Climatology

MEAN TEMPERATURE DEVIATIONS AS A FUNCTION OF OBSERVATION TIME

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ABSTRACT

This investigation examines the variation of January, July and annual mean temperature as a function observation time, and is based upon three years of hourly air temperatures measured at Newark, N.J. International Airport from January 1976 to December 1978. These deviations were found to vary sinusoidally as a function of observation time and length of day and were compounded in the estimation of seasonal heating and growing degree day values.

1. INTRODUCTION

A major problem in the study of temperature trends is the multitude of random and systematic errors inherent in temperature and temperature-derived data. The causes of these errors are complex, but the most obvious are inconsistent station location, nonstandardized instrumentation, and observer changes. Daily mean temperature is defined as the sum, over a given 24-hour period, of the maximum and minimum temperatures divided by two. The observation time of the daily maximun or minimum temperature defines the end of each 24-hour period from which the daily mean temperature is calculated. Systematic variations in daily mean temperatures often result from shifts in the time of observation. Unitl recently, inadequate attention has been given to the extent and impact of this factor.

At major Weather Service stations, the observation reporting times are 1200 GMT for the overnight minimum temperature (12 hours), 1800 GMT for the 24 hour minimum temperature, 0000 GMT for the daytime maximum temperature (12 hours), and 0600 GMT for the 24 hour maximum. Twenty-four hour maximum and minimum temperature observations are also recorded at midnight, Local Standard Time (LST).

Most cooperative observers, however, use either early morning or late afternoon observation times usually 0600-0800 and 1600-1800 LST or Daylight Saving Time (DST), whichever is applicable. A comparison of mean temperature data with these disparities in observation time may destroy interstation homogeneity. If the mean temperature deviations from the midnight-to-midnight value are known for the other observation times, methods of coping with the disparities can be devised.

Mean temperature deviations due to variation in observation times are systematic and can be cumulative. This error can have an increasing impact on temperature-derived quantities such as Heating Degree-Days (HDD), and Growing Degree-Days (GDD). Such systematic errors may affect accuraacy and usefulness of these values.

This study will evaluate the mean daily temperature as a function of variation in the observation time, and will quantify the variability of this deviation. Factors that may influence these variations in mean temperature will be identified. Unless otherwise identified, all subsequent times discussed will either be LST or DST, whichever applies.

2. LITERATURE REVIEW

Several earlier studies evaluated the existence and magnitude of systematic mean temperature deviations sulting from the difference in mean, daily temperatures between the midnight-to-midnight means, and that of other 24-hour periods.

Rumbaugh (3) conducted a study using six years of data from Twin Falls, Idaho using the 8 A.M., 5 P.M., and midnight observation times. His results showed positive monthly and yearly mean temperature deviations at 5 P.M. and sunset, and generally negative deviations at 8 A.M. The maximum positive deviations ranged from 1.0^{o}F in January to 1.4^{o}F in July, while the 8 A.M. mean temperature deviations varied from -0.6^{o}F in February to +0.3^{o}F in July. He concluded that identical data can yield a change in monthly or annual mean temperatures by shifting the observation time, and that the 8 A.M. E.S.T. observation time had the smallest mean temperature deviations. His study, however, did not examine mean temperature variations for a succession of hourly observation times.

Mitchell (4) conducted one of the first comprehensive studies by calculating the annual and monthly mean temperature deviations for each hourly observation time between successive midnights. This study used hourly temperature data from eight first order stations from various climatic regions of the United States. Mitchell was the first to evaluate the effect of arbitrarily small changes in observation times. He derived mean temperature deviations for each station and calendar month at all observation times. Differences in the direction and magnitude of these deviations show up between each month and station. Although the greatest mean temperature deviation varies with the station and season, it always occurs during the hours near sunrise and in mid-afternoon. These time periods correspond to the usual time of occurrence of minimum and maximum temperatures. In Mitchell's study, the maximum mean temperature deviation varied from 0.3°F in July at Tampa, Florida, to 3.4°F in January and November at Austin, Texas.

Historical changes in observation times at cooperative climatological stations since 1900 may have introduced a systematic change in mean temperature. It may have contributed to the climatic cooling reported to have occurred between 1940 and 1984, and also had an effect on HDD and GDD totals. In a more recent study, Schaal and Dale (5) evaluated monthly mean temperature deviations at 0000, 0600, 1200 and 1800 GMT observation times at Indianapolis International Airport for 1973 and 1974. They found that a station with a 0700 observation time averaged 1.6°F cooler than one with a 1900 observation time, while the station observing at 1900 averaged 2.1°F warmer than stations using a midnight observation time. Considering the systematic change away from afternoon observation times at cooperative stations in Indiana between 1905 and 1975, Schaal and Dale found that the climate in Indiana cooled 1.2°F between 1925 and 1975 due to these changes.

Baker (6) investigated the effects of observation time on mean daily temperatures at St. Paul, Minnesota from 1962 to 1964. He calculated a daily mean by averaging 24 hourly temperatures, a daily mean derived from minimum and maximum temperatures between successive midnights, and a daily mean of maximum and minimum temperatures observed at all other hours of the day. These means were respectively defined as the true mean, the first order mean, and the cooperative mean.

He then determined the mean temperature deviations between the true mean and the first order mean temperature and the cooperative means for successive observation times. A plot of these deviations varied sinusoidally with negative mean temperature deviations for the 0100 to 0900 observation times and positive mean temperature deviations extending through the remaining observation time period.

Baker used monthly first order and cooperative mean temperatures to calculate seasonal May to September GDD and seasonal HDD. He found that a difference up to +700 HDD could result solely because of a change from a morning to afternoon observation time. This difference amounts to more than 8 percent of the annual HDD totals for Minneapolis, St. Paul. With GDD's, differences of nearly 300 result from changing observation times. This is equivalent to 13 percent of the May through September 50°F base GDD totals.

3. PROCEDURE

The true daily mean, defined as the average of 24 hourly temperature observations between successive midnights, is used in this study to determine temperature deviations from mean temperatures obtained from cooperative climatological stations. At volunteer or cooperative climatological stations, observations are taken at various times, usually in the morning or late afternoon. A climatological day may end at a 0800 or 1600 observation time, having started from the same 0800 or 1600 observation time of the previous day. The mean temperature calculated from these two cooperative station observation times on the same calendar day may be derived from minimum and maximum temperatures recorded from two different 24-hour periods. In this study, cooperative means are defined as those calculated using daily maximum and minimum temperatures from all hours, other than those for the midnight-to-midnight period.

Hourly temperaures recorded in °F for 1976, 1977, and 1978 for the National Weather First Order Station in Newark, N.J. were used to calculate January, July and annual true means and cooperative means. Temperatures obtained from the National Climatic Data Center were compiled on magnetic tape and indexed by consecutively counting each hourly temperature value from 0000 of January 1, 1976 to 0000 on January 1, 1979.

The daily true mean was computed by averaging the 24-hour values from one midnight to the next. Twenty-three of the 24 values were the hourly temperatures from the 0100 to 2300 observation times, with the 24th value calculated as the mean of the two midnight temperatures starting and ending each 24-hour day. This gave equal weight to each hourly value even though two midnight values were used in each daily mean. The daily cooperative means were obtained from the minimum and maximum temperatures within each 24-hour period extending from 0100 to 0100, 0200 to 0200, and sequentially to the 2300 to 2300 24-hour period. This was done by averaging the highest and lowest temperature of the 25 hourly sequential values between 0100 to 0100, 0200 to 0200, etc. The 24th value was calculated as the mean of the first and last value for each 25-hour sequence. The differences, or deviations, between the true and cooperative means were then tabulated and graphed. For purposes of this study, the annual values and those for January and July for each hourly observation time were evaluated and presented.

Annual HDD base 65° and GDD base 50° totals were computed from the true and the cooperative means. The observation time dependent differences in the annual HDD and GDD were tabulated and graphed for each of the 0100 to 0000 observation times for the three-year period.

4. RESULTS

Figures 1 and 2 illustrate the hourly mean temperature deviations between cooperative and true means for January and July. The sequential temperature deviations approximate sine curves and indicate temperature differences for each hour. The largest mean temperature deviation occurred in July at the 1500 observation time with a value of +1.5°F. In

January, the largest mean temperature deviation was $+1.4^{\circ}$F at 1500. The greatest negative mean temperature deviation was -0.9°F at the 0700 observation time in January. In July, the 0500 observation time had a mean temperature deviation of -0.6°F.

Figure 3 indicates the annual mean temperature deviations of the cooperative means from the true mean. As with the monthly deviations, the annual mean temperature deviations appear to follow a sine curve. The annual mean temperature deviations varied from -0.6°F at the 0500 observation time to $+1.4^{\circ}$F at the 1500 observation time.

The range in hourly deviations of mean temperature was 2.3°F in January and 2.0°F in July. The periodicity of mean temperature deviations follows the diurnal temperature cycle and is a function of day length. The lowest mean cooperative temperature deviations occur with an observation time within one hour of sunrise, and vary from about 0800 in January to 0500 in July. Maximum mean temperature deviations occur with observation times close to the time of the daily maximum temperatures.

Annual mean temperature deviations can result in significant variations in HDD and GDD totals as a result of cumulative computations. Cooperative mean temperature from most observation times will underestimate HDD totals, while the 0100 to 0700 cooperative observation time period will yield overestimates of HDD totals. The underestimation ranged up to 400 HDD at the 1600 observation time, while an overestimation on annual HDD of 120 occurred at the 0500 observation time (Figure 4).

Annual GDD values were, conversely, overestimated at most of cooperative means observation times except for the 0100 to 0600 observation time period. Variations were of comparable magnitude with overestimations of 300 GDD for the 1500 and 1600 observation times, and a small underestimation of only 122 GDD at the 0500 observation time (Figure 4).

5. CONCLUSION

The time of the daily temperature observation is critical to the comparability of mean temperature values with the mean temperature deviations a sinusoidal function of day length and diurnal temperature cycle. Time of observation induced differences in mean daily temperature have serious consequences on HDD and GDD approximations since they are summed over a period of several months. Care must be taken in the application of the recently issued 1951-1980 normals of temperature, HDD and GDD for both first order and cooperative stations, since these data are not corrected for deviations due to the time of observation.

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FOOTNOTES AND REFERENCES

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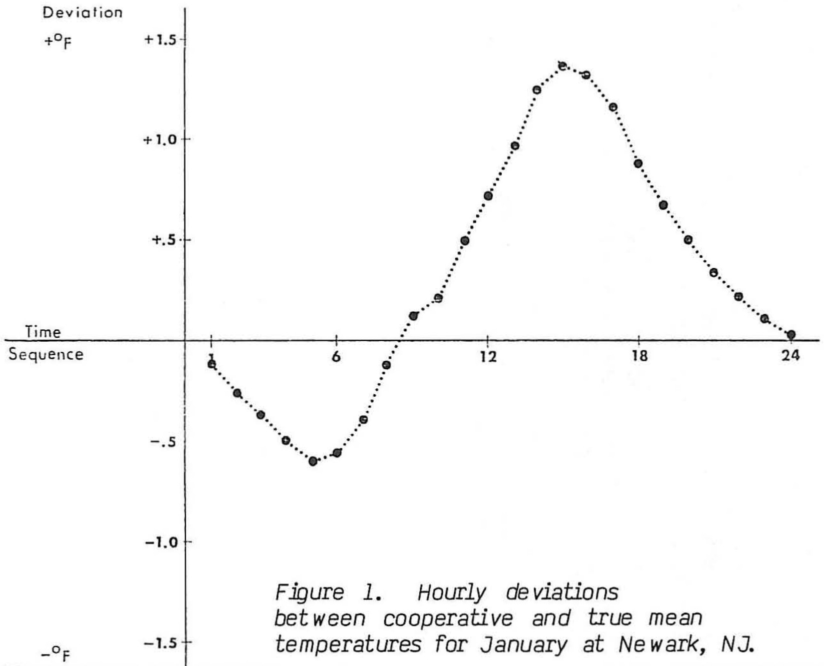

Figure 1. Hourly deviations between cooperative and true mean temperatures for January at Newark, NJ.

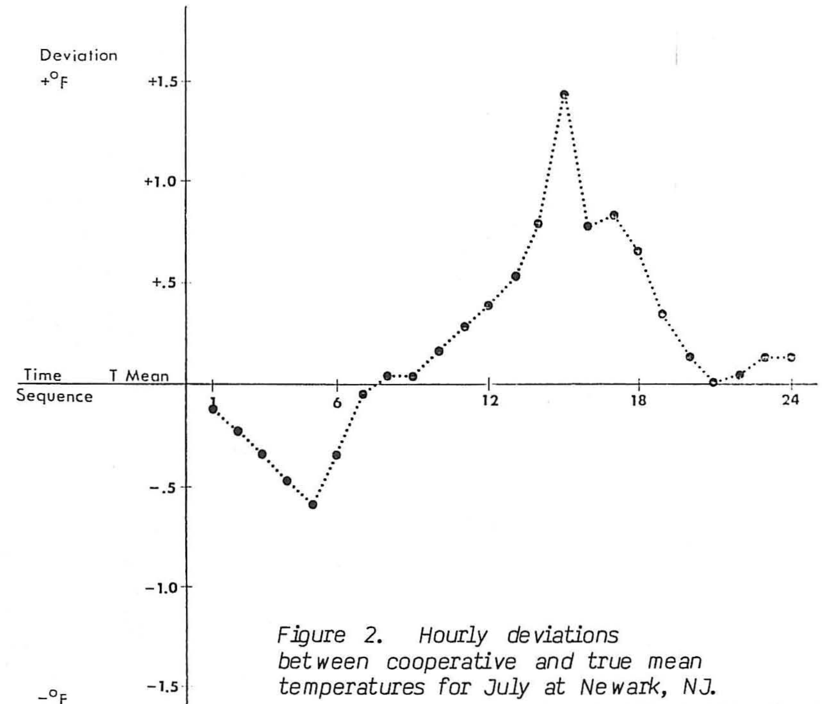

Figure 2. Hourly deviations between cooperative and true mean temperatures for July at Newark, NJ.

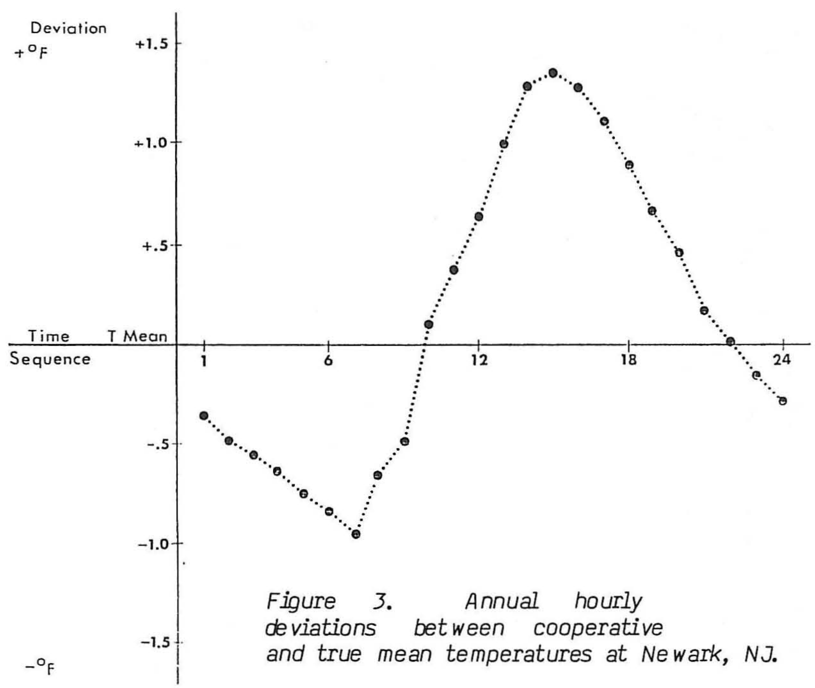

Figure 3. Annual hourly deviations between cooperative and true mean temperatures at Newark, NJ.

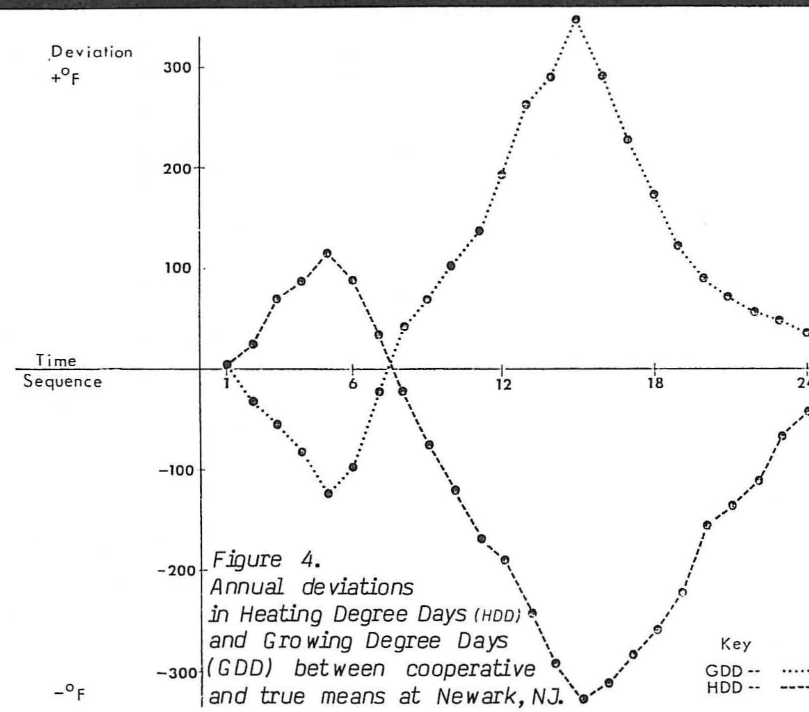

Figure 4. Annual deviations in Heating Degree Days (HDD) and Growing Degree Days (GDD) between cooperative and true means at Newark, NJ.