

TEMPERATURE ANOMALIES DURING THE DROUGHT OF 1988: HIGH DAILY RANGES THROUGH EARLY SUMMER IN INDIANAPOLIS, INDIANA

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INTRODUCTION

The early part of summer 1988 was characterized by a severe drought which affected a large area of the United States, extending from the Northern Plains across the Midwest and Ohio Valley and down into the Southeast. By mid-July, severe-to-extreme drought covered nearly 45% of the country, making 1988 the third worst in terms of geographic area affected in the twentieth century (Heim, 1988). Between late April and early July, a steady succession of cloudless days prevailed, bringing high temperatures and little rainfall (National Oceanographic and Atmospheric Administration/U.S. Department of Agriculture Joint Agricultural Weather Facility, 1988). The recurrent weather pattern not only produced widespread drought and growing deficits in precipitation, but also generated increasingly abnormal high diurnal ranges in temperature.

Several important factors contributed to the extreme dryness: 1) a lack of moisture in the air; 2) the absence of rain-producing mechanisms; and 3) the persistent nature of the weather pattern once it was established (Ludlum, 1988a,b). Warm, humid air masses normally begin to move northward in the spring and summer, spreading Gulf moisture through the Plains and Upper Midwest. Under the influence of high pressure, both at the surface and aloft, the supply of moisture was cut off. Upper air patterns were controlled by a ridge of high pressure centered over the midwestern U.S. (Ludlum, 1988a; National Oceanic and Atmospheric Administration National Weather Service Climatic Analysis Center, 1988), which displaced the storm track well to the north of its normal position. Cyclonic storms were diverted into Canada (Ludlum, 1988b; Martell, 1988); frontal passages occurred only infrequently (Ludlum, 1988a). Beneath the ridge, stable, warm, dry air masses dominated. The resultant clear skies, low humidity (dry air), and light winds prevailed day after day. Maximum insolation was received; high temperatures and sparse rainfall were the rule over an extensive geographic area (Ludlum, 1988b).

Weather conditions favorable to a low daily range of temperature were largely absent during the early part of the summer. Cloudy skies, high humidity, strong winds, and wet weather, which often accompany low pressure patterns and frontal systems, lower daytime temperatures but cause nights to remain warm. The resultant daily range of temperature is reduced considerably. Clouds are most

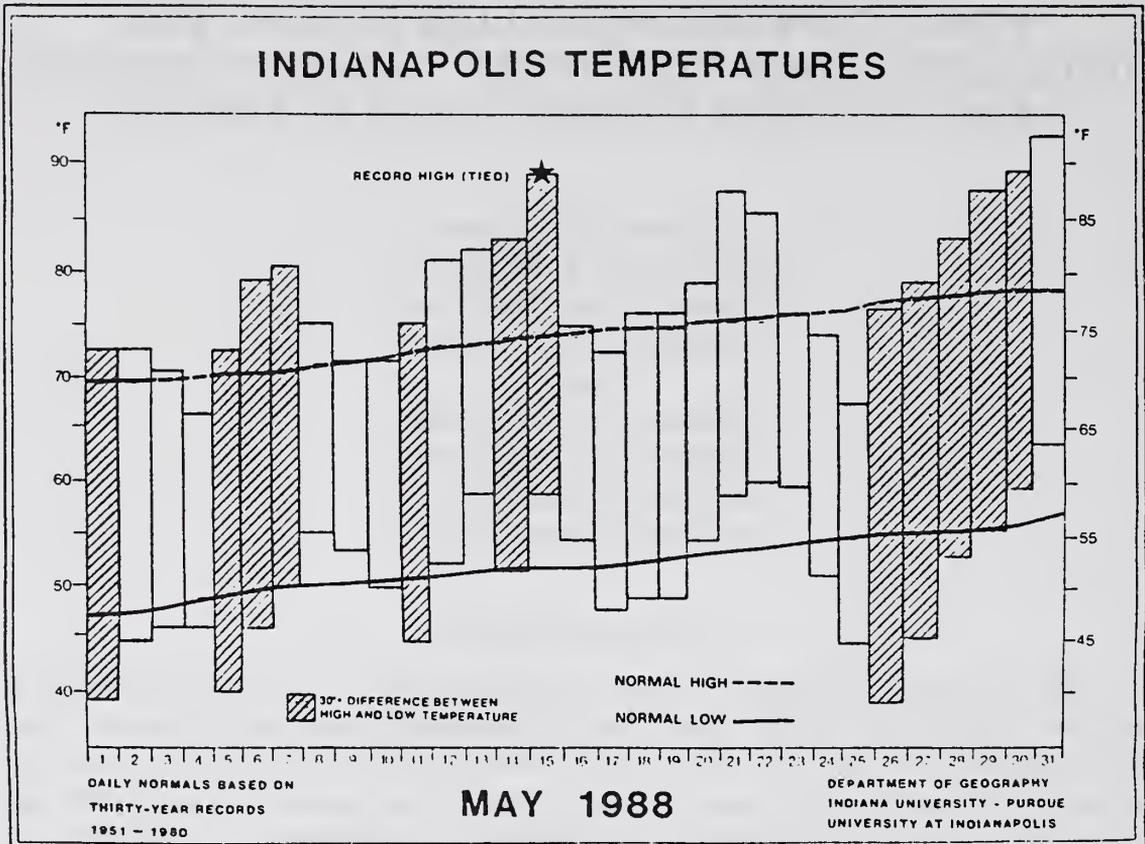


FIGURE 1. Daily maximum and minimum temperatures recorded at the Indianapolis airport for May 1988. Normal high and low temperatures are also shown. Days on which the daily temperature range was 30.0°F (16.7°F) or greater are shaded.

important, because they block incoming solar radiation (short-wave) and reduce heating during the day (Lutgens and Tarbuck, 1988). A higher percentage of the available radiant energy is diverted toward evaporation (latent heat) instead of warming the air (sensible heat). At night, outgoing terrestrial radiation (long-wave) from the surface is absorbed by moisture (i.e., clouds and humidity) in the air (Ahrens, 1988). Radiational cooling is slowed considerably. Winds play a dual role by mixing the air, which prevents rapid surface cooling, and by advecting warmer air into the area (associated with southerly flow).

Clear skies, dry air, light winds, and fair weather under the influence of high pressure produce a widespread difference between daily high and low temperatures. Abundant insolation causes rapid heating during the day. Evaporation is greatly reduced by extreme dryness, as a higher percentage of the sun's energy is used for surface and sensible heating, which increases both daytime warming and resulting air temperatures (Ahrens, 1988). At night, the lack of cloud cover and moisture in the air permits rapid radiational cooling and allows temperatures to cool considerably overnight without any mixing by winds. Larger diurnal temperature ranges are the product of warmer days in conjunction with cooler nights.

In this study, the anomalously high diurnal temperature ranges which occurred in Indianapolis, Indiana during an extended stretch of hot, dry weather through the early summer 1988 are described. The paper will detail the relation-

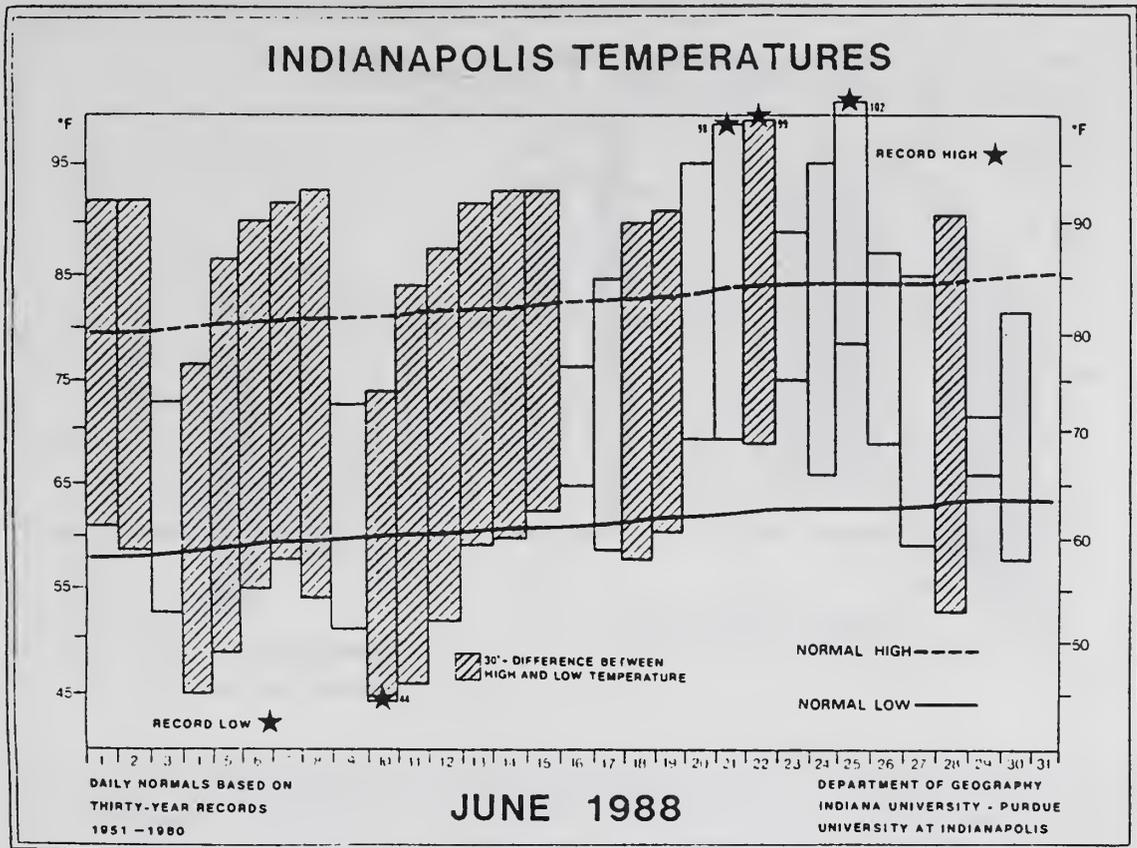


FIGURE 2. Climatic conditions for June 1988 (see Fig. 1 for explanation).

ships between the persistent weather pattern and associated parameters and the ensuing severe drought and widespread day-night variations in temperature. The recurrent conditions which characterized the drought period will be compared with climatic normals (1951-1980) and to values from the preceding two years (1986-1987) from May, June, and the first 10 days in July.

METHODS

Daily maximum and minimum temperatures, along with related weather conditions, were obtained from the National Weather Service forecast office at the Indianapolis airport. For comparative purposes, records from May, June, and early July 1986 and 1987 were used in addition to the current year (National Oceanic and Atmospheric Administration National Climatic Data Center, 1986, 1987, 1988). Climatic normals of temperature and precipitation for the same period are based on 30-year records from 1951-1980 (National Oceanic and Atmospheric Administration National Climatic Data Center, 1982).

Daily temperature ranges were determined from daily maximum and minimum values recorded in May, June, and the first 10 days in July. Cumulative totals and monthly averages were calculated for 1986, 1987, and 1988; the results were compared between years as well as to climatic normals. The data were also examined in relationship to associated weather conditions, such as average daily maximum and minimum temperatures, average monthly dew point, monthly precipitation, and percent possible sunshine.

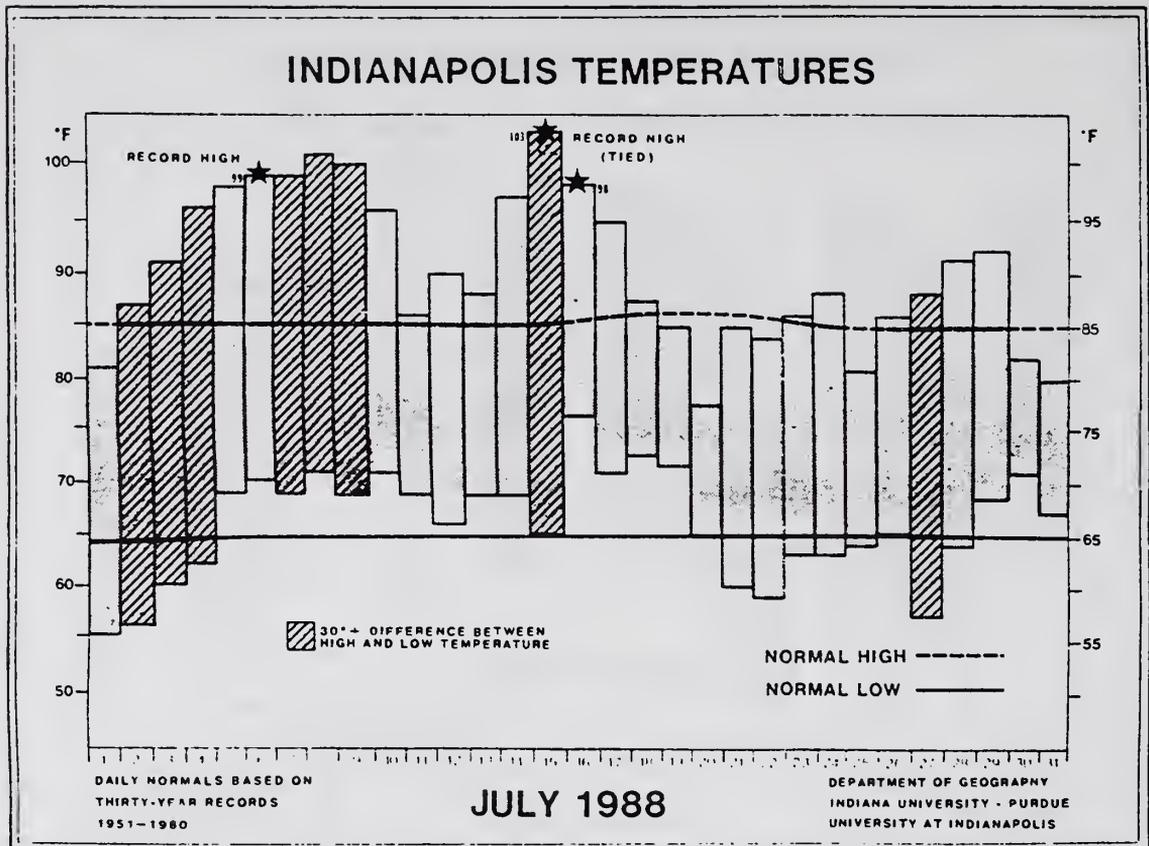


FIGURE 3. Climatic conditions for July 1988 (see Fig. 1 for explanation).

TABLE 1. Indianapolis weather conditions for May.

	May 1988	May 1987	May 1986	Normal
Average Daily Maximum	78.1°F	80.4°F	72.9°F	73.4°F
Average Daily Minimum	50.6	55.8	54.0	51.5
Average Daily Mean	64.4	68.1	63.5	62.5
departure from normal	+1.9	+5.6	+1.0	—
Average Daily Range	27.5	24.5	18.9	21.9
departure from normal	+5.6	+2.6	-3.0	—
Average Dew Point	46.0	53.9	53.6	—
Monthly Precipitation	1.06"	1.77"	7.37"	3.66"
departure from normal	-2.60"	-1.89"	+3.71"	—
Percent Possible Sunshine	73%	74%	56%	60%
clear days	12	11	5	7
partly cloudy days	11	12	5	9
cloudy days	8	8	21	15

RESULTS

Daily temperature range. Daily maximum and minimum temperatures recorded at the Indianapolis airport are shown for May, June, and July 1988

TABLE 2. Indianapolis weather conditions for June.

	June 1988	June 1987	June 1986	Normal
Average Daily Maximum	87.6°F	84.8°F	82.6°F	82.3°F
Average Daily Minimum	59.2	62.5	63.0	60.9
Average Daily Mean	73.4	73.7	72.8	71.6
departure from normal	+1.8	+2.1	+1.2	—
Average Daily Range	28.4	22.3	19.6	21.4
departure from normal	+7.0	+0.9	-1.8	—
Average Dew Point	50.7	61.8	62.5	—
Monthly Precipitation	0.36"	4.11"	3.58"	3.99"
departure from normal	-3.63"	-0.12"	+0.41"	—
Percent Possible Sunshine	81%	65%	62%	66%
clear days	14	10	6	7
partly cloudy days	12	4	8	11
cloudy days	4	16	16	12

(Figures 1-3). The widespread difference between daily high and low temperatures is immediately evident. The remarkable consistency of the graphs is indicative of the persistent weather pattern which produced both the extremely dry weather and the unusually large daily ranges of temperature. Days on which the daily range was 30.0°F (16.7°C) or higher are shaded on the graphs. There were 12 days in May with a range of 30.0°F (16.7°C) or more, with a maximum 38.0°F (21.1°C) range recorded on the 26th (Figure 1). More than half the days in June (17) experienced ranges of 30.0°F (16.7°C) or above, including a maximum difference of 39.0°F (21.7°C) on the 8th (Figure 2). The two days in June having the lowest daily ranges, 11.9°F (6.1°C) on the 16th and 6.0°F (3.3°C) on the 29th, were the two cloudiest days in the month, and two of the four days which received small amounts of rain. Only eight days in July recorded daily ranges of 30.0°F (16.7°C) or above, but six of these came during the first 10 days of the month (Figure 3). An abrupt change to a cloudy, humid, rainy weather regime occurred on July 10, which greatly reduced the diurnal ranges of temperature for the rest of the month. The onset of the new pattern is clearly depicted on the graph.

In May, the average daily range of 27.5°F (15.3°C) was 5.6°F (3.1°C) above normal, 25% greater than average. Daily ranges in June increased 33% from normal, averaging 28.4°F (15.8°C) or 7.0°F (3.9°C) above the norm. For the first part of July, a 46% increase above the normal daily range occurred in the 10-day period; the average diurnal spread was 9.3°F (5.2°C) higher than expected.

Five of the ten weeks from May 1 to July 9 experienced daily ranges in temperature which averaged more than 28.8°F (16.0°C), including the week of June 5-11, when the average daily range reached 33.9°F (18.8°C), and July 3-9 with a 30.6°F (17.0°C) average (data not shown). Over a three-week stretch from May 29 through June 18, the average daily temperature range exceeded 30.0°F (16.7°C) in each week (Figures 1 and 2).

Comparative weather conditions for May. The highest average daily range was in May 1988, 5.6°F (3.1°C) above the normal of 21.9°F (12.2°C). Daily

TABLE 3. Comparative conditions during July 1988.

	July 1988 all month	July 1-10 1st 10 days	July 11-31 last 21 days
Average Daily Maximum	90.5°F	94.8°F	88.5°F
Average Daily Minimum	66.1	65.2	66.5
Average Daily Mean	78.3	80.0	77.5
departure from normal	+ 3.2	+ 4.9	+ 2.4
Average Daily Range	24.4	29.6	22.0
departure from normal	+ 4.1	+ 9.3	- 1.7
Average Dew Point	62.5	54.0	66.5
Monthly Precipitation	4.71"	0.04"	4.67"
departure from normal	- 0.39"	- 1.38"	+ 1.77"
Percent Possible Sunshine	66%	80%	59%
clear days	10	4	6
partly cloudy days	9	4	5
cloudy days	12	2	10

maximum values were 4.7°F (2.6°C) **above** normal while daily minimum readings were actually 0.9°F (0.5°C) **below** normal (Table 1). The average daily range was 2.6°F (1.4°C) above average in May 1987, because maximum temperatures averaged 7.0°F (3.9°C) warmer than normal. Minimum temperatures were also much warmer than expected; the overall monthly mean was 5.6°F (3.1°C) above normal. By contrast, the average daily range in May 1986 was 3.0°F (1.7°C) below normal due to cool days and warm nights under a cloudy, humid, rainy weather pattern (Table 1).

Conditions for May 1986 indicate that the two most critical factors controlling the diurnal temperature range are cloud cover and the amount of moisture in the air. May 1986 received more than 7 inches (18 cm) of rain, 3.71 inches (9.42 cm) above normal, and only 56% of possible sunshine as cloudy skies prevailed on 21 days (Table 1). By comparison, May 1988 was characterized by limited amounts of both cloud cover and atmospheric moisture. The reduced cloudiness is indicated by above average insolation (73%) and a greater number of clear and partly cloudy days (23 out of 31). Lack of moisture is clearly shown by monthly rainfall which totaled 1.06 inches (2.69 cm), the sixth driest on record and 2.60 inches (6.60 cm) below normal. In many respects, weather parameters in May 1988 were similar to those from the preceding year, yet the average daily range of temperature was 3.0°F (1.7°C) higher as compared to 1987. The dew point, which indicates atmospheric moisture content, averaged only 46.0°F (7.8°C) in May 1988, almost 8.0°F (4.4°C) below the comparable value in 1987 (Table 1). Drier air masses dominated in May 1988, and this not only decreased rainfall totals below normal, but also greatly increased daily temperature ranges.

Comparative weather conditions for June. The contrast between 1988 and the two prior years is even more distinct in the June data (Table 2). Near normal conditions prevailed in June 1986 and 1987; June 1988 weather was clearly abnormal. The average daily range of 28.4°F (15.8°C) was 7.0°F (3.9°C) above normal. Daily maximum temperatures were 5.3°F (2.9°C) **above** normal, while

TABLE 4. Indianapolis weather conditions for July (first ten days of month only).

	July 1988	July 1987	July 1986	Normal
Average Daily Maximum	94.8°F	83.0°F	85.0°F	85.0°F
Average Daily Minimum	65.2	66.8	66.3	64.7
Average Daily Mean	80.0	74.9	75.7	74.9
departure from normal	+5.1	+0.0	+0.8	—
Average Daily Range	29.6	16.2	18.7	20.3
departure from normal	+9.3	-4.1	-1.6	—
Average Dew Point	54.0	68.7	66.1	—
Monthly Precipitation	0.04"	6.14"*	1.42"	1.42"
departure from normal	-1.38"	-4.72"	+0.00"	—
Percent Possible Sunshine	80%	41%	63%	67%
clear days	4	0	5	3
partly cloudy days	4	4	1	4
cloudy days	2	6	4	3

*5.09" on 1st.

daily minimums dropped 1.7°F (0.9°C) **below** normal. June was a very sunny month: only four days were classified as cloudy, while skies were clear on 14 days; the 81% of possible insolation was 15% above normal. The monthly rainfall totaled only 0.36 inches (0.91 cm), which made June 1988 the driest on record (dating back to 1871). The lack of rainfall was due to a lack of appreciable moisture in the air. The extremely low average dew point of 50.7°F (10.4°C) stands in stark contrast to average dew points greater than 60.0°F (15.6°C) in June 1986 and 1987, years of normal rainfall (Table 2).

July 1988 weather. The weather of July 1988 was distinguished by extremely high daytime temperatures (Table 3). On 16 days, daily highs reached 90.0°F (32.2°C) or higher, exceeding 100.0°F (37.8°C) three times. The record-tying 103.0°F (39.4°C) temperature, which occurred on July 15, was the hottest temperature in Indianapolis since 1936.

The weather of July 1988 was divided into two distinct but opposite patterns. The drought pattern and abnormal conditions of May and June continued through the first 10 days of the month. A complete transition then returned weather patterns to more normal conditions over the last three weeks of July. Between July 1 and 10, both daily maximum temperatures and daily ranges of temperature were more than 9.0°F (5.0°C) above normal (Table 3), and clear skies, dry air, and negligible rainfall continued to prevail. Insolation was high (80% possible sunshine), and average dew points were low (54.0°F or 12.2°C). The only rainfall in the 10 days fell on July 10 at the onset of a wetter regime and the end of the drought pattern.

Daily temperatures remained 2.0-3.0°F (1.1-1.7°C) above normal for the rest of the month, but the average daily range dropped to 22.0°F (12.2°C) (Table 3). Cloudy skies occurred on 10 days (of 21) and reduced insolation to 59% of possible and slightly below the norm. Over the three-week period, 4.67 inches (11.86 cm) in rainfall were received, 1.77 inches (4.50 cm) above average. Dew points rose

to near 70.0°F (21.1°C), reflecting higher moisture in the air, which not only contributed to greatly increased precipitation but to lower daily temperature ranges as well. Conditions from July 11-31 were much closer to normal.

Comparative weather conditions, first 10 days of July. Only the first 10 days of July were analyzed in comparing weather conditions in 1988 to the two preceding years and to normal values over the 10-day period. Daily maximum temperatures averaged 94.8°F (34.9°C) between July 1 and 10, 1988, 9.8°F (5.4°C) above normal, causing daily ranges to average 9.3°F (5.2°C) above normal (Table 4). In both 1986 and 1987, diurnal ranges were below normal over the same period, as minimum temperatures remained warmer than average overnight. The main factors which resulted in the extreme daily temperature ranges during the first part of July 1988 were limited atmospheric moisture content and lack of cloud cover. The average dew point for the first 10 days of the month was only 54.0°F (12.2°C), and rainfall was negligible. The predominant clear skies and dry air allowed maximum daytime heating, pushing daily highs above 90.0°F (32.2°C) on eight days and producing the anomalously high temperature ranges.

In contrast, the same period in July 1987 was very wet, as rainfall was well above normal with 6.14 inches (15.60 cm) for the month and a record 5.09 inches (12.93 cm) on July 1. The high dew point (68.7°F or 20.4°C) reflects the large amount of moisture in the air (Table 4). Cloud cover shows a similar distinction between the two years: the 10-day period in July 1988 received 80% possible insolation with only two cloudy days as compared to only 41% possible insolation and six cloudy days through the same period in the preceding year. The cloudy, humid, wet regime in 1987 limited the diurnal temperature range to only 16.2°F (9.0°C), a departure of 4.1°F (2.3°C) below normal over the first 10 days of the month. Weather conditions between July 1 and 10, 1986 were normal in most respects (Table 4), in sharp contrast to those in either 1987 or 1988.

CONCLUSION

The early summer of 1988 in Indianapolis, Indiana was characterized by an extended period of hot, dry weather. Once established, the pattern persisted into early July. Widespread drought ensued, as skies remained cloud-free and little rainfall occurred. The recurring clear skies and dry air responsible for the drought also favored large daily temperature ranges. Days were sunny and hot, with daytime heating at a maximum and high temperatures climbing well above normal. On the other hand, nights were cool and clear, and minimum temperatures dropped below normal as cloudless skies facilitated rapid radiational cooling. From May through July 10, diurnal ranges in temperature averaged more than 28.0°F (15.6°C), an increase of 31% above normal.

Throughout the period, a stationary ridge of high pressure suppressed the development of clouds and rainfall. Cloud cover and moisture content are the two most important factors controlling the diurnal range of temperature, so the absence of clouds and limited supply of moisture greatly increased daily temperature ranges. The percent of possible sunshine was 14% above average during the early summer, with less than half the normal number of cloudy days. The dryness of the air was clearly indicated by low dew point temperatures around 50.0°F (10.0°C), in sharp contrast to average dew points in the preceding two years. Rainfall between April 23 and July 9 measured only 1.53 inches (3.89 cm), 15.9% of the rain expected in Indianapolis during that period. Total rainfall was 29% of

normal in May, only 9% of normal in June, and just 3% of normal over the first 10 days of July. June was the driest on record dating back to 1871.

The persistent combination of clear skies, dry air, and minimal rainfall that prevailed during the early summer 1988 produced unusually large daily ranges in temperature in Indianapolis, Indiana. In comparison to earlier years and to climatic normals, the weather conditions experienced in May, June, and early July 1988 represent a climatic anomaly which departed significantly from normal.

Given the recent occurrence of a severe drought in early summer 1988, the present paper is a descriptive analysis of both the anomalous conditions associated with the hot, dry weather and accompanying unusually large daily ranges in temperature. This analysis raises several questions for further research: how abnormal were the high daily temperature ranges experienced in Indianapolis, Indiana during the past summer; what significant correlations exist between daily range and moisture (rainfall, dew point temperature) or cloud cover (number of cloudy days, percent of possible sunshine); what is the estimated return period for the occurrence of extreme events such as severe drought or abnormal daily temperature ranges?

Another set of questions broadens the geographic scope of the research. As noted previously, the drought was characterized by widespread areal coverage. How extensive an area was affected by extreme high daily temperature ranges? How do abnormal temperature values in Indianapolis compare with normal conditions at steppe and desert climatic locations to the west across the Plains? What regional patterns were displayed by the temperature anomalies produced by the persistent hot, dry weather of early summer 1988? Work is already in progress to compile data from a number of stations throughout the drought-afflicted region and to review applicable literature for comparative purposes in examining the abnormal temperature and rainfall conditions in historical perspective.

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