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IS OUR INDIANA CLIMATE WARMING?

Robert F. Dale
Agronomy Department
Purdue University
West Lafayette, Indiana 47907

INTRODUCTION

This summer's severe drought spawned many news media accounts (e.g., *Newsweek*, July 11, 1988, and *Fortune*, July 4, 1988) of "record climatic warmth in the 1980s", and there were suggestions that this warming may be caused by an enhanced greenhouse effect. Note that the author has added the word "enhanced" to the greenhouse effect, because the media accounts led readers into believing that the atmospheric greenhouse effect was bad. On the contrary, it is what makes the earth habitable by reducing the temperature extremes from those which would occur without a protective atmosphere, such as the extremes which occur on the moon.

In introductory meteorology, the student is taught that the three major atmospheric greenhouse gases are carbon dioxide (CO_2), ozone (O_3), and water vapor (H_2O). The media have written about the increasing CO_2, chlorofluorocarbons, methane, and other trace gases but have ignored the most important variable greenhouse gas, water vapor. Briefly, these atmospheric gases allow the solar, or short wave, radiation to pass through the atmosphere with little absorption, but they absorb and reradiate the returning earth, or longwave, radiation. Thus, in the radiation balance, the atmosphere acts as if it were the glass on a greenhouse. There is no doubt that CO_2 and the other dry greenhouse gases are increasing, except possibly for O_3. Thus, it seems logical that as the greenhouse gases increase, the earth's air temperature should also increase. The atmosphere is a complex physical system, however, and temperatures over a portion of the northern hemisphere are not necessarily a reflection of the hemispheric radiation balance.

Reports on climatic warming have been based on two information sources: first, on estimates of historical, or current, climatic warming; and second, on projections of warming into the 21st century, using climatic models in which usually a doubling of the CO_2 content of the atmosphere has been assumed. In this paper, only the first information source will be discussed—historical temperature trends—recognizing that observed climatic trends are nearly always a mixture of large-scale natural and anthropogenic climatic effects and of local environmental effects (Lowry, 1977).

The principle media sources for the global warming have been Hansen and Lebedeff (1987), who reported the global annual mean temperature had increased + 0.5 to 0.7 deg C in the past century, and Jones, *et al.* (1986; Jones, 1988), who found the Northern Hemisphere annual mean temperature was 0.4 deg C warmer in the 1921-84 period than in the 1851-1920 period. Although the data base in these and other temperature trend studies is derived primarily from the Smithsonian, U.S. Weather Bureau, and U.S. Department of Commerce World Weather Records (WWR), slight differences occur in their temperature trend analyses. The

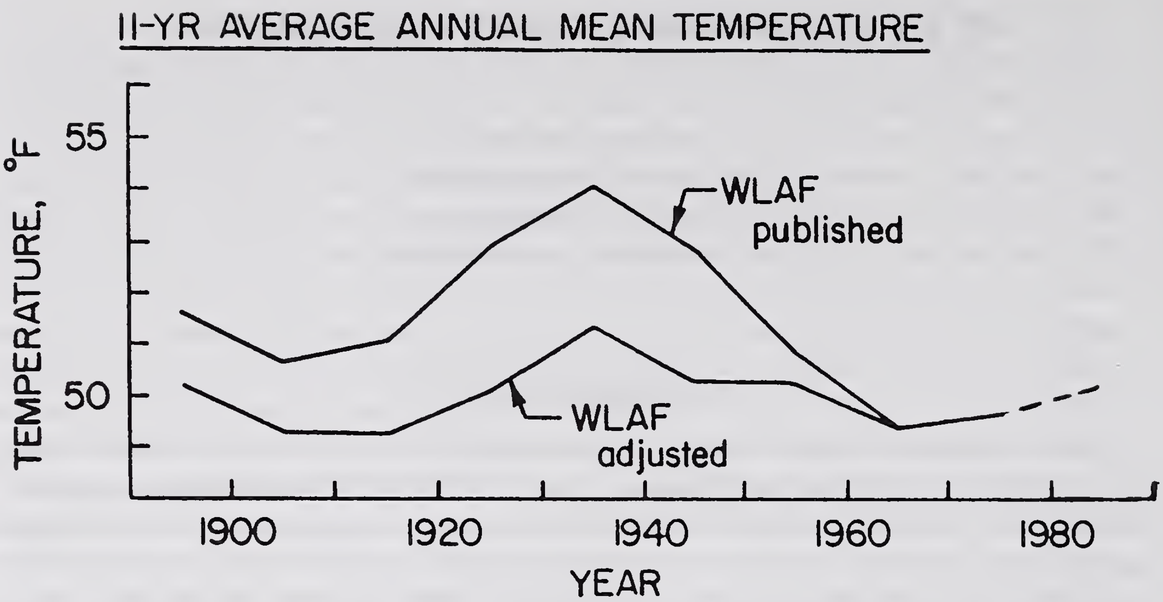

FIGURE 1. Mean annual temperature for indicated decade (11-yr average plotted at middle year), 1890-1990, adjusted to present location of West Lafayette 6NW Indiana (from Epperson and Dale, 1984).

differences result from different interpolation methods, reference periods, and considerations of "non-climatic" trends caused by changes in the observational network or the local environment. For example, an important bias in a hemispheric or global air temperature trend is caused by the growth of cities and attendant heat sources around most of the long-record WWR stations, producing what is commonly called the urban heat island effect (Landsberg, 1981; Kukla, *et al.* 1986). The WWR stations used to obtain a temperature average for a grid point in the Indiana area would be Cairo IL, Chicago IL, Cincinnati OH, Columbus OH, Madison WI, Nashville TN, St. Louis MO, Urbana IL, and Wooster OH. All of these cities have grown rapidly. These urban-influenced temperature records are carried into the grid point averages, which are used for determining the hemispheric and global temperature averages. Hansen and Lebedeff (1987) and Jones, *et al.* (1986) recognized this problem and tried to adjust for the urban effect. Karl and Jones (1989), using an enhanced U.S. Historical Climate Network (HCN), estimated the urban temperature bias in area-averaged surface air temperatures in the United States. They concluded that in the period 1901-1984 the urban-caused bias (+ 0.1 to 0.4 deg C) was larger than the overall U.S. temperature trend for the same period (+ 0.16 deg C/84 years). Unfortunately, there has not been a similar study of the effect of the urban bias in the hemispheric or global average temperature trends.

Rather than attempt to evaluate the urban temperature bias for all of the global weather stations, as Karl and Jones did for the U.S., the annual mean temperature from single homogeneous rural climatological stations in the middle to high latitudes can be used to monitor Northern Hemispheric warming (just as the Mauna Loa Observatory (CDIAC, 1988) has been used to monitor CO_2). There will be greater year-to-year variability in the annual mean temperatures from a single station than for the Northern Hemispheric temperature means, because regional anomalies tend to average out over the Northern Hemisphere. Jones

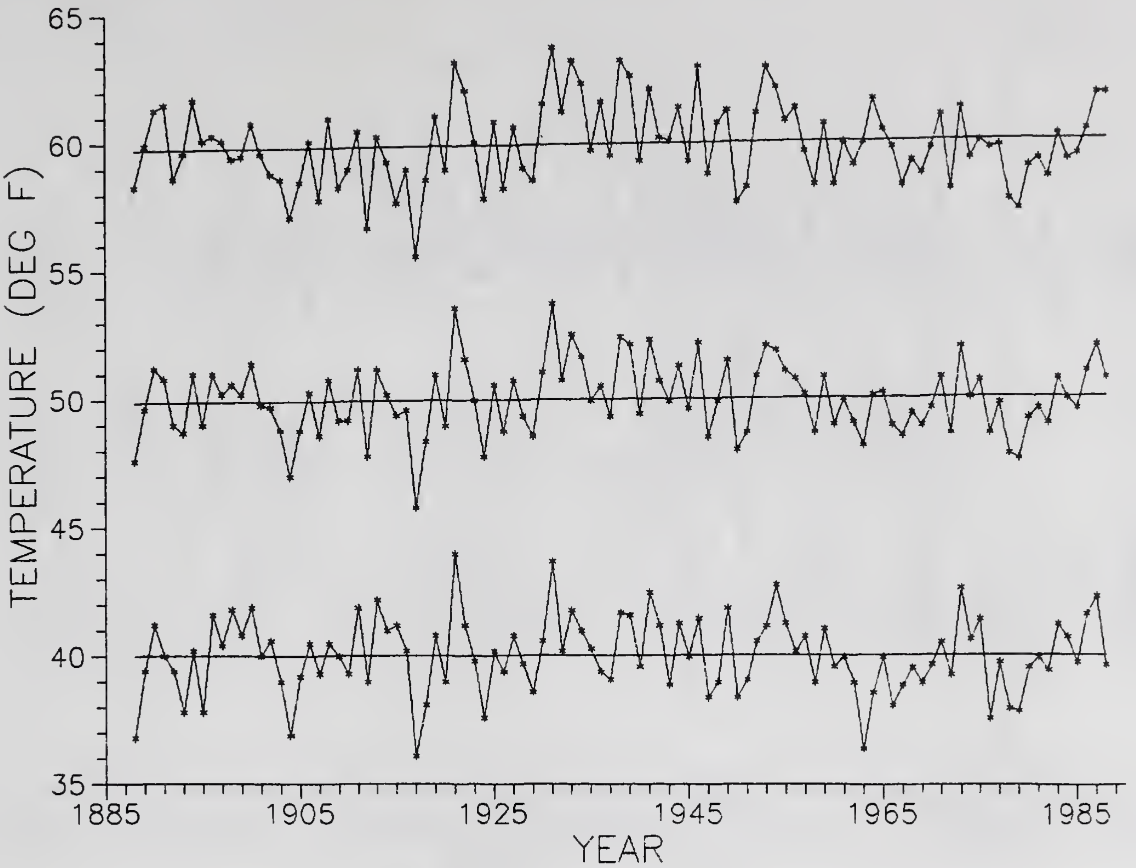

FIGURE 2. Annual mean daily maximum, mean, and mean daily minimum air temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for annual mean daily maximum + 0.007 deg F/yr (r = 0.13), for mean + 0.004 deg F/yr (r = 0.08), and for mean daily minimum = 0.001 deg F/yr (r = 0.02).

(1988, Figure 2) charted regions of cooling and warming in the Northern Hemisphere during the 1967-1986 period, but any long-term trend in natural climatic warming should be reflected in a time series of annual mean air temperatures from a rural climatological station, i.e., averages of 365 daily maximum and 365 daily minimum temperatures for each year.

Few, if any, long record climatological stations have been in the same location with an unchanging local environment. Consequently, the time series of temperatures reflects not only the climatic variability but also the nonclimatic variability and trends. Since the fifties, short term operational weather and hydrologic forecasting needs, with moves toward automation of observations, have had priority over maintenance of homogeneous climatic networks. Consequently, climatologists must make sense of an increasingly heterogeneous climatological base. For example, just by changing the time of a once-daily climatological observation (at Indianapolis) from 1900 EST to 0700 EST, the January mean air temperature would be decreased 2.6 deg F (Schaal and Dale, 1977). Nelson, *et al.* (1979) showed that a sufficient number of stations had experienced this time of observation change (PM to AM for operational reasons) to create a "non-climatic" cooling of Indiana summers of about 0.8 deg F from 1949 to 1979. In the U.S., where cooperative observers are relied on more than in other areas of the world, the time of observation bias tends to offset the urban warming bias.

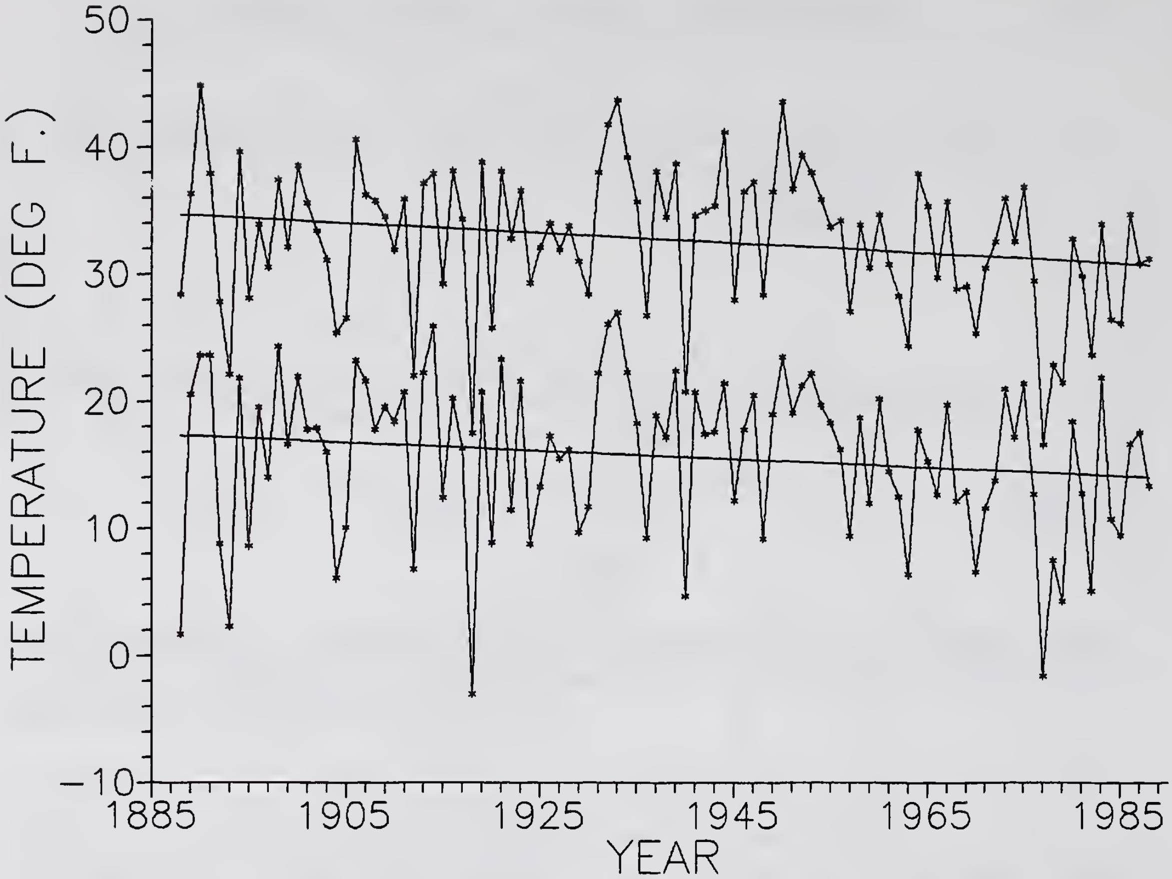

FIGURE 3. January mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.04 deg F/y (r = − 0.20*) and for mean daily minimum − 0.03 deg F/yr (r = − 0.15). * Significant at 0.05 level.

The WWR data base used in the climatic warming literature has only monthly and annual mean temperatures. The enhanced HCN data base used by Karl and Jones has monthly mean daily maximum and mean daily minimum temperatures. However, they did not use them in their analysis. Since there is no short wave radiation at night, the minimum temperature is almost exclusively controlled by the longwave radiation budget. Thus, one might expect that an enhanced greenhouse effect would be more evident in the mean daily minimum than in the mean daily maximum or in the mean temperatures. Therefore, the mean daily temperature range (mean daily maximum – mean daily minimum) should decrease, if there were an enhanced greenhouse effect.

In this paper, mean daily minimum, mean, and mean daily maximum temperature data from a rural climatological station in northern Indiana were adjusted for non-climatic biases from 1888 through 1988 and then examined for trend for evidence of climatic warming. In addition, the mean daily temperature range was examined for downward trend as evidence of an enhanced greenhouse effect.

MATERIALS AND METHODS

The data used were the mean daily maximum and mean daily minimum temperatures for January, for July, for the whole summer (June-August), and for

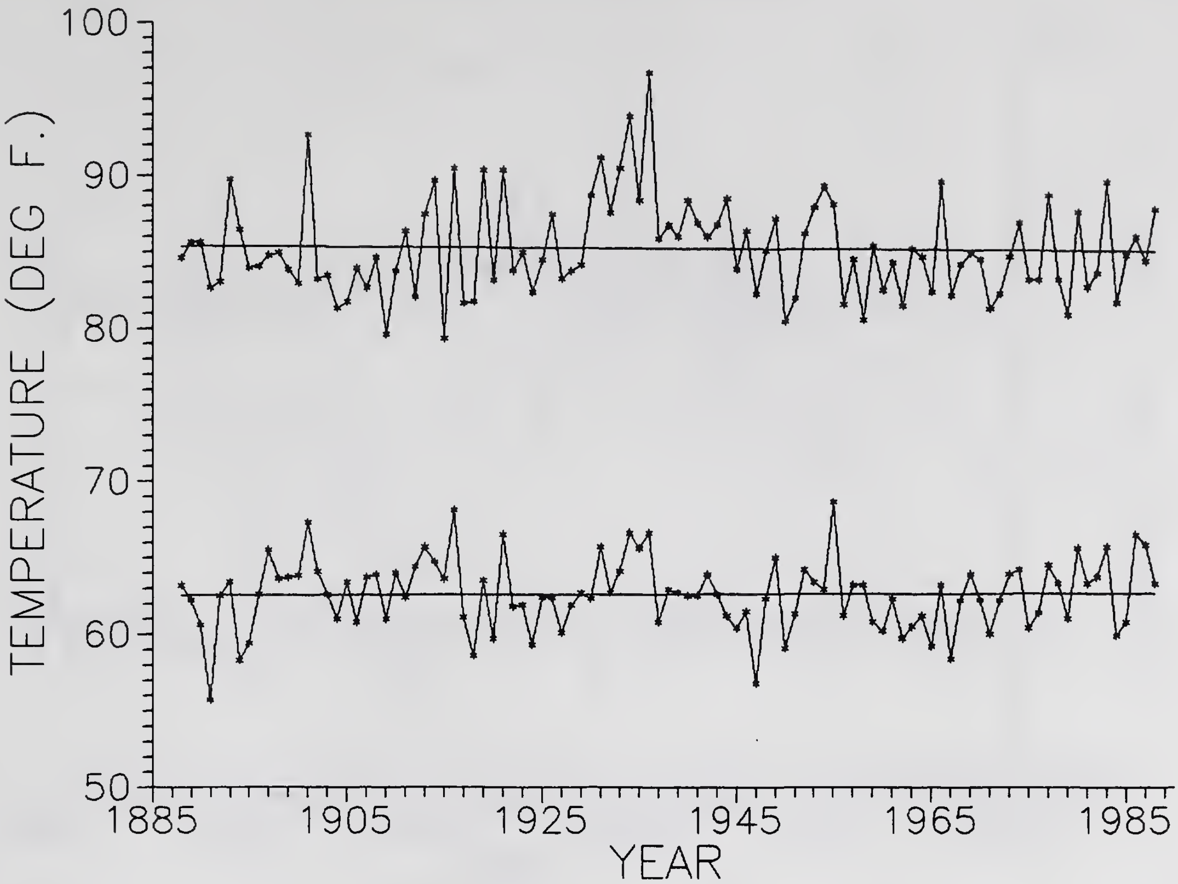

FIGURE 4. July mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.004 deg F/yr (r = − 0.03) and for mean daily minimum + 0.001 deg F/yr (r = 0.01).

the year from West Lafayette 6NW, Indiana at 40 deg 28 min N, 87 deg 00 min W (U.S. Weather Bureau and U.S. Department of Commerce, NOAA, 1888-1988). The West Lafayette 6NW climatological station (# 9430) now has an ideal rural location at the Purdue University Agronomy Farm, about 10 km northwest of West Lafayette. Climatological observations are taken at 0800 EST with temperatures from standard liquid-in-glass thermometers exposed in a Cotton-Region Shelter. The station locations before 1954, however, were not always ideal. Using a series of overlapping observations from Whitestown, 80 km southeast of West Lafayette and one of the best reference climatological stations in Indiana since 1909, Epperson and Dale (1984) developed non-climatic temperature bias estimates to be applied to monthly annual mean daily maximum and mean daily minimum temperatures from each of the earlier locations to adjust the temperatures recorded during the respective location period to those for the present rural location. For example, from July 1, 1917 to January 31, 1949 the thermometer shelter for the West Lafayette climatological station (# 9427) was located on the roof of the Purdue University Agricultural Administration Building with observations taken at 2000 EST. During this period, the annual mean daily maximum temperatures were reduced 2.4 deg F and the annual mean daily minimums 3.2 deg F (2.8 for mean) to be equivalent to those recorded at the present rural location of West Lafayette 6NW. In like manner, the mean daily maximum and minimum temperatures for other periods were adjusted to create the climatological series

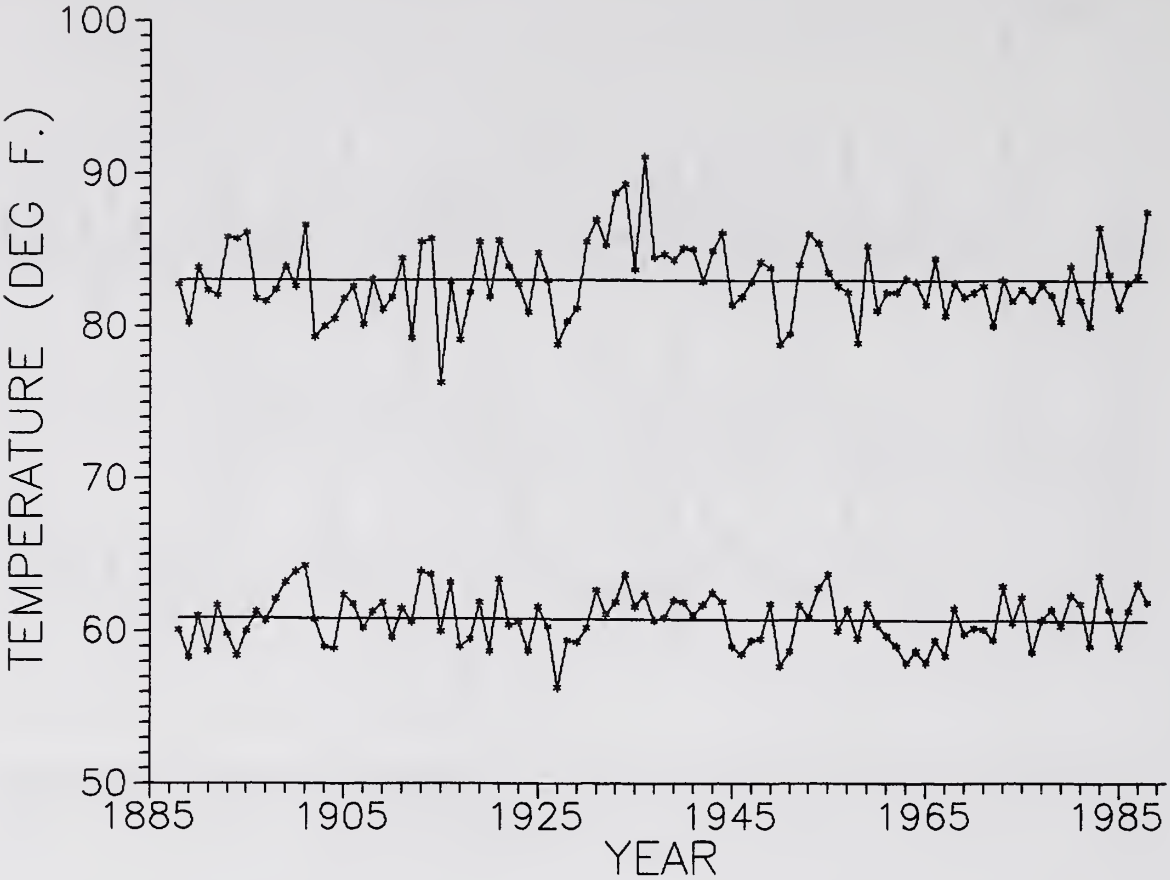

FIGURE 5. Summer (June-August) mean daily maximum and mean daily minimum temperatures for indicated year, 1888-1988, adjusted to present location of West Lafayette 6NW Indiana. Linear time trend for mean daily maximum − 0.0006 deg F/yr (r = − 0.007) and for mean daily minimum − 0.003 deg F/yr (r = − 0.04).

used in this paper. For comparison, the decadal (11-year) adjusted annual means, as well as those from the published (unadjusted) record (U.S. Weather Bureau and NOAA, 1888-1988), are reproduced from Epperson and Dale (1984, Figure 5) in Figure 1.

In addition, the mean daily air temperature ranges (mean daily maximum − mean daily minimum) were calculated and plotted by year for each of the January, July, summer, and annual periods. Finally, linear time trends for each of the temperature variables were fitted by least squares regression on year for the 101-year records.

RESULTS AND DISCUSSION

The mean decadal temperatures plotted in Figure 1 were extended through 1985 (representing the 1980-1990 mean) by using the 1960-1988 means for the 1989 and 1990 annual means. Although there is an upward temperature trend from 1960 through 1990, it is not as great as that from 1910 to 1940, the adjusted annual mean temperatures for the 1930-1940 period averaging 51.7 deg F, compared to the preliminary 1980-1990 11-year mean of 50.2 deg F.

The annual mean daily maximum, mean, and mean daily minimum temperatures for 1888 through 1988 (using November and December 1960-1987 means

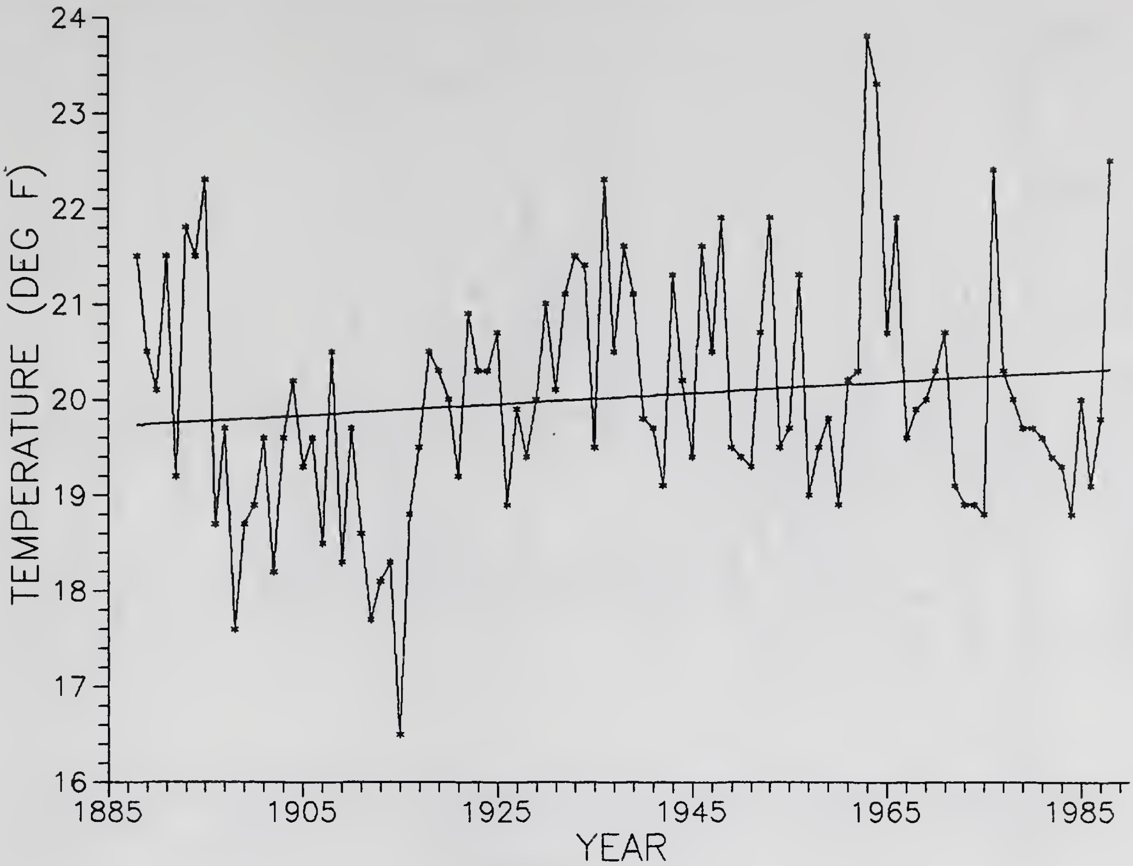

FIGURE 6. Annual mean daily temperature range, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend for annual mean daily temperature range + 0.006 deg F/yr (r = 0.14).

to complete 1988) are shown in Figure 2. Note that the total range in the annual means is 8.0 deg F, from a low of 45.8 deg F in 1917 to a high of 53.8 in 1931. This is more than three times the total range of about 2.4 deg F in Hansen and Lebedeff's (1987) annual mean temperatures for the Northern Hemisphere. The linear trends are not significant (slopes of + 0.007, + 0.004, and + 0.001 deg F/yr, respectively, with correlation coefficients (r) of 0.13, 0.08, and 0.02). Although there is a visible upward trend since 1979, one can see similar historical short period trends from below the 101-yr trend line to above it. The data in Figure 2 were also fitted with a 10th order polynomial which smoothed the pattern to show cooling from about 1938 to 1978 followed by warming. However, multiple correlation coefficients (0.52, 0.42, and 0.31 for the annual mean daily maximum, mean, and mean daily minimum temperatures, respectively) were nonsignificant, indicating the folly of predicting future trends, especially with the distorted tails of the polynomial regression fit.

The January daily mean maximum and daily mean minimum temperatures for the last 101 years were plotted in Figure 3. The downward trend in the mean daily maximum temperature of − 0.04 deg F/yr or − 4.0 deg F in the 101-yr period was the only linear trend (r = − 0.20) significant at the 0.05 level reported in this paper. Yet the trend was associated with only 4% of the year-to-year variability in the mean daily maximum temperatures. The January mean daily

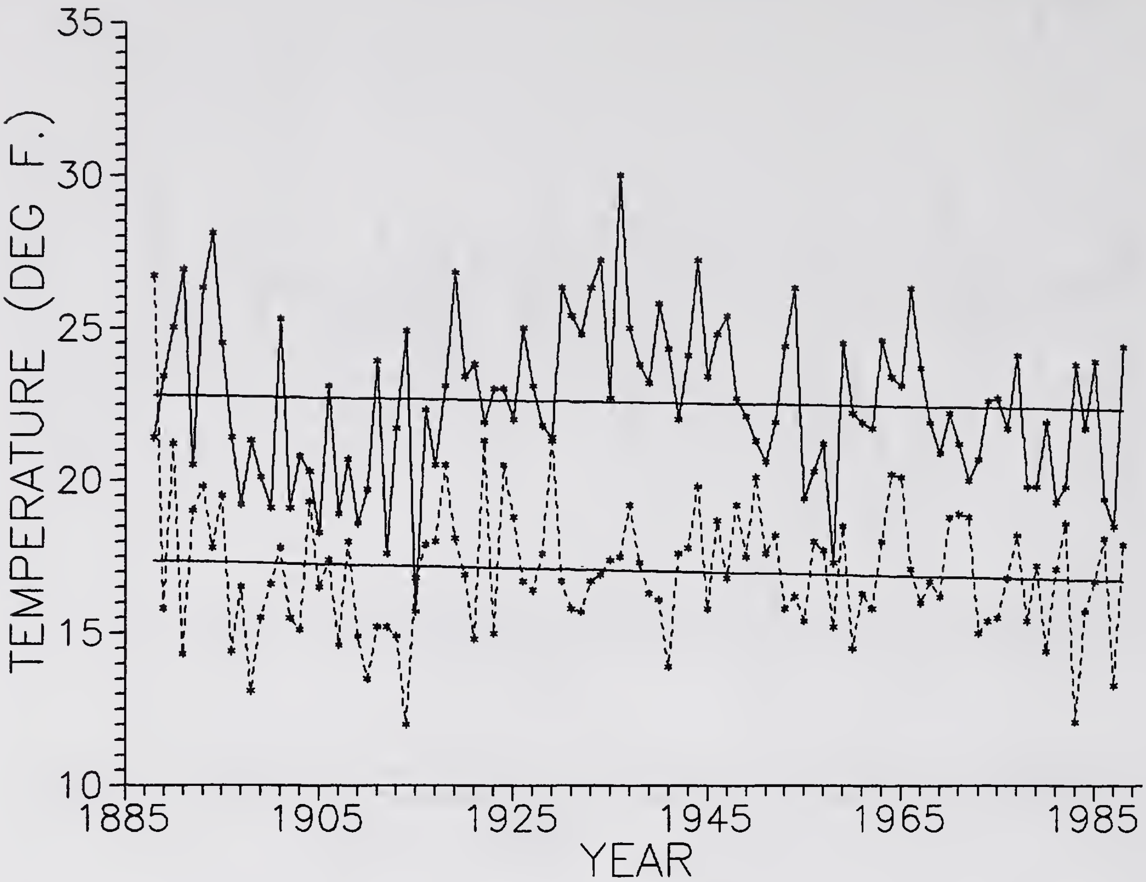

FIGURE 7. January (bottom) and July (top) mean daily temperature ranges, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend in mean daily temperature range for January − 0.006 deg F/yr (r = − 0.09) and for July − 0.005 deg F/yr (r = − 0.05).

minimum temperatures also showed a downward (but nonsignificant) trend (− 0.03 deg F/yr, r = − 0.15).

The July mean daily maximum and mean daily minimum temperatures (Figure 4) showed no significant linear time trend (slopes − 0.004 and + 0.001 deg F/yr.) The fraction of the variance in the time series associated with regression was 0.001 for both the mean daily maximum and mean daily minimum temperatures.

The summer mean daily maximum and mean daily minimum temperatures (Figure 5) also showed no significant linear time trend over the last 101 year (slopes of − 0.0006 and − 0.003 deg F/yr). Note that at West Lafayette 6NW the summer of 1988 was not the hottest of record. It averaged below those of 1936, 1934, and 1933. The mean daily maximum temperature was 91.1 deg F in 1936 compared to 87.5 in 1988.

The annual mean daily temperature range was plotted for each year in Figure 6. Instead of the range decreasing, as was hypothesized with an enhanced atmospheric greenhouse effect, the range increased 0.006 deg F/yr. Again, the trend was nonsignificant (r = 0.14).

The range between the mean daily maximum and mean daily minimum temperatures for both January and July was plotted in Figure 7. Neither time

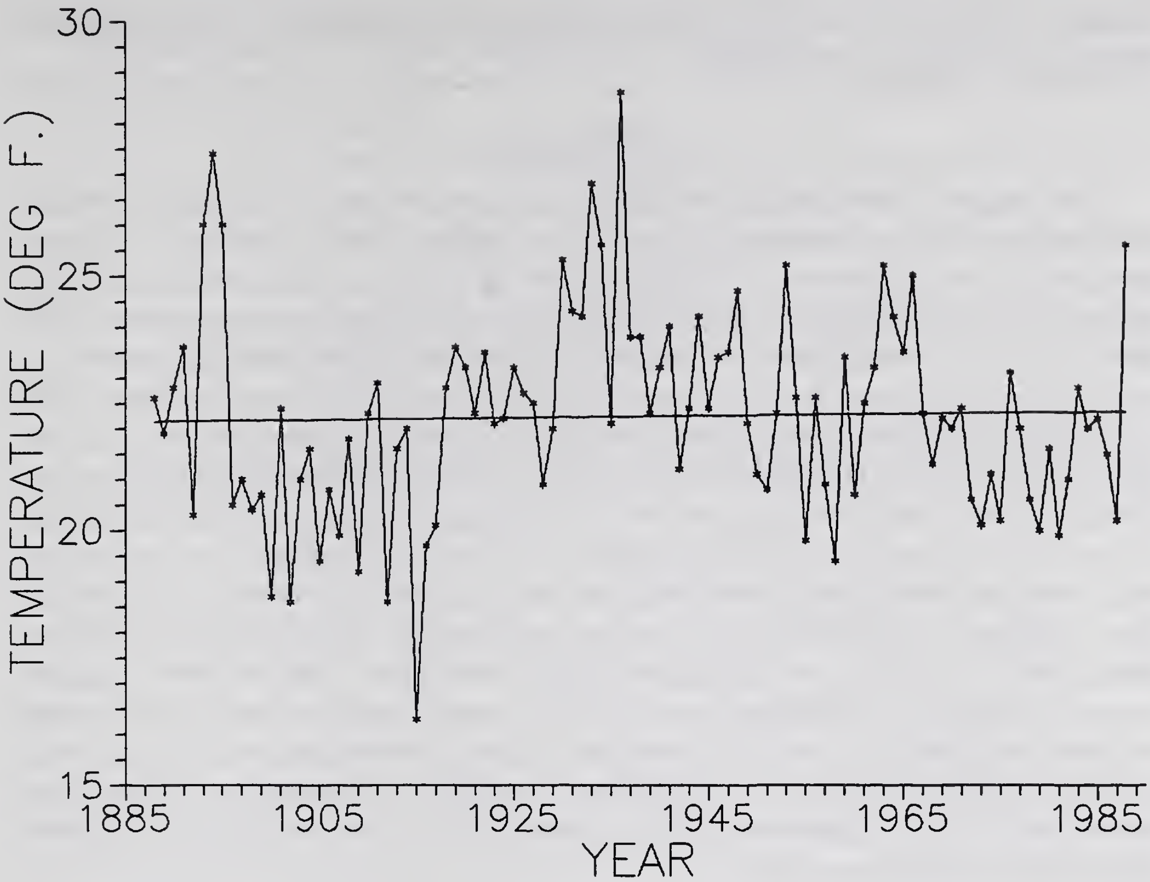

FIGURE 8. Summer mean daily temperature range, mean daily maximum – mean daily minimum, for indicated year, 1888-1988, for West Lafayette 6NW Indiana. Linear time trend in mean daily temperature range + 0.002 deg F/yr (r = 0.03).

trend was significant. Similarly, there was no significant linear time trend in the summer temperature range (Figure 8). The hypothesized decrease in the mean daily temperature range with an enhanced atmospheric greenhouse effect has not occurred, at least at West Lafayette, Indiana.

In the July and summer time series, there appears to be a tendency for an upward trend (greater diurnal temperature range) up to 1936 and then downward from that time. The diurnal range is greatly affected by drought. If there were ample soil moisture, the net radiation from the shortwave and longwave radiation balance would be expended mainly in latent heat, or in evaporating water from the soil and plants (transpiration). With low soil moisture, the net radiation is expended more in sensible heat (i.e., warming the air), and maximum temperatures are high. Also, during a drought situation, usually there is less water vapor in the atmosphere, and this decrease in one of the important atmospheric greenhouse gases allows less longwave radiation to be absorbed and reradiated than would occur with higher atmospheric humidity. This results in lower minimum temperatures. Thus, maximum air temperatures are higher and minimum air temperatures lower during droughts than those observed when there is adequate soil moisture. The occurrence of droughts produces greater variance about any trend in the mean daily temperature range and reduces the chance of finding a significant trend caused by an enhanced atmospheric greenhouse effect caused by the dry air gasses. The hypothesis that the diurnal temperature range will decrease as a response to an enhanced greenhouse effect should be tested in a marine climate not subject to droughts.

SUMMARY

The reported hemispheric and global air temperature trends are not representative of the natural climatic regime, but rather reflect the effect of a disproportionately large number of WWR stations in growing urban areas. Karl and Jones (1989) have confirmed this for the U.S. annual mean air temperatures. The examination of air temperature records for a single rural climatological station, independently adjusted for non-climatic biases, showed no climatic warming. The variability in the time series decreases as one proceeds from the monthly (January and July) to the seasonal and annual temperature means for a single station. This variability decreases even further for the hemispheric and global averages, which makes any temperature time trends more obvious and perhaps more important than deserved, unless the urban temperature bias can be properly evaluated. Of the 13 different temperature time series examined for West Lafayette 6NW Indiana, there was only one significant linear trend from 1888 to 1988 (January mean daily maximum temperature), and that trend was downward. There is little evidence for climatic warming in northern Indiana, which can be used as a proxy for the northern hemisphere. In addition, the diurnal temperature range is not decreasing in West Lafayette 6NW Indiana, as it should be with an enhanced atmospheric greenhouse effect.

LITERATURE CITED

Carbon Dioxide Information Analysis Center. 1988. Mauna Loa, 30 years of continuous CO_2 measurements. CDIAC Communications, Oak Ridge Nat. Lab., Oak Ridge, Tennessee.

Epperson, D.L. and R.F. Dale. 1984. Comparison of climatologies for existing heterogeneous temperature records with those for adjusted records for West Lafayette and Whitestown, Indiana. Proc. Indiana Acad. Sci. 93: 395-404.

Hansen, J. and S. Lebedeff. 1987. Global trends of measured surface air temperature. J. Geophys. Res. 92:D11:13,345-13,372.

Jones, P.D. 1988. Hemispheric surface air temperature variations: Recent trends and an update to 1987. J. Climate 1: 654-660.

__________, S.C.B. Raper, R.S. Bradley, H.F. Diaz, P.M. Kelly, and T.M.L. Wigley. 1986. Northern hemisphere surface air temperature variations: 1851-1984. J. Clim. Appl. Meteorol. 25: 161-179.

Karl, T.R. and P.D. Jones. 1989. Urban biases in area-averaged surface air temperature trends. Bull. Amer. Meteorol. Soc. 70: 265-270.

Kukla, G., J. Gavin, and T.R. Karl. 1986. Urban warming. J. Clim. Appl. Meteorol. 25: 1265-1270.

Landsberg, H.E. 1981. The urban climate. Int. Geophs. Ser. 28, Academic Press, New York, 261 pp.

Lowry, W.P. 1977. Empirical estimation of urban effects on climate: A problem analysis. J. Appl. Meteorol. 16: 129-135.

Nelson, W.L., R.F. Dale, and L.A. Schaal. 1979. Non-climatic trends in divisional and state mean temperatures: A case study in Indiana. J. Appl. Meteorol. 18: 750-760.

Schaal, L.A. and R.F. Dale. 1977. Time of observation temperature bias and "climatic change". J. Appl. Meteorol. 16: 215-222.

Smithsonian Institution. 1927. World weather records. Smithsonian Inst. Misc. Col. 79, Washington, D.C.

____________. 1935. World weather records. Smithsonian Inst. Misc. Coll. 90, Washington, D.C.

____________. 1947. World weather records. Smithsonian Inst. Misc. Coll. 104, Washington, D.C.

U.S. Weather Bureau and U.S. Dept. of Commerce. 1959-1982. World weather records, 1941-1950 (1361 p.), 1951-1960 (Vols. 1-6), 1961-1970 (Vols. 1-6). U.S. Dept. Commerce, Washington, D.C.

____________ and ____________. Climatological data, Indiana. 1888-1988. Indianapolis, IN (1888-1948); Chicago, IL and Kansas City, MO (1949-1954); Asheville, NC.