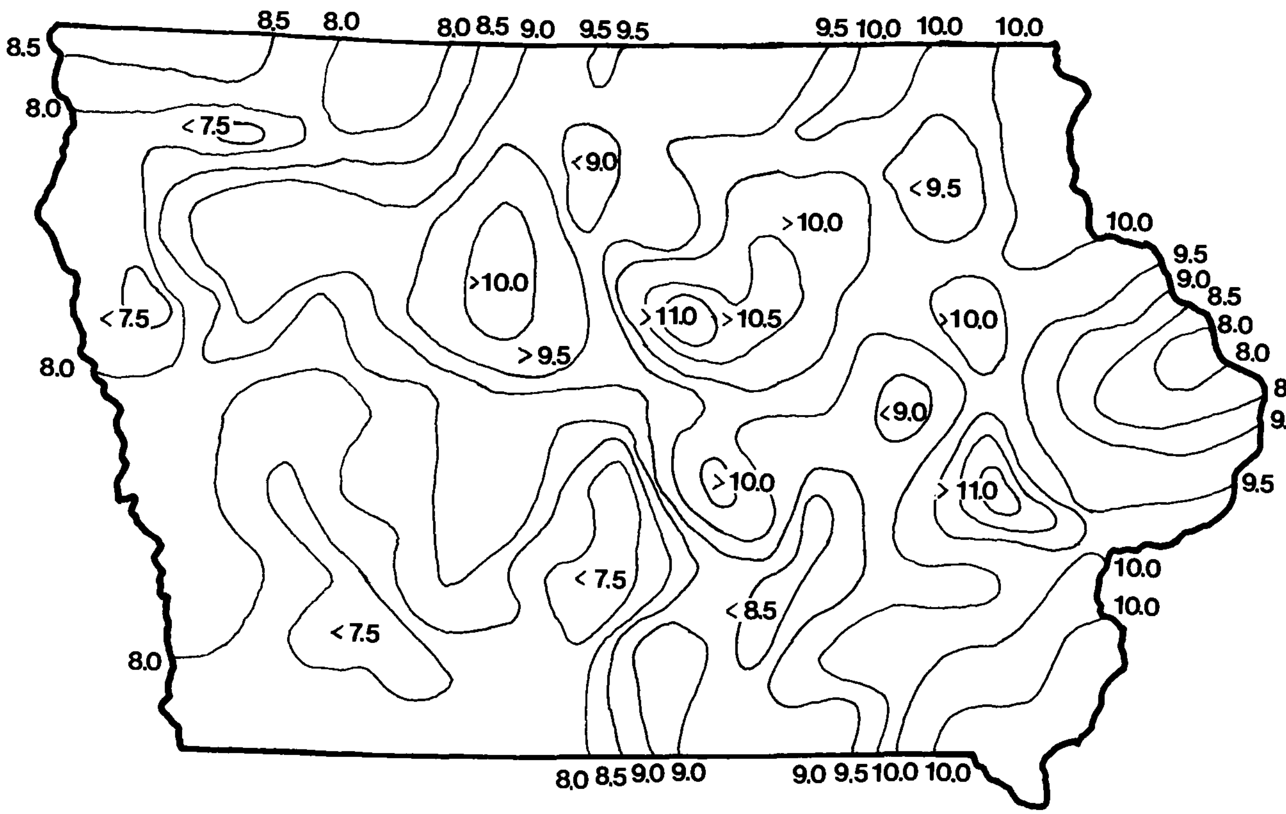

Fig. 10. Median July rainfall for 1934-1984.

tion of region and soil type must be made. As previously shown, there is a positive bias in the anticipated moisture supply at specific locations, due to the skewed nature of the summer rainfall distribution. In short, many of the summer moisture deficiencies are well within statistical probability and should not be referred to as drought events.

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