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Changes in the Frequency of Extreme Warm-Season Surface Dewpoints in Northeastern Illinois: Implications for Cooling-System Design and Operation

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ABSTRACT

Warm-season (1 May–30 September) hourly dewpoint data were examined for temporal changes at two weather stations in northeastern Illinois during a 42-yr period (1959–2000). This area has dense population (greater than 8 million), and shifts to more or less atmospheric moisture have major implications on cooling demands. The 42-yr period was analyzed as two separate arbitrarily chosen equally sized periods, the early (1959–79) and the later (1980–2000) periods. Analyses of data from Chicago's O'Hare International Airport and the Greater Rockford Airport showed a statistically significant increase in the number of hours with dewpoints greater than or equal to 24°C (an important cooling-plant threshold) in the latter period. Examination of heat-wave periods indicated that later (especially 1995 and after) heat waves contained many more extreme dewpoint values. These increases in extreme dewpoint characteristics in northeastern Illinois affect the operation of, and suggest shifts in design criteria for, air-conditioning systems and affect summer peak electrical loads.

1. Introduction

A July 1995 heat wave caught Chicago, Illinois, officials off guard and was blamed for over 500 deaths (Centers for Disease Control and Prevention 1995). Kunkel et al. (1996) determined that the extreme heat event was the most intense heat wave of the latter half of the twentieth century and concluded that it was the result of unusually high dewpoint values. Of importance was that analyses indicated that the highest observed dewpoint values occurred in the upper Midwest, suggesting they were generated regionally in association with high soil-moisture levels, not advected from the Gulf of Mexico into the region (Kunkel et al. 1996). More recent, in July of 1999, a similar heat wave with high dewpoints occurred in the Midwest (Palecki et al. 2001). These high dewpoint values came from heavy antecedent precipitation in and west of the Midwest.

Those who manage air-conditioning systems on the campus of Northern Illinois University (NIU) sought dewpoint frequency, duration, and intensity information as they recently addressed two issues: 1) Were cooling systems put in place in the 1960s not working as efficiently because climate had changed (especially during these recent ''hot'' summers)? 2) As new cooling systems are acquired for the campus, what extreme weather conditions should these systems be designed to accommodate (M. Saari 2001, personal communication; King 2001)? Their concerns related to a perceived increase in the number of hours/days with extreme dewpoints in northeastern Illinois. The existing cooling systems continually pump chilled water into a system in which evaporative cooling occurs and air temperatures are reduced. However, when atmospheric dewpoints exceed 20°C, the cooling efficiency of these systems begins to decrease (M. Saari 2001, personal communication). When dewpoints exceed 24°C, the cooling systems struggle to keep indoor air temperatures at moderate levels (~27°C). To cool air in these situations, the cooling plant uses significantly more electricity to cool down the water that flows through the system. Because most air-conditioning systems in northeastern Illinois, a region of 8 million people and extensive commercial and industrial activities, were designed in a manner similar to those put in place in the 1960s at NIU, economic impacts related to increases in extreme dewpoints could be significant to the region, according to M. Saari (2001, personal communication). The high dewpoint concerns posed by these users are held by others across the United States (Cohen and Kosar 2000).

A number of studies have examined temporal changes in surface dewpoints across the United States over the past half century. Recent research (Knappenberger et al. 1996; Ross and Elliott 1996; Elliott and Angell 1997;

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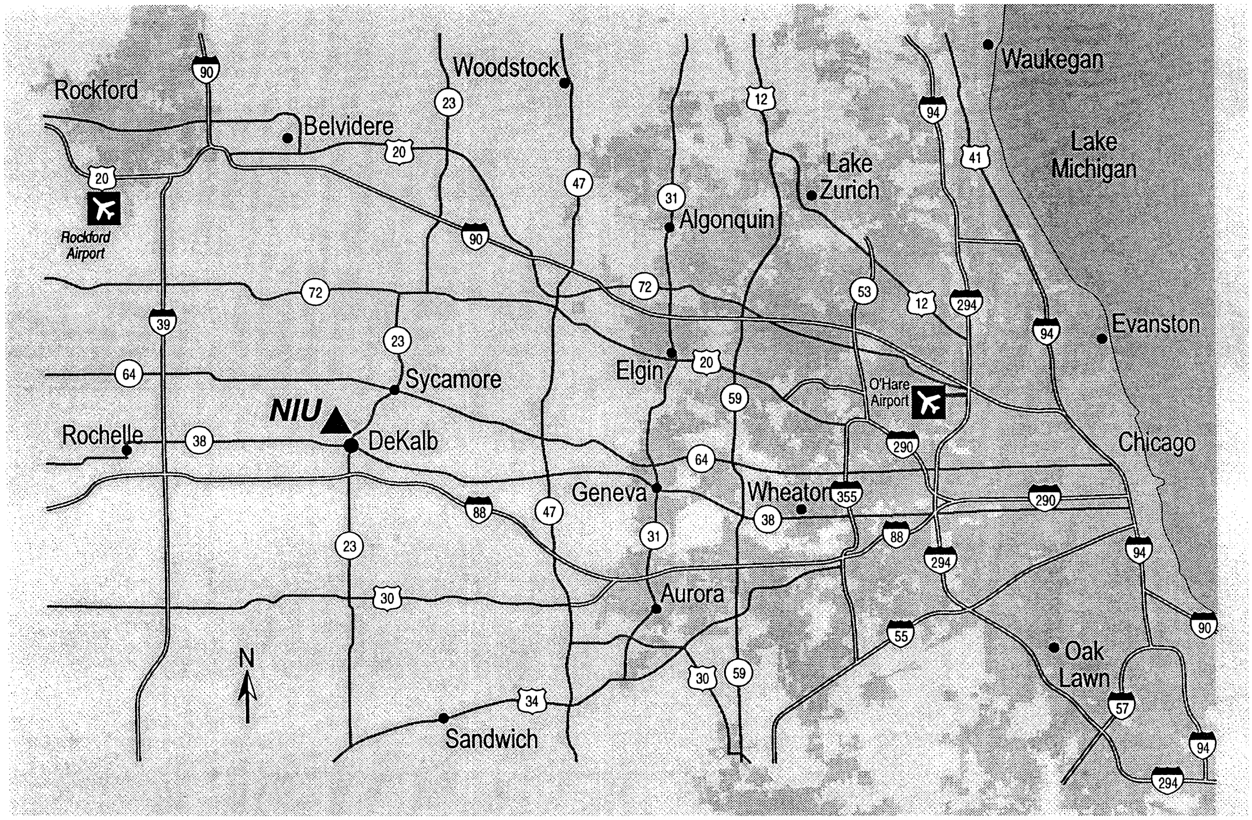

FIG. 1. Map of northern Illinois region: relative location of RFD and ORD first-order weather stations in relation to NIU (DeKalb, IL).

Gaffen and Ross 1998, 1999; Robinson 1998, 2000; Schwartzman et al. 1998) generally indicated (depending on period-of-record used) that summer surface and upper-atmospheric water vapor amounts had increased over the Midwest and other regions of North America since about 1960. Robinson (2000) showed that, for the 1961–90 period, average summer dewpoint values in the United States increased by approximately 1°–2°C $(100\ \mathrm{yr})^{-1}$ and in the areas west of the Great Lakes by as much as 6°C $(100\ \mathrm{yr})^{-1}$. A study by Ross and Elliott (1996) identified that, during a 21-yr period (1973–93), North American dewpoint temperature trends (increases) were greater than air temperature trends and that increases in summer precipitable water were found in the central and eastern United States. Regional coherence in the changes in surface dewpoint levels (Schwartzman et al. 1998; Robinson 2000) and apparent temperature (Steadman 1984; Gaffen and Ross 1998) suggested that urban influences are a minor factor because many data points are not in or near urban areas. Furthermore, Robinson (1998) found that, when comparing the records for two nearby stations, dewpoint characteristics appeared to be related to regional rather than local moisture sources.

This study assessed the frequency and duration of high dewpoint temperatures (greater than or equal to 24°C) to ascertain whether values had shifted since 1959 (when data began for Chicago's O'Hare International Airport). For high dewpoint temperature characteristics, how do recent heat waves compare with others in the climate record? Understanding temporal changes in the high dewpoint values, especially as they relate to extreme multiday events, may be important to decision makers, such as cooling-plant managers, who are impacted by them. Examination of extreme dewpoint characteristics from two stations, Chicago's O'Hare International Airport and the Greater Rockford Airport, were assessed to determine whether these two northeastern Illinois sites experienced similar temporal changes.

2. Data and methodology

Hourly dewpoint data for the two first-order weather stations, Chicago O'Hare (ORD) and Rockford (RFD), were obtained from the Midwestern Regional Climate Center for the 1959–2000 period. These two stations were chosen because of the availability of quality data and their location relative to the NIU campus in DeKalb, Illinois (Fig. 1). The data period started in 1959 when O'Hare International Airport opened and hourly dewpoint observations began. Prior to 1959, Chicago dewpoint observations were taken inside the urban area (Midway Airport), which represents a different local climate than O'Hare. Because of the interest in extreme

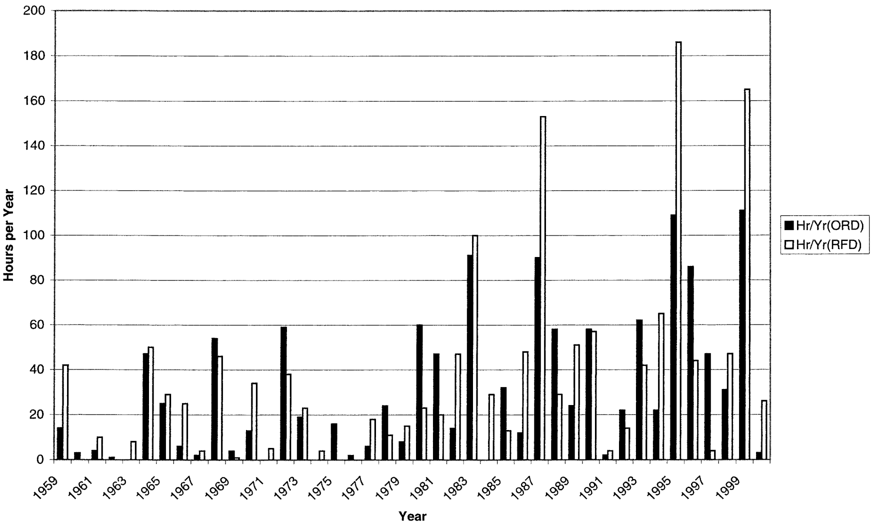

FIG. 2. The total number of hours per year with a dewpoint of 24°C or higher at ORD and RFD for 1959–2000.

dewpoint characteristics, only the warm season (May–September) dewpoint observations were assessed. Discussions with the NIU cooling-plant manager indicated that a dewpoint temperature of 24°C was the critical level at which cooling efficiency decreased dramatically (M. Saari 2001, personal communication).

Digital records of hourly dewpoint observations were available at Chicago O'Hare for all years except for two periods, 1965–67 and 1969–72, when only every third hourly value (eight per day) was available. At Rockford, the periods when only eight observations per day were available included 1965–72 and 1978–81 (Horton et al. 2000). Because airmass dewpoint characteristics are generally stable over short periods (a few hours) and the focus of this research was on identifying extreme high hourly dewpoints (greater than or equal to 24°C), values between the 3-hourly spaced values were interpolated. Both hourly observations within a 3-h interval that began and ended with a dewpoint of 24°C or greater were counted as hours greater than or equal to 24°C. For example, on 17 June 1970, the 0900 LST dewpoint value was 24°C at O'Hare, and 3 h later at 1200 LST the dewpoint value was 26°C. The 1000 and 1100 LST dewpoints were assumed to be at or above 24°C. In cases in which the 3-h interval began with or ended with a dewpoint greater than or equal to 24°C and the other end of the 3-h interval had a dewpoint less than 24°C, only one of two nondigitized hours in the interval was counted as an extreme dewpoint. Excluding those nondigitized observations (described above), the number of missing observations at the two sites was less than 0.1% of the total warm-season observations.

There have been changes to the instruments used to measure dewpoint during the 42-yr period. As described in Elliott (1995), Gaffen and Ross (1999), and Robinson (2000), instruments used included sling psychrometers (up through the early 1960s), lithium chloride hygrothermometers (the early 1960s through the mid-1980s), and the hygrothermometer model HO-83 (the mid-1980s through the mid-1990s). A modified HO-83, associated with the implementation of the Automated Surface Observing System, was placed in use at these two stations in the mid-1990s (Gaffen and Ross 1999; Robinson 2000). Their research indicated that these equipment changes were not associated with detectable changes in the dewpoint characteristics over the period from 1961–95 at first-order stations. A number-of-runs test (Burt and Barber 1996), used to test for data homogeneity, was also performed. This test involves determining the median value of the dewpoint data and assigning each observation either a plus (above the median) or a minus (below the median). The number of runs (defined as unbroken series of plus or minus signs) throughout the period tests homogeneity using a normal sampling distribution of runs with the acceptance range given by the 5% and 95% values in the distribution. The test showed no indication of abrupt changes at the time of instrument changes at either station. Robinson (2000) compared dewpoint measurements from the National Weather Service (NWS) to those of nearby naval air stations (NAS) and determined that data trends at both stations could not be traced back to instrumentation changes. Robinson (2000) compared accumulated differences between NWS sites and nearby NAS sites in four locations. Upon thorough comparisons of these paired records for 40 yr of data, he concluded that uncertainties in dewpoint measurement, which could amount to ± 1°C, are present because of instrument changes but that 1) changes in trends at the time of instrument changes did not always occur, 2) trend changes at NWS stations also occurred during periods when the equipment changes did not occur, and 3) the impact of equipment changes that oc-

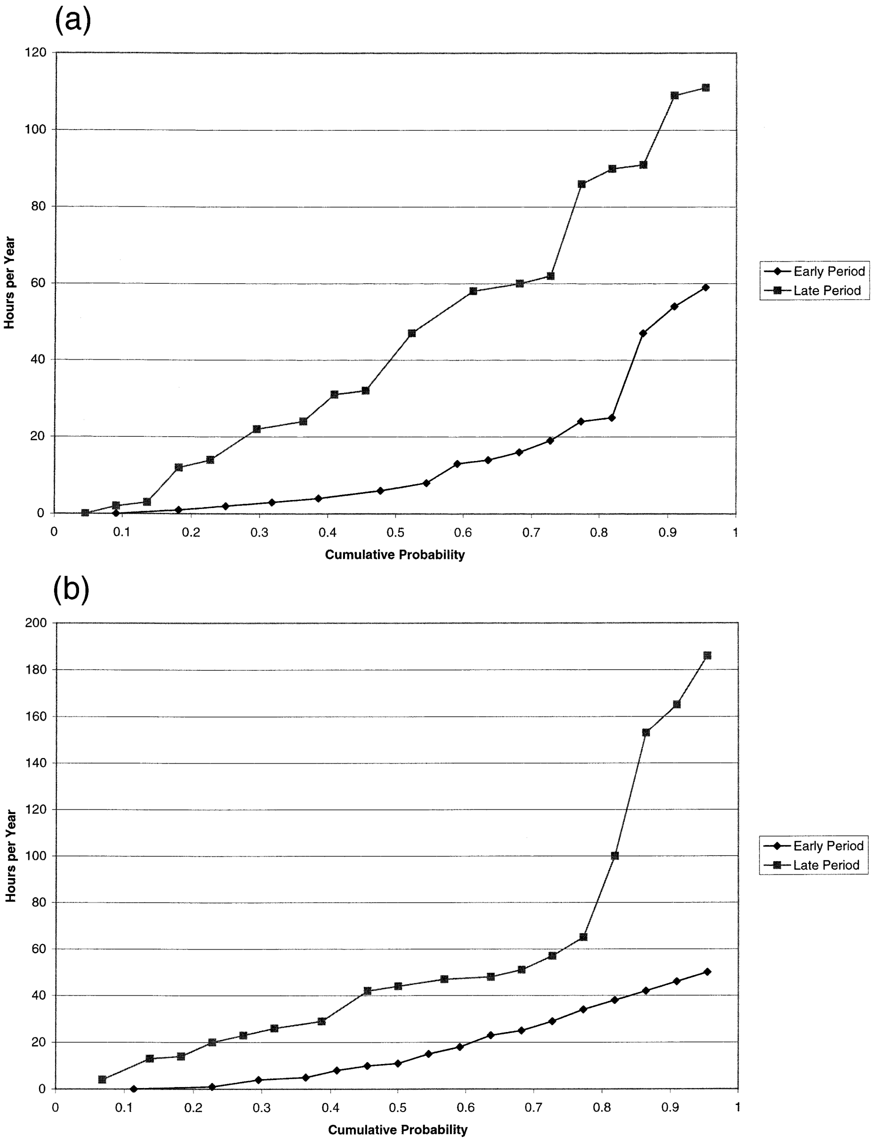

FIG. 3. The early (1959–79) and late (1980–2000) period ogives showing the total hours per year with extreme dewpoints at (a) ORD and (b) RFD.

curred at the NAS was hard to identify. Because there was no clear evidence of a substantial change in dewpoint characteristics over time due to instrument changes, the original published hourly dewpoint values were not altered in this study.

Nonparametric statistical tools were used to describe changes in the frequency of extreme dewpoints (i.e., those hours when dewpoint exceeded 24°C). These tools are generally considered to be more robust and are less affected by the presence of outliers or issues of nonnormality (Hoaglin et al. 1983; Siegal and Castellan 1988; Lanzante 1996). Two methods were chosen to examine temporal changes in the extreme dewpoint characteristics. The first focused on examining four characteristics of extreme dewpoints that were of interest to the NIU cooling-plant manager: 1) the number of hourly dewpoint values that exceed 24°C each year, 2) the average number of hours per day when an hourly observation of dewpoint greater than or equal to 24°C was reported, 3) the number of days each year with at least one hourly observation of dewpoint greater than or equal to 24°C and, 4) the number of days when 12 or more hours (out of 24) experienced a value of 24°C or higher. To assess temporal change over the 42-yr period, two equal-sized periods were chosen arbitrarily to be examined: the early (1959–79) and late (1980–2000) periods. Cumulative probability curves (or ogives) were developed, and medians of these measures were compared using the robust rank-order distributional test for location (Lanzante 1996). This test for

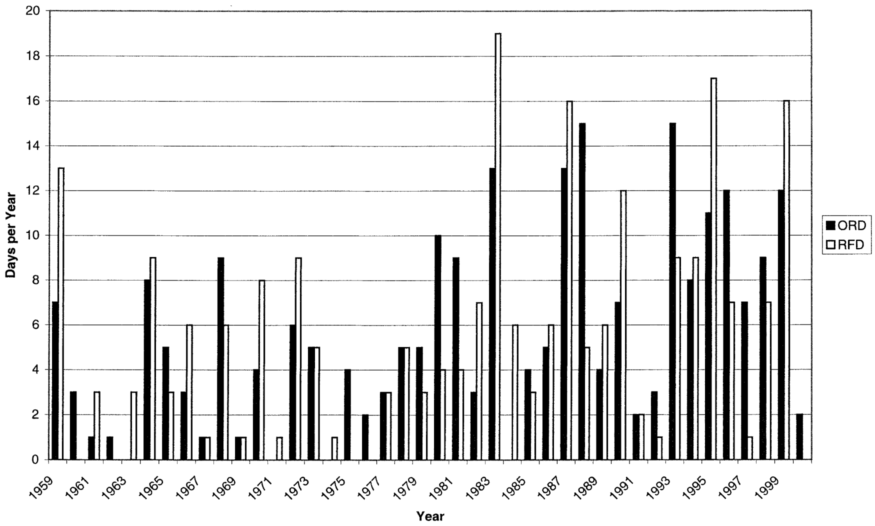

FIG. 4. The total number of days per year with at least one hour of dewpoint of 24°C or higher at ORD and RFD for 1959–2000.

equality of medians is similar to the Wilcoxon–Mann–Whitney test; however, the rank-order test does not assume that the variance of the parent populations is the same (Siegel and Castellan 1988). The second method examined heat-wave events during the 42-yr period. Heat-wave events in this study were defined as periods during which the minimum air temperature at O'Hare remained greater than or equal to 24°C for three or more consecutive days. Earlier studies by Kalkstein and Davis (1989) and Kunkel et al. (1996) indicated that a heat wave, one that had significant impacts on the economy and the health of individuals, was characterized by consecutive days with high minimum temperatures. Furthermore, 24°C was chosen as the threshold value because minimum temperatures and dewpoint temperatures are generally related.

3. Results

a. Extreme dewpoint characteristics

The annual numbers of warm-season hours that experienced extreme dewpoints for Chicago O'Hare and Rockford are shown in Fig. 2. A general increase is observed at both stations, especially to higher values in the latter 15–20 yr. The shift at RFD was much greater, especially during the extreme years when 100 or more hours of extreme dewpoint occur (1983, 1987, 1995, and 1999). When comparing the early period (1959–79) with the later period (1980–2000), the median values increased from 6 to 47 h yr^{-1} at ORD and from 11 to 44 h yr^{-1} at RFD. Both increases were found to be significant at the $P < 0.0001$ level. Evaluations of individual years during the 42-yr period showed no evidence that one station always had more extreme dewpoints than the other. Each ogive (with reversed axes to show early vs later differences) demonstrated how the entire distribution had shifted to higher values in the later period at both stations (Figs. 3a,b). Impressive differences existed at cumulative probabilities greater than 0.80 on each graph, suggesting that the number of extreme dewpoint hours experienced had increased dramatically in the recent period, especially during extreme summers.

The number of days each year on which one or more hours of extreme dewpoint were recorded represents another way to characterize the extreme dewpoint behavior (Fig. 4). The median number of days per year with at least one hour of extreme dewpoint increased over time from 3 to 8 days yr^{-1} at ORD and from 3 to 6 days yr^{-1} at RFD (both increases statistically significant at the $P = 0.005$ level). The ogives once again demonstrate how the whole distribution had shifted (increased) from the early to the late period (Figs. 5a,b).

The increased severity of heat events was represented well in the rising number of hours per day with dewpoint greater than or equal to 24°C (Fig. 6). During the early period at ORD, 11 of the 21 yr experienced an average of two or fewer hours per day for which a dewpoint of 24°C was achieved, whereas in the most recent 21 yr, only 3 yr experienced an average of two or fewer hours per day. On average, six or more hours were experienced for 2 yr during the early period versus 11 yr in the later period. Similar results are found at RFD. Overall, the median value significantly increased from 2 to 6 h day^{-1} ($P < 0.0001$) at ORD and from 4 to 5.8 at RFD ($P = 0.005$).

The NIU cooling-plant manager indicated that when the number of hours with extreme dewpoints exceeded 12 on any given day the demands on the systems were excessive and much more electricity was required (M. Saari 2001, personal communication). Figure 7 shows that the number of years with days experiencing 12 or

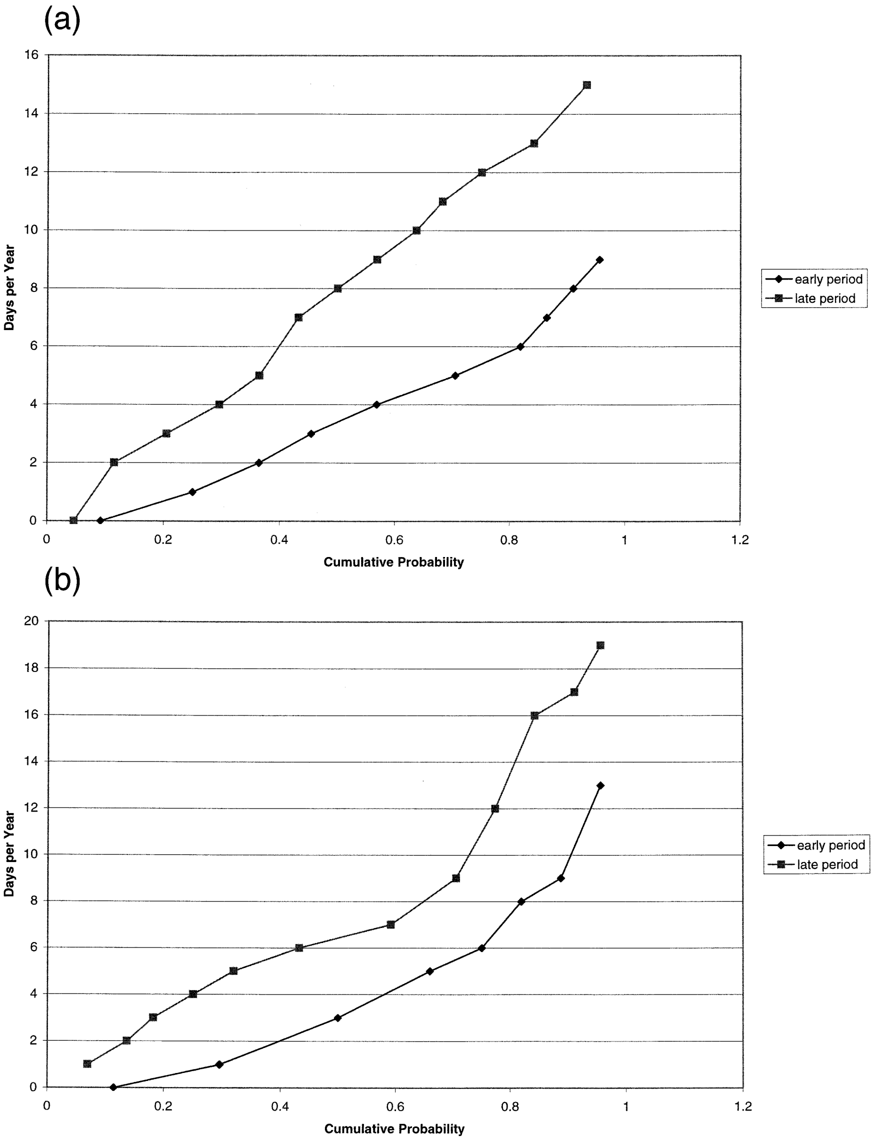

FIG. 5. The early (1959–79) and late (1980–2000) period ogives showing the total number of days per year with at least one hour of extreme dewpoint at (a) ORD and (b) RFD.

more hours with extreme dewpoints has increased since 1980. During the early period (1959–79), most years experienced no such days, whereas after 1979 most years have experienced at least one of these days. At RFD, there was 1 yr in the early period with two or more days, whereas in the late period the number of years was 9. In a similar way, at ORD the number of years with two or more days with 12 or more hours of extreme dewpoints increased from 2 to 8.

b. *High-heat events*

High-heat events during the 42-yr period were assessed to determine whether the number and frequency of extreme dewpoints had changed in these events over time. In this study, high-heat events were defined as occurring when the minimum air temperature at ORD remained at or above 24°C for three or more consecutive days. Ten high-heat events were identified for ORD using this threshold, and dewpoint characteristics associated with these events were characterized for RFD and ORD (Table 1). Of interest, the number of events was equal in each period. However, the dewpoint characteristics associated with these events were very different. Comparison of values in the early (1959–79) versus later (1980–2000) periods revealed the median number of hours experiencing extreme dewpoints during an event more than doubled at ORD (from 14 to 30) and increased by more than 4 times (from 9 to 41) at RFD. Similar findings were found for the average number of

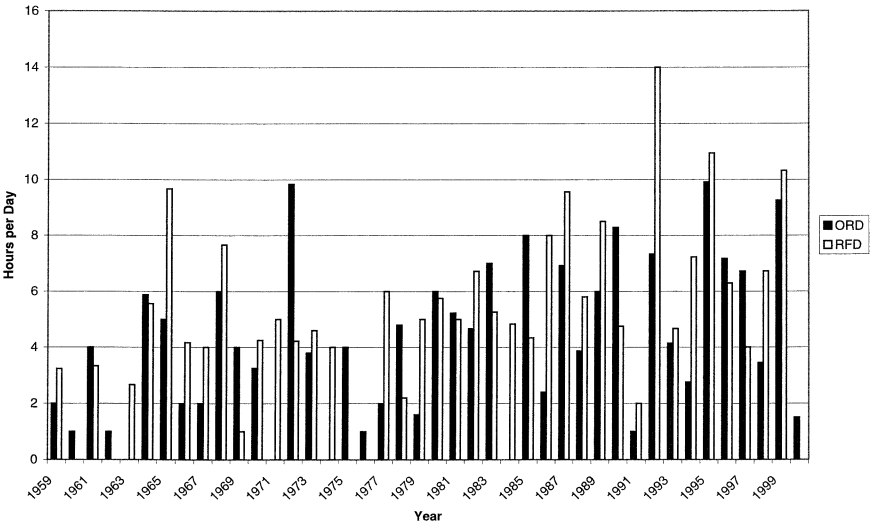

FIG. 6. The total hours per day with dewpoint of 24°C or higher at ORD and RFD for 1959–2000. These values were found by dividing the total number of hours per year with a dewpoint of 24°C or greater by the total number of days per year with at least one hour of dewpoint 24°C or greater.

extreme dewpoint hours per day. Because both stations experienced considerable increases since 1980 in extreme dewpoint characteristics associated with high-heat events, these results combined with those of the previous section further indicate that, despite their local land-use differences (suburban vs rural), a regional source of atmospheric water vapor is an important factor for explaining the increased frequency of extreme dewpoints.

4. Discussion and conclusions

Hourly dewpoint data were examined for northern Illinois in an effort to determine whether the frequency, duration, and/or intensity of extreme dewpoints (a dewpoint $\geq$ 24°C) had changed over time. This study was undertaken because of concerns raised about air-conditioning operations in this heavily populated area.

When comparing the 1980–2000 period to that of 1959–79, assessment of dewpoint characteristics at both stations indicated that there were significant increases in the number of hours per warm season, number of days, and number of hours per day when extreme dewpoints occurred. Dewpoint characteristics also greatly increased during high-heat events that have occurred since 1980 (especially in the mid- to late 1990s). Gaffen and Ross (1998) found similar trends when examining

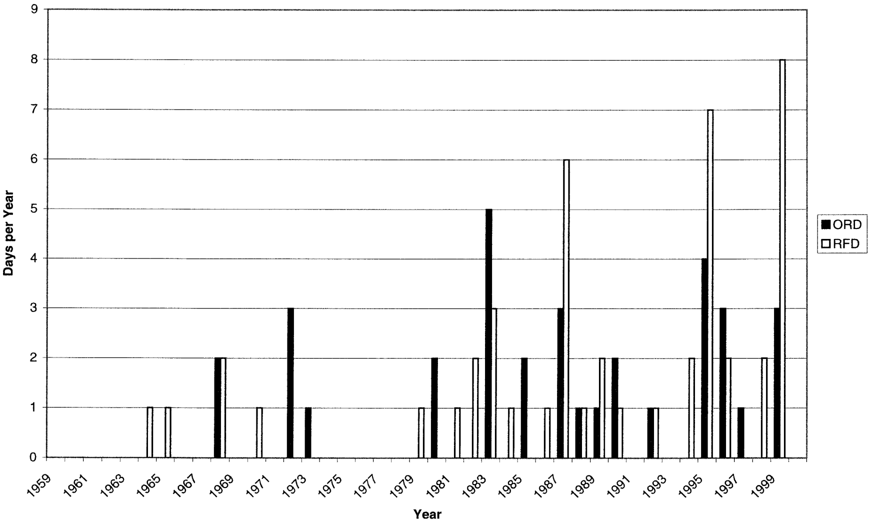

FIG. 7. The total number of days per year with 12 or more hours of dewpoint 24°C or higher for ORD and RFD.

TABLE 1. Dewpoint (Td) characteristics for high-heat events.

Date	No. of days in event	Hours Td ≥ 24°C (ORD)	Avg No. of hours/day (ORD)	Hours Td ≥ 24°C (RFD)	Avg No. of hours/day (RFD)
22–24 Aug 1968	3	14	4.67	9	3.0
30 Jun–2 Jul 1970	3	9	3.0	17	5.67
21–24 Jul 1972	4	27	6.75	9	2.25
26–28 Aug 1973	3	15	5.0	9	3.0
4–6 Jul 1977	3	5	1.67	12	4.0
2–5 Aug 1988	4	4	1.0	0	0
13–15 Aug 1988	3	22	7.33	21	7.0
13–15 Jul 1995	3	53	17.7	57	19.0
12–14 Aug 1995	3	30	10.0	48	16.0
3–5 Jul 1999	3	41	13.67	41	13.67

changes in extreme apparent temperatures and high-heat events in the central and eastern United States. Further research, with longer dewpoint datasets, is necessary to determine 1) whether multidecadal fluctuations in extreme dewpoint frequencies exist at other locations in the United States and 2) whether these shifts (if they do exist) can be explained. The increases in extreme dewpoint characteristics noted in this study have explained recent increases in operational problems experienced by NIU's air-conditioning systems and have been linked to increased electricity usage during the summer (M. Saari 2001, personal communication).

One of the major conclusions from these analyses is that the increase in extreme dewpoint values over the 42-yr period was similar at both stations and is probably primarily regional in nature. Robinson (1998, 2000) noted that increases in average summer dewpoints were due to regional, not local, changes in atmospheric water vapor levels. Both the 1995 and 1999 midwestern heat waves exhibited record or near-record levels of dewpoint across the northern Midwest (Kunkel et al. 1996; Palecki et al. 2001). These results can be used to revise cooling-system design criteria in northeastern Illinois.

Evidence provided in these studies indicated that already-high dewpoints were enhanced regionally through processes other than advection. Record dewpoints generally occurred in an area that overlies the major corn-growing areas of the United States from eastern Nebraska to Indiana. The temporal increases in total precipitation across the Midwest defined by Karl and Knight (1998) were considerably greater than increases in streamflows (Lettenmaier et al. 1994; Lins and Slack 1999). This fact reveals that there has been a regional increase in available moisture, reflected in higher soil-moisture values and higher atmospheric moisture and partly reflected in increases in cloud cover (Elliott and Angell 1997). Increased planting densities for corn and soybeans in the Midwest would facilitate greater evapotranspiration. Robinson (2000) suggested that increases in dewpoints experienced in summer may be partially related to increases in evaporation rates. Furthermore, increases in dewpoints have been found to be greater during the day than at night (Knappenberger et al. 1996; Schwartzman et al. 1998). Studies by Gaffen and Ross (1998, 1999) showed that extremes in both air temperature and humidity indices (e.g., apparent temperature) have increased since 1960, with humidity indicators increasing at a faster rate. A similar result was found for northeastern Illinois, as the number of extreme high-temperature days (number of daily maximum temperature greater than or equal to 35°C and number of daily minimum temperature greater than or equal to 24°C) per year increased from the early to later period (Hall et al. 2001) but at rates less than those found for extreme dewpoint characteristics. Overall, these studies point to higher levels of atmospheric moisture; however, it is difficult to isolate atmospheric changes (e.g., enhanced greenhouse effect) from land-use changes (e.g., urbanization, irrigation, farming practices) as a cause for the increases. Analysis of such ''speculation'' is beyond the scope of this paper. Further research is necessary, such as that described by Feddes et al. (2001).

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