A Practical Method of Correcting Monthly Average Temperature Biases Resulting from Differing Times of Observation

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ABSTRACT

Biases in monthly average temperatures reported by cooperative weather observers arise from once-daily observations of maximum and minimum temperatures at times of day other than local midnight. A scheme for adjusting these reports to eliminate the biases and make them conform to the midnight-to-midnight reports of first-order weather stations is described. This scheme has been applied to climatological reports of the Washington, DC, cooperative network.

1. The problem and its consequences

While the official first-order weather stations take their 24-hour observations at midnight, most cooperative weather observers record their maximum and minimum temperatures for the previous 24 hours around dawn, or in the afternoon or evening. The effects of these differences are often overlooked, even though they can have adverse effects on models and forecasts that relate average temperatures and various degree-day bases to seed germination, plant growth, insect emergence and fungi growth. Studies by scientists and engineers using degree-day bases can also be thrown off by these differences. When a cooperative station changes its time of observation, a fictitious climate change results.

This note proposes a computer programmable method of determining and correcting, on a month-to-month basis, the biases in monthly average temperatures attributable to differences in times of observation. Observations taken at midnight are defined as having zero error. Adjustments for non-midnight averages may then be applied each month to "correct" readings to the equivalent midnight values. All times are local standard times (LST).

Baker (1975), using a carefully calibrated three-year study of the effects of the time of observation on average temperatures at St. Paul, Minnesota found an annual average difference of 2.5°F between a sunrise and a 1500–1600 LST time of observation. This translated into a difference of 320 in the seasonal growing degree days (base 50) and over 700 in the annual heating degree days. The average difference was the largest (~3.0°F) from February through May, and smallest (1.6°F) in December.

Schaal and Dale (1977) noted a gradual, but significant, apparent cooling of Indiana's climate between 1935 and 1975, due to a gradual change in the predominant time of observation. In 1935, there were only 8 morning, but 58 afternoon temperature observers, while in 1975, there were 51 morning and only 29 afternoon observers. Schaal and Dale stated "The climate has 'cooled' 1.2°F in the past 40 years, solely because of a change in the time of observations". This cooling may have been overlooked, in part, because it paralleled a similar fictitious cooling occurring at the first-order sites as they were gradually moved from city offices to the cooler airports, and then in many cases, from second floor roof airport locations to the still cooler center-field sites.

2. An example of the problem

We assume that maximum temperatures of 45, 75 and 55°F occurred on 30 April, 1 May and 2 May, respectively. We assume further that each maximum occurred at 1600. An observer taking readings at 1600 on these dates would record maxima (the highest temperatures to have occurred during the previous 24 hours) of 75°F on both the 1st and 2nd. A 0700 observer would record maxima of 45 and 75°F on the 1st and 2nd (with these values actually having occurred on the previous calendar day), and the midnight observer would record maxima of 75 and 55°F, respectively. It is assumed that the midnight observer is the "correct" one (i.e., with readings having no "errors"). A comparison of the results is shown in Table 1.

The total divided by 31 (right column) indicates the effects of the time of observation of the 1 and 2 May maxima alone, on the monthly average May temperature. The 30°F difference between the 0700 and 1600 sums (150 minus 120) thus creates an "error" in the monthly average of 0.97°F (30 divided by

TABLE 1. Problem results.

Observation time	Reported maximum temperatures		Sum of maximum temperatures	Difference from midnight observations	
	1 May	2 May	1 + 2 May	Total	Total/31
Midnight	75	55	130	0*	0
0700	45	75	120	−10	−0.3
1600	75	75	150	+20	+0.6

* By definition.

31 days). By the same reasoning, if yesterday's *minimum* were 30°F, occurring at 0700 and today's low were 50°F an 0700 observer would show minima of 30°F both dates, while the 1600 and midnight readers would show 30 and 50°F, respectively. This difference would cause a 0.7°F "error" in the monthly average minimum.

The total "error" for an entire month should be approximately proportional to the average day-to-day variation in extreme temperatures. For example, if the successive maxima on 30 April, 1 May and 2 May above had all been 75°F, the resulting "errors" would have been zero.

3. Effects of month-end temperatures on averages

Maximum and minimum temperatures on the final day of the month can cause significant biases. For example, both the high and low recorded by an 0700 observer on the first day of the month may have occurred in the previous month. In the autumn, using a 31 October maximum in an 0700 observer's November record is likely to create a positive bias, since in a majority of cases, the 31 October maximum will be higher than the 30 November high, (which will appear in the December records). Note in the example in Section 2, that the 0700 observer's 1 May maximum of 45°F actually occurred in April.

4. Computation of Washington DC area adjustments

Over 200 volunteer weather observers in the Washington, DC metropolitan area take readings between 0600 and 1000 or between 1600 and midnight. Each month since 1974, thermograph traces have been used to determine average monthly maxima and minima for 24-hour periods ending at the above times.

Table 2 shows a 7-year average of adjustments that were applied to monthly average temperatures. These particular adjustments are applicable to other areas of the United States only in a general way. Washington area month-to-month adjustments often show large departures from these averages. Months with frequent frontal passages have higher variations in day-to-day extremes, and thus require larger adjustments. Table 3 expresses Washington area adjustments as percentages of daily variations in extremes.

5. A proposed scheme for computing monthly temperature adjustments

A computerized monthly temperature adjustment scheme requires access to hourly temperatures, such as those transmitted from 24-hour observing sites on NOAA or aviation communications systems. Also needed is a program that scans these hourly temperatures and "remembers" the highest and lowest readings midnight to midnight for each day of the month. Maxima and minima must also be extracted for 24-hour periods ending at other times of day at which cooperative stations take observations. A comparison of these with midnight readings averaged over the full month, would yield the required monthly adjustments. For agricultural purposes, some time other than midnight might be selected as the time to which other readings would be adjusted.

Adjustments to cooperative station averages should only be based on data from reasonably nearby 24 hour sites. For example, monthly averages from Indiana cooperative stations might be adjusted to whichever of the Fort Wayne, South Bend, Indianapolis, Terre Haute, Louisville or Evansville stations were closest. Blending adjustments from two 24-hour sites would usually result in more accurate results.

Data to be used in long-term climatological records should not be adjusted, as this would alter the "climate" for those stations.

TABLE 2. Average monthly adjustments (°F) as a function of local standard time of observation, Washington, DC area.

Time*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0600	0.65	1.02	1.15	1.08	0.77	0.63	0.45	0.42	0.42	0.43	0.42	0.42
0700	0.65	0.97	0.93	0.58	0.18	0.03	−0.05	−0.07	0.03	0.20	0.33	0.42
0800	0.45	0.53	0.53	0.22	0.00	−0.20	−0.22	−0.33	−0.32	−0.27	−0.03	0.17
1600	−1.57	−1.60	−1.65	−1.58	−1.32	−1.05	−0.90	−1.02	−1.23	−1.50	−1.62	−1.62
1700	−1.43	−1.40	−1.45	−1.35	−1.05	−0.78	−0.63	−0.72	−0.88	−1.08	−1.23	−1.28
1800	−1.02	−1.08	−1.08	−1.03	−0.82	−0.65	−0.50	−0.52	−0.62	−0.82	−0.85	−0.83

* All times are local standard.

TABLE 3. Adjustments expressed as a fraction of variability.

Time*	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0600	0.11	0.18	0.19	0.18	0.14	0.13	0.13	0.12	0.10	0.09	0.08	0.08
0700	0.11	0.17	0.16	0.10	0.03	0.01	−0.01	−0.01	0.01	0.04	0.06	0.08
0800	0.08	0.09	0.09	0.04	0.00	−0.04	−0.06	−0.09	−0.08	−0.06	−0.01	0.03
1600	−0.28	−0.28	−0.28	−0.27	−0.24	−0.22	−0.25	−0.28	−0.30	−0.33	−0.32	−0.29
1700	−0.25	−0.24	−0.24	−0.23	−0.19	−0.17	−0.18	−0.20	−0.22	−0.24	−0.24	−0.23
1800	−0.18	−0.19	−0.18	−0.17	−0.15	−0.14	−0.14	−0.14	−0.15	−0.18	−0.19	−0.18

* All times are local standard.

6. Conclusions

Significant biases in monthly average temperatures, caused solely by the time at which observations are taken, can cause serious "errors" in climatological averages and degree-day computations. These, in turn, cause problems with crop modeling, fuel usage and other computations based on degree days. These "errors" can be corrected. A program can be written that 1) scans hourly temperatures from 24-hour observing sites, 2) selects from these temperatures the highest and lowest readings for 24-hour periods ending at whatever times cooperative stations take observations, 3) determines adjustments needed to "correct" these readings to a common time of observation (i.e., midnight), and 4) applies this correction to nearby observing sites taking readings at other than the "common" time. Where the above programming is not feasible, but day-to-day variations in extremes can be determined, adjustments shown in Table 3 should be used. If daily variations are not known, Table 2 adjustments will be better than no adjustments at all.

REFERENCES

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