Journal of the Iowa Academy of Science: JIAS

Volume 97 | Number

Article 3

1990

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Jour. Iowa Acad. Sci. 97(3):77-81, 1990

Climate Trends in Iowa[1]

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Long-term trends for various weather elements are presented for the period 1900-1988. Summer and winter season, and annual air temperature patterns are statistically weak because of large interannual variability, but trends are evident. There was a general warming from 1900 until the 40's, with a leveling or slight cooling following. Since the mid-70's, a warming trend seems to be taking place, but this cannot be confirmed. Spring season air temperatures showed no trend except that the most recent 4 years (1985-1988) were decidedly warmer than normal. Winter season air temperatures showed a change in trend in the 30's, but the large amount of interannual variability during the last 15 years clouds any recent trend. Fall season air temperatures reveal no trends.

Derived air temperature variables, growing degree days and the length of the growing season, for the Ames weather station reveal no definite trends. When averaged overall available stations, the length of the growing season seemingly has increased about 1 day/decade. A heat-stress variable shows periods of both stressful and benign time periods during this century. The major benign period was 1957-1975. Before 1957, considerable interannual variability is evident. Years following 1975 may be showing a return to more interannual variations, but extrapolation forward in time is not possible.

INDEX DESCRIPTORS: Climate change, Climate variability, Heat stress, Growing degree day, Runs of weather.

The state of our climate on earth is on the minds of many people at this time. The popular media contain frequent accounts about the Greenhouse Effect, the Ozone Hole, El Nino, etc. Scientists are directing their attention to the possibility of a changing environment in which crops are grown (Rosenberg, 1981; Baker *et al.*, 1989; Climate Board, 1982). Increasing amounts of carbon dioxide and other trace gases are thought to directly affect the atmosphere by differentially increasing air temperature in a complex manner over various regions of earth. Atmospheric computer models predict that this effect will change air flow and precipitation patterns (Manabe and Wetherald, 1986; Anthes and Kuo, 1986). Some areas are predicted to become more favorable for crop production, with other regions becoming less favorable. Although there are many uncertainties with these complex mathematical formulations of the atmosphere (Schneider, 1989; Houghton and Woodwell, 1989; Kerr, 1989), most point to a warmer earth in future years.

The economy in Iowa is strongly tuned to the "weather machine" and its many whims. This provides an invigorating seasonal climate for Iowa's inhabitants, but at the same time, it provides both good times and lean times. For these reasons, a study of Iowa's climate was undertaken, including an examination of weather variables closely associated with agricultural production. Attention is given to the trends of these variables and the amount of interannual variability expressed.

METHODS

Weather data, including daily values of maximum and minimum air temperatures, were obtained for 21 stations from the U.S. Department of Commerce (1988). This data set covered the period 1900-1988. From this weather data set, monthly average temperatures were computed after correction for missing daily temperatures values using adjacent stations. Various weather variables closely associated with agriculture were computed and summarized. These included a heat-stress variable [daily calculation of the number of degrees accumulated each month when maximum temperatures exceeded 30°C], growing degree days [10°-30°C base temperatures], frost-free season, and runs of excessive heat stress. Additional programs were prepared to summarize the air temperature data on an annual and seasonal basis by using one station from each of the nine districts of Iowa. Normals were calculated over the entire period of record. These stations were Algona, Ames, Cedar Rapids, Clarinda, Denison, Fayette, Indianola, LeMars, and Washington. Station history records located at the office of the State Climatologist were searched to determine the time of observation and major location changes over this time period for these stations. Location and/or exposure changes were noted, but no attempt was made to correct for these possible sources of error. The difference in annual and monthly air temperatures between each station and the Ames station was plotted over the entire period of record by year. This methodology was used to identify major location and/or exposure changes. These plots basically revealed a random pattern for all stations, except Washington. I consulted the State Climatologist of Iowa (personal communication, Mr. H. Hillaker). He examined available records in detail, but the reason for the divergent pattern for the Washington station could not be determined. It remained in the 9-station data set because no other good substitute station was available in that district of Iowa. Relative to time of observation differences over this period, these stations were read primarily during late afternoon hours between 1700-2000. The two exceptions noted were for Cedar Rapids and Clarinda from 1903 to 1918 when the time of observation was 0700. Based on the work of Dutcher (1989), this created a difference of approximately 0.2°C on an annual basis after adjustment to a midnight observation. Thus, data were not corrected for time of observation differences. This 9-station set formed an Iowa average value and was employed to reduce the "noise" commonly observed at single stations and to adequately represent Iowa geographically. Additionally, these nine stations had the least number of missing daily air temperatures of the possible sites within each district. Each of the time series representing annual, spring (March, April, and May), summer (June, July, and August), fall (September, October, and November), and winter (December, January, and February) air temperature data sets were subjected to multistage regression analysis. This is a procedure described by Solow (1987) which tests for changing temperature patterns by using the following models

$$T = b_0 + b_1 X \text{ for } X < C1 \qquad (1)$$

$$T = b_0 + b_1 X + b_2 (X - C1) \text{ for } C1 < X < C2 \qquad (2)$$

$$T = b_0 + b_1 X + b_2 (X - C1) + b_3 (X - C2) \text{ for } X > C2 \qquad (3)$$

where b_0, b_1, b_2, and b_3 are regression coefficients, X is years coded by (X-1900), and C1 and C2 are years where changing temperature trends occur. Statistical significance between the above models was determined by appropriate F tests (Solow, 1987) and iterative computations were accomplished using Statistical Analysis System (PROC NLIN) after an estimate of each coefficient was placed into the above models. These estimates were made by visual and graphical analysis

[1]Journal Paper No. J-13649 of the Iowa Agric. Home Econ. Exp. Stn., Ames, IA 50011. Project No. 2397.

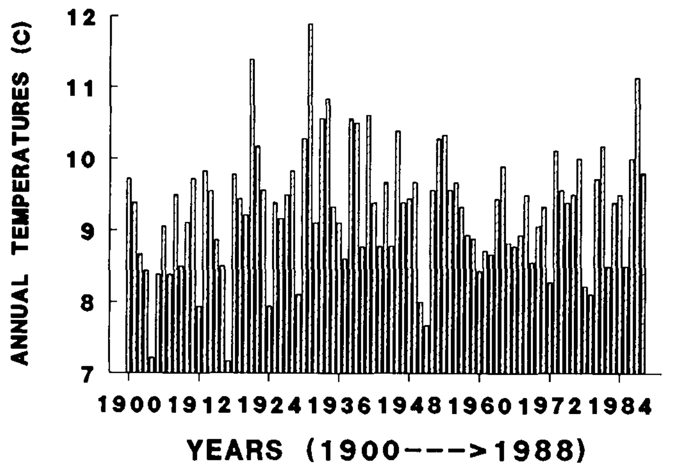

Fig. 1. Annual air temperatures for Iowa from 1900 to 1988, mean = 9.3°C.

of each time series. The change-year estimates were quite robust. For example, for the annual air temperature series in Fig. 1, initial estimates of C1 and C2 were 1923 and 1965 with the final estimates after iteration being 1931 and 1979.

RESULTS

The annual pattern for air temperatures is shown in Fig. 1. As is true with other long-term weather data sets, much year-to-year variation is exhibited (Skaggs and Baker, 1989; Hanson *et al.*, 1989), especially for continental stations. The period from 1900 until the early 40's trended upward, followed by a downward trend through the late 60's. Since that time, fairly normal annual air temperatures have been experienced, with the 80's averaging above normal. Multistage regression analysis indicated marginally significant (5-10% level) annual air temperature trend changes around 1931 and 1979. The regression coefficients for 1900-1931, 1931-1979, and 1979-1988 were 0.03, −0.05, and 0.14°C/year, respectively. The signs for the first two coefficients are similar to national patterns (Hanson *et al.*, 1989), but the magnitude of the coefficients must be viewed with caution. The steep increase since 1979 is over a relative short period of time and primarily reflects the warmth of the eighties.

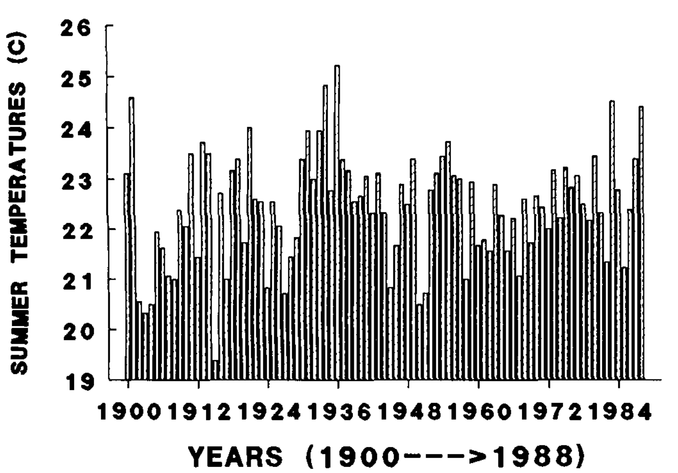

Fig. 2. Summer air temperatures for Iowa from 1900 to 1988, mean = 22.4°C.

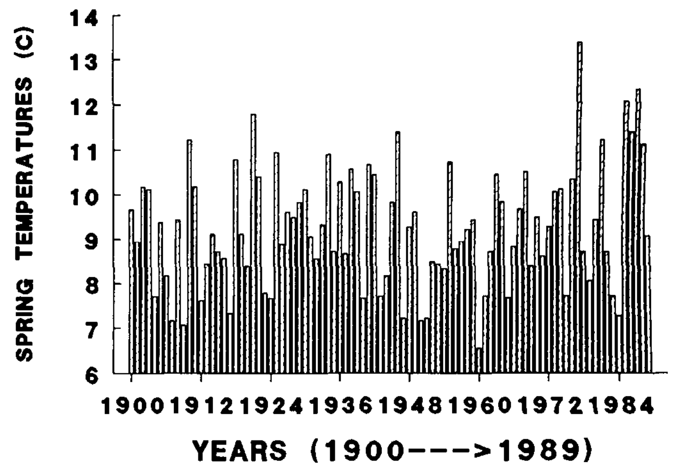

Fig. 3. Spring air temperatures for Iowa from 1900 to 1989, *mean* = 9.3°C.

It is noteworthy that 12 of 16 years since 1973 have been warmer than normal. It is not, however, possible to project from data in this figure, or from any other presented here, beyond 1989.

Summer air temperatures are shown in Fig. 2. This pattern is somewhat like that in Fig. 1. The multistage regression analysis indicated summer air temperature trend changes marginally significant (5-10% level) around 1936 and 1960. The regression coefficients for 1900-1936, 1936-1960, and 1960-1988 were 0.02, −0.06, and 0.11°C/year. These coefficients warrant the same consideration as was stated previously for annual air temperature. The magnitude of the coefficients is somewhat dependent on the time period selected for analysis. For example, if 1900 and 1901 were deleted from this analysis, a rather large coefficient would result for the first three decades of this century. This comment would be relevant for other time series discussed in this report.

The 30's are famous in Iowa's history as being very stressful, but note from Fig. 2 that 15 consecutive years beginning with 1930 were warmer than normal. The years 1934 and 1936 were extremely warm, but 1983 and 1988 in recent history were also warm. At the other end of scale, 1915 stands out as the coolest summer. During that year, some stations in Iowa did not have maximum air temperatures exceeding 30°C. In addition, this year was unusual in that there

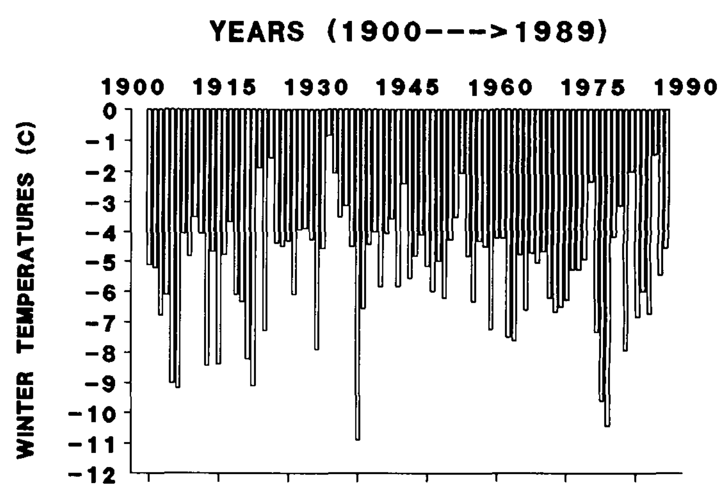

Fig. 4. Winter air temperatures for Iowa from 1900 to 1989, mean = −5.3°C.

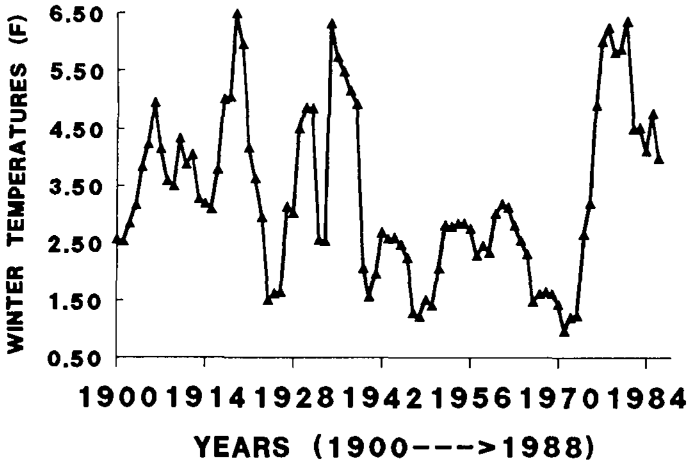

Fig. 5. 5-year moving standard deviations in Fahrenheit units for winter air temperatures from 1900 to 1988.

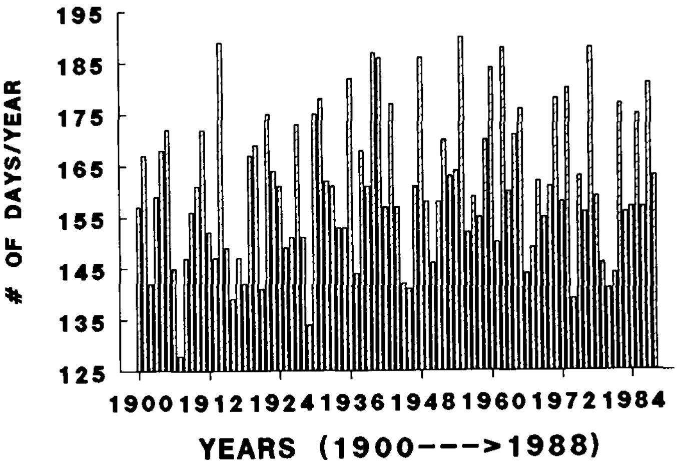

Fig. 7. The length of the frost free season for Ames, Iowa, *from* 1900 to 1988, mean = 161 days.

was a killing frost and freezing temperatures over the northeastern counties of Iowa in August, and frost occurred at some place in the state every month of the year. The cool air temperatures slowed crop development (Iowa Department of Agriculture, 1915).

Although not shown in this paper, fall air temperatures revealed very weak trends, with each year fluctuating around a long-term mean value. Spring air temperatures were similar to those of fall except that the last 4 years of record beginning in 1985 were all well above normal (Fig. 3). Indeed, 6 of the past 12 springs have been well above the long term normal. This was very unusual, not occurring elsewhere in this historical record. The year of 1989 seems to be dropping back judged by near normal spring air temperatures. A similar long-term pattern has been reported on a national level (U.S. Dept. of Commerce, 1989).

Winter air temperature trends are shown in Fig. 4. The trends evident in Fig. 1 can also be seen in this depiction. Multistage regression analysis indicated a marginally significant (5-10% level) single change of trend near 1931. Of recent interest is the large interannual variability beginning in 1976. Two back-to-back years of near record cold were followed by 3 to 4 years of very warm winter air temperatures. To examine this in more detail, 5-year moving mean and moving standard deviations were calculated. In this context, a moving mean and moving standard deviation were calculated for 5 consecutive years beginning in 1900, then another calculation beginning in 1901, etc. until the last 5 years of the time series. The changing pattern of moving standard deviations is shown in Fig. 5. It shows that the period from the early 40's to the early 70's was quite stable, with little interannual variability. The later part of this time series appears more like the first 40 years of this century. The winter of 1936 stands out in Fig. 4 as a singular cold period. December and January of that year were cold, but February was extremely cold relative to normal.

The patterns for derived air temperature variables are given in Figs. 6-11 using the centrally located Ames weather station. Keep in mind that patterns and trends of weather parameters can differ seasonally between stations. Growing degree day trends in Fig. 6 reveal no definite pattern for this station. This probably relates to the fact that when this variable is calculated for each day, the maximum and minimum air temperatures are bounded by 30°C and 10°C, respectively. These two cardinal temperatures represent the extremes of corn (*Zea mays* L.) growth response to temperatures as reported by Coelho and Dale (1980). The seasonal extremes of growing degree days vary greatly over this period producing both slow and rapid corn development responses. It is of interest to note that trend analyses

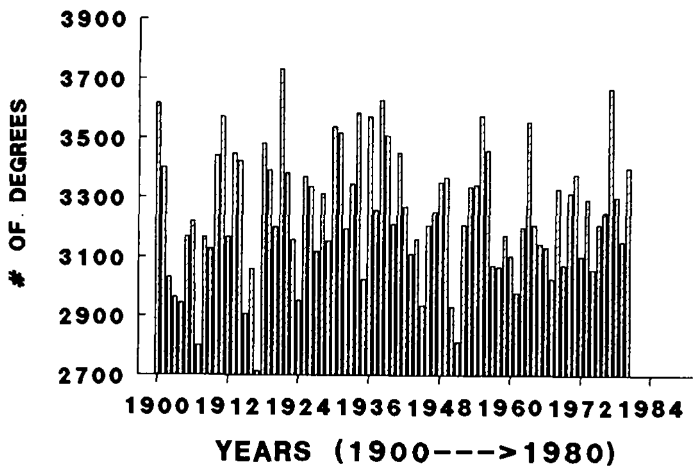

Fig. 6. Growing degree days for Ames, Iowa from 1900 to 1980, mean = 3249° in Fahrenheit units.

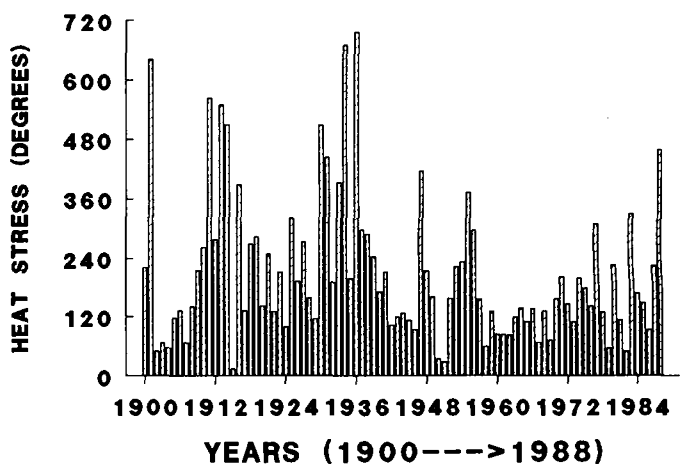

Fig. 8. Seasonal heat stress for Ames, Iowa, from 1900 to 1988, mean = 210° in Fahrenheit units.

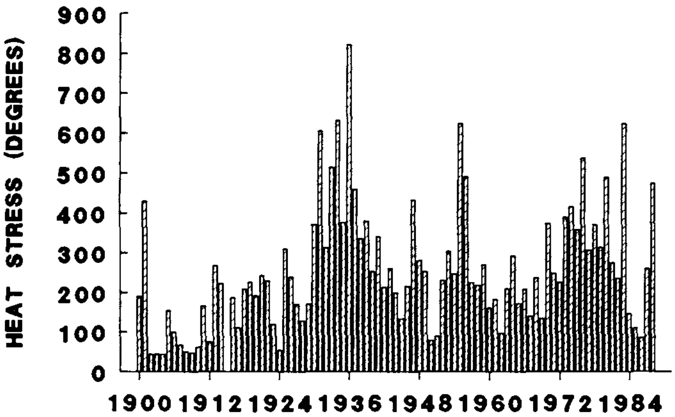

Fig. 9. Seasonal heat stress for LeMars, Iowa, from 1900 to 1988, mean = 256°.

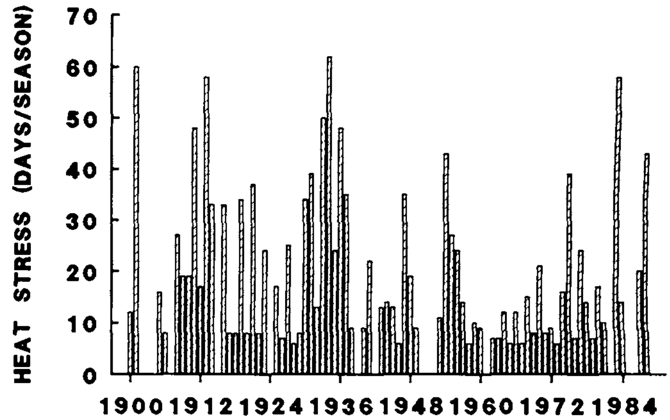

Fig. 11. Number of days per year contained in runs of greater than 5 consecutive days with maximum daily air temperatures exceeding 30°C for Ames, Iowa, from 1900 to 1988.

were performed for each of the 21 stations over the period 1900-1980, and 5 revealed statistically significant quadratic responses. They were Corning, LeMars, Marshalltown, Storm Lake, and Washington. This appeared to be caused by coolness during the first 3 decades of this century and the great warmth of the thirties.

The frost-free season is defined as the number of days between the last and first 0°C minimum in the spring and the fall, respectively. No significant trends were found for Ames, as is shown in Fig. 7. This is not unexpected for a single station because the length of the growing season defined in this manner can be controlled by short-lived air mass movement with associated cold air advection as well as general cool air temperatures. Even during a warm fall or spring, a cold event can produce just one or two damaging nights followed by warmer air temperatures. Examination of all 21 stations in Iowa revealed 5 stations showing statistically significant trends toward longer growing seasons. These were not the same stations mentioned above relative to growing degree days. Averaged over all stations, the length of the growing season in Iowa has increased approximately 9 days from 1900 to 1988. A similar result is reported by Waylen and LeBoutillier (1989) for Regina, Saskatchewan, Canada.

The heat-stress variable depicted in Fig. 8 reveals an interesting pattern showing the extremes of Iowa's climate and periods of hostile or benign weather. Values greater than 150-200 Fahrenheit units for

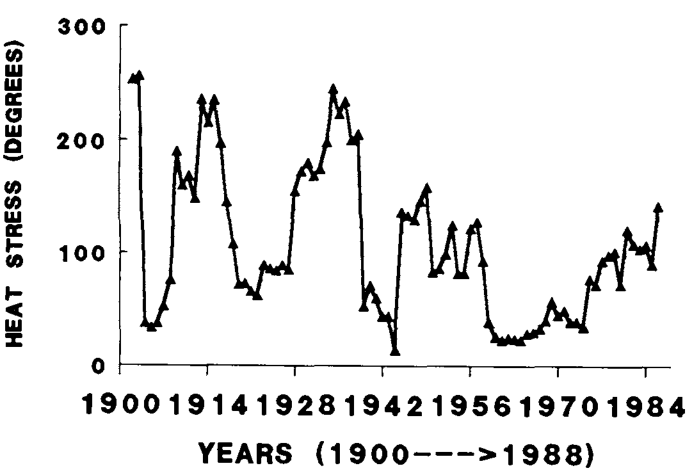

Fig. 10. Five-year moving standard deviations for seasonal heat stress for Ames, Iowa, from 1900 to 1988 in Fahrenheit units.

this variable can be expected to reduce crop yields, if summer soil moisture levels are not adequate (Carlson, 1990). Before 1956, considerable interannual variability is evident with frequent highs and lows. From 1957 through the early 70's, little heat stress was present, and soil moisture levels were high (Carlson, 1990); thus, Iowa yields were primarily limited by production practices. After 1975, the interannual variability present during the first part of this century shows some evidence of return. In the past 12 years, 4 have had heat-stress values high enough to reduce yields. This figure represents only one station (Ames), but generally similar patterns were evident for the other long-term sites in Iowa. Fig. 9 shows the pattern for this same variable at LeMars to indicate that different patterns do occur for various reasons from site to site across the state of Iowa. At LeMars, the heat stress during the teens was not as intense as experienced by Ames. This pattern between these two stations is somewhat reversed for the seventies. Five-year moving standard deviations were calculated for this variable at the Ames station, with the results given in Fig. 10 where hostile and benign time periods can be identified. Since the mid-60's the interannual variability seems to be on the increase, but it has not reached the level evident during much of the first half of this century. Thompson (1988) discusses this in terms of crop yields and weather.

Fig. 11 is another variable closely related to the heat stress depicted in Fig. 8. Fig. 11 shows stressful daily runs of weather where maximum air temperatures exceed 30°C on consecutive days. The first half of this century was quite severe, with the benign period in the late 50's through the early 70's evident again. This pattern also seems to show a return to more stressful times since the mid-70's.

CONCLUSIONS

The climate of Iowa on the average is a very favorable place on earth to provide ample bounty for its inhabitants. As evidenced by long-term trends for various elements of weather presented here, climatic extremes take place, which unfavorably stress the agricultural economy.

Trends for most of the data sets presented here are fairly weak because of the large amount of interannual variability. The data to be collected in the 90's and the first decade of the next century will help to tell if air temperatures are indeed on an upward swing as many "Greenhouse" proponents suggest.

Of importance for near-term agricultural production, the heat-stress variable is one that warrants attention. If the climate is starting to have greater year-to-year variations, agricultural production risk will increase from both a yield and management aspect.

ACKNOWLEDGEMENTS

The author would like to thank the numerous, volunteer weather observers throughout Iowa that have faithfully collected the data used in this manuscript over these many years. Thanks are also due to Drs. Symanowski and Hinz of the ISU Statistics Department for help with the multistage regression analysis and to Stewart Ireland for help assembling the air temperature data set.

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