Comparison of Climatologies for Existing Heterogeneous Temperature Records with Those for Adjusted Records for West Lafayette and Whitestown, Indiana

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Introduction

Most published historical temperature records contain heterogeneities resulting from moves of the site of the temperature observations, changes in time of once-daily observations, change in instrumentation, and sometimes non-representative changes in the environment immediately surrounding the station (Nelson et al., 1979). Consequently we rarely have a true "climatological series", defined as a sample from a single population. Unless the historical temperature records are adjusted, statistical summaries can lead to misleading and biased results. In fact, at a time when there is concern about the increasing CO_2 in the earth's atmosphere and possible future climatic warming (Kerr, 1983), we should point out that "non-climatic" temperature changes in some weather station records may be as great or greater than the predicted climate warming in the next 100 years.

Since most all of the maximum and minimum temperatures published in Climatological Data (USDC, 1890-1980) have been observed and recorded from liquid-in-glass thermometers exposed in standard white, louvered instrument shelters, the primary sources of temperature heterogeneities have been changes in time of observation and changes in location, especially when the shelter has been moved to or from a roof. Rooftop locations usually affect minimum more than maximum temperatures because of the usual nighttime temperature inversions. Hence minimum temperatures observed at rooftop locations are usually higher than those observed at ground locations. Biases caused by time of observation at cooperative climatological stations result from the necessary procedure of setting the minimum and maximum thermometers at the time of the once-daily observation (Schaal and Dale, 1977). Since minimum thermometer readings for the next observational day cannot be higher than the temperature at the time of observation, a "set min" temperature at 7AM may carry over to the next morning, biasing daily minimum and mean temperatures downward. Since maximum thermometer readings for the next observational day cannot be lower than the ambient temperature at time of observation, a "set max" at 5PM may carry over to the next afternoon, biasing mean daily maximums and means upward. This is particularly vexing in those regions using daylight time during the summer, e.g., a 5PM daylight time observation is actually 4PM local standard time, increasing the bias.

The objective of this paper is to adjust for heterogeneities in two of the better climatological station records in Indiana, West Lafayette and Whitestown, about 80 km SE of West Lafayette, and to compare the temperature trends for the heterogeneous and adjusted temperature series.

Data and Procedures

An examination of the substation histories (U.S. Dept. of Commerce, 1955) and more recent substation reports (USDC, 1956-1982) for West Lafayette and Whitestown showed that the Whitestown station had been in essentially the same ground location from January 1, 1909 to the present, with the same observer, Clyde O. Laughner, until 1965. Only the time of observation changed, from 6PM to 9AM on October 1, 1965 and to 7AM on July 1, 1967. This probably is the most homogeneous temperature record in Indiana. The West Lafayette temperature observations considered in this study began January 1, 1888 with a ground location on the Purdue University campus, observation time at 8PM. The instrument shelter was moved to the roof of the Agricultural Experiment Station Building July 1, 1917, about 18 m above ground. The time of observation was changed to 7AM February 1, 1949, and on July 1, 1953 the station was moved to a ground location at the Purdue University Agronomy Farm, about 6 miles northwest of the AES site, with observations taken between 7 and 8AM to the present.

The temperature records from 1890 to 1980 for West Lafayette (WLAF) and Whitestown (WHIT) were divided into six periods of "co-stable" locations and observation times, as shown in Table 1. Because both stations now have standard ground locations and the observation time preferred by the National Weather Service for operational purposes (Schaal and Dale, 1977), the mean temperatures for both stations were adjusted to correspond to their present status. The adjustments were determined with differences in temperatures, WLAF-WHIT, within periods. Mean daily maximum and mean daily minimum temperatures were adjusted separately. The adjusted mean temperatures were obtained by averaging the adjusted mean daily maximum and minimum temperatures, $(\overline{T}_{max} + \overline{T}_{min})/2$. Frequencies of different weather situations, such as frontal passages, fog and strength of temperature inversions, affect the temperature adjustments, but it was assumed that if individual adjustments were determined for each month there was a sufficient number of years in each period to give a reasonable estimate of the seasonal temperature adjustments.

The first step in the process was to adjust the Whitestown temperatures for the PM observational time in periods 1-4 downward to the present AM base in period 5. Since WLAF had the same location and observational time in periods 4 and 5, the only cause for differences between mean temperatures for those two periods at West Lafayette should be climate change, while at WHIT the difference results from changes in both climate and observational time. Assuming that the climate change at WHIT was the same as at WLAF, the adjustment factor used to correct the WHIT PM temperature records was computed in three steps:

TABLE 1. *Periods of co-stable weather station locations and times of observation for West Lafayette 6 NW, elevation 215 meters, and Whitestown Indiana, elevation 250 meters.*

PERIOD NO	PERIOD	YEARS	LOCATION	OBSV TIME
0	1890-1908	19	WLAF-ground	8PM
1	1909-1916	8	WLAF-ground	8PM
			WHIT-ground	6PM
2	1919-1948	30	WLAF-rooftop*	8PM
			WHIT-ground	6PM
3	1949-1952	4	WLAF-rooftop*	7AM
			WHIT-ground	6PM
4	1954-1964	11	WLAF-ground	8AM
			WHIT-ground	6PM
5	1966-1979	14	WLAF-ground	8AM
			WHIT-ground	7AM

* ROOFTOP 18 METERS ABOVE GROUND

1) $WL_{4-5} = WLAF_4 - WLAF_5 =$ CLIMATE change at both WLAF and WHIT between periods 4 and 5

2) $WH_{4-5} = WHIT_4 - WHIT_5 =$ CLIMATE plus OBSV time change at WHIT

3) $$\begin{bmatrix} \text{CWH, 4} \\ \text{ADJUSTMENT} \\ \text{DIFFERENCE} \end{bmatrix} = WH_{4-5} - WL_{4-5} = \begin{bmatrix} \text{CLIMATE} \\ \text{and OBSV} \\ \text{time change} \end{bmatrix} \text{ minus } \begin{bmatrix} \text{CLIMATE} \\ \text{change} \end{bmatrix} = \begin{bmatrix} \text{OBSV} \\ \text{time} \\ \text{change} \\ \text{ONLY} \end{bmatrix}$$

This three-step process was applied in each month to both max and min mean temperatures for WHIT. These differences were used to adjust the Whitestown temperature in periods 1-4 to convert the entire record to an AM observation time.

The adjusted WHIT temperature record was then used as the base to adjust the WLAF temperatures. Again the climatic change at WHIT was assumed to be the same as that at WLAF, and a similar three-step process was used to determine the temperature differences needed to adjust the WLAF record to an AM observational time, ground location base. For example, the steps used to establish the WLAF corrections needed in period 3 were:

1) $WH_{3-4} = WHIT_3 - WHIT_4 =$ CLIMATE change at both WLAF and WHIT between period 3 and 4

2) $WL_{3-4} = WLAF_3 - WLAF_4 =$ CLIMATE change plus ROOF location change at WLAF

3) $$\begin{bmatrix} \text{CWL, 3} \\ \text{ADJUSTMENT} \\ \text{DIFFERENCE} \end{bmatrix} = WL_{3-4} - WH_{3-4} = \text{ROOF location change at WLAF}$$

These same procedures were used to adjust WLAF temperatures for Periods 1 and 2. For period 2 adjustments, the subscripted 3's were replaced with 2's and the 4's with 3's in the above set of equations. Then to determine the adjustment for period 1, the subscripted 2's were replaced with 1's and the 3's with 2's. WLAF also had an earlier PM observation in period 0, when there were no WHIT records. Since the same base held for period 0 and 1, the same adjustments determined for period 1 were used for period 0.

The adjustments determined for the WLAF and WHIT temperature records were applied to the respective mean daily minimum, maximum, and mean temperature data series, and the adjusted temperatures compared against the original series.

Results and Discussion

The calculated adjustments for the published Whitestown mean daily minimum and maximum temperatures from January 1, 1909 to September 30, 1965 to make them equivalent to those for the present AM observational base are shown in Table 2 for each month and the year. The greatest adjustments at Whitestown were needed for the January and February mean daily minimum temperatures, which had to be decreased 2.5 F. No adjustment was necessary for August mean daily maximum temperatures.

TABLE 2. *Differences to be subtracted from the published mean daily maximum and minimum temperatures (°F) at Whitestown, IN, 1 January 1909 to 30 September 1965, to adjust them to an AM observation, ground location base for the indicated month and year.*

Month	Mean daily maximum temperature	Mean daily minimum temperature
J	0.6	2.5
F	1.2	2.5
M	1.9	1.7
A	1.3	1.5
M	1.1	1.0
J	0.7	0.5
J	0.2	0.5
A	0.0	1.0
S	-0.2	2.0
O	0.3	0.9
N	0.6	1.4
D	0.4	1.7
YR	0.7	1.4

At West Lafayette, the adjustments needed to make the mean daily maximum and minimum temperatures equivalent to those for the present ground location and

TABLE 3. *Differences to be subtracted from the published mean daily maximum and minimum temperatures (°F) at West Lafayette IN for indicated record period, to adjust them to an AM observation, ground location base for the indicated month and year.*

Period		0,1	2	3
Record Period	Month	1-1-1888 To 6-30-1917	7-1-1917 To 1-31-1949	2-1-1949 To 6-30-1953
Mean Daily Maximum Temp.	J	1.5	2.5	0.6
	F	1.8	3.3	0.8
	M	2.7	4.2	1.8
	A	2.4	3.3	0.8
	M	1.7	2.7	2.3
	J	1.7	1.9	2.6
	J	1.8	1.6	2.8
	A	1.7	1.6	2.8
	S	1.2	1.2	2.4
	O	2.1	2.5	2.6
	N	2.2	2.4	1.9
	D	1.6	1.8	1.1
	YR	1.8	2.4	1.9
Mean Daily Minimum Temp	J	1.1	4.2	0.7
	F	1.3	4.1	0.4
	M	1.4	3.3	-0.2
	A	1.2	2.7	0.8
	M	1.2	2.7	1.9
	J	-0.2	2.3	2.4
	J	0.5	2.7	3.5
	A	0.8	3.0	3.2
	S	2.2	3.7	3.0
	O	0.6	2.9	1.1
	N	0.8	3.1	1.0
	D	0.7	3.8	1.1
	YR	0.8	3.2	1.6

AM observations are shown in Table 3. With the exception of the differences calculated for the mean daily minimum temperature for June and September in periods 0 and 1, the adjustments display a fairly smooth seasonal pattern in Table 3, (as well as those for Whitestown in Table 2), and were not statistically smoothed. The largest temperature biases occurred during the winter in period 2, when there were PM observations and rooftop exposures. Daily mean minimum temperatures in January and mean daily maximum temperatures in March averaged 4.2°F warmer than those recorded for AM observations at the present location. In the summer months the temperature biases for period 3 (rooftop and AM observations) were greater than those for period 2.

Unless these "non-climatic" temperature differences evaluated in Tables 2 and 3 are considered, these two stations give different estimates of the regional climatic change. For example in Fig. 1, the published annual mean daily minimum temperatures for West Lafayette and Whitestown have been plotted against year from the beginning

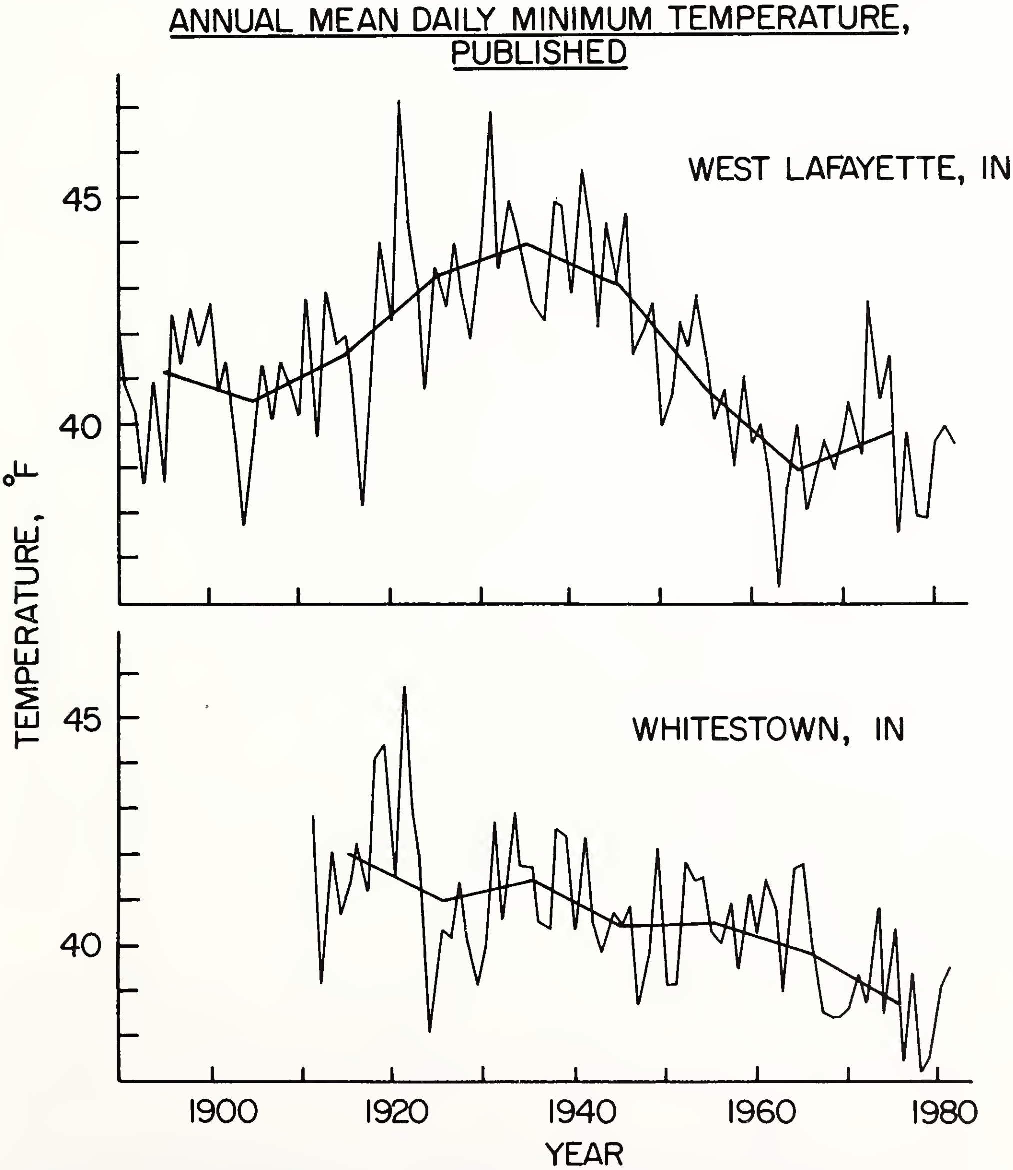

FIGURE 1. *Plot of published annual mean minimum temperatures on year for West Lafayette and Whitestown, IN. Heavy line connects average decadal (11-year) means plotted on middle year of decade.*

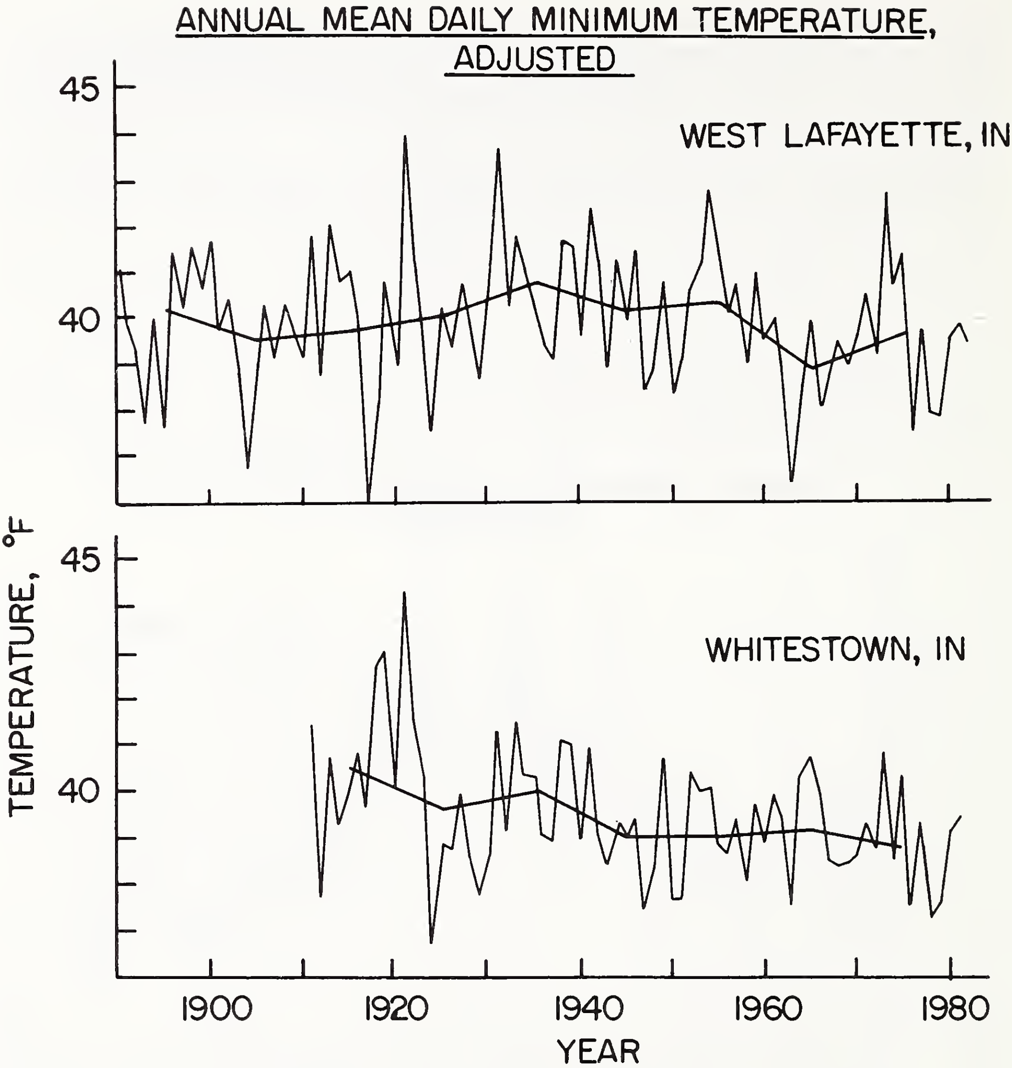

FIGURE 2. *Plot of adjusted annual mean daily minimum temperature on year for West Lafayette and Whitestown IN. Heavy line connects average decadal (11-year) means plotted on middle year of decade.*

of record through 1981. Decadal (11-year) means have also been plotted for the middle year of each decade to help show the climatic trend. The West Lafayette temperatures show a strong warming trend from the 1900s to the 1930s and then rapid cooling to 1960. On the other hand, Whitestown shows gradual cooling from the 1910s to the present.

The adjusted time series of annual mean daily minimum temperatures is shown in Fig. 2. Although there are still differences in the curves, the -3.2 correction (Table 2) for the period of rooftop temperature observations at West Lafayette decreased the warming in the 1930s, which had been artificially enhanced by the rooftop location and PM observations.

The annual mean daily minimum, maximum and mean temperatures for the five periods of published records are shown for both Whitestown and West Lafayette in Fig. 3. There are no consistent temperature differences between the two stations and five periods, minimums averaging lower at Whitestown than at West Lafayette in periods

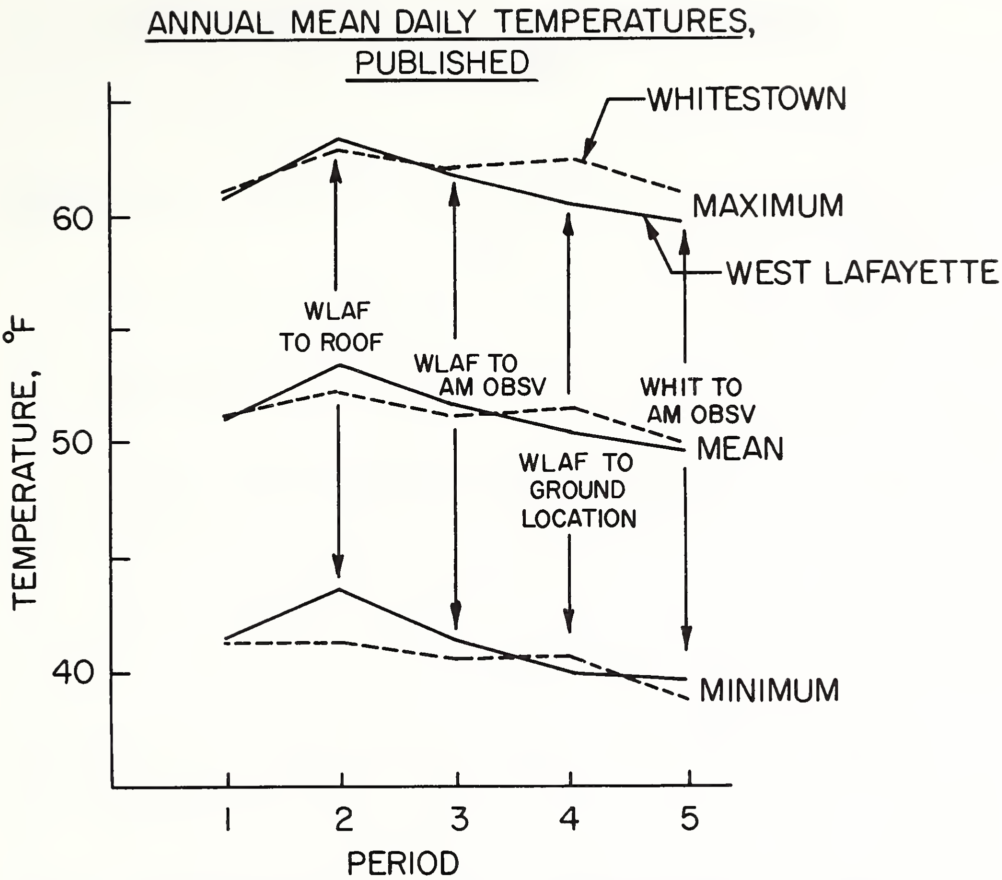

FIGURE 3. *Annual mean daily maximum, minimum and mean temperatures from published records for West Lafayette and Whitestown IN for indicated periods (Table 1).*

1, 2, 3, and 5, and above in period 4. After the temperatures have been adjusted the differences were much more consistent, as shown in Fig. 4. Plots of the differences between the published mean daily minimum and maximum temperatures at West Lafayette and Whitestown, WLAF - WHIT, showed great variability from month to month and period to period. For example in period 3 for the mean daily minimum temperatures, the WLAF - WHIT temperature differences ranged from between -1 to -2 °F in January, February and March to between +3 and +4 °F in July and August. When adjusted temperature records were used, the mean daily minimum temperature differences, WLAF - WHIT, typically ranged from near 0 in the winter months to near +1 for the fall months in all periods. Mean daily maximum temperature differences for the adjusted series ranged between -1 and -2°F for all months in all periods.

The usual statistic used by climatologists to show climatic trend is annual mean temperature. Decadal (11-year) mean temperatures have been plotted on the middle year of the decade in Fig. 5 for the published and adjusted West Lafayette temperatures, from the 1890s to the 1970s. The published curve is essentially the same as that reported by Agee (1980, Fig. 1), which shows the same warming peak in the 1930s as discussed previously for the mean daily minimum component of the mean. The adjusted curve still shows the warmest period in the 1930s but the climatic change has been cut in half. The range from the highest to lowest decade means for the mean daily minimum, maximum, and mean temperatures are shown for both West Lafayette and Whitestown in Table 4.

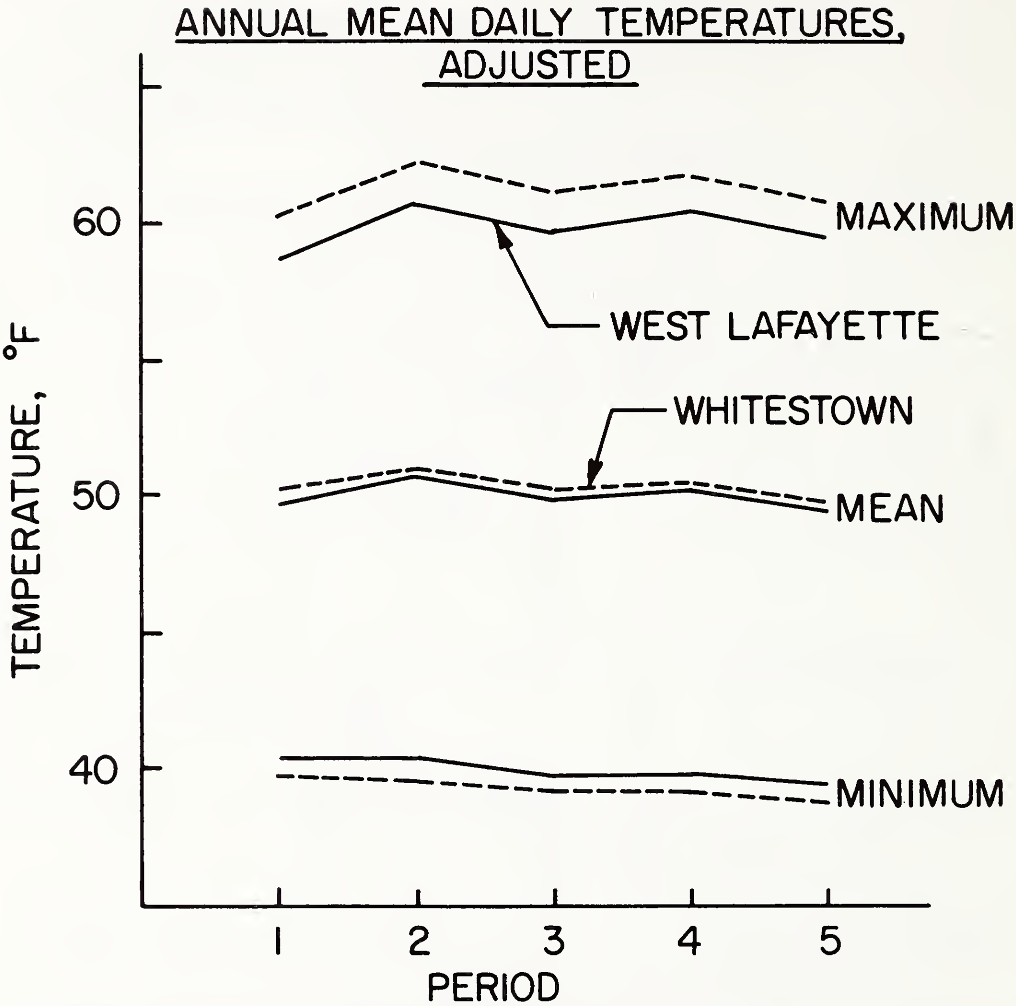

FIGURE 4. *Annual mean daily maximum, minimum and mean temperatures for adjusted records for West Lafayette and Whitestown IN for indicated periods (Table 1).*

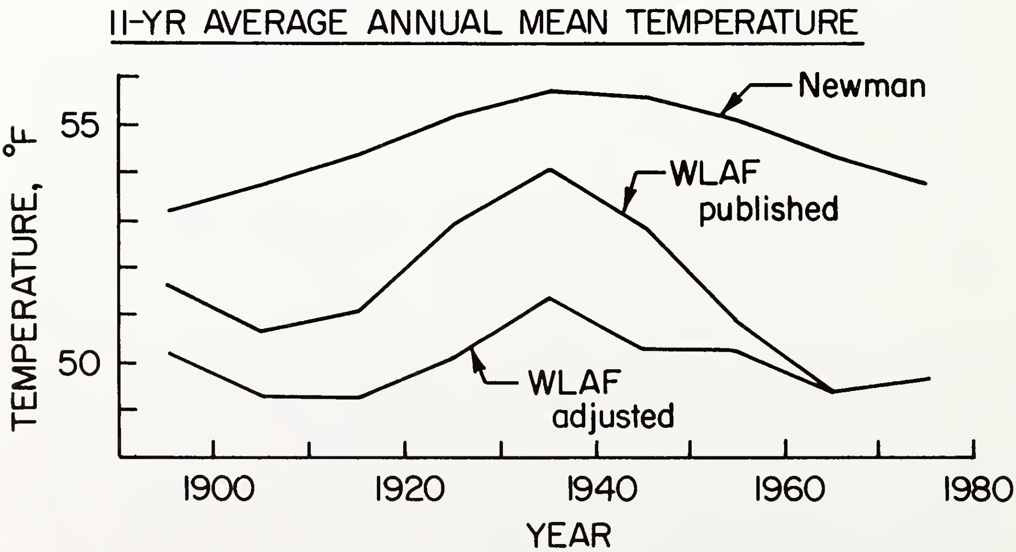

FIGURE 5. *Climate change over the past 80 years as illustrated for central Indiana by Newman (1982), the published WLAF record (Agee, 1980), and the adjusted WLAF record, using 11-year means of the annual daily mean temperatures.*

TABLE 4. *Range from highest to lowest 11-year average annual mean daily maximum, minimum and mean temperature for the published and adjusted West Lafayette and Whitestown records.*

		RANGE F°	
STATION	TEMP MEAN	PUBLISHED	ADJUSTED
WLAF	MAX	4.5	2.9
	MIN	5.0	1.8
	MEAN	4.7	2.0
WHIT	MAX	3.1	3.1
	MIN	3.2	1.7
	MEAN	2.7	1.6

A study conducted by Newman (1982) used the mean temperature obtained from five central Indiana stations (Greencastle, Indianapolis, Richmond, Rushville, and Terre Haute) to show the climate change in central Indiana over the past 100 years. Newman selected stations with no history of rooftop locations, but there were changes in times of observation, observers, and site locations. The range from highest to lowest 11-year means in the Newman study was 2.5 °F. Newman also reported the climate fluctuation for the entire northern hemisphere over the past 100 years was about 1.8-2.0 °F. The adjusted WLAF and WHIT temperature records compare favorably to these independent measures of climatic change, as opposed to the published records used by Agee (1980). Newman's 11-year means are also plotted in Fig. 5 to show that the general climatic trend agrees with that of the WLAF corrected record, although the more southern locations of the stations used in the Newman study result in higher temperatures.

Conclusions

The use of heterogeneous temperature records can produce biased results in climatological studies, and interpretation of these results can be misleading. In this paper, the climate change at West Lafayette, IN was interpreted as being extreme in its warming and cooling when the original published record was used. When the "non-climatic" heterogeneities in the record were removed, the general climatic trends of warming and cooling were decreased.

A must in any climatological study is the use of a climatological series. The biases inherent in the use of heterogeneous temperature data are transmitted to indices such as heating, cooling, and growing degree days as well as to timing of temperature threshholds. These indices are published and compared to those for past years regularly. If a temperature record contains heterogeneities, these indices will also contain biases, and may negate their use in management and planning studies. The results of any study can only be as reliable as the data which have been used.

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