An Adjustment for the Effects of Observation Time on Mean Temperature and Degree-Day Computations

GREGORY P. BYRD

School of Meteorology, University of Oklahoma, Norman, OK 73019

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ABSTRACT

Biases in mean temperatures due to differing times of daily maximum and minimum temperature observation cause problems in evaluation of temporal and spatial anomalies in temperature and derived degree day values. These biases were examined using six years (1973–78) of digitized hourly temperature data taken at Oneonta, New York. An annual mean temperature difference of 2.5°F is noted between means computed with the 0600 LST and 1500 LST observation times, with individual monthly differences as high as 4.4°F. Maximum seasonal degree day biases were 743 heating degree days (HDD) (10.2%), 169 cooling degree days (CDD) (43.3%), and 299 growing degree days (GDD) (14.3%).

A modified version of the Blackburn method for adjusting mean temperature data for observation time bias is presented. The modified method involves adjusting data to a "true" mean obtained by averaging all hourly temperature values for the 24-hour period ending at midnight, rather than adjusting to the midnight standard observational mean obtained by averaging the maximum and minimum values over the same period. The adjustments are applied to mean temperatures from stations with different observation times in the region around Oneonta, resulting in spatial analysis fields which are believed to be more representative than those using the published data. This suggests that application of such an adjustment scheme results in a more homogeneous climatological data set.

1. Introduction

The National Weather Service Cooperative Observer Network is the primary data source used to determine detailed temperature climatology for the United States. Daily mean temperatures derived from these data are computed by averaging the maximum and minimum temperatures, and these means are used in the calculation of heating degree day (HDD), cooling degree day (CDD), and growing degree day (GDD) values. Daily values are usually tabulated in monthly and annual form and included in the climatological summary for the particular region in which the observing station is located. However, mean temperatures and degree day values computed from cooperative data may possess biases due to a number of factors, including differences in sensor type and placement and differences in time of observation, the latter of which this note addresses.

Documentation of observational time biases in mean daily temperature data dates back to Ellis (1890) and Bigelow (1909). It was found that mean temperatures computed by averaging maximum and minimum temperature values were highest if the observation was taken in the late afternoon and lowest if the observation was taken near sunrise. An observation time near midnight local standard time (LST) was found to yield the most representative mean temperature when compared to a "true" daily mean calculated by averaging 24 individual hourly values. These findings were further substantiated in more recent years by Mitchell (1958), Baker (1975), and Schaal and Dale (1977). In addition, Schaal and Dale (1977) showed that historical changes in observation time effected a "climate change" in Indiana. A practical method for adjusting temperature data for observation time biases was offered by Blackburn (1983).

The current study utilizes six years (1973–78) of digitized temperature data recorded at the State University of New York College at Oneonta, located in the Eastern Plateau Climate Division of Upstate New York. This study is divided into two parts, the first of which is an investigation of mean temperature and degree day biases due to the time of observation. To date, no intensive study of this type has been carried out over the interior section of the northeastern United States, a region with high winter energy demands which is very dependent upon accurate mean temperature and HDD values to estimate these demands. The Oneonta temperature and degree day biases are compared with those provided by previous studies. In the second part, a method of adjusting for observation time biases will be presented.

2. Methodology

Using the digitized hourly temperature data from Oneonta, "true" daily means were computed by sum-

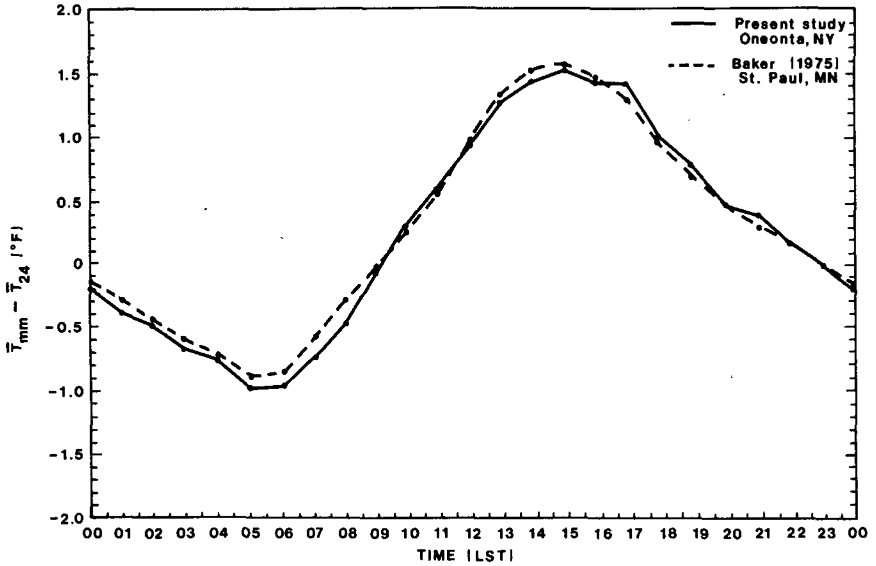

FIG. 1. Average annual deviation from mean temperatures computed from maximum and minimum values at different observation times ($\bar{T}_{mm}$) from the "true" daily mean ($\bar{T}_{24}$). (Monthly deviations shown in Table 1.)

ming the 23 hourly values from 0100 LST to 2300 LST with the average of the two midnight values and then dividing by 24, according to the method of Baker (1975). This "true" daily mean temperature served as the standard to which means obtained at different observation times were compared.

Mean temperatures for 24 individual hourly observation times from 0100 LST to midnight LST were obtained by averaging the maximum and minimum temperature values derived from the 25 digitized hourly values for each daily interval ending at the time in question. Although this method does not account for intra-hourly extremes, the mean temperatures varied by less than 0.2°F[1] from means computed from actual extremes for the midnight, 0700 and 1700 LST observing times. Monthly and annual mean temperatures were then tabulated.

In addition, degree day computations were made from the "true" means and the 24 observation time means. The HDD and CDD computations were performed using a standard base temperature of 65°F and the GDD computation used a base temperature of 50°F using a method outlined in Schaal and Dale (1977). The monthly and annual summaries of mean temperature, HDD, CDD and GDD form the basis of results discussed in the next section.

3. Results

Figure 1 shows the average annual deviation of observational day mean temperatures at various observation times ($\bar{T}_{mm}$) from the "true" daily mean ($\bar{T}_{24}$), with the results of Baker (1975) for St. Paul, Minnesota included for comparison purposes. The Oneonta data show that the largest negative deviation (−1.0°F) occurs with 0500 or 0600 LST observation time and the largest positive deviation (+1.5°F) with the 1500 LST observation. This makes for a possible range in annual mean temperature of 2.5°F, due only to the difference in observation time. The observation times most representative of a "true" annual mean temperature are 0900 LST and 2300 LST; however, these times may not necessarily be the best at certain times of the year. For instance, the most representative observation times are 1100 LST and 2200 LST for January and 0200 LST and 0800 LST for August. Comparison with the results of Baker (1975) shows a striking similarity in the temperature deviation, with the differences between the two curves seldom exceeding 0.1°F.

Monthly maximum deviations from the "true" mean temperature are given in Table 1, which shows the most negative values for each month to be near the time of sunrise and the most positive values to be from 1400 to 1600 LST. Table 1 also shows that ranges of mean daily temperature deviations are comparable to those found by Baker (1975). Ranges in the deviations were considerably higher for individual months than the six-year monthly means, with values as high as 4.4°F (March 1976).

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[1] This paper makes reference to published temperature data which are reported in degrees Fahrenheit. In addition, mention is made of degree day computations which are based on the Fahrenheit scale. Consequently, °F is used when reporting temperature data, for the purpose of clarity.

TABLE 1. Deviations (°F) from "true" mean temperatures for indicated month and observation time.

	Oneonta, NY (1973–78)			St. Paul, MN (1962–64)
Month	Largest positive deviation (Time)	Largest negative deviation (Time)	Range	Range Baker (1975)
Jan	+1.5 (1500)	−1.1 (0700)	2.6	2.8
Feb	+1.1 (1500)	−1.6 (0700)	2.7	3.2
Mar	+1.4 (1500)	−1.4 (0600)	2.8	2.9
Apr	+1.5 (1600)	−1.4 (0600)	2.9	2.9
May	+1.5 (1600)	−1.6 (0500)	3.1	3.0
Jun	+1.3 (1500)	−1.0 (0500)	2.3	2.4
Jul	+1.3 (1600)	−1.0 (0500)	2.3	1.9
Aug	+1.6 (1500)	−0.6 (0500)	2.2	2.3
Sep	+1.8 (1500)	−0.5 (0500)	2.3	2.7
Oct	+2.0 (1500)	−0.7 (0600)	2.7	2.8
Nov	+1.7 (1400)	−0.4 (0700)	2.1	2.2
Dec	+1.4 (1400)	−0.8 (0700)	2.2	1.6
Annual	+1.5 (1500)	−1.0 (0500)	2.5	2.6

In the interest of further comparison, Table 2 was constructed, showing monthly ranges in mean temperature deviations between 0700 LST and 1800 LST observation times, as provided by several studies. This comparison is especially appropriate, since observations at most cooperative climatological stations are taken at or near one of these two times. In general, regions with greater maritime influence (e.g., Washington, DC) have smaller ranges in mean temperature deviation while more continental regions such as Minneapolis have larger ranges, with the greatest values occurring during the winter and spring months. However, large ranges are also observed in the modified continental regime of Oneonta, with relatively high values extending through the summer months. When considered on an annual basis, the range of Oneonta temperature deviation appears to be larger than that at any of the other locations, suggesting that continentality is not the only factor controlling the magnitude of the range of temperature bias caused by differing times of observation. Apparently the frequent migration of Canadian polar surges and maritime tropical air masses into the interior Northeast maximizes observation time temperature bias in this region. Clearly the effects of other factors such as cloudiness, interdiurnal temperature change and daily temperature range must be investigated, as suggested by Mitchell (1958).

Degree-day biases were computed for the different observation times, from the mean temperature values. On an annual basis, 0600 LST observations overestimate the HDD by 320 (4.4%) and 1500 LST observations underestimate by 423 HDD (5.8%). This represents a range in the possible bias of 743 HDD (10.2%) due only to time of observation, slightly larger than the 700 HDD bias for St. Paul reported by Baker (1975). The annual CDD values were underestimated by 42 CDD (10.9%) and overestimated by 125 CDD (32.4%) for the 0500 LST and 1600 LST observations times, respectively. This represents a range in the possible bias of 169 CDD (43.3%) on an annual basis. The range between the 0700 and 1900 LST observations is 91 CDD (23.6%) which is 20 CDD larger than the range for Indianapolis observed by Schaal and Dale (1977), despite the fact that Indianapolis averages twice as many annual CDD. The 0500 LST observation underestimates May–September GDD by 37 (1.8%) and the 1600 LST observation overestimates by 262 (12.5%), for a maximum bias range of 299 GDD (14.3%) due to the time of observation. This is comparable to the 300 GDD bias for St. Paul reported by Baker (1975).

4. A method of adjusting temperature data for observation time bias

Blackburn (1983) suggested a very practical method for correcting temperature values to a common observation time (midnight LST) using digitized hourly temperature data. This method involves finding maximum and minimum temperatures from the hourly data for the midnight to midnight period, as well as for the 24 hour period ending at any time of observation within the cooperative network. The daily mean temperatures, obtained by averaging the maximum and minimum values for each day, are averaged on a monthly basis for midnight LST and any other once-daily observational time. By using the deviations of all cooperative observing time means from the midnight mean, the monthly mean temperature data for each observing site may be adjusted to the midnight standard.

TABLE 2. Mean T(1800 LST)*-mean T(0700 LST) for various locations (and record periods) across the United States (°F).

Month	Oneonta (1973–78)	Washington, DC** (1974–80)	St. Paul† (1962–64)	Indianapolis§ (1973–74)
Jan	2.1	1.7	2.2	1.7
Feb	2.2	2.1	2.6	2.3
Mar	2.5	2.0	2.3	2.5
Apr	2.3	1.6	1.9	1.4
May	1.9	1.0	1.6	1.3
Jun	1.5	0.7	1.2	0.6
Jul	1.9	0.6	0.4	0.3
Aug	1.7	0.6	0.8	0.7
Sep	1.4	0.7	1.4	0.8
Oct	1.6	1.0	1.4	1.5
Nov	1.6	1.2	1.3	1.1
Dec	1.2	1.3	1.1	1.0
Annual	1.8	1.2	1.5	1.3

* 1900 LST for Indianapolis
** from Blackburn (1983)
† from Baker (1975)
§ from Schaal and Dale (1977)

TABLE 3. Monthly bias of mean daily temperature (°F) calculated from maximum and minimum for day ending at midnight LST.

Month	Mean bias	Bias standard deviation
Jan	−0.2	0.47
Feb	−0.4	0.31
Mar	−0.2	0.38
Apr	−0.2	0.39
May	−0.3	0.37
Jun	−0.2	0.25
Jul	−0.2	0.20
Aug	+0.1	0.43
Sep	0	0.35
Oct	0	0.36
Nov	+0.1	0.41
Dec	−0.4	0.29
Annual	−0.2	0.20

While adjusting to the National Weather Service midnight standard is convenient and appears to be accurate when compared to the "true" mean on an annual basis, (cf. Fig. 1), results of the present study show that the midnight mean of the maximum and minimum is usually slightly lower than the "true" hourly mean for the individual months. Table 3 shows the midnight bias of the mean temperature relative to the "true" mean for each month averaged over the six year period. The standard deviations of the bias or departure are included to give the reader an idea of the year to year variability of the monthly biases. The magnitude of the mean bias is as high as 0.4°F in December and February, when about 16% of the individual months may depart by as much as 0.7°F from the "true" mean. In addition, the standard deviation indicates that 32% of all Januarys have biases which differ from one another by at least 0.94°F. With this in mind, a modification to the adjustment scheme of Blackburn (1983) is offered.

The mean temperature for the 24-hour period ending at each observation time may be computed following the Blackburn method. The monthly averages may then be compared to the "true" mean values, rather than the midnight mean of the maximum and minimum values, in order to determine monthly adjustments. These monthly adjustments may in turn be applied to various cooperative observing stations located reasonably near the 24-hour observing site.

Since the Oneonta site is near the center of the Eastern Plateau Climate Division, the adjustments were applied to temperature data for each station within this zone. The qualitative effects of such an adjustment on the areal mean temperature pattern can be seen in Figs.

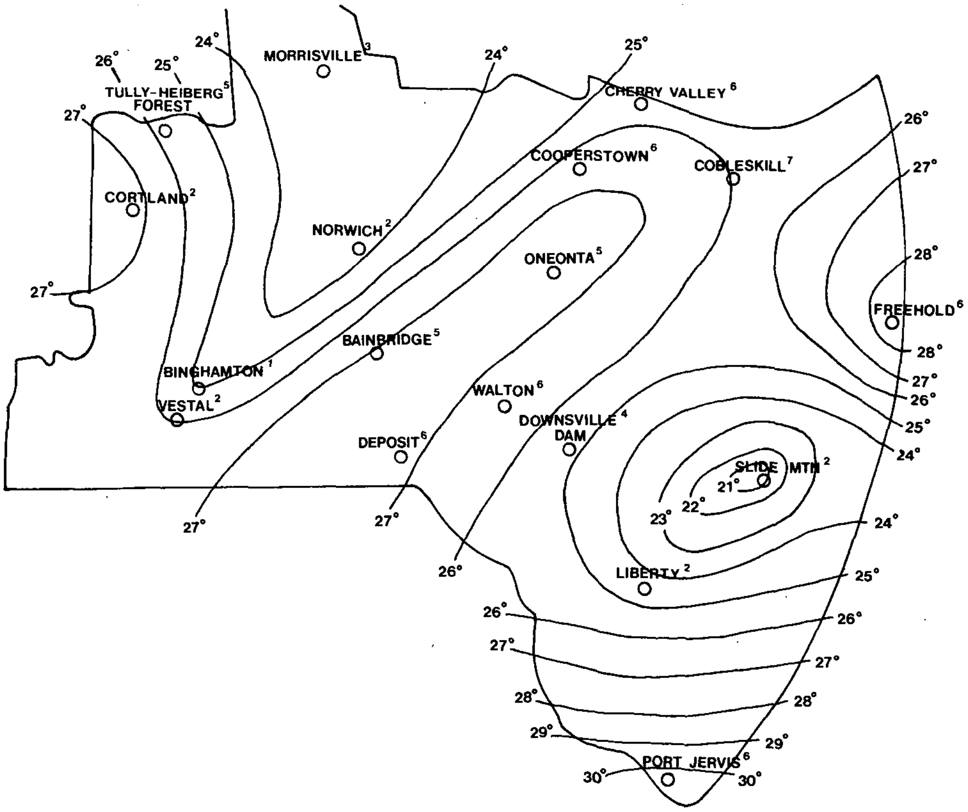

FIG. 2a. January 1975 published mean temperatures (°F) in the Eastern Plateau Region of New York.

2a and b. In the analysis of the published data (Fig. 2a), the most striking feature is the relatively cool region near Slide Mountain (elevation 808 m), located in the east central portion of the map. A very strong temperature gradient (9.9°F) exists between Slide Mountain and Port Jervis (elevation 143 m) to the south. Fairly significant temperature gradients are also noted between local warm and cold regions in the central and western portions of the analysis area. Adjusting the mean temperatures for the time of observation (Fig. 2b) smooths the pattern, especially in the region around Slide Mountain. In fact, the gradient in mean temperature between Slide Mountain and Port Jervis decreases to 6.9°F, a reduction of 3.0°F (30%) resulting from the adjustment for temperature bias alone.

The temperature adjustments may be applied to subsequent degree-day computations on a monthly and annual basis. This results in a smoother and more homogeneous data set after adjustment for observation time. The overall means of temperature and degree-days for the entire Eastern Plateau Division may be adjusted for the period 1973–78. If all of the cooperative observations are included in the division average, then the mean annual temperature and seasonal degree-day values must be adjusted by −0.34°F, +70 HDD, −53 CDD, and −129 GDD.

5. Summary and conclusions

Differences in observation time between climatological observing stations can result in significant errors in temperature and degree-day calculations. The difference in mean temperatures computed from the 0700 LST and 1800 LST observations at Oneonta was higher than the values observed at other locations, suggesting that observation time biases are just as, if not more, significant in the interior Northeast than those found in other, more continental locations in the United States. Other factors besides continentality, such as cloudiness, frequency of frontal passages, and diurnal temperature range may explain the monthly variability in the magnitude of observation time bias.

A modified version of Blackburn (1983) adjustment scheme for observation time bias has been applied to climatological temperature data in Upstate New York. The modification involves adjustment to a "true" daily mean obtained by averaging hourly values for the 24 hours ending at midnight, which is somewhat more

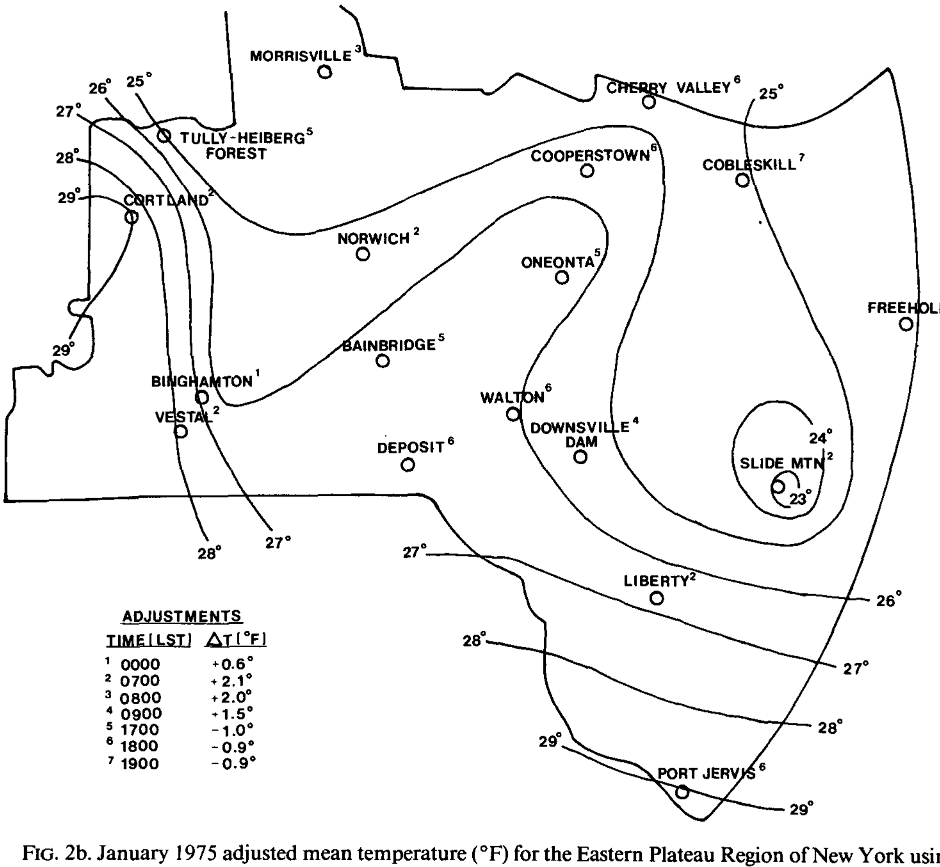

FIG. 2b. January 1975 adjusted mean temperature (°F) for the Eastern Plateau Region of New York using the adjustment scheme for observation time bias. The adjustment for each observation time (indicated by a superscript) is given at the lower left.

accurate than using an average of the maximum and minimum temperatures for the same period. The subsequent adjusted analysis fields appear smoother, with many anomalous regions being eliminated, suggesting that the data set is more homogeneous. Adjustments to mean temperatures using this scheme could be applied monthly, using the nearest 24-hour reporting station (or stations, using a weighting by inverse distances).

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