# TOBS - Time of Observation

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Since my previous examination of the historical record of climate temperatures for my home town of Lebanon, Missouri back in 2010, I have been curious about how Time of Observation (TOBS) bias corrections were made to that record. For my home town of Lebanon, Missouri, I saw a warming trend of about 0.6 degrees Celsius over the last century. The NASA Goddard Institute for Space Studies (GISS) data showed TOBS bias adjustments of up to 0.8 degrees Celsius:

( *See http://climate.n0gw.net/GISS%20vs%20Raw.pdf* )

This is my effort at satisfying that curiosity about the reasoning behind those adjustments.

## Time of Observation?

What is Time of Observations (TOBS)? Well, that is simple: it is the time an instrument reading was taken. Technicians and engineers take instrument readings. Scientists make temperature "observations." They are all doing the same thing but "observation" sounds more sciencie. TOBS is thus simply the time that a temperature measurement was done. This observation time is always recorded along with the daily temperature readings though, as you will see, not always in a form that is particularly useful.

The best description I found on the subject of Time of Observation issues was in a document named "A Model to Estimate the Time of Observation Bias Associated with Monthly Mean Maximum, Minimum, and Mean Temperatures for the United States" by Karl, Williams, Young, and Wendland. (Journal of Climate and Applied Meteorology, Volume 25, February 1986.) Unfortunately that 28 year old article ended with the statement "*An ANSI FORTRAN-77 computer program is availble from the authors at cost…*" That, along with the description of the temperature data sets they worked with made me decide to learn more about the subject before trying to track that ancient FORTRAN program down.

There was a more recent paper attempting to evaluate that 1986 paper. It was titled "An evaluation of the time of observation bias adjustment in the U.S. Historical Climatology Network" by Russell S. Vose, Claude N. Williams Jr., Thomas C. Peterson, Thomas R. Karl, and David R. Easterling. This article claimed that their checks using hourly temperature data from 500 stations verified the correction algorithm described by Karl et al. Unfortunately, insufficient information was supplied to identify the stations tested or the exact algorithms employed to achieve that verification. That article did not improve my understanding of Time of Observation issues.

Something important has happened in recent years that makes an investigation into the subject of Time of Observation bias corrections feasible for amateur's like me. That is the establishment of the U. S. Climate Reference Network (USCRN) of 114 high accuracy climate monitoring stations. Many of the station records now cover several years of five minute triple redundant temperature readings.

While the relatively small number of years of USCRN data is probably still a little on the short side for analysis as performed for this document, it does provide fifty thousand to over one hundred thousand hourly data points to work with for each station. Additionally, the overall climate temperature trend has been relatively flat during that period, minimizing that as a possible confounding factor in analysis.

## TOBS Bias Correction?

TOBS bias corrections are adjustments made to temperature records to attempt to tweak the historic temperature records to be more accurate. I suppose the first question to answer is: Why do we need a time of observation correction on carefully collected temperature data? After all, as long as daily records show the average temperature for the previous 24 hours, why should it matter what time of day those reading were collected?

Well, time of observation would likely not matter very much if we were dealing with true average values. Unfortunately, only the sophisticated computerized stations of the USCRN (U. S. Climate Reference Network) provide true average temperature values. Most historic records were collected by people reading glass Min/Max thermometers once per day. These thermometers register the lowest and highest temperatures they were exposed to since last reset – the minimum and maximum – Min/Max. Each time the thermometers were read, they were reset. Some arbitrary time like 7AM or 5PM would be chosen but sometimes that changed. This may seem at first to be a little sloppy scientifically but it was not.

It should be understood that this century old data collection effort is a tremendous success story. Before it began, little more than anecdotal information was available about the temperature ranges experienced in different parts of the United States and the rest of the world. Within the design of the historic temperature data collection effort, changes in observation times were not very important. After all, the goal was to catalog the relative climate at many different places. High accuracy mercury in glass minimum and maximum temperature indicating thermometers were installed in very specific enclosures – the Stevenson Screen, also known as the Cotton Region Shelter. Additionally, installation site requirements were specified. When properly installed and correct observation protocols were followed, temperatures recorded with these stations were very likely within a degree or two Fahrenheit of true air temperature. Those 19$^{th}$ century scientists that designed and established this temperature monitoring system deserve our respect. An accuracy of plus or minus a couple of degrees Fahrenheit was certainly good enough to understand what might be expected for climate in one location versus another. Unfortunately, in recent decades, questions about possible global climate change have arisen but the available Min/Max temperature record is all that is available for analysis. That data does not provide sufficient accuracy in its original form to measure climate change as it has been experienced in recent decades. So…

## TOBS Corrections?

What are we attempting to correct with TOBS corrections? The first thing is fairly obvious when you think about it.

**Figure 1** shows the hourly temperature profile for each month of the year for Joplin, Missouri. This station is very near the center of the United States thus seemed a reasonable starting place for my investigation. If you look carefully, you will notice that the lower traces for the winter months show a shorter daytime temperature hump than the upper summer traces. That is simply reflects the shorter number of daylight hours during the winter. That means, of course, that in the winter there are more cool hours in the day than warm hours and vice versa for summer.

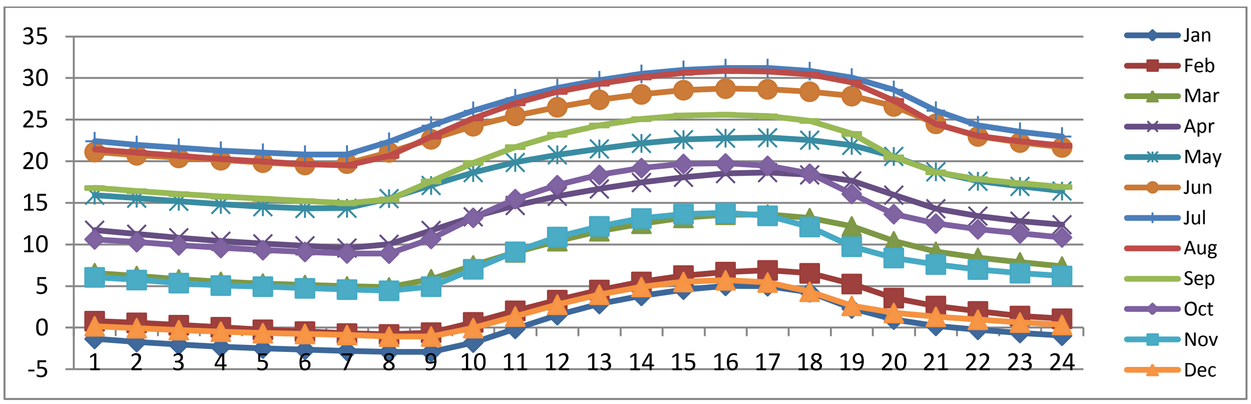


***Figure 1:*** *Joplin, Missouri hourly temperature profile.*
*(Vertical scale is in degrees Celsius)*

Current practice with Min/Max records is to assume the median of the day's high and day's low temperature is the average temperature for the day. Stated differently, we use a temperature half way between the Min and Max readings for the previous 24 hours as the day's average temperature. With the day to night length differences each month, we can expect Min/Max derived temperatures to vary from true average by different amounts each month.

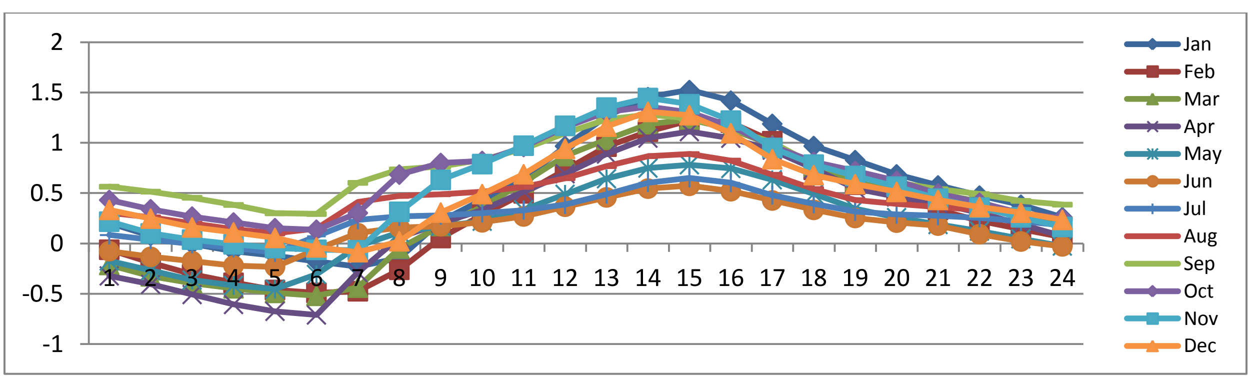


***Figure 2:*** *True daily average versus Min/Max derived daily average temperature.*
*(Degrees Celsius as calculated at the same hour. Joplin, Missouri)*

**Figure 2** demonstrates the problem with Min/Max for use in determining daily average temperature. Depending upon what hour of the day we 'observe' air temperature, it will differ from true average and that difference will vary from month to month. Next, we can also see that if we are change from observing temperatures at 7:00 AM to 'observing' them at 5:00 PM, we will introduce somewhere around a degree Celsius jump in our recorded temperatures – at least for Joplin, Missouri as shown.

By now, you are probably wondering about the shape of the curves in **Figure 2** above. If the difference between Min+Max divided by two and the true average is the result of the difference in the day/night hour ratio, why aren't the lines straight? Those lines because Min/Max temperature observations can contain the high or low temperature from the previous day. As an example consider a 7 AM observation time. That is around the time of daily minimum temperature. If the previous day's temperature at that the time of observation was lower than the current day's temperature, it is that previous day's low that will be left in the Min/Max thermometer set. That carryover from one day to the next will cause colder mornings to register for two consecutive days. A similar effect occurs when collecting observations in the warm part of the day where previous day's high temperatures can override the current day's temperatures.

We can also see in **Figure 2** that each month's bias curve shape varies. You will likely realize is due to seasonal variations. In spring time, day to day temperatures are slowly rising so carryover from previous cooler days will include the small offset from them being simply one day earlier. Likewise, autumn day to day temperatures are cooling so carry over from a previous day adds a small positive bias to afternoon observations. As before, since we are using the median of Min and Max, those offsets impact our monthly averages.

## Midnight Min/Max

But wait, there's more! Recall that the historic records are Min/Max with no true average for reference. A true average record is really only available from the new USCRN network stations. Instead, a somewhat arbitrary but reasonable choice was made to use the midnight Min/Max median temperature as the daily average and to 'correct' recorded values by applying a TOBS bias correction.

**Figure 3** shows Min/Max derived daily temperatures for each hour versus what would have been recorded at midnight. You will no doubt notice that **Figures 2 and 3** are similar. **Figure 3**, however, shows all of the curves converging at midnight (hour 24). That is because it is the reference hour. The curves gradually diverge going back through the hours until 1 AM the previous night (hour 1).

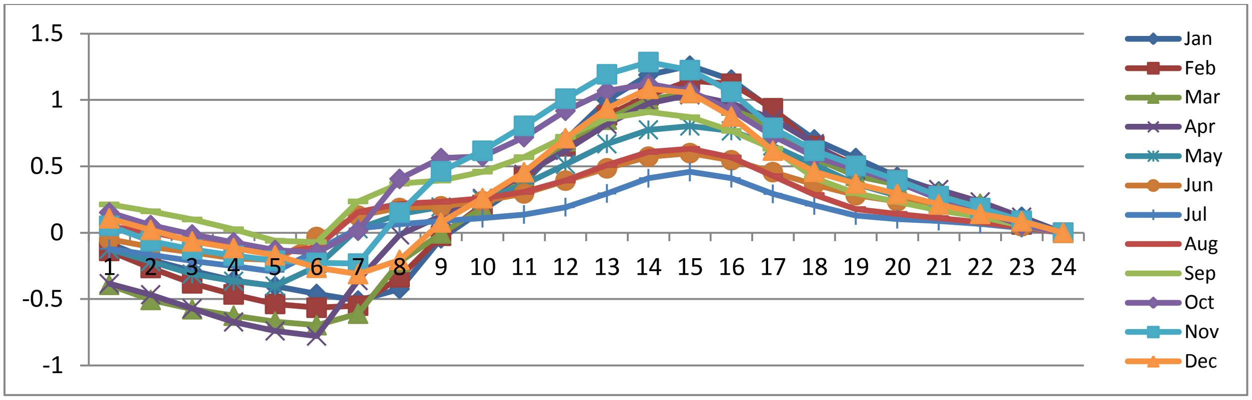


***Figure 3:*** *Midnight versus hourly Min/Max derived daily average temperature.*
*(Degrees Celsius. Joplin, Missouri)*

So now we have a multiple source of offset or bias using the historic Min/Max temperature data sets as compared to true average temperature for each day. First with have the issue of daylight versus night time hour differences each month, then carry over issues, and then the issue of our midnight reference value itself being offset by some amount from true value. How large is that second midnight Min/Max median error from true average?

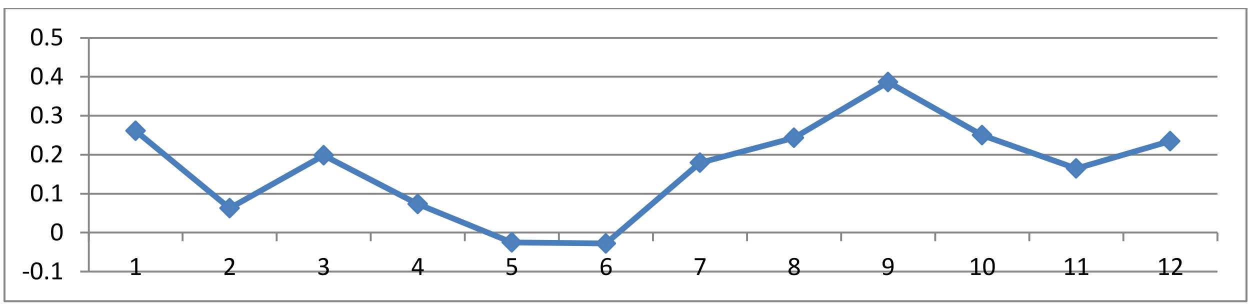


***Figure 4:*** *Midnight true average versus midnight Min/Max median temperature for each month.*
*(Degrees Celsius. Joplin, Missouri)*

**Figure 4** shows that there is a bias of approximately 0 to plus 0.4 degrees Celsius between true and the Min/Max median midnight temperature. This bias is currently ignored in climate studies. There is not much use attempting to adjust for it if all you have to work with is Min/Max data. The irregular temperature steps in figure 4 indicate that the seven years of Joplin USCRN records available cover too short a time span for definitive diagnostic results.

## But what is the Observation Time?

There is another problem and that is about time. While I mentioned specific times for TOBS above, unfortunately those are merely guesses. While I haven't examined all of the historic record images, some of the earlier documents that I did see list times as "Evening", "Morning", or some other non-time-specific word. Examine **Figure 3** above again looking at the morning and evening areas. Notice that morning and evening are when the greatest hour-to-hour changes in TOBS bias occur. That presents a problem in attempting to decide what bias correction to use when given the “Morning” or “Evening” descriptors.

Even when specific times are given (or assumed), the use of local standard time is another problem. As and example of this issue, consider two closely spaced stations on either side of a time zone line. Each will be recording similar temperature readings but for different Local Mean Time hours. Those two stations would then be given different bias correction values based upon the recorded times.

Then again, the issue of time zones itself is a problem. The currently existing four U.S.A. time zones were established and made into law in 1918. Prior to that, many cities and counties used solar time based upon almanac sun rise and set times. At one time, it was estimated some 300 different time zones existed in the U.S. Furthermore, the four time zones were shifted over time, typically with the boundries shifting slightly westward with each of these changes.

Of course, Daylight Savings Time enters into the time of day issue also. It is difficult to determine which stations recorded their temperature readings based upon Local Mean Time or Daylight Savings Time though Local Mean Time was usually specified. Determining if Daylight Savings Time was in effect on any given day at any specific site is quite problematic. Until the mid twentieth century, observation of Daylight Savings Time was region by region and even city by city.

The solution to the time zone problem is to convert station times to solar time. Solar time is a function of longitude and in the case of Joplin at 94.58 degrees west longitude, 12:00 noon local standard time would actually be about 11:37 AM local solar time. Thus station time zone difference would be reduced. That is, reduced if we know the actual TOBS and not that it was “Morning” versus “Evening. ” Oh, and also what the time zone and Daylight Savings Time status for a station for the day that a high/low temperature observation was recorded.

It is a very large leap of faith to assume we know exactly what time a temperature observation was made and recorded in our historic records. Depending upon individual station climate characteristics, errors of only plus or minus one hour could introduce as much as about 0.5 decrees Celcius (about 1 degree Fahrenheit) error.

## Didn’t They Know About This?

OK, this all makes sense but didn’t the original designers of the system know about this problem? Probably they did. However, it was likely to be of only minor concern for them. They were attempting a massive project with the knowledge they would be dealing climate differences between locations of greater than 50 degrees Celsius during the course of the year. That was the information they were trying to capture.

But that is not the end of the story. There have been second hand reports that early monitoring station data recorders were instructed on the TOBS problem and were taught techniques to minimize it. In other words, some stations may have had manual correction for TOBS error at the time of data collection. Simply applying a TOBS correction to all historic data may not be correct. That issue aside, let's continue…

## Monthly Min/Max Data

So far I have discussed hourly data shown for each month of the year. The temperature value that most analysis is done with is the median of the monthly averages of Min and Max. Thus the analysis is done using just 12 values per year. Of course, when you have a century of Min/Max data, you have 1200 data points to work with. So what is the big deal with this?

TOBS bias adjustment becomes a large issue when using monthly temperature records. The time of observation information is lost. Especially with manually collected Min/Max temperature values, the time of observation often varied a little from day to day. Fortunately system administrators did manage to have most large shifts in observation times occur at the beginning of a month. That was not always the case though. If TOBS bias corrections are to be applied, they must be done to daily records before those records are used to develop monthly averages.

## TOBS Drift

In the Karl, Williams, Young, and Wendland article mentioned above, pages of discussion are dedicated to something called 'drift.' This referes to a potential bias introduced into the monthly temperature records by the inclusion of hours of Min/Max information from previous months. As an example of this, consider temperature observations made at 1 AM every day. Very likely both the minimum and maximum temperatures recorded on the first day of a month would actually be those that occurred during the last day of the previous calandar month. Depending upon the actual time of observation, some degree of data 'drift' would show up in monthly data values. Of course, the part of the current month's data would also be stolen to show up in the following month's data.

This monthly temperature drift would could result in up to one day's shift in each month's timing, producing a lower monthly average than otherwise in the spring and a higher monthly average in the fall. Recall that few, if any, historic temperature observations were collected at 1 AM. Temperature observations collected at more realistic times of day will, of course, show less drift. In terms of long term temperature trends, the spring and fall drifts cancel any total annual drift bias to under a few hundredths of a degree Celcius. As interesting as the subject of drift due to month boundry overlap is, I was unable to determine this has introduced a particularly noticeable annual bias into the historic records in spite of the examples presented in the Karl, Williams, Young, and Wendland article.

## Joplin, Missouri TOBS bias vs. TOBS corrections for nearby USHCN station

I thought it might be interesting and perhaps informative to compare the TOBS offset values from the USCRN data for Joplin to those applied by USHCN to temperatures from a nearby US Hisortic Climate

Network station. The USHCN data is available on line. It is simple to create a plot of the TOBS corrections applied to that data by subtracting the raw data from the TOBS corrected data.

The nearest USHCN station to Joplin, Missouri turned out to be Neosho, Missouri. Neosho is about 15 miles south of Joplin and in similar terrain and elevation. It has a continuous record of daily high and low temperatures from 1893 to present. **Figure 4** below is plot of the TOBS corrections applied to the Neosho temperature record.

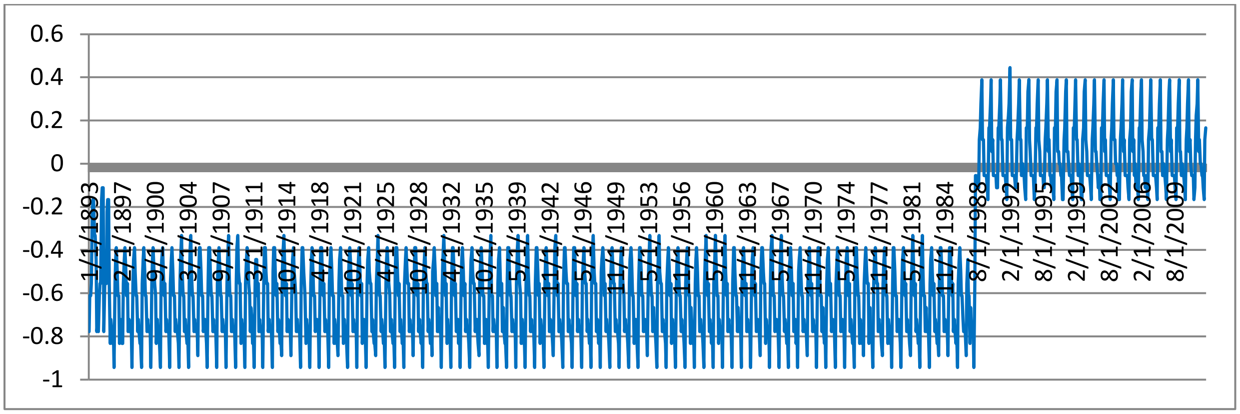


***Figure 4:** Neosho TOBS corrections (Degrees Celsius)*

You may notice that there are two major TOBS correction profiles applied to the Neosho data. The first for about 1895 through 1987 and the second from 1987 through the present. These two profiles are for temperature observations done two different times of day. The Pre 1987 observation times varied from 4:30 PM to 5 PM and the post 1987 observation times were 8 AM.

So, what can we do with this? We can produce the monthly TOBS values for these two periods and then compare them to the USCRN Joplin monthly values for the same time of day.

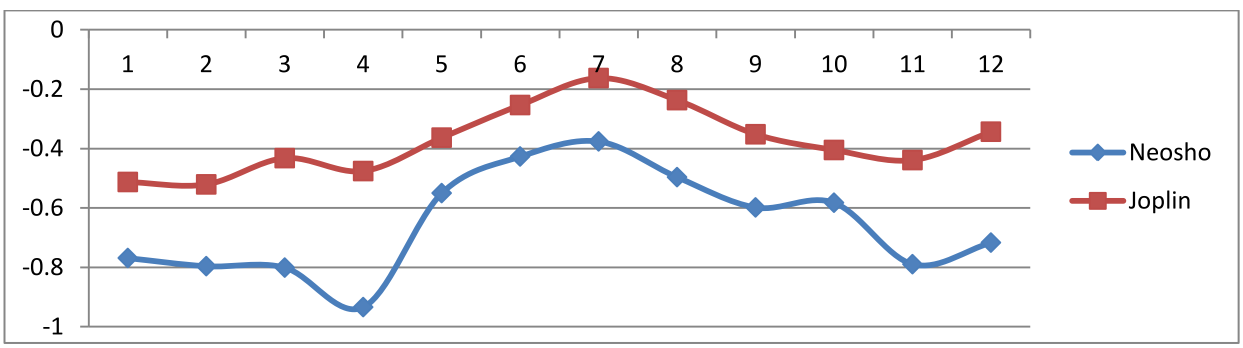


***Figure 5:** Comparing 5 PM Neosho TOBS correction to Joplin calculated correcton (Degrees Celsius)*

The blue trace in **Figure 5** above shows the corrections applied by USHCN to the Neosho, Missouri historic data for the years 1896 through 1986. The red trace shows the calculated correction needed for 5 PM temperature data collection versus midnight time of observation. The two traces are similar in shape but different in magnitude. Averaged over the 12 month period, the TOBS correction for Neosho cause run 0.3 degrees Celsius greater negative than what would expected if the calculated correction values from Joplin were used.

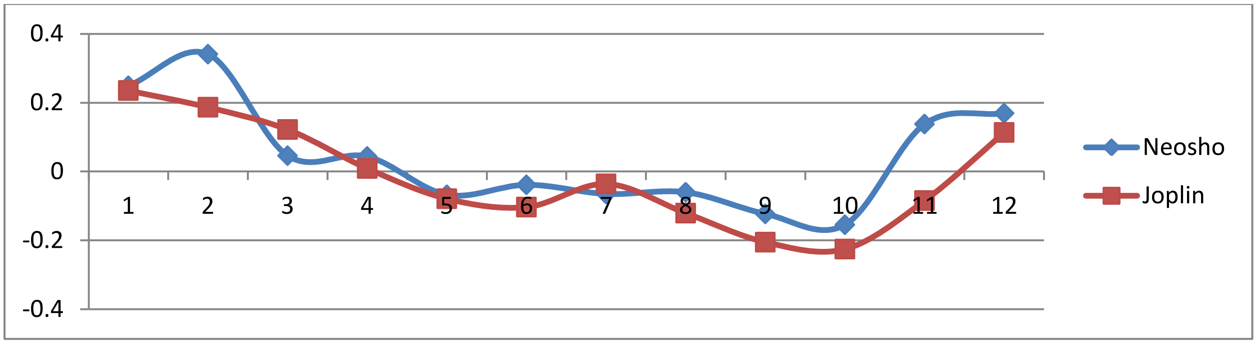


***Figure 6:*** *Comparing 8 AM Neosho TOBS correction to Joplin calculated correcton (Degrees Celsius)*

In **Figure 6** above, we can again see that the Joplin calculated and the Neosho TOBS correction traces are similar in shape. The difference in magnitude is much smaller. Averaged over the year, the USHCN TOBS corrections to the Neosho temperatures are 0.06 degrees Celsius greater than indicated by the Joplin midnight observation time corrections.

What does the Joplin-Neosho comparison tell us? Keep in mind that the Joplin calculated values are based on a very small number of years. The Joplin values must be used with caution. However, differences between what Joplin's calculations show and what was actually used to correct Neosho are great enough to indicate that the Neosho TOBS corrections should be flagged for further investigation. As it stands now, the Joplin calculated TOBS correction values indicate the USHCN TOBS corrections are adding a false 0.3 degrees Celcius warming to the Neosho records.

## Joplin, Missouri? What About Other Places?

As I said earlier, I chose Joplin, Missouri as a well known location close to the center of the contental U.S. What do the graphs look for other locations? There are 114 USCRN high accuracy climate monitoring stations scattered around the USA. While it is certainly possible for me to provide graphs and comments on all of them, I doubt your interest in the subject would survive my providing them in this document. Instead, I am providing a small number of examples in Appendix A to this document.

## Location, Location, Location

The temptation at this point might be to suggest that we could use the data from our 114 USCRN stations to correct the historic Min/Max station records. That would require us to make several questionable assumptions. First, of course, is assuming that the hourly and monthly temperature profiles of historic climate stations are similar to their closest USCRN stations. After all, some stations began in what were literally one horse rural towns that became or were engulfed in major urban cities. Some were moved.

Each historic temperature monitoring station had it own unique site environment. Very few, if any, of the historic monitoring stations were located in carefully prepared and protected sites like the USCRN stations. It is unlikely that many would have the same exact TOBS bias profile as any nearby USCRN station.

## Preliminary conclusion

My opinion is that attempting to correct for TOBS bias as is currently performed is not likely to reliably improve overall ***accuracy*** of historic temperature records. Midnight daily Min/Max median temperatures exhibit offsets from true averaged temperatures values for most temperature monitoring stations. However, much more effort has been placed in achieving ***consistency*** in historic records.

Consistency is obviously impacted for any single station if the hour of temperature observation is changed. A shift in temperature increase of approximately one degree Celsius (about 2 degrees Fahrenheit) or more could be expected at some sites when shifting from morning to evening observation times. Likewise, a shift from evening to morning could produce a similar amount of decrease in recorded temperatures. Then, of course, knowing what time historic temperature observations were actually made and reliably correcting them to solar time is likely impossible. There is also the question of whether our historic temperature stations have maintained observation quality and precision to make TOBS bias corrections meaningful when other sources of error and bias are considered.

I am left with the conclusion that current efforts to remove TOBS bias from historic records are a false path to improvement. That does not mean I do not believe there is a TOBS bias in our historic records. In fact I have verified to my own satisfaction that is does exist. The problem is in how that bias is estimated and corrected. Insufficient information exists in our historic records to determine both the exact solar time of temperature observations and the associated bias at all but a very few historic sites.

What are we to do about TOBS bias? There is likely little that we should do. The difficulty, of course, is that the system was never intended or designed to reliably show the small and glacially slow global temperature drift we may have experience over the current span of our historic records. Instead we should acknowledge the true accuracy (or if you prefer: inaccuracy) of our historic temperature records. The results of our historic temperature monitoring efforts are magnificent. We have over a century of historic climate information about all parts of the U.S.A. and other parts of the world. Attempting to second guess the efforts of a century of dedicated field observers is not productive. Acknowledge the limits of our knowledge!

# Apendix A

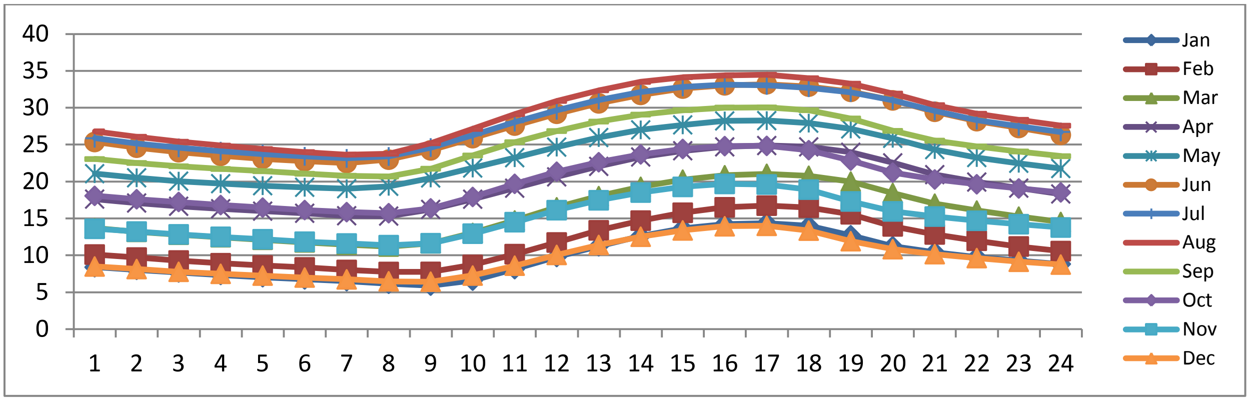


***Figure A1:*** *Austin, Texas temperature profile – (Celsius)*

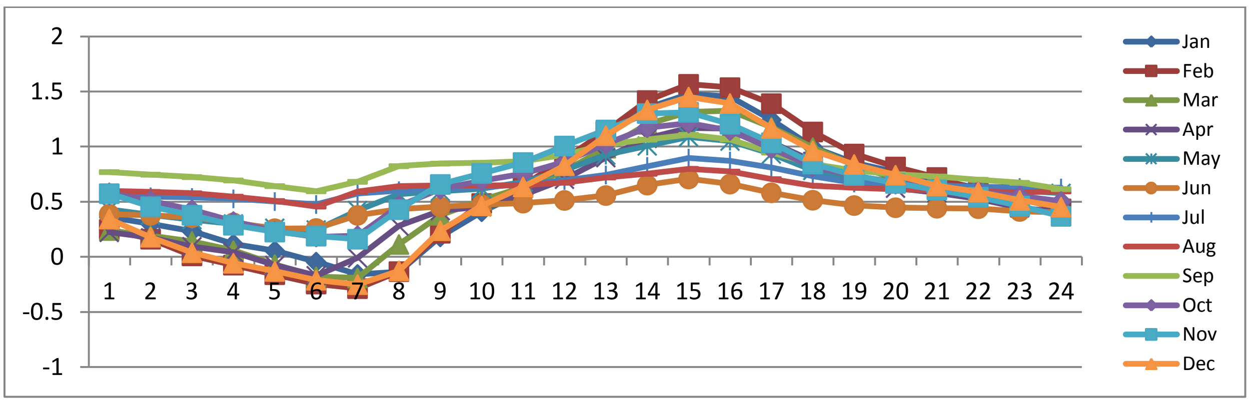


***Figure A2:*** *Austin, Texas Min/Max versus true midnight average – (Celsius)*

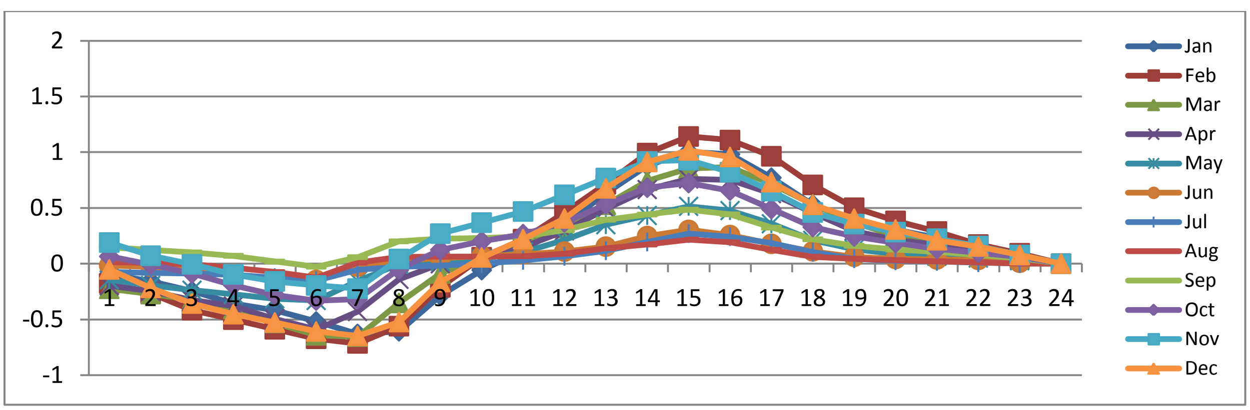


***Figure A3:*** *Austin, Texas 24 hour Min/Max versus midnight 24 hour Min/Max – (Celsius)*

Austin, Texas: We can see in **Figure A2** that midnight 24 hour Min/Max values are centered around +0.5 degrees Celsius above the true average. In fact, most of Austin's Min/Max 24 hour values are above true average. As for Joplin, Missouri, the difference between 7AM and 5PM bias is about 1 degree Celsius.

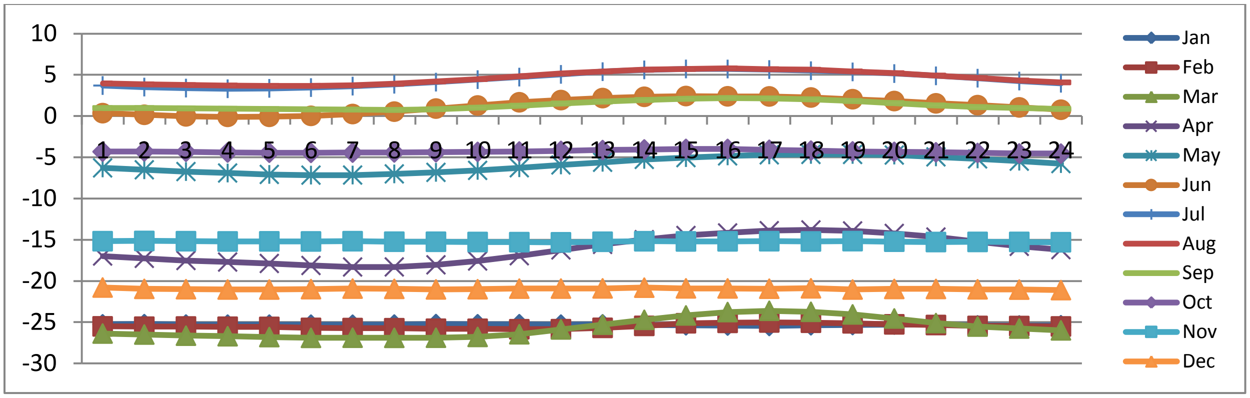


***Figure A4:*** *Barrow, Alaska temperature profile – (Celsius)*

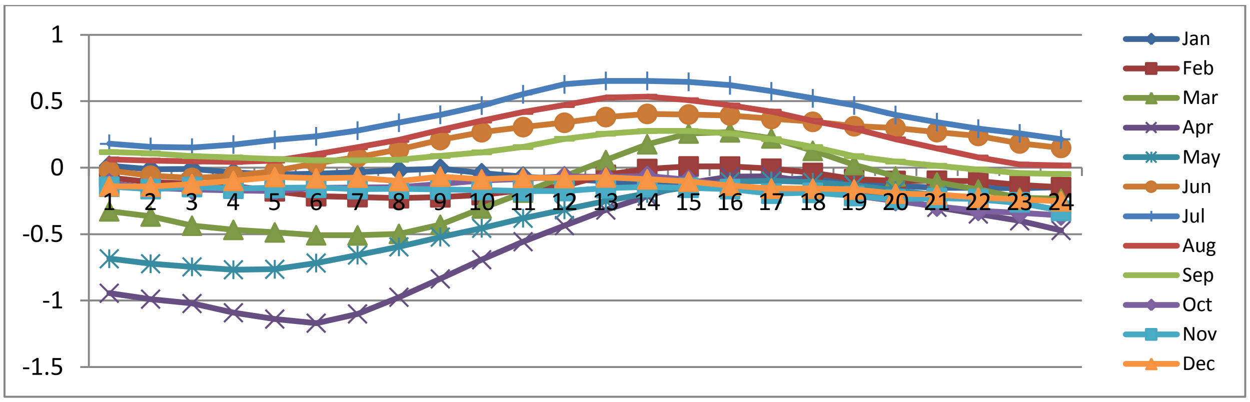


***Figure A5:*** *Barrow, Alaska Min/Max versus true midnight average – (Celsius)*

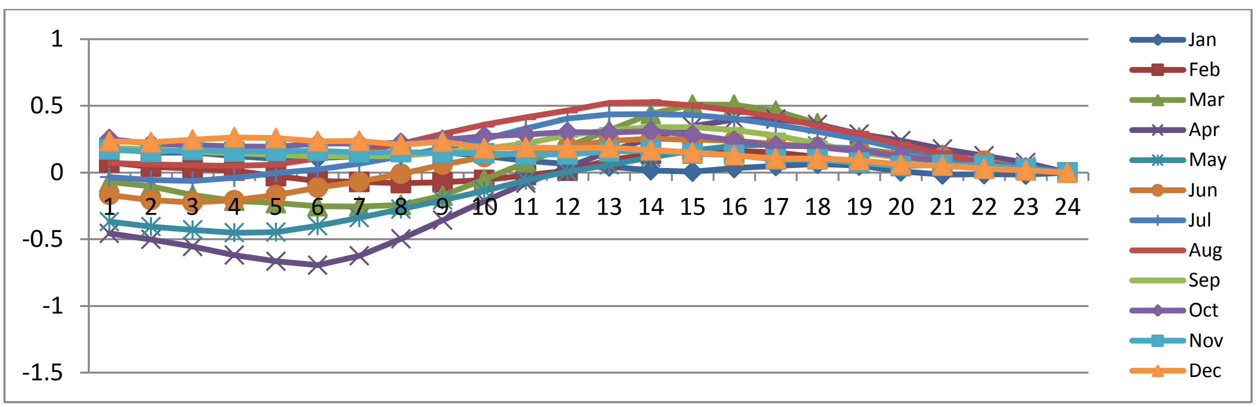


***Figure A6:*** *Barrow, Alaska 24 hour Min/Max versus midnight 24 hour Min/Max – (Celsius)*

Barrow, Alaska: I find the temperature profile in **Figure A4** above a bit outside my comfort zone. Only averages for June, July, August, and September make it above freezing. I think what is unique in **Figure A4** above is how winter average temperatures remaing flat for the day. I believe this reflects the lack of sunlight during the winter months. Obviously relatively little TOBS bias would be evident during those months.

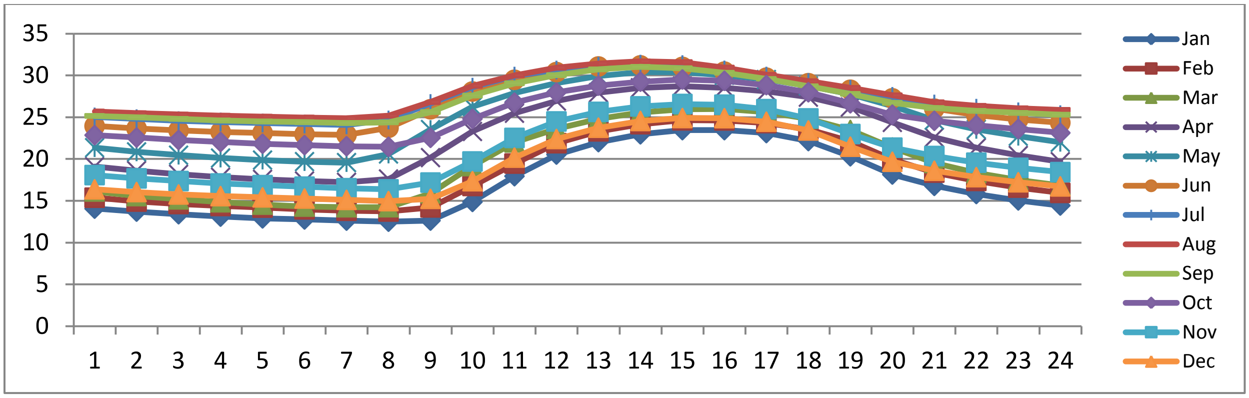


***Figure A7:*** *Everglades, Florida temperature profile – (Celsius)*

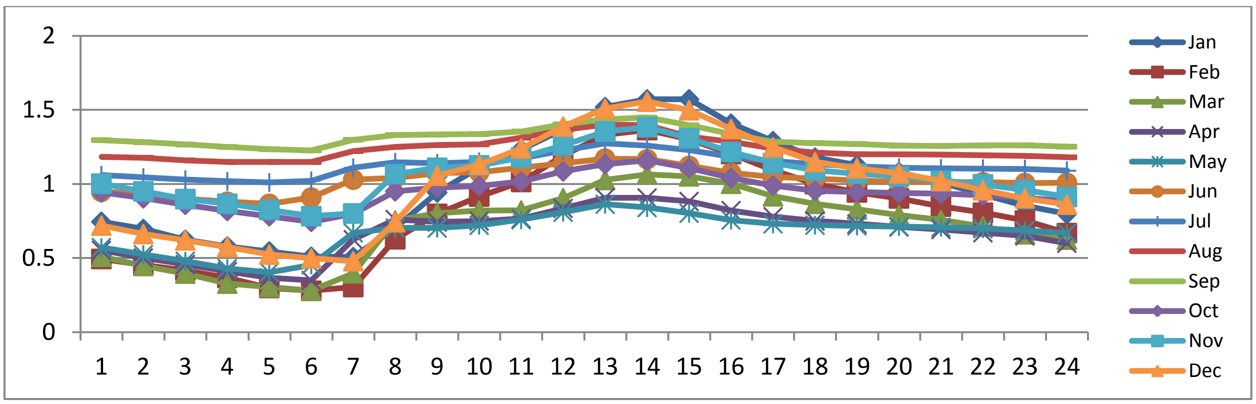


***Figure A8:*** *Everglades, Florida Min/Max versus true midnight average – (Celsius)*

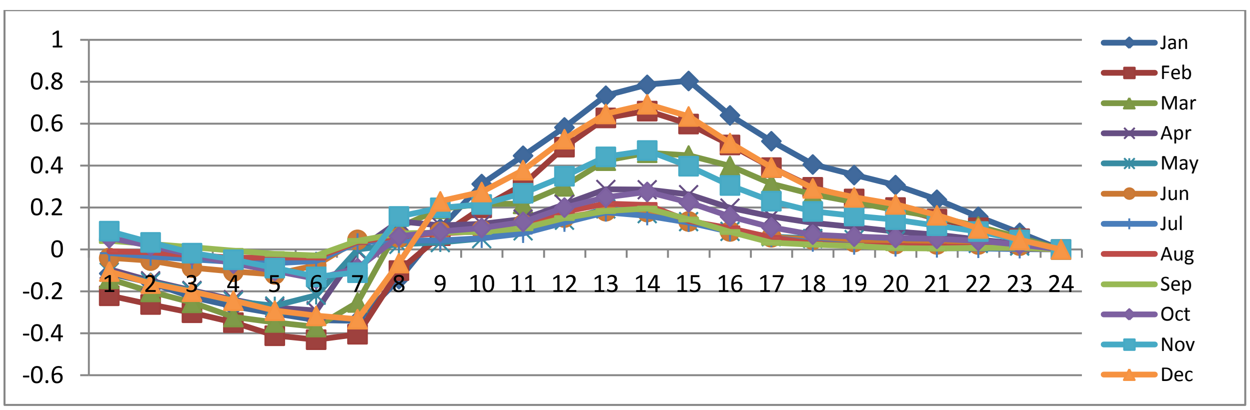


***Figure A9:*** *Everglades, Florida 24 hour Min/Max versus midnight 24 hour Min/Max – (Celsius)*

Everglades, Forida: I have to admit, the Everglades plots surprised me more than the Barrow, Alaska plots. Summer/Winter and Night/Day variations are smaller than other plots I have done. I expected that the TOBS bias problem would be much less here. In fact, winter months here show a wide bias span in **Figure A9**.

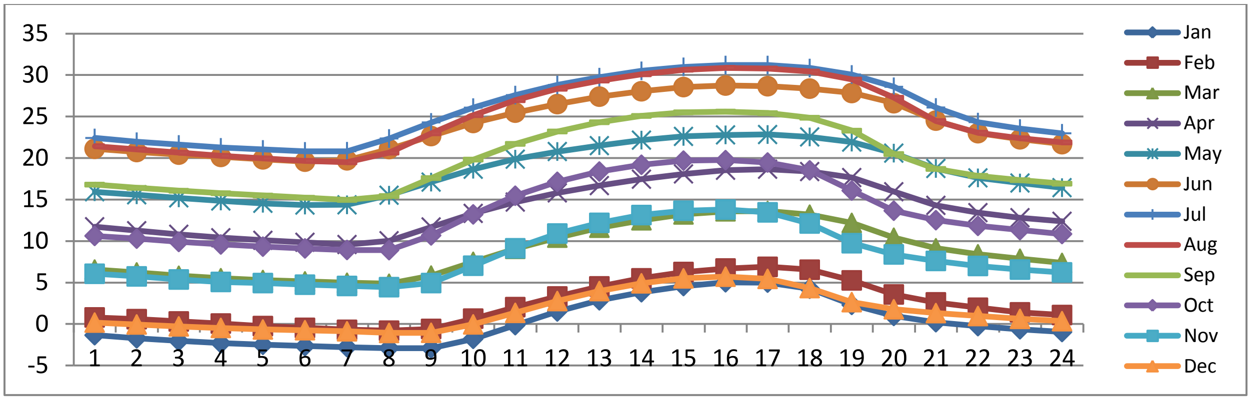


***Figure A10:*** *Joplin, Missouri temperature profile – (Celsius)*

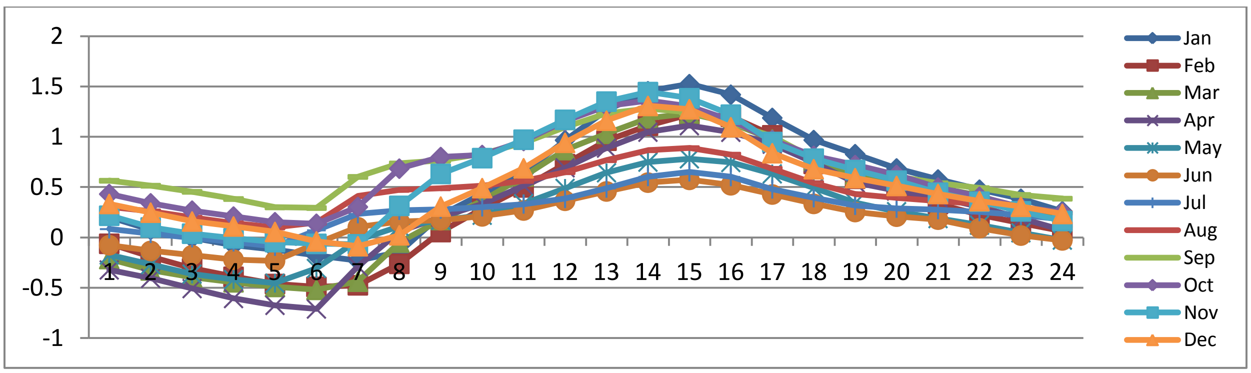


***Figure A11:*** *Joplin, Missouri Min/Max versus true midnight average – (Celsius)*

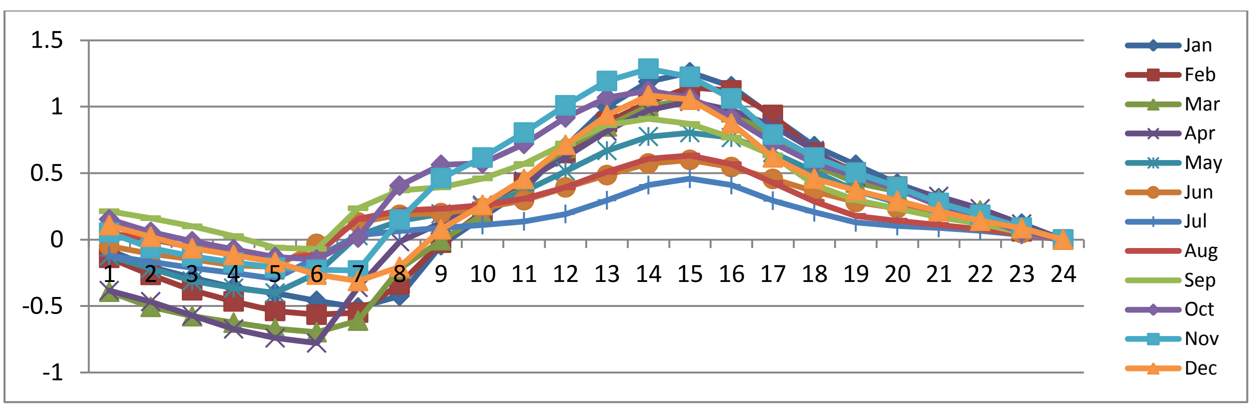


***Figure A12:*** *Joplin, Missouri 24 hour Min/Max versus midnight 24 hour Min/Max – (Celsius)*

Joplin, Missouri: Discussed in the main text.

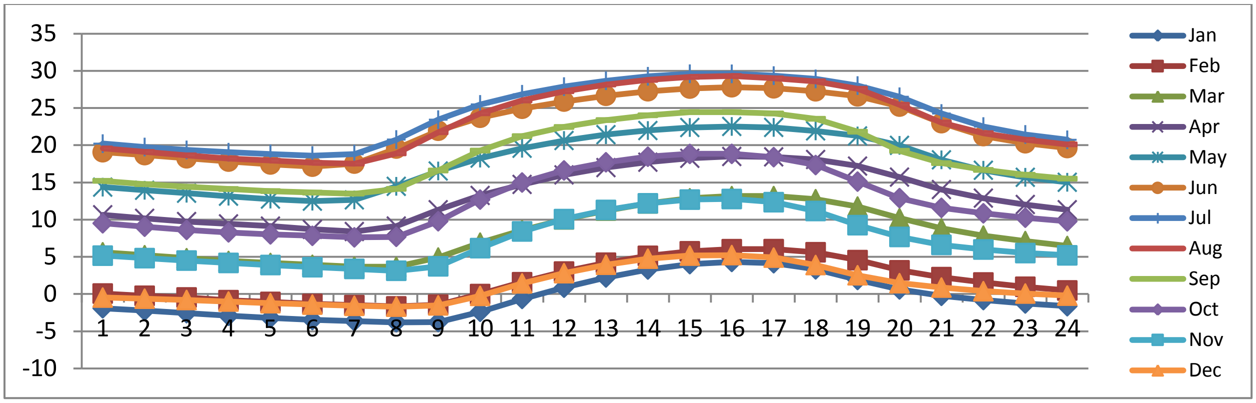


***Figure A13:*** *Salem, Missouri temperature profile – (Celsius)*

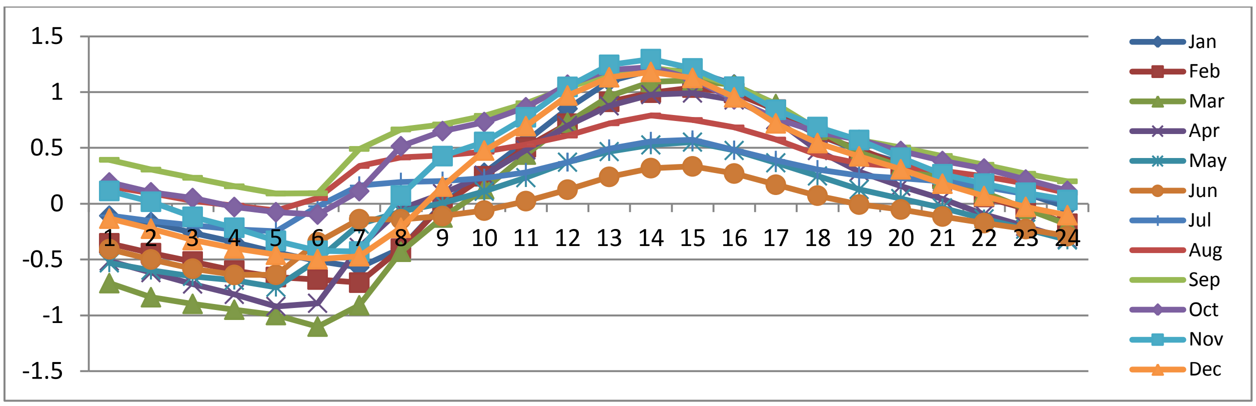


***Figure A14:*** *Salem, Missouri Min/Max versus true midnight average – (Celsius)*

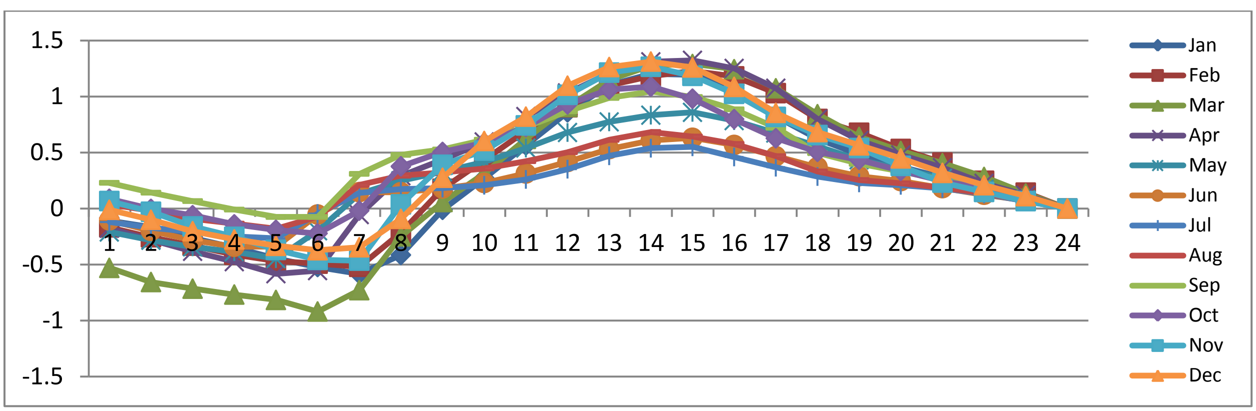


***Figure A15:*** *Salem, Missouri 24 hour Min/Max versus midnight 24 hour Min/Max – (Celsius)*

Salem, Missouri: Joplin, Missouri is only about 160 miles due west of Salem. That distance is sufficient that Figures A12 and A15 exhibit significant differences. Those differences are sufficient to call into question using them to interpolate bias adjustment values for other nearby sites.