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A Search for Average, Extremes, and Runs of Unusual Weather in Iowa

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Temperature and precipitation during the past decade have exhibited wide variation throughout Iowa. Is this unusual? An attempt was made to answer this question by computing various statistical parameters that characterize variation in Iowa's long term climatic record. Absolute deviations were used to identify the most and least variable months and years since 1900. Overall, 1936 with a very cold winter and very warm summer was the least normal year. Runs of daily weather showed that heat and cold stress could often persist for more than 1 month. Runs of dry days were much longer than runs of wet days. Rank analysis showed that 1993 was indeed unusual relative to excess rainfall and that 1992 summer temperatures were also unusual, even though both evenrs had comparable analogs in the historic weather record. Annual and seasonal 10-year moving means and standard deviations revealed different patterns of interannual variation between seasons. Winter was most variable, while summer, spring, and fall variability increased during the past two decades. Only during the 1940's and 1960's were the seasons similar for this statistical measure.

INDEX DESCRIPTORS: climate change, climate variability, runs of weather.

It is common to hear comments like "today's weather seems more variable than it used to be" or maybe "it was much hotter and drier during the 1930's than it is now." Unless weather events were extreme or impacted directly upon the individuals activity, human recollection of weather conditions seems tuned to relatively recent events This may be partly caused by increased media coverage of anomalous weather events. Recent years have exhibited several extremes in weather as exemplified by the weather-related variation in Midwestern crop yields in recent decades (Baker et al. 1993). Weather has exhibited wide gyrations during this same period. The excess 1993 rainfall was a marked deviation from what is expected as were the cool summer temperatures of 1992. But, comparable precipitation and temperature events, respectively, were experienced during 1881 and 1915.

Current weather conditions are frequently compared to "normal." From the Glossary of Meteorology (AMS 1989), normal is defined as

1. Referring to a normal distribution.
2. Regular or typical in the sense of lying within the limits of common occurrence, but sometimes denoting a unique value, as a measure of central tendency. Either sense presupposes a stable probability distribution.
3. As usually used in meteorology, the average value of a meteorological element over any fixed period of years that is recognized as standard for the country and element concerned.

The length of time in years needed to establish the "normal" period is given by Brooks and Carruthers (1953) and Kunkel and Court (1990). The National Climate Data Center defines climate normals using 30 year periods (i.e., 1961–1990). Hence, this has become the standard base value for climate comparisons. Additionally, the expected value of a weather element is given by the mean, with variation about the mean described by the standard deviation or variance. For some weather elements, which do not exhibit normal distributions such as precipitation, the use of the median is sometimes preferred over the mean. Precipitation, for example, exhibits a gamma-type distribution with a skewness toward numerous low-precipitation events.

Variables derived from the basic weather elements offer insight into the impact of weather conditions on agricultural production or other human activities. For example, growing degree-days accumulated very slowly in 1951 at Ames, Iowa demonstrating why crops were slow to develop that year. They were damaged by an early frost that fall. As another example, cooling degree-days during the summers of 1954, 1955, and 1956 were above normal. For those fortunate enough to have residential air conditioning, their utility bills were likely higher than normal.

The time period spanned by these unusual events can greatly influence societal activities in either positive or negative senses. Consecutive days with cloudiness in winter can greatly moderate or lessen the likelihood of extreme low temperatures, but the cloudiness may also lead to very gloomy conditions and depressed people.

For these reasons, we searched through selected climatic resources of Iowa for some of these unusual temperature and precipitation events.

METHODS

Weather data consisting of daily maximum and minimum air temperatures and precipitation for the period from 1900 through 1994 were obtained from Climatological Data (U. S. Department of Commerce, 1900–1994). Individual cities used for analysis were selected based on the amount of missing data and weather element homogeneity (Carlson et al. 1994). Because of these selection criteria, different cities were used for the various types of analyses. Monthly temperatures and other derived variables such as growing degree-days were computed from the daily data. Daily, weekly, and monthly means and standard deviations were computed. Monthly and annual

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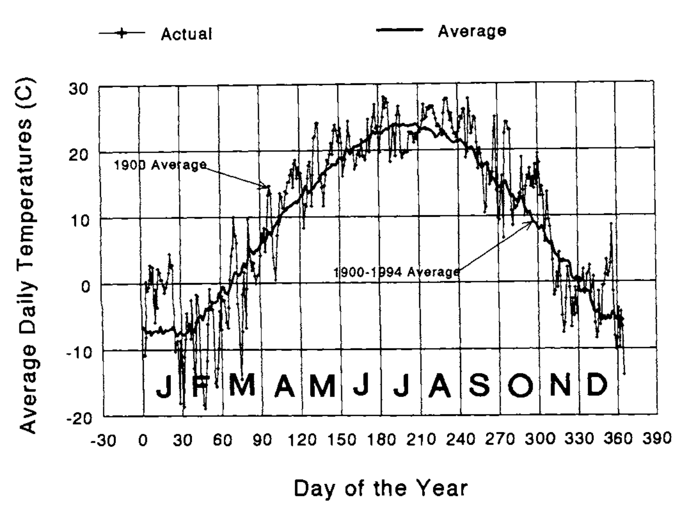

Fig. 1. Average daily air temperatures for Ames, Iowa, during 1900. The dark black line denotes 1900–1994 average daily temperatures. Note that the monthly designation along the abscissa is approximate.

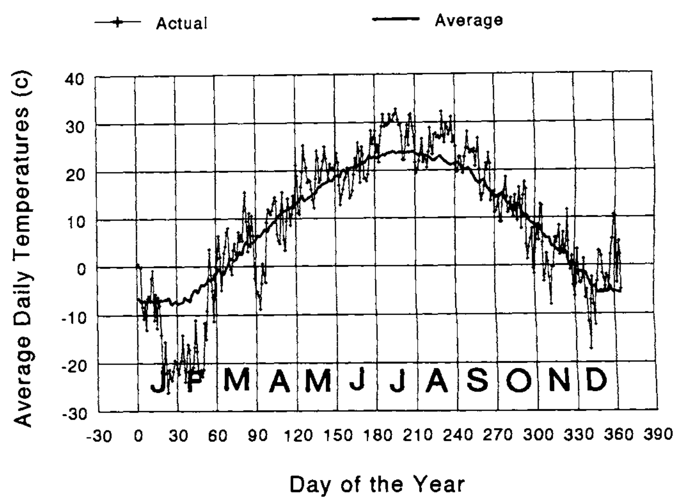

Fig. 2. Average daily air temperatures for Ames, Iowa, during 1936. The dark black line denotes 1900–1994 average daily temperature. Note that the monthly designation along the abscissa is approximate.

absolute deviations were computed by summing the absolute difference between each daily value and the daily mean value for all days each month or year. Daily averages were computed over the entire period because there were no strong upward or downward temperature trends in evidence for these weather stations. The time trends of some of these weather elements were reported by Carlson (1990a). Additional moving means and standard deviations, runs of various weather elements, and passages between above and below mean daily average temperatures were computed. Our search was limited to only a few weather stations, so some events were likely missed. Air temperatures were emphasized because they are spatially more homogeneous than precipitation. Thus, temperature at individual weather stations will generally represent a wider area than will precipitation.

RESULTS

Deviations of Air Temperatures From Expected

Average daily temperatures were above the 1900–1994 mean in January 1900, but dropped precipitously near the end of the month (Fig. 1). The daily temperature trace swung above and below the daily mean frequently that year. There were several sizable departures and lengthy runs of air temperature above or below average throughout 1900.

Examination of Figure 1 and Table 1 confirms the low absolute deviation for June 1900 (rank = 1). The first five and last five lines in Table 1 are the most and least "normal" years and/or months at Ames, Iowa, over this time, respectively, based upon this criterion. In contrast, Figure 2 illustrates the variation of the least "normal" year, 1936 (rank = 95) as listed in Table 1. It can be easily seen why so many "senior" citizens recall the frightful winter of 1936 and the following hot summer. January-like temperatures persisted well into February that year. Several months that year rank as extremely variable. They were January (91), February (95), July (95), and August (94) (Table 1). The run of low temperatures in January and February will be addressed later. It is also interesting to note that three of the four most variable Decembers have occurred in the 80's—1983(95), 1989(93), and 1985(92) (Table 1). All years were associated with below-average temperatures. The absolute deviations for all Februarys in the Ames record confirm the deviant behavior of 1936 (Fig. 3). For no obvious reason, since 1976, the absolute deviations have been larger than expected with the exception of 1980. Other months do not show a similar pattern.

Table 1. Months and years with the 5 smallest and largest average absolute daily average temperature deviations for Ames, Iowa; 1900–1994.

RANK	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	25[a]	56	58	33	48	00	43	01	77	29	46	52	57
2	53	69	31	23	37	62	63	69	32	60	48	47	22
3	83	80	61	84	51	65	82	26	76	65	94	69	49
4	75	55	57	64	50	86	85	70	66	57	72	71	61
5	93	75	59	69	20	32	93	39	58	03	23	15	69
91	36	30	12	15	67	02	34	88	85	30	37	19	17
92	19	81	46	31	18	20	11	83	47	76	64	85	51
93	42	06	65	28	11	31	30	92	42	17	51	89	13
94	63	05	10	77	65	34	01	36	84	63	59	17	30
95	12	36	60	10	34	33	36	47	27	25	91	83	36

[a]Number corresponds to year (e.g., 25 = 1925); the rank 95 is most variable and rank 1 is least variable

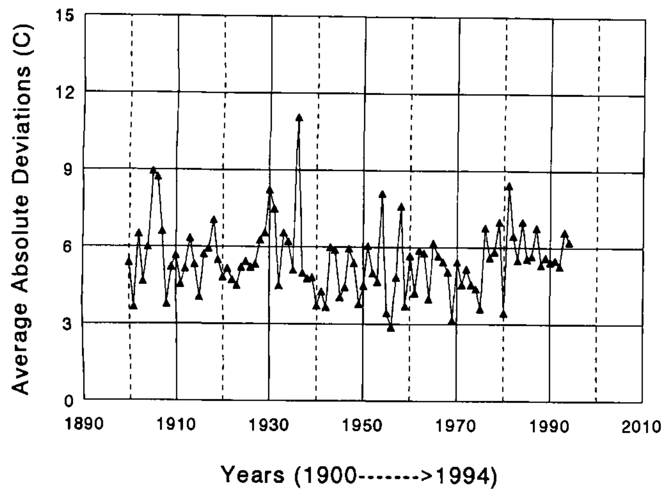

Fig. 3. Average absolute deviations for February 1900–1994 for Ames, Iowa.

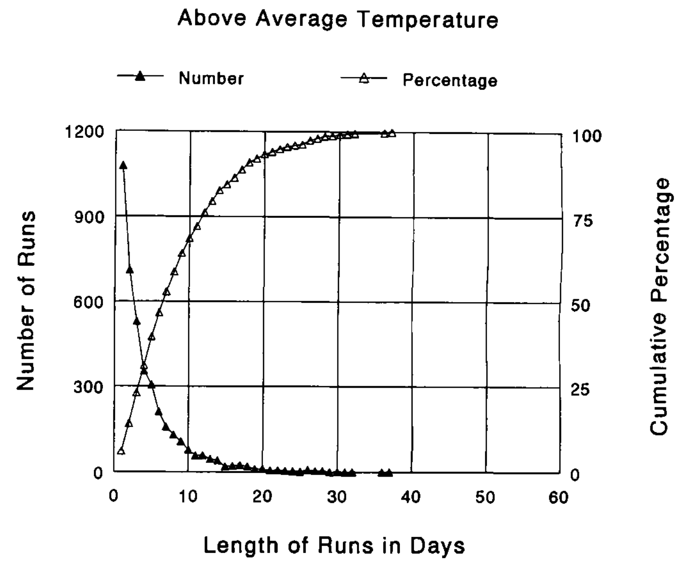

Fig. 4. Length of runs and cumulative percentage for average daily temperatures above average for Ames, Iowa; 1900–1994.

The consistency of the deviation relationships (Table 1) with other weather stations throughout Iowa was assessed by computing pairwise rank correlations (r) for all possible combinations of the nine locations. These nine locations which were selected from each of the nine climatic districts of Iowa included LeMars, Algona, Fayette, Denison, Ames, Cedar Rapids, Clarinda, Indianola, and Keosauqua. As expected, the correlations were quite high varying as a function of distance between each pair of weather stations. Nearby weather stations generally exhibited the highest simple correlations. All correlations ranged from $r = 0.69$ to $r = 0.91$ with 21 of 36 being greater than $r = 0.80$. Thus, the data in Table 1 for Ames appear representative of Iowa.

Fluctuations About Expected Air Temperature

Although not directly related to absolute deviations, the number of times the average temperature curve passes through the mean trace is another measure of temperature variation, or persistence (Figs. 1 and 2). The same nine weather stations were analyzed; little difference in this record was noted among these weather stations. The average number of swings from above or below to the opposite side of the average temperature trace was about 85 times per year, with a standard deviation of 9.5. When the number of swings/year was plotted versus year, no significant trends for any of these nine weather stations were evident.

A Ranking of Extreme Monthly Air Temperatures

Monthly average temperatures were computed for Ames (Table 2). This confirms the low temperatures just discussed for December of 1983 (rank 1) and 1985 (rank 2). February 1936 was indeed the coldest February of this long span of years as stated before.

Temperatures during 1907 were remarkably below-normal from April through the first part of August. Note its rank in April (1), May (1), June (2), and July (4) from Table 2. Growing degree-days were also considerably below average that year, leading to poor field crop and orchard development while heat stress was limited (USDA, 1907). Indeed, at the time, the summer was being compared to the infamous "summer of 1816," which was extremely cold with frequent crop damaging frosts. It is of interest on the other extreme that, when considering the months or years from the warmest five, nearly 30% occurred in the decade of the 30's.

Table 2. Months and years with the five coldest and warmest average daily temperatures for Ames, Iowa; 1900–1994.

RANK	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	12[a]	36	60	07	07	45	92	15	18	25	91	83	17
2	79	06	65	20	35	07	50	92	93	17	59	85	51
3	40	79	12	50	17	03	58	86	49	18	85	19	50
4	82	78	69	83	47	35	07	50	74	76	55	17	79
5	77	29	51	53	24	51	71	46	43	52	51	09	24
91	44	84	68	81	11	71	55	13	78	56	22	18	38
92	21	87	21	55	62	31	16	00	33	38	30	13	30
93	89	30	45	25	88	11	30	36	19	00	09	23	21
94	90	31	46	77	77	33	36	83	25	47	31	31	87
95	33	54	10	15	34	34	01	47	31	63	13	65	31

[a]Number corresponds to year (e.g., 25 = 1925); rank 95 is warmest and rank 1 is coldest

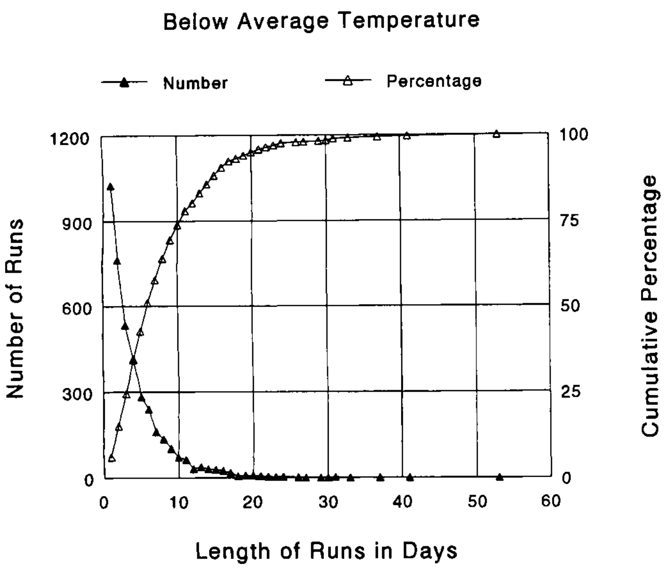

Fig. 5. Length of runs and cumulative percentage for average daily temperatures below average for Ames, Iowa; 1900–1994.

Runs of Extreme Daily Weather

It was noted that the 21 consecutive days above normal in January of 1900 (Fig. 1) was extraordinary. Similarly, from Figure 2, lengthy runs of above and below normal average daily temperature during 1936 were, respectively, in July (17 days) and in August (21 days), and during January and February (37 days). Were these runs unusual? How long does a run of weather last? Runs of both above- or below-normal temperatures can be exceedingly detrimental to society. Higher than normal utility bills, heat stress reducing crop yields, and dangerous conditions for chronically ill persons are obvious examples. This was further analyzed and resulted in the data depicted in Figures 4 and 5, and Table 3.

For Ames, Iowa, the longest runs of days with above-normal and below-normal average daily temperatures, respectively, were 37 (ended 20 December 1913) and 53 (ended 18 March 1978) days. Runs of above- and below-mean average temperatures last less than 1 week (6 to 7 days) 50% of the time: note the 50% cumulative percentage lines on the right axis (Figs. 4 and 5). On more than 1000 occasions, the runs of either weather type (above or below average) persisted for only 1 day. Runs, as defined in this manner, need to be interpreted carefully because, on occasion, their length is terminated by only 1 day being different. For example, in January through April of 1912, four runs of below-mean average daily temperatures occurred. Their lengths were 23, 20, 18, and 17 days (78 out of 100 days). Those events created a very long and cold winter for the citizens of Central Iowa, with nearly 80% of the days being below average.

On the other extreme, beginning on 13 November 1913 and ending on 3 February 1914, runs of above mean average daily temperature of 37, 2, 14, and 22 days were experienced. Indeed, 91% of the days were above average during that span of 82 days. During the first 7 months of 1921, 76% of the days were warmer than expected. Many other examples like this could be cited from these Iowa time series.

Additional runs for specific temperature and precipitation combinations were computed. The following extremes relative to runs of daily weather were found for Ames, Iowa.

Maximum Air Temps > 86°F (30°C)—38 days ending 30 July 1901
Maximum Air Temps > 100°F (38°C)—18 days ending 26 July 1901
Minimum Air Temps < 0°F(−18°C)—17 days ending 28 January 1963
Minimum Air Temps < 32°F (0°C)—124 days ending 17 March 1904
Days without Precipitation—62 days ending 14 February 1976
Days with Precipitation—13 days ending 23 May 1982
Below Normal Temps with Precipitation—8 days ending 29 June 1902

As can be seen from these examples, it is difficult in Iowa for consecutive days with rain to persist when compared with days without rain. Although the weather data from other cities in Iowa may be somewhat different from those reported for Ames, the authors believe that Ames has been an excellent weather station over these many years (Carlson et al. 1994). These examples give a representative picture of runs of both temperature and precipitation anomalies. Cities to the north (south) would show longer runs of colder (warmer) temperatures, respectively. Similar patterns for daily precipitation runs would follow a northwest-southeast pattern mimick-

Table 3. The most extreme runs of days for various weather elements for 9 Iowa cities; 1900–1989.

	WEATHER ELEMENT					
STATION (DISTRICT)	MAX T >30°C	MIN T <0°C	MIN T <−18°C	DRY DAYS	WET DAYS[b]	MISSING
LeMars (NW) 29 (12)[a]		147 (44)	35 (6)	65 (79)	11 (20)	354[c] (11)
Algona (NC)	21 (9)	144 (44)	35 (6)	60 (77)	9 (21)	548 (15)
Fayette (NE)	22 (8)	123 (46)	20 (6)	58 (74)	12 (24)	522 (14)
Denison (WC)	35 (10)	125 (43)	35 (5)	86 (79)	10 (21)	123 (3)
Ames (C)	38 (10)	124 (42)	17 (4)	62 (77)	13 (23)	14 (0)
Cedar Rapids (EC)	27 (11)	119 (41)	17 (4)	55 (75)	9 (24)	446 (12)
Clarinda (SW)	44 (15)	141 (41)	17 (3)	59 (77)	11 (22)	162 (5)
Indianola (SC)	40 (13)	106 (39)	16 (4)	54 (76)	12 (23)	554 (17)
Keosauqua (SE)	35 (15)	97 (38)	12 (3)	41 (76)	11 (23)	538 (13)

[a]Percent of days over the entire time period that exhibit this characteristic
[b]Wet is defined as a day with precipitation totaling 0.02 or more
[c]No. of days, number in parentheses indicates number of whole months missing

Table 4. Months and years with the five least and most number of precipitation days for Ames, Iowa; 1900–1994.

RANK	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	**81**[a]	70	10	26	34	33	16	76	52	52	76	05	76
2	76	17	28	10	39	88	30	71	08	75	**04**	08	10
3	**48**	31	94	49	88	59	36	18	76	58	10	10	88
4	**28**	87	18	39	92	11	23	69	39	45	12	28	30
5	77[b]	33[b]	11	07[b]	61[b]	92	13	47[b]	30[b]	64	69	34[2]	01
91	82[b]	51[b]	51[b]	37[b]	18	57	07[b]	23[b]	92[b]	77	31[2]	35[2]	73[b]
92	57	36	52	86	08	75	92	85	61	41	92	51	02
93	49	19	46	78	82	90	62	40	86	84	91	41	51
94	41	40	73	51	93	93	02	54	41	59	57	45	57
95	36	62	44	84	03	02	93	93	73	81	83	92	93

[a]Number corresponds to year (e.g., 25 = 1925); rank 1 is fewest number of precipitation days and rank 95 is the most number of precipitation days
[b]Tied with a few other years
Years indicated by bold print received no measurable precipitation during those years

ing the expected precipitation gradient across Iowa. Selected runs from other Iowa cities are given (Table 3) to confirm these expectations. In these analyses, one station was selected from each of the nine climatic districts of Iowa to spatially represent this geographical area.

The latitudinal variation of air temperature is clearly evident for runs of extreme temperatures (Table 3). Heat stress (Max Temp > 30°C) (Carlson, 1990b) runs in excess of a month occurred at five of the nine stations, but on average, only 15% of the time (or less) are the daily maximum temperatures greater than 86°F (30°C). There are, however, frequent occurrences of minimum temperatures less than freezing (32°F; 0°C). Fortunately, minimum temperatures less than 0F (−18°C) occur less than 6% of the time. Some rather long runs, greater than 30 days, in the northern and west-central districts are indicated (Table 3).

The precipitation data must be interpreted cautiously because missing data are very common (see Table 3, last column). The numbers in parentheses under Dry and Wet days do not total 100% because of this. Ames, Clarinda, and Denison probably are the most reliable weather stations relative to this issue, but the numbers associated with precipitation in Table 3 for the other weather stations are generally not greatly different. Again, it is much more likely that dry periods will persist longer than wet ones (Table 3).

A Ranking of Extreme Monthly Precipitation

Tables 4 and 5 show further precipitation anomalies for Ames, Iowa, listing the five least and most years for number of precipitation days and amounts, respectively. It is notable that only 7 complete months out of 1140 received no precipitation at this station (Table 4). The summer of 1993 stands out for the greatest number of rainfall days during May through August (71 of 123 days, 57.8%) and for the highest annual precipitation total (rank = 95; Table 5). The months of June and July, specifically, had numerous rainfall events and large 24-hour totals (Fig. 6). When warmer than normal summer air temperatures accompany the low rainfall totals (Table 5), deleterious effects on Iowa's crops can be expected. One of the drier years, 1910, received only 18.65 inches (Fig. 7). There was only one rainfall event greater than 2 inches and not nearly as many rainfall events compared to 1993. There were 144 rainfall events totaling more than 2 inches between 1900 and 1995 for this station, so 1910 was somewhat below the mean. During the cool season of 1910, there were frequent long runs of dry days.

Table 5. Months and years with the 5 lowest and the 5 greatest precipitation totals for Ames, Iowa; 1900–1994.

RANK	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1	**28**[a]	70	94	26	34	92	36	76	52	52	76	89	10
2	**48**	31	07	10	25	22	30	84	66	45	**04**	34	30
3	76	68	16	32	81	33	47	71	76	58	69	03	80
4	81	46	88	07	39	34	11	09	40	64	14	00	56
5	86	67	80	34	92	77	23	35	08	53	89	80	34
91	46	28	46	68	22	35	00	23	14	77	28	11	90
92	32	76	52	09	90	41	58	93	61	47	34	31	73
93	49	39	61	19	03	02	92	77	36	14	92	19	02
94	44	15	91	84	74	67	20	87	41	08	83	82	83
95	35	71	90	91	44	47	93	54	26	83	31	09	93

[a]Number corresponds to year (e.g., 25 = 1925); rank 1 is lowest precipitation total and rank 95 is the highest precipitation total
Years indicated by bold print received no measurable precipitation during those years

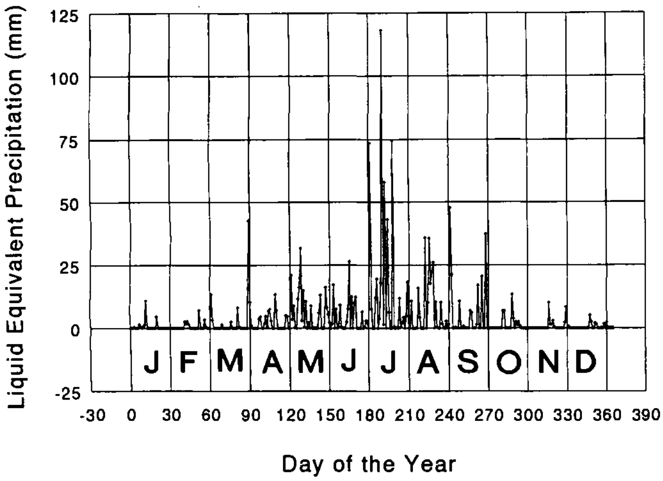

Fig. 6. Precipitation events for Ames, Iowa, during 1993.

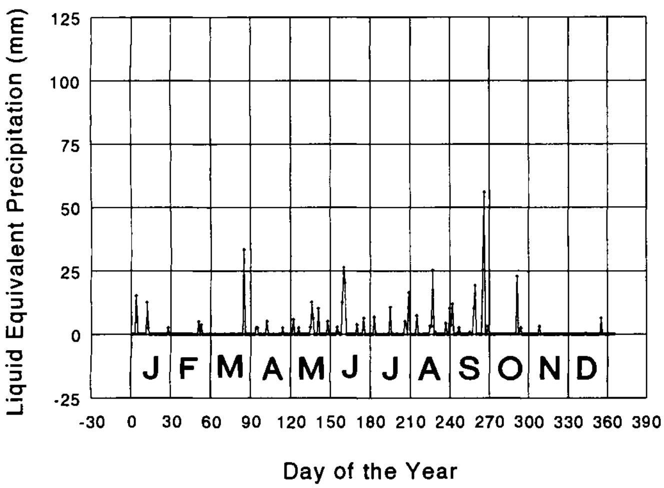

Fig. 7. Precipitation events for Ames, Iowa, during 1910.

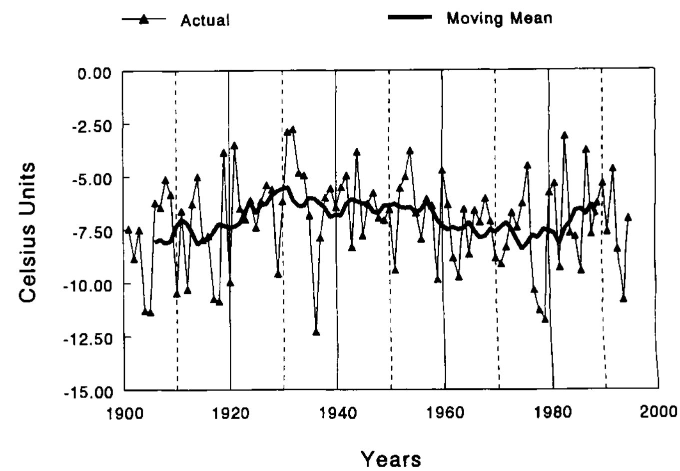

Fig. 8. Average winter (Dec.–Feb.) temperatures for Fayette, Iowa. 10-year moving mean centered on year 6 is highlighted.

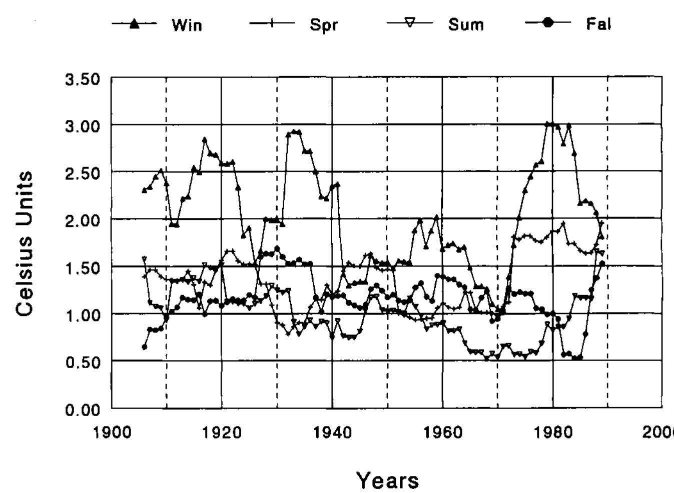

Fig. 9. Moving 10-year seasonal standard deviations centered on year 6 for Fayette, Iowa.

Identifying Patterns of Variation by Using Moving Means and Standard Deviations

Other extremes, or trends, of weather can sometimes be identified by using 10-year moving means and/or standard deviations. Figures 8 and 9 show this feature for December through February average temperatures for Fayette, Iowa. Average winter temperatures (Fig. 8) edged upward during the first part of this century until about 1930. This trend reversed through 1980. Since then, average winter temperatures have apparently increased. However, the magnitude of year-to-year changes (called interannual variability) is not consistent throughout the period. Between 1900 and 1936, the year-to-year change in average winter temperatures is quite large when compared to the period between 1937 and 1975. Moving 10-year standard deviations (Fig. 9) for the four seasons exhibit these variations. The year-to-year average winter temperatures for this station were quite variable from 1900 through approximately 1940, followed by minor year-to-year variations through the early 1970's. After that, considerable year-to-year variation has occurred as evidenced by high levels of the 10-year moving standard deviation. Similar features in winter temperatures and its seasonal variability were observed for the other 27 weather stations analyzed including the nine listed in Table 3.

A feature common to each weather station is the interannual variability of average summer temperatures. The lowest year-to-year variation occurred during the late 50's, 60's, and early 70's at every station. This has been termed the "benign period" relative to agricultural production in the Midwest (Carlson 1990b, Baker et al. 1993). Greatest interannual average summer temperature variation was mostly found during the droughty 10's and 30's, but all stations tested showed increasing variation through the 80's and 90's using this 10-yr measure of variation.

The interannual variability of average spring temperatures for these weather stations increased during the last decade to the highest levels for the period of record. In contrast, the other transitional season, fall, shows smaller, seemingly random changes in the interannual variability of average temperature over time. It is, however, interesting that the actual average fall temperatures have decreased during the last 6 years of this time series at many of these locations. The falls of 1991, 1992, 1993, and 1995 all ranked in the coldest 15–20% of all years.

With the exception of a short period in the 1920's, it is curious that, only from the early 1940's until approximately 1970 were the variations nearly equal for all four seasons. Before and after that period, they were more divergent, especially during winter. This seems to agree with the "benign" period already discussed.

CONCLUSIONS

The last 100 years in Iowa gives but a brief glimpse of the many types of weather that can occur in this geographic region of the world. It does, however, give a sampling of the wide variations typical of a continental climate in the mid-latitudes. These patterns should be expected to continue into the near future. Although abnormal, the extremes of the 1980's and 1990's are not so different from those during other decades of this century. During the late 1950's, the 1960's, and the early 1970's, however, fluctuations were small, benefiting Iowa in many ways. For example, crop production, with few exceptions, was rather stable during that period because heat stress was minimal and precipitation was generally adequate and timely.

Analysis of interannual variability of seasonal temperatures showed that winter was most variable with spring, summer, and fall being quite comparable throughout the first seven decades. The variation of all four seasons was similar only during the 1940's and 1960's. Summer interannual temperature variability was least during the benign period mentioned earlier, but it has been increasing during the last two decades. The same is true of the interannual variability of spring and fall temperatures during the 1980's and 1990's.

Runs of certain daily temperature and precipitation were identified and revealed spatial variability across this state that generally follows climatic gradients of temperature and precipitation. Runs of dry weather were much longer than runs of rainy weather.

The extreme wetness of 1993 was found to be very unusual for this century in two ways. First, the amount of rainfall was abundant and, second, the number of rainfall events during the summer was very high. The most comparable year to 1993 occurred in 1881.

ACKNOWLEDGMENTS

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