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REGIONAL VARIATION OF MEAN TEMPERATURES BIASES AS A FUNCTION OF THE TIME OF OBSERVATION

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INTRODUCTION

When attempting to relate the mean temperature of one station with that of another, or when investigating temperature for temporal stability, the data must be as error-free as possible. The daily mean temperature for National Weather Service (NWS) Cooperative Stations is currently computed from the daily readings from maximum-minimum thermometers, read once per 24 hrs at some hour convenient to the observer. The time of daily observation may impact daily, monthly, and annual mean temperatures to such a degree that spatial or temperal comparisons are not reliable. Time of observation biases may equal the magnitude of real change, (see, e.g.,) Mitchell, 1953; Schaal and Dale, 1977; Dale *et al.*, 1983).

If a cooperative observer reads the maximum thermometer at 1600 hrs, near the time of maximum daily temperature, that maximum temperature may be recorded for that day and also for the next day. (i.e., carried-over maxima) This will occur if the maximum for the next day is less than that of the previous day that it occurs later than 1600 hrs. Extreme minimum temperatures would be recorded on 2 successive days if the observations are taken near the time of minimum temperature for similar reasons.

Because the time of observation bias is a systematic error (Mitchell, 1958; Baker, 1975), observations may be appropriately corrected. Mitchell (1961) and Nelson *et al.*, (1979) discussed methods to remove the time of observation bias from mean temperatures for some stations, but corrections for stations on a synoptic scale are not available. Further, corrections previously published were determined from relatively short time series of data. In consideration of studies based on small data sets, this study determines the long term time of observation biases introduced into mean temperature for the Midwest and High Plains determined from 15 years of hourly observations from National Weather Service first-order stations.

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LITERATURE REVIEW

The first known published report of the effect of the time of observation on mean temperatures was that of W. Ellis in 1890 (Nichols, 1934). Since that time, at least eight other papers appeared, either analyzing the magnitude of the time of observation bias for one or a few stations, based on only a few years of data. These papers are reviewed in Mitchell (1958), Baker (1975) and Dale *et al.* (1983), and will not be repeated here.

DATA AND PROCEDURES

Fifteen years (only 10 yrs data from Peoria) of quality hourly temperatures were acquired from 10 NWS first-order stations from the Midwest and High Plains for the period 1948-1964. Table 1 lists the stations, number of missing hourly observations, length of record, and location. Missing data were interpolated using a 4-point Lagrange linear interpolating scheme. If more than 6 successive values were missing in any given sequence of 14 temperatures, that day's data were deleted from the study. Only one day's data were so treated. Missing data accounted for less than 0.1% of any data set.

The mean of the highest and lowest hourly temperatures within the 25 hours ending at each hour of the day was calculated for all days of each month of all years. For each 24-hour period at least one reading was from the preceding calendar day. These calculations were made to simulate means derived from maximum and minimum thermometer observations made once per day at any hour of the day for each month of the year. Fifteen-year means (ten year means for Peoria) were then derived for each month using the above series of daily means. The means derived from the hourly temperatures for any given observation hour were defined as:

$$\frac{1}{D}\sum_{i=1}^{D}\left[\frac{\max(T_h)+\min(T_h)}{2}\right]_i \qquad h=1,2\ldots 25 \qquad 1)$$

where D is the number of days in the years of record, T_h is the hourly temperature, max (T_h) is the maximum value of the 25 hourly temperatures (h = 1, 2 . . . 25), and min (T_h) is the minimum value of the 25 hourly temperatures.

Means derived from 25 hourly readings ending at midnight are herein termed "midnight means." Means from hourly readings with the day ending at any other hour of the day are termed "hourly means."

The biases are herein defined as the magnitude of the hourly minus the midnight mean temperatures. These biases for each hour were plotted on graphs for all months for each station. Maximum positive and negative biases (regardless of the hour) for each month were also computed at each station.

GENERAL RESULTS AND DISCUSSION

Figure 1 presents the biases for Des Moines for August and December, the two extreme months which exhibit extreme magnitude biases. They are representative of the shape of the bias curves of all stations studied. Mean temperatures generated from readings beginning between 0100 hours and about 2 hours after sunrise are generally lower relative to midnight-to-midnight means (*i.e.*, a negative bias). The sign and magnitude of the bias at any hour is related to the number of carryover maxima or minima from one day to the next, thus raising or reducing, respectively, the resulting means. Negative biases are therefore the result of carryover of more frequent minima, and positive biases because of more frequent maxima.

Figure 1 clearly exhibits asymmetric distribution about the zero bias. The areas above and below the zero bias for August are clearly different from those of December. In general, for those stations, the area under the zero bias increases from November to March. The negative area decreases from April to October. From September to November the biases for 0100 and 0200 are positive. This is due to a more frequent occurrence of previous day maxima carryover for these particular hours during these months. Minimum biases generally occurred within an hour of sunrise, (more often following sunrise) whereas maximum biases tended to occur between 1400 and 1600 hours. There is an obvious resemblance of the bias curves to the march of diurnal temperature, (Fig. 1). e.g., (1) the rapid rise of the bias to zero deviation approximately 2 hours after the maximum negative bias, in most cases, (2) to the maximum maximum positive bias, and (3) the decrease thereafter. This is expected since the greatest negative biases for a given month are expected to occur near the time of minimum temperature (i.e., the time with most frequent minima carryover). The largest positive bias should occur around the time of the maximum temperature. The areas above the negative portion of the bias curves are smaller than the corresponding area under the positive portion bias because temperatures near a day's normal minimum is more nearly the same from day-to-day than those near the maximum (Landsberg, 1966). Thus, even though minima carryover dominates early morning readings, the frequency of minimum carryover year round is relatively less than that of maxima carryover for late morning and afternoon to evening hours.

Figure 2 presents the greatest negative and positive biases for each month for the 10 stations. This figure is important for showing any trends or similarities that exist in the extreme biases during the year. The greatest positive and negative bias curves are similar in shape for most stations, *i.e.*, the minimum and maximum positive bias centers on July and October-November, respectively. Sault Ste. Marie was an exception, reaching its maximum in May, and minimum in March or December, with a secondary minimum in August. Also, while most stations' minima occurred in March, Sault Ste. Marie reached a minimum in February. Flint's greatest positive bias curve peaked in September, with minima occurring in mid-winter and late summer. The biases for these two stations are affected by proximity to the Great Lakes.

For most stations the greatest magnitude of the extreme negative and positive biases occurred near March and November, respectively. Baker (1975) attributed the former to the fact that temperatures in March are increasing at a maximum rate for the year. Thus, when readings are taken at a given hour near the time of morning minimum (*i.e.*, the negative bias), the minima at the beginning of March are generally lower than those at the end of the month (compared to all other months). Hence, the minimum for a day is more frequently included as the minimum for the following day in addition to the normal carryover tendency for morning readings. The greatest positive bias was generally found in November, but for the opposite reason, *i.e.*, daily mean temperatures at this time of year are decreasing at the maximum rate. The maximum temperatures at the beginning of November are almost always higher than those near the end.

The annual march of the greatest biases for 1400-1600 hours reflects the importance of the relationship between diurnal sun control (temperature response to solar forcing) and frontal passage frequency on interdiurnal temperature change (see Fig. 2). In the lower latitude stations (e.g., Dodge City, St. Louis) the pronounced minimum in the positive bias curves in summer is due to the relatively stable (although large in amplitude relative to winter) diurnal variation of temperature during these hours (*i.e.*, maximum temperatures change relatively little from day-to-day). Studies by Calef (1950), Sumner (1953), Visher (1954), Landsberg (1966), and Crowe (1971) support this claim. The curves of the more northern stations have a less defined minimum in summer. This is because the effects of frequent frontal passage and cyclones in these regions dampen the impact of diurnal sun control (Reihl, 1942; Trewartha and Horn, 1980). This is especially true in Sault Ste. Marie and Flint, where the frequency of cyclonic events is greater than at other stations of the study area (Reitan, 1974; and Zishka and Smith, 1980).

A decrease in magnitude of the negative bias generally occurs from March to November (Fig. 2). This is due to the changing trend of annual temperature from decreasing positive slope from March to July to increasing negative slope from July to November.

SUMMARY

The time of observation bias has been recognized by researchers since the late 1800's, although past studies focussed on the bias at one or two stations, and the biases were calculated from temperature records of only a few years length, and thus may have been unstable.

The time of least bias generally occurred between 1 and 3 hours after sunrise and again near midnight. Mean temperatures derived from once per day readings taken after midnight but before the time of zero bias were generally lower than the 2400 hours mean (*i.e.*, negative biases). Means from readings after the time of zero bias until midnight were higher than the midnight means (positive biases).

The biases can be used to correct mean temperatures calculated from maximum-minimum thermometers read once per day at any consistent hour within the study area. For example, mean temperatures derived from observations of a given hour, whose corresponding bias is negative, under-estimates a midnight-to-midnight mean, and must be increased by the magnitude of the bias. This will correct the mean temperature upward to a best estimate of the mean calculated from maximum-minimum temperature readings recorded at midnight during the same period. A positive bias indicates that the calculated mean is greater than a midnight reading by the magnitude indicated.

The following findings were central to this study. Biases for means calculated from once per 24 hour observations of maximum and minimum thermometers were determined for each hour for each month for 10 Upper Midwest and High Plains stations. The specific results for Des Moines, a station central to the area, are summarized in detail below. Relative differences between these results and those from the other 9 stations follow. For mean temperatures for Des Moines, determined from 1500 hours local time observations:

(1) the bias ranges from + 1.0°C to +1.1°C from January through April;
(2) the bias decreases to +0.8°C in May to +0.7°C in June and July;
(3) the bias increases to +0.8°C in August and +1.1°C in September; and
(4) the biases range from +1.2°C for October to +1.3°C for November and December.

At this station a change in the observation time from 1500 to 0600 hours in April, say, would result in a decrease of 1.8°C in the calculated mean temperatures.

For the entire study area, the spatial land temporal changes were found to be as follows:

1. For most months positive biases were greatest in the west and least in the east and northeast of the study region.
2. Monthly negative biases were relatively uniform (ca. 0.5 degrees C) in magnitude across the region, except during November when they were greatest in the southwest and least in the northeast.
3. Positive biases were greatest in late autumn and winter, (up to 2.5°C) and least in summer (ca. 0.5°C). This difference in the magnitude of the biases between seasons was greatest in the south and least in the north. The positive biases of Sault Ste. Marie and Flint were greatest in late spring and early fall, and least in winter, due to their proximity to the Great Lakes.
4. Negative biases were greatest in late winter (−1°C), and least in the autumn (ca. 0.2°C) with gradual changes in the negative biases for months between these extremes.

Areas of similar correction can be delineated, *e.g.*, Peoria, St. Louis, and Indianapolis all exhibit a bias of about +0.6°C in July for a 1500 hours observation. Stations located between these 3 stations would experience a similar correction. In March, the corrections at 1500 hours are +1.2°C at Springfield, MO and St. Louis, +1.0°C at Des Moines, +0.9°C at Peoria, and +1.1°C at Indianapolis.

Actual correction values from each of the 10 stations for any hour for any month are too voluminious for presentation here, however, they may be obtained by communicating with the North Central Regional Climate Center, Illinois State Water Survey, 2204 Griffith Dr., Champaign, IL 61820.

Corrections by this method can be applied to the many weather station records throughout the region. However, large bodies of water, aspect and local topography can modify the biases. Caution must be used when interpolating between stations of different local geography.

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REFERENCES

Baker, D.G., 1975: Effect of Observation Time on Mean Temperature Estimation. *J. Appl. Meteor.*, *14*, 471-476.

Calef, W., 1950: Interdiurnal Variability of temperature Extremes in the United States. *Bull. Amer. Meteor. Soc.*, *31* 300-302.

Crowe, P.R., 1971: Concepts in Climatology. Longman Group Limited, London.

Dale, R.F., Nelson, W.L., and McCarranan, J.P., 1983: The Effect of Bias in Divisional and State Mean Temperatures on Weather-Crop Yield Model Predictions - A Case Study in Indiana. *J. Clim. and Appl. Meteor.*, 22 1942-1952.

Landsberg, H.E., 1966: Interdiurnal Variability of Pressure and Temperature in the Coterminous United States. U.S. Weather Bureau, Washington, D.C., Tech. Paper, 56, 53 pp.

Mitchell, J.M., Jr. 1953: On the Causes of Instrumentally Observed Secular Temperature Trends. *J. Meteor.* 10, 244-261.

Mitchell, J.M., 1958: Effect of changing Observation Time on Mean Temperature. *Bull. Amer. Meteor. Soc.*, *39*, 83-89.

Mitchell, J.M., Jr., 1961: *The Measurement of Secular Temperature Change in the Eastern United States.* U.S. Dept. of Commerce, Weather Bureau Research Paper No. 43. Washington. 80 p.

Nelson, W.L., Dale, R.F., and Schaal, L.A., 1979: Non-Climatic Trends in Divisional and State Mean Temperatures - A Case Study in Indiana. *J. Appl. Meteor.*, *18*, 750-760.

Nichols, E.S., 1934: Time Limits of the Day as Affecting Records of Minimum Temperature. *Mon. Wea. Rev.*, *62*, 337-343.

Reitan, C.H., 1974: Frequencies of Cyclones and Cyclogenesis for North America, 1951-1970. *Mon. Wea. Rev.*, *102*, 861-868.

Riehl, H., 1942: Introduction to the Atmosphere, 2nd E., McGraw-Hill, Inc. New York.

Schaal, L.A., and Dale, R.F., 1977: Time of Observation Temperature Bias and "Climate Change". *J. Appl. Meteor.*, *16*, 215-222.

Sumner, A.K., 1953: Standard Deviations of Mean Monthly Temperatures in Anglo-America. *Amer. Geog. Society*, *43*, 50-59.

Trewartha, G.T., and Horn, L.H., 1980: An Introduction to Climate. McGraw-Hill Book Company, New York.

Visher, S.S., 1954: Climate Atlas of the United States, Harvard Univ. Press Cambridge.

Zishka, K.M., and Smith, P.J., 1980: The Climatology of Cyclones and Anticyclones over North America and Surrounding Ocean Evirons for January, and July, 1950-77. *Mon. Wea. Rev.*, *108*, 387-401.

Table 1. Station locations, the years covered by the data, and the number(#) of missing values.

Station	Years Covered	# Missing Hourly	Latitude[1]	Longitude[1]	Elevation[2]
Bismarck	1950-64	8	46	100	1650
Des Moines	1950-64	21	42	93	940
Dodge City	1950-64	11	37	100	2580
Flint	1950-64	8	43	83	750
Indianapolis	1950-64	114	39	86	790
Peoria	1950-64 & 1957-64	26	40	89	650
St. Cloud	1950-64	11	45	94	1030
St. Louis	1950-64	7	38	90	540
Sault Ste. Marie	1950-64	1	46	84	720
Springfield	1950-64	59	37	93	1270

[1]Whole degrees
[2]Nearest tens of feet

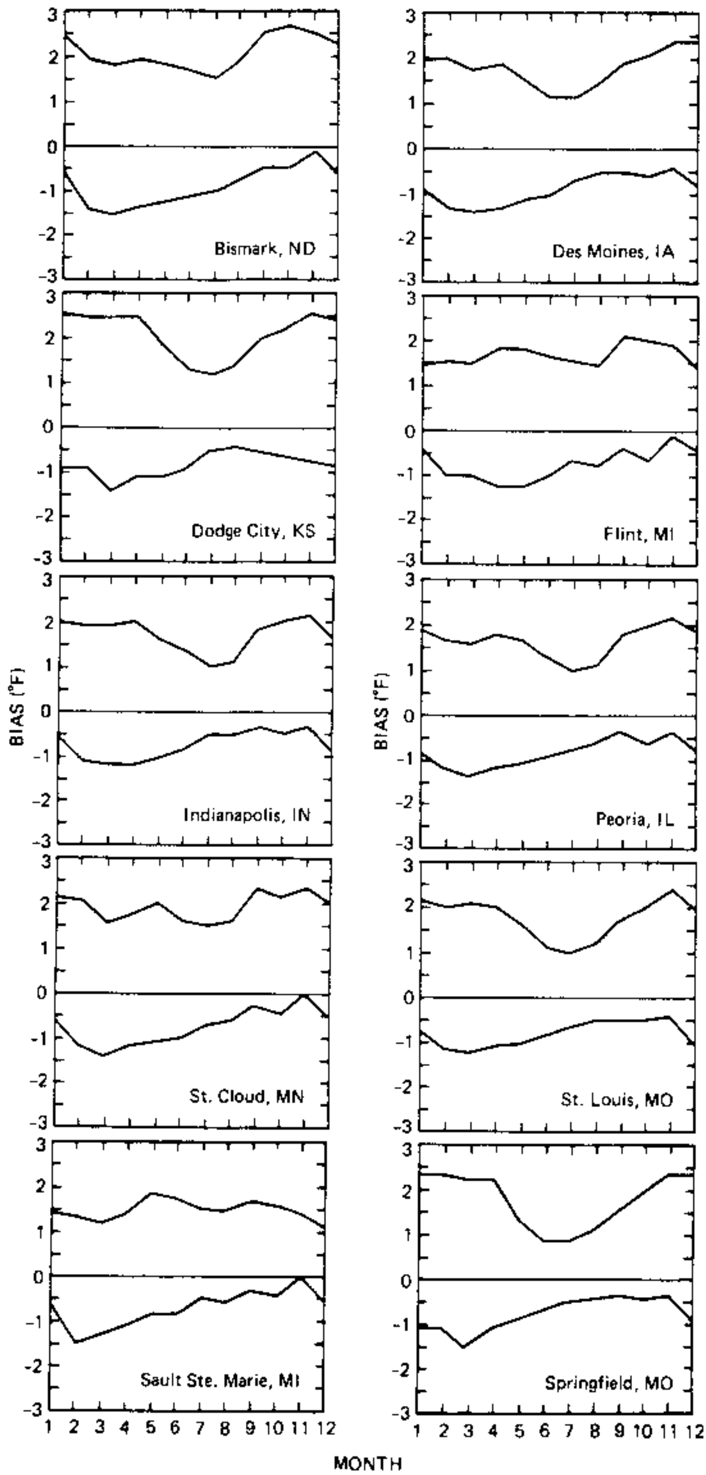

Fig. 1. Hourly biases (°F) for Des Moines IA for August and December.

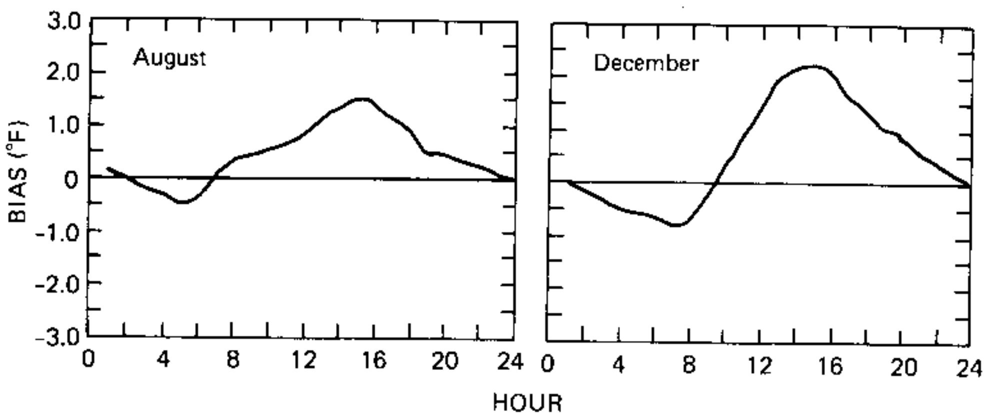

Fig. 2. Greatest positive and negative biases (F°) for each month by station.