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ANNUAL DISTRIBUTION OF DAILY RECORD HIGH TEMPERATURES THROUGH THE PERIOD OF RECORD FOR SELECTED STATIONS IN THE CENTRAL USA

Juliann Meyer
Missouri Basin RFC
NWS, Pleasant Hill, Missouri

Lee W. Larson
National Weather Service, Prairie Village, Kansas (retired)

1. INTRODUCTION

It could be assumed that the occurrence of daily record high temperatures at a given location would be distributed somewhat evenly through the period of record. If not, it would be of some value to show when, at each location according to year, an unusual number of record high temperatures were set. It was also felt it would be of interest to determine if there is some long-term trend in the frequency of occurrence of daily record high temperatures. An analysis of when daily record high temperatures were recorded at each location should be of value in helping to determine trends in long-term climate changes.

2. METHOD

Twelve locations throughout the Great Plains and Midwest, ten in urban areas and two in rural areas were selected for examination as shown on Figure 1. All stations are National Weather Service (NWS) observation sites and have records in excess of 100 years. All data used in this paper were obtained from NWS Weather Forecast Office (WFO) or regional climate center websites. Data examined were from the beginning of record through February 2016 for each location. The maximum temperature records for each day of the calendar year for the entire period of record were totaled for the year in which they occurred. The number of daily high temperature records for each calendar day were then summed and plotted by year. Trend lines were added to show general slopes of the data. Negative slopes would tend to show that daily record high temperatures occurred more frequently in the early part of the data record while positive slopes would tend to show the opposite. Zero or near-zero slopes would tend to show that the record daily highs were distributed evenly throughout the period of record. A Student's t-test analysis was done to show whether the trend line slopes at each location were statistically significant.

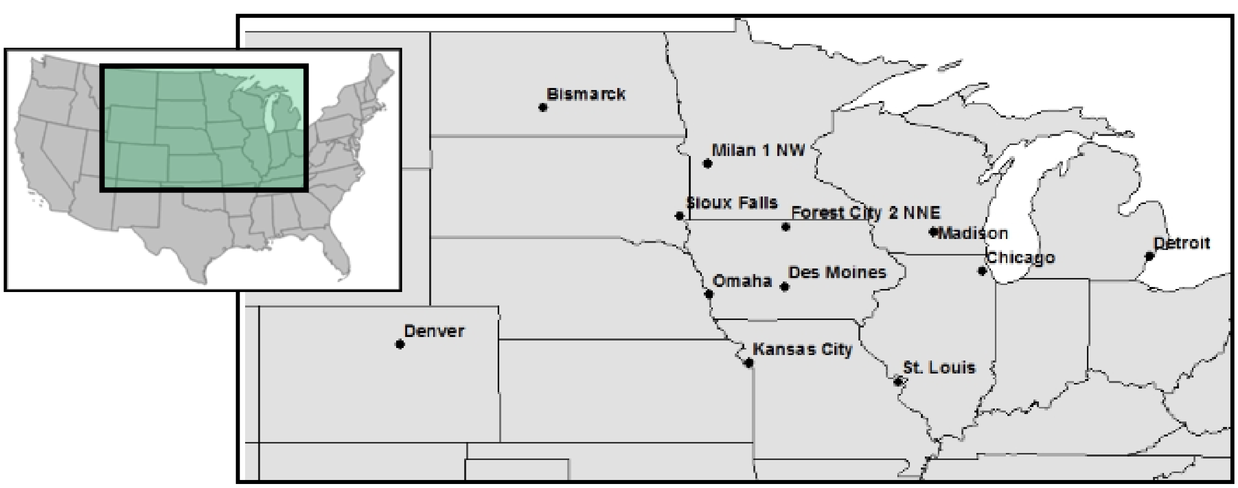

Fig. 1. Location of temperature stations

3. LOCATIONS AND DISCUSSIONS

Bismarck, North Dakota: Bismarck has 142 years of record. Record highs are fairly evenly distributed through the period of record as shown in Figure 2. Years with the greatest number of record highs are: 1988 with 13 occurrences, 2012 with 12 and 1936 with 10. The regression line has a positive slope of 0.016. The daily high temperature record at Bismarck does not have periods of record highs clustered around one or two years. Except for 1988 and 2012, the rest of the 142 years seem to deviate from the median fairly evenly (median would be about 2.6 record high temps per year). Bismarck was affected by the Dust Bowl years with the third highest daily totals in 1936.

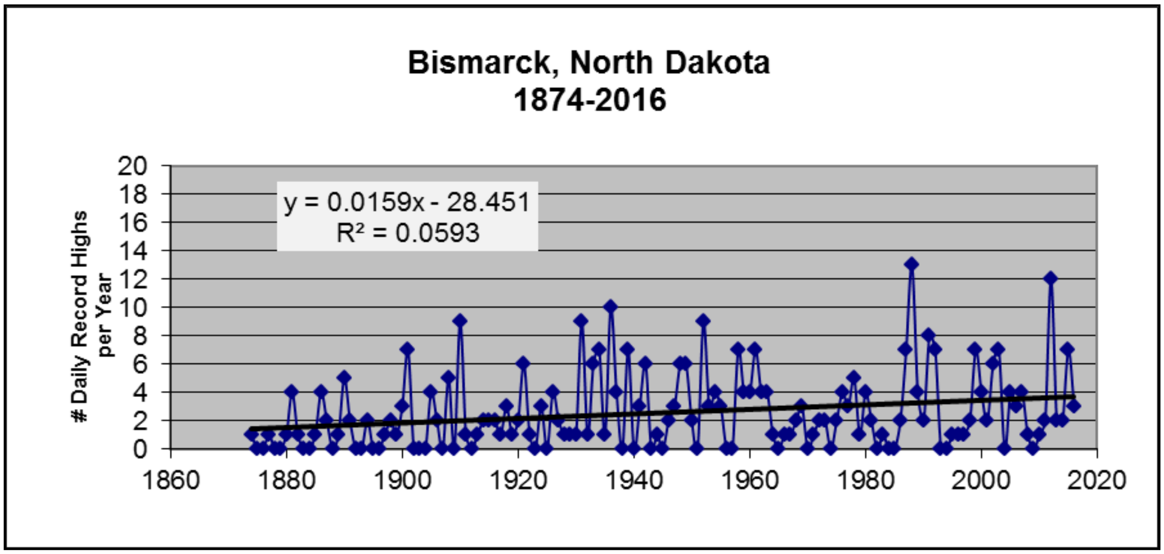

Fig. 2. Plot of number of daily record highs per year for Bismarck, North Dakota.

Chicago, Illinois: Chicago has a period of record of 142 years. There are six years that had a well-above-average number of record high temperatures, 1911 (7), 1930 (8), 1953 (13), 1971 (13), 1988 (11), and the last and largest 2012 (14) as shown in Figure 3. The best-fit trend line shows a positive slope of 0.018. The peak highs occur fairly regularly throughout the period of record, occurring about every 20 years or so. The most significant year was 2012, 41 years after the previous peak year in 1971.

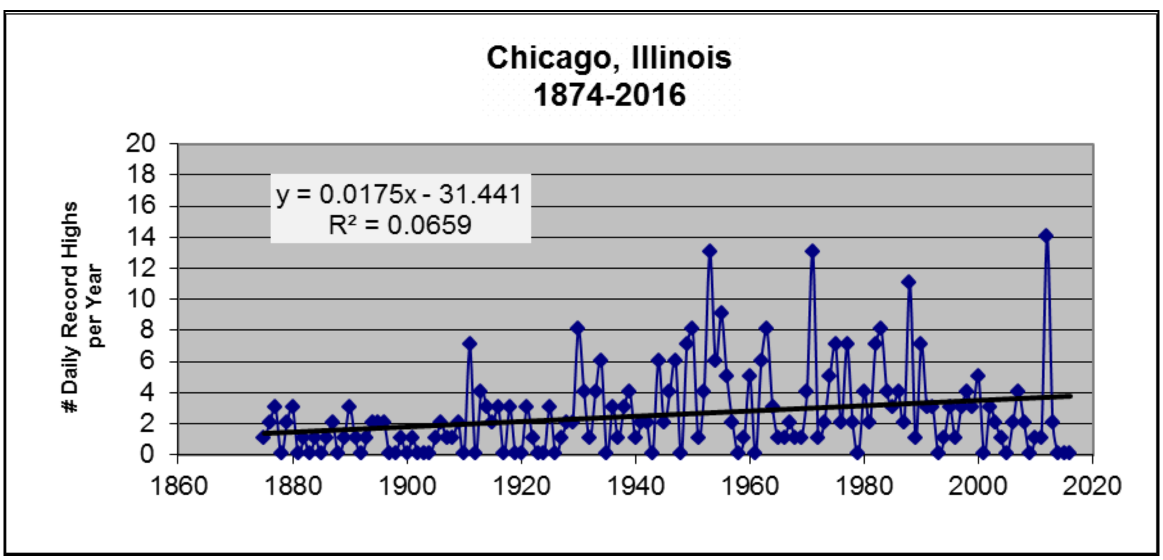

Fig. 3. Plot of number of daily record highs per year for Chicago, Illinois.

<u>Denver, Colorado:</u> Denver has a period of record of 145 years. There are seven years that had a well-above-average number of record high temperatures. The years 1950, 1980 and 1986 all have 7, the years 1989, 2012 and 2005 have 14 and the year with the most daily record high temperatures is 2006 with 17 as shown in Figure 4. Most of the daily record high temperatures have occurred in the last half of the record from about 1950 on with the majority occurring in the last quarter of the record. The best fit trend line shows a positive slope of 0.038, the highest of all the locations examined.

The climate observations at Denver have been taken at several locations over the period of record. Up until about 1931, observations were taken at several different locations in urban downtown Denver. In 1931, the observations were moved to what was then the east side of Denver at what eventually became Stapleton International Airport. In 1995, the observations were moved some 10 miles northeast to the new Denver International Airport. The micro-climate at Stapleton had evolved into an urban area by 1995. Denver International Airport is located on open prairie and is a much different micro-climate. How much, if any, the change of location for observations might have on daily record high temperatures is a legitimate question. At the very least, Denver shows a much more pronounced trend towards more record daily high temperatures being set in recent years.

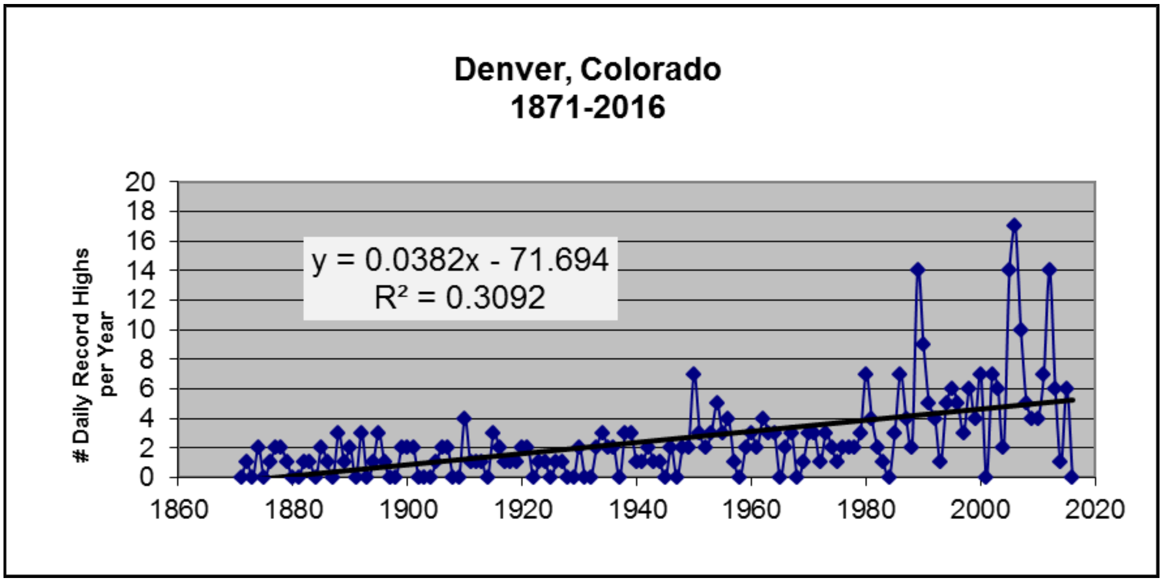

Fig. 4. Plot of number of daily record highs per year for Denver, Colorado.

<u>Des Moines, Iowa:</u> Des Moines has a period of record of 136 years. There are five years that had a well-above-average number of record high temperatures. They are 1934 with 16, 1936 with 18, 1939 with 11, 2002 with 11 and 2013 with 11 as shown in Figure 5. The period with the most record daily highs is in the 1930s with single years in 2002 and 2013. The year with the most daily record high temperatures is 1936, right in the middle of the Dust Bowl era. The trend of the best fit regression line is 0.009.

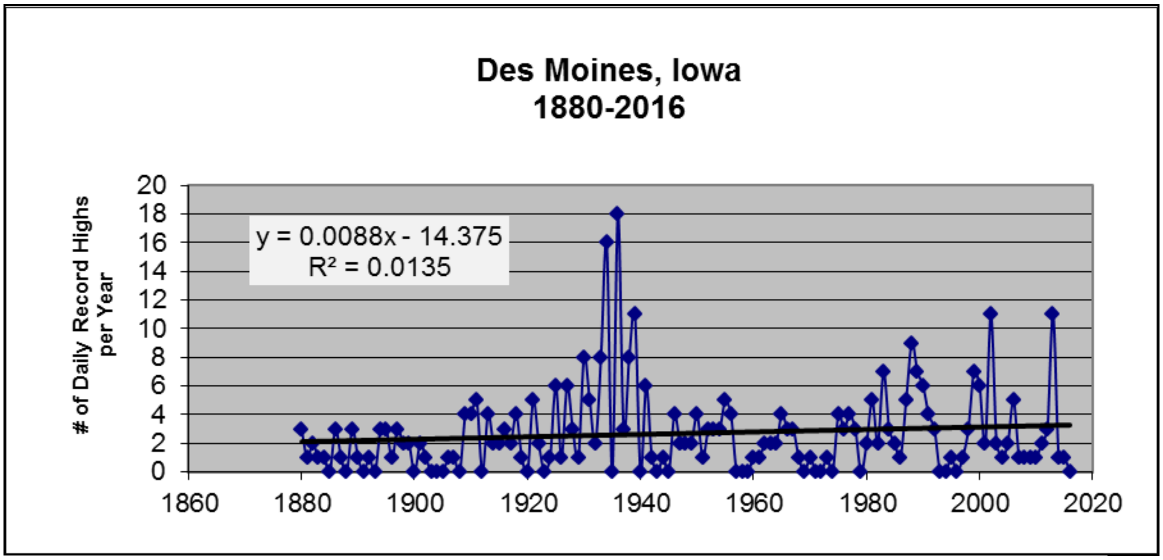

Fig 5. Plot of number of daily record highs per year for Des Moines, Iowa.

Detroit, Michigan: Detroit has a period of record of 147 years. The peak years were 1977 and 1988, both with nine record daily highs as shown in Figure 6. The distributions of daily record highs are distributed fairly evenly though out the period of record. The best fit trend line is 0.017 indicating an upward trend towards record daily highs being set later in the period of record.

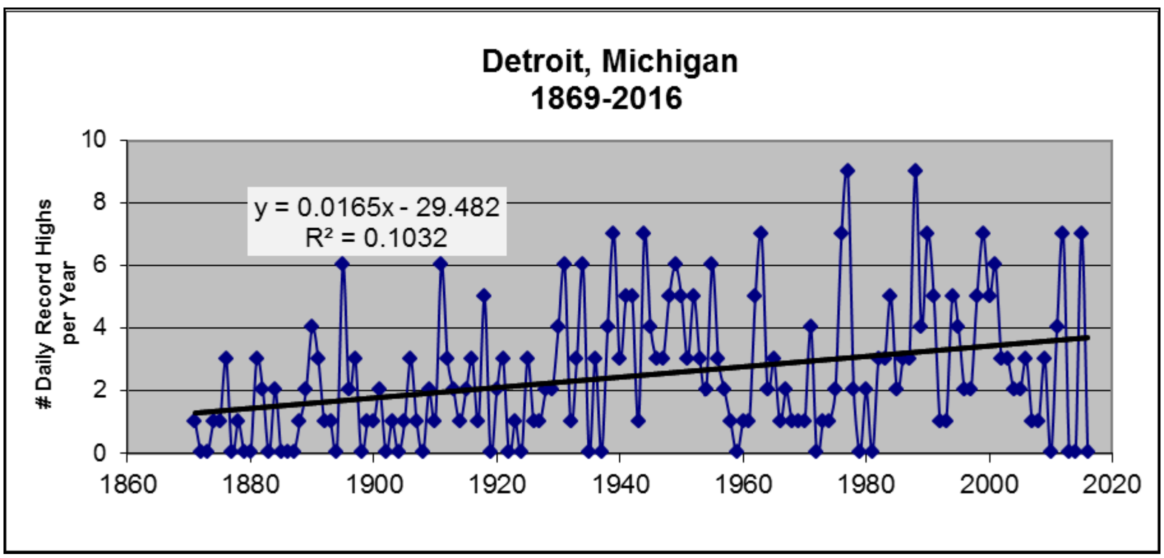

Fig 6. Plot of number of daily record highs per year for Detroit, Michigan.

Forest City 2 NNE, Iowa Forest City has a continuous temperature record of 122 years. The Dust Bowl years have four of the five top years of daily high temperature records. They are 1936 with 18, 1934 with 16, 1939 with 13, and 1933 with 10 as shown in Figure 7. The year 2012 is the fifth period with 13. The trend of the best fit regression line is 0.002.

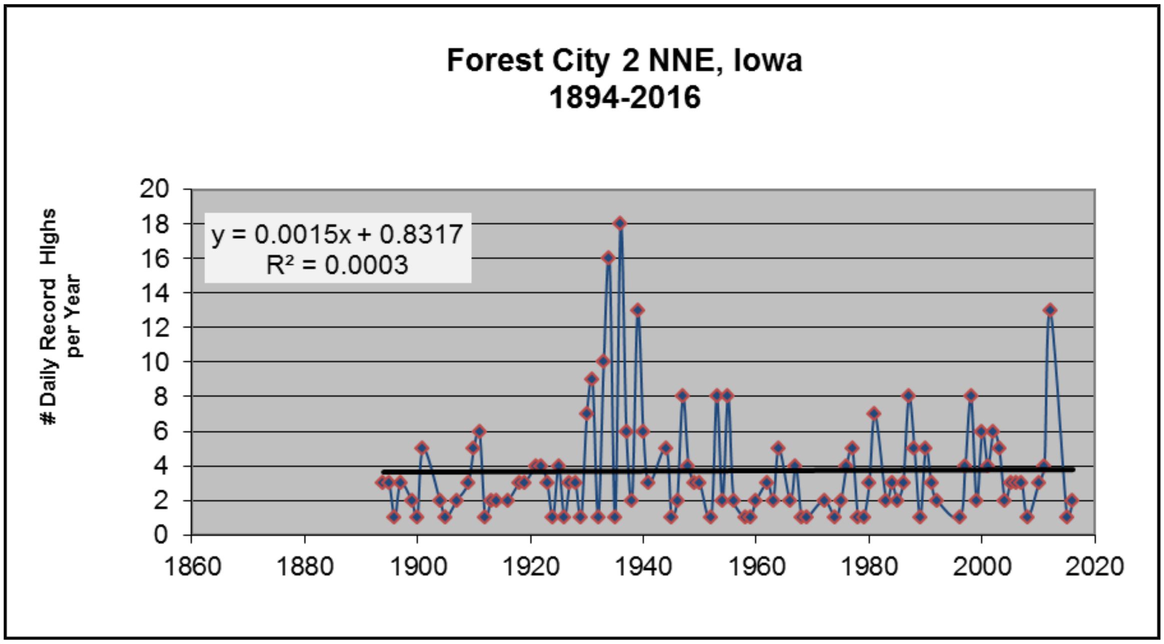

Fig. 7. Plot of number of daily record highs per year for Forest City 2 NNE, Iowa.

Kansas City, Missouri: Kansas City has a continuous temperature record of 127 years. The year 1934 has the most record daily high temperatures at 28, followed by 1936 with 26 as shown in Figure 8. This is the period of the Dust Bowl years and is plainly evident in the plot below. Except for 1934 and 1936, the number of daily record high temperatures is fairly evenly distributed throughout the period of record including the most-recent years. The other years with well-above-average occurrences of record high temperatures were in 1939, 1954, and 1963. The bulk of high temperature records were set in the mid-1930s. The best fit trend line has a slope of 0.004 indicating a very slight upward trend of daily record high temps toward the latter years of the period of record.

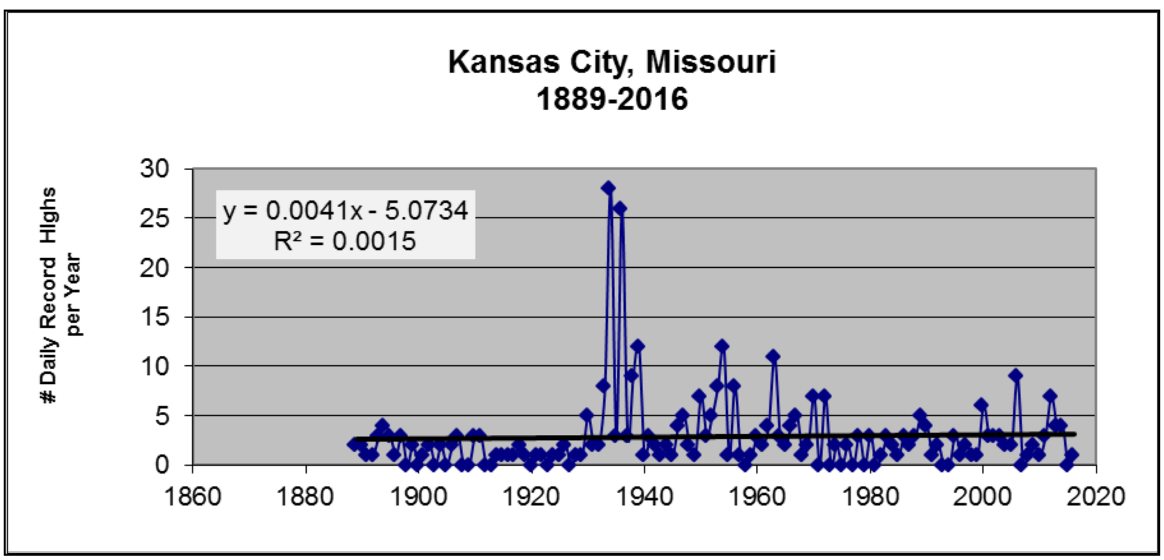

Fig. 8. Plot of number of daily record highs per year for Kansas City, Missouri.

Madison, Wisconsin: Madison has a period of record of 146 years. There are five years of record highs of note: 1934 with 11, 1936 with 10, 1947 with 11, 1953 with 16, 1955 with 11, and 2012 with 17 as shown in Figure 8. The regression line has a positive slope of 0.016. Except for 2012, most of the maximum high temperatures at Madison have been from the 1930s to the 1950s.

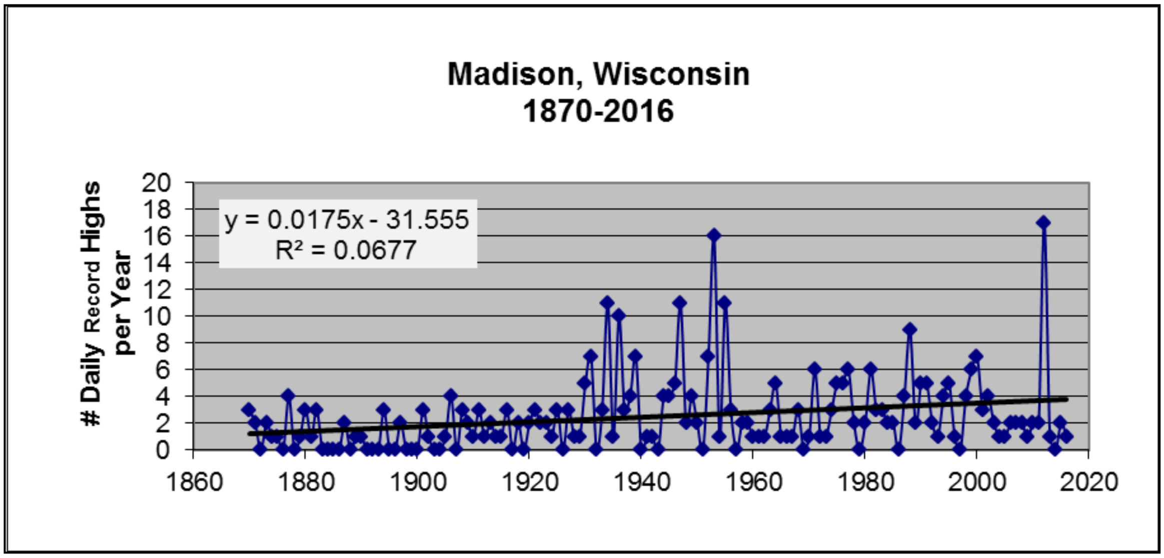

Fig. 9. Plot of number of daily record highs per year for Madison, Wisconsin.

Milan 1NW, Minnesota Milan 1NW has a period of record of 123 years. The same family has taken daily records for four generations on their farm. There are seven periods of daily record highs of note. They are 1934 with 15, 1931 with 14, 2012 with 14, 1933 with 12, 1976 with 12, 1939 with 11 and 1988 with 11 as shown in Figure 10. The regression line has a positive trend of 0.016.

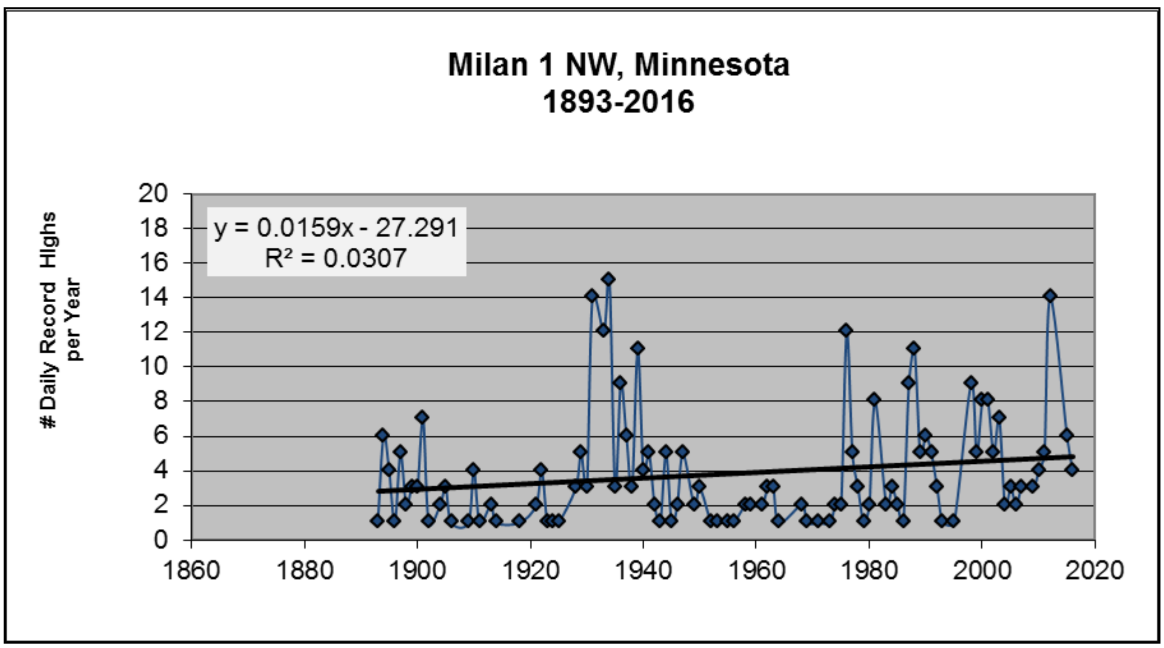

Fig. 10. Plot of number of daily record highs per year for Milan 1 NW, Minnesota.

Omaha, Nebraska: Omaha has a period of record of 142 years. There are five years with well-above-average number of daily record highs. They are 1930 with 8, 1934 with 17, 1936 with 15, 1939 with 12 and 2012 with 16 as shown in Figure 11. Clearly the most significant period of record highs at Omaha is the Dust Bowl era, the mid 1930s. The regression line is positive at 0.016.

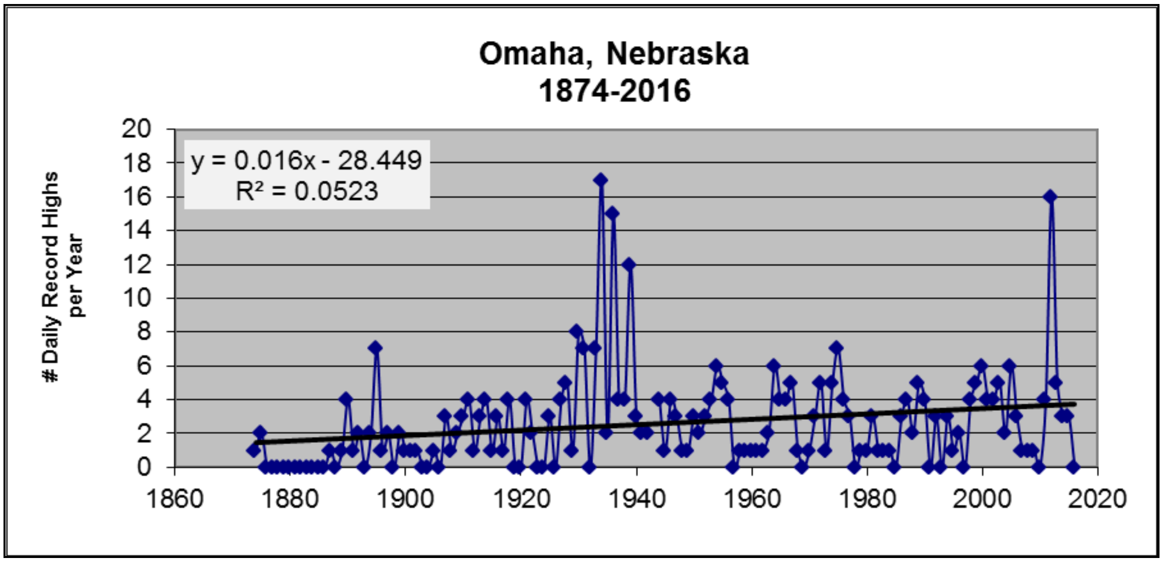

Fig. 11. Plot of number of daily record highs per year for Omaha, Nebraska.

St. Louis, Missouri: St. Louis has a 140-year period of record. There are three years with well-above-average number of record high temperatures. Twenty-four record high temperatures occurred in 1936, 13 in 1953, and 2012 has the most record high temps at 24 as shown in Figure 12. The trend of the regression line is positive at 0.021.

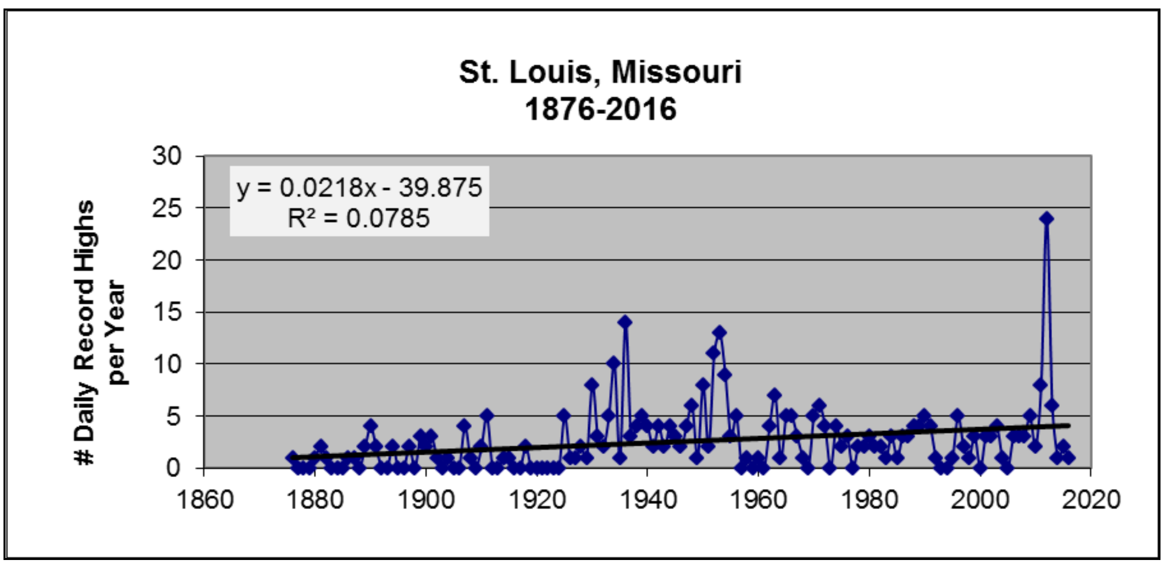

Fig. 12. Plot of number of daily record highs per year for St. Louis, Missouri.

Sioux Falls, South Dakota: Sioux Falls has a period of record of 132 years. There are three definite years with well-above-average number of record high temperatures: 1910, 1934, and 2012 (Figure 13). The year with the most daily record highs was 1934 with 16. Again, this was a Dust Bowl year. This was followed closely with 14 daily record highs in 2012 and 11 in 1910. The best-fit trend line for Sioux Falls is -0.003, the only location of the ten locations investigated that has a downward trend in the data, indicating that most of the daily record highs tended to be in the early part of the record with a downward trend towards recent years.

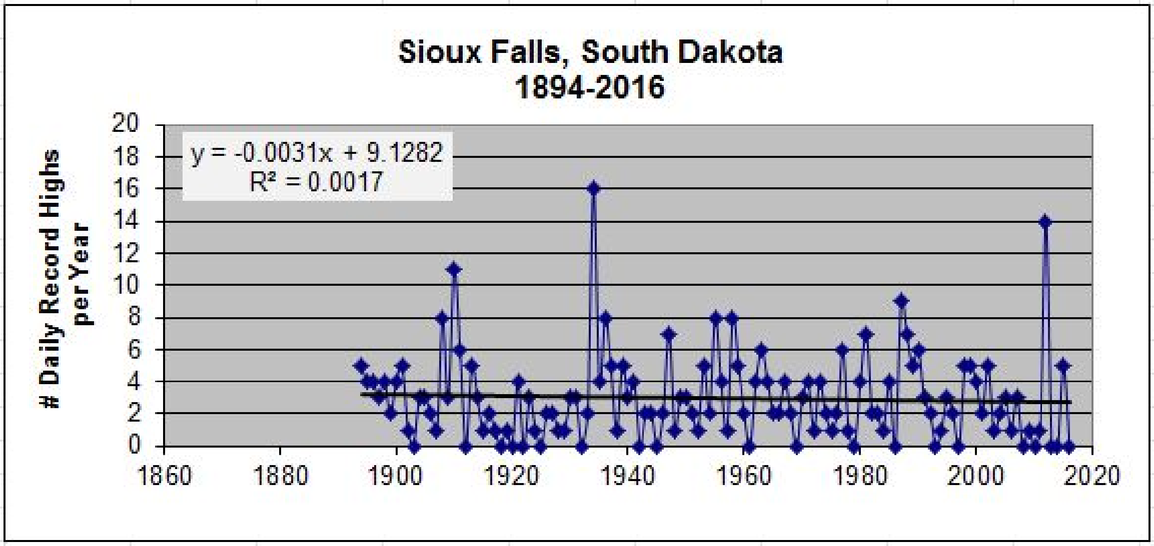

Fig. 13. Plot of number of daily record highs per year for Sioux Falls, South Dakota.

4. SUMMARY AND CONCLUSIONS

Table 1 shows the slope (regression coefficient) of the best-fit trend line, years of record and a value for t (Student's t-distribution). The Student's t-distribution is a statistical technique for testing hypotheses (Spiegel 1961). The hypothesis being tested is that the regression coefficient for the trend lines is statistically the same as zero, indicating uniform distribution of daily record high temperatures through the period of record. In this case, if $t<1.65$ (95% confidence and 140 degrees of freedom), the hypothesis is accepted (not rejected) and if $t > 1.65$, the hypothesis is rejected. Although each specific location had a slightly different number of years of record, Student's t values with n greater than 120 all converge to a value of about 1.65 so that value was used at each location for hypothesis testing.

Location	slope (a)	years of record	Student's t	Hypothesis
Bismarck	0.016	142	9.50	reject
Chicago	0.017	140	6.70	reject
Denver	0.038	145	14.70	reject
Des Moines	0.009	136	1.61	accepted
Detroit	0.017	147	7.00	reject
Forest City 2 NNE	0.002	122	.41	accepted
Kansas City	0.004	127	0.63	accepted
Madison	0.011	146	7.00	reject
Milan 1NW	0.016	123	4.19	reject
Omaha	0.016	142	5.80	reject
St. Louis	0.022	140	6.80	reject
Sioux Falls	-0.003	122	0.58	accepted
Average	0.014	136		

Table 1. Regression coefficients, years of record and Student's t values for selected sites.

Student's t values were calculated for each location. In the cases of Des Moines, Kansas City, Forest City, and Sioux Falls, t was <1.65 and we "failed to reject the hypothesis" (i.e., the hypothesis was accepted). So, the regression coefficients were not statistically different from zero. In all other cases in Table 1, t >1.65 and, therefore, the hypothesis was rejected for those locations. This means that the regression coefficients for these locations were statistically significant and different from zero. So, eight of the twelve locations did show increased daily record highs in the latter part of their records while four did not. A subjective judgement would be that Madison showed a minor increase, Omaha, Milan, Bismarck, Detroit and Chicago showed an increase between minor and moderate while St. Louis and Denver showed moderate increases. Des Moines, Kansas City, Forest City, and Sioux Falls showed even distributions of record daily high temperatures throughout their period of record.

It is interesting to note that in the cases of Sioux Falls, Chicago, St. Louis, Omaha and Madison the distribution of daily record highs were fairly uniform except for one year 2012 (in some cases a year or two on either side of 2012). The year 2012 was exceptionally rare having been identified by the NWS as the third warmest La Niña on record (Osborne and Blunden 2012). Since 2012, few daily record highs have been set at any of the locations. Had the 2012 La Niña not occurred, all of the stations regression coefficients for these locations would have been more similar to Kansas City, Des Moines or Sioux Falls. For example, if 2012 was removed from the data for Omaha, the regression coefficient drops from 0.016 to 0.011.

In almost every case shown here, the Midwest Dust Bowl era of the 1930s is very prominent and the period with the greatest number of high temperature records. Denver, to the west and Detroit to the east, are the only stations where the 1930s are not the major event affecting the temperature records. Denver is also a unique location in that there is an erratic distribution of daily record highs over the last 30 years or so. This could possibly be due to at least three moves of the observing location. The observing station at Denver may also be affected by its proximity to the Front Range, the Cheyenne Ridge, and the Palmer Divide. In general, it appears that when plotting this type of temperature data, once the regression coefficient of the best-fit trend line exceeds about 0.01, then the trend becomes statistically significant.

In terms of the general positive trends of the regression coefficients some other issues are worth consideration. The first would be the issue of NWS changes in equipment for temperature measurements. In the early 1980s, the NWS switched from traditional glass thermometers to digital thermometers primarily for automation reasons. There was some concern about possible differences in capabilities between glass thermometers and automated equipment (Watts 2009).

There also have been concerns about the urbanization affecting the micro-climates around long-term stations thus affecting temperature measurements. These potential impacts would tend to raise record high temperatures thus causing a long-term and gradual increase in record highs as the site locations become more and more affected by urbanization surrounding the gages. Watts (2009) is a source investigating this concern. This project, which visited some 860 recording NWS sites, found that, in their opinion, nine out of ten stations no longer met NWS siting standards and were affected by urbanization. The conclusion was that these sites were "likely" reporting higher temperatures than in fact were occurring. Menne (2010) looked at the issues raised by Watts and concluded that a more detailed data analysis of station siting and exposure needs to be performed in order to gauge if a bias due to poor exposure exists and to quantify the bias. The data analysis done by Menne did indicate there is some bias but that it found no indication that poor siting was a significant contributing factor.

Finally, for locations where station siting requirements are not in question and increasing temperature trends over time are statistically defensible, it can be said that the climate in these locations is non-stationary, meaning that it is changing over time. The impact of any bias due to equipment changes or station location on long-term trends in the number of daily records set in any given year may be small or negligible. In summary, eight of the twelve stations analyzed had statistically significant upward trends in the number of record highs late in their records. But, three had no significant change in the long-term history of record high distributions and one had a trend showing fewer record highs in recent history.

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