II.7-CALB-MAT CALIBRATION SYSTEM MEAN AREAL TEMPERATURE (MAT) COMPUTATIONAL PROCEDURE

Bookmarks

Purpose . . . . [Bookmark]
Estimation of Missing Max-Min Temperature Data . . . . [Bookmark]
Theory of Estimation . . . . [Bookmark]
Non-mountainous Areas . . . . [Bookmark]
Mountainous Areas . . . . [Bookmark]
Elevation Weighting Factor (Fe) . . . . [Bookmark]
Computation of MAT from Max-Min Temperature Data . . . [Bookmark]
Use of Synthetic Stations . . . . [Bookmark]
Max-Min Temperature Time Series . . . . [Bookmark]
Conversion of Max-Min Temperature Data to 6 Hour Time Series . . . . [Bookmark]
Computation of Areal Means . . . . [Bookmark]
Checking the Consistency of Max-Min Temperature Data . [Bookmark]
Figures . . . . [Bookmark]
[Bottom]

Contents

Page

Purpose 1
Estimation of Missing Max-Min Temperature Data 2
  Theory of Estimation 2
  Non-mountainous Areas 3
Mountainous Areas 4
  Elevation Weighting Factor (Fe) 5
Computation of MAT from Max-Min Temperature Data 5
  Use of Synthetic Stations 6
  Max-Min Temperature Time Series 6
  Conversion of Max-Min Temperature Data to 6 Hour Time Series 6
  Computation of Areal Means 7
Checking the Consistency of Max-Min Temperature Data 8

[Next] [Previous] [Bookmarks] [Top]

Purpose

This Chapter describes the procedures used to compute Mean Areal Temperature (MAT) for use in model calibration.

Recommended steps to follow in computing MAT are described in Section IV.1.2-MAT [Hyperlink].

Mean areal temperature estimates for use in model calibration are based solely on observations of max-min air temperature. The network of climatological max-min temperature stations is adequate for computing MAT in most areas of the United States. This is partly due to the fact that spatial variations in temperature are relatively small or can be adequately estimated (as in the case of variations with elevation) in most meteorological situations. In only a few cases, mainly certain high elevation mountain locations, is the max-min temperature network inadequate.

One problem with using only max-min temperature data to compute MAT is that the diurnal variation in temperature is unknown. A typical diurnal pattern is used in the computational procedure. Large errors in MAT values can occur when there is an atypical diurnal temperature variation. One of the things that air temperature data are used for is determination of the form of precipitation. The errors in MAT values caused by abnormal diurnal temperature patterns will increase the number of times that the form of precipitation is incorrectly determined. Errors in the form of precipitation affecting large precipitation amounts should be corrected by editing the corresponding MAT value. Once the MAT data are edited to correct for errors in the form of precipitation, the remaining errors in the MAT time series caused by variations in the diurnal temperature pattern will have an insignificant effect on model parameter values. The 3 hour observations of air temperature could be used to approximate the actual diurnal variation in temperature, but there is no provision in the current MAT program for the use of the 3 hour air temperature data. The eventual use of these data in the MAT program should reduce the number of MAT values that need to be edited to correct for errors in the form of precipitation. However, except for reducing the amount of editing, the use of 3 hour air temperature data will have little effect on the calibration process. For operational forecasting, instantaneous temperature data should be used since the objective is the most accurate forecast possible, whereas in model calibration, the objective is determination of the values of the model parameters.

This Chapter describes the methods used to estimate missing max-min temperature data, compute 6 hour mean areal temperature from the max-min temperature data and check the consistency of the max-min temperature data.

[Next] [Previous] [Bookmarks] [Top]

Estimation of Missing Max-Min Temperature Data

Since maximum and minimum air temperature data are measured as point values, the use of these data to compute mean areal values involves, implicity or explicitly, inferences concerning the air temperature at all other points within the area. This section outlines a method of estimating the maximum and minimum daily air temperatures at any point as a function of maximum and minimum temperatures at surrounding points. This method is used in the MAT computational procedure to estimate missing max-min temperature data.

[Next] [Previous] [Bookmarks] [Top]

Theory of Estimation

In Figure 1 [Bookmark#1] let point X be the point at which the maximum or minimum air temperature is to be estimated and points A through G are points at which the maximum or minimum temperature is known.

Perpendicular lines through point X divide the surrounding area into quadrants. Perpendicular axes of any orientation can be used. Not more than one station in any quadrant is used to estimate temperature at point X. This ensures that the estimators are in different directions from point X. The use of the quadrant system of selecting estimators is also based on the fact that the same system had previously been used successfully for the estimation of precipitation amounts.

The estimate of temperature at point X is computed as a weighted average of 'adjusted' station temperatures, using the station within each quadrant with the largest station weight. The 'adjusted' station temperature for each estimator is the temperature at each station adjusted so as to have the same long-term mean as the temperature at point X. Thus, the estimate of the temperature at any point X can be expressed as:

$$T_x = \frac{\sum_{i=1}^{n} (T_i + N_x - N_i) * W_i}{\sum_{i=1}^{n} W_i} \qquad (1)$$

where T_x is the maximum or minimum temperature at the station being estimated
- i is the station used as an estimator
- n is the number of estimators (the station with the largest station weight in each quadrant is used as an estimator)
- W_i is the weight function for station i
- N_x is the mean maximum or minimum temperature at the station being estimated
- T_i is the maximum or minimum temperature at estimator station i
- N_i is the mean maximum or minimum temperature at station i

If the temperature value is missing at an estimator station, then that station is treated as if it did not exist. If the temperature values are missing at all stations within a given quadrant or if there are no stations in a quadrant, then there is no estimator station in that quadrant. For example, in Figure 1 [Bookmark#2], there are no stations in quadrant 1 since station E is assigned to quadrant 4.

If the temperature value is missing at all stations, then no estimate is made. Previously, estimated values are not used to estimate other temperature values.

The weight functions used in Equation 1 depend on whether the area is classified as mountainous or non-mountainous.

[Next] [Previous] [Bookmarks] [Top]

Non-mountainous Areas

As far as the temperature estimation procedure is concerned, an area is classified as non-mountainous when both the mean maximum and minimum temperatures at all stations can be considered to be the same. In this case, the spatial temperature gradients are assumed to be a linear function of distance. Thus, the weight function is equal to the reciprocal of the distance from the estimator station to point X. Therefore, the estimation equation for non-mountainous areas is:

$$\cdot = \frac{\sum_{=}^{=} \left(\cdot * \frac{}{} \right)}{\sum_{=}^{=} \frac{}{}} \qquad (2)$$

where $d_{i,x}$ is the distance from the station being estimated to the estimator station i in terms of map coordinates

[Next] [Previous] [Bookmarks] [Top]

Mountainous Areas

Conversely to a non-mountainous area as far as temperature estimation is concerned, an area is classified as mountainous when both the mean maximum and minimum temperatures at all stations cannot be considered as being equal. In regard to the station weight function, the most important factors affecting the spatial variation in temperature are probably elevation and distance. If two stations are equidistant from station X, studies have shown that the one closer in terms of elevation is usually the best estimator. For these reasons, the weight function used in the estimation procedure includes both elevation difference and distance. A functional form for W_i which has produced improved estimates of temperature in mountainous areas is:

$$= \frac{}{\cdot \ \ell * \quad + \cdot \quad * \Delta} \qquad (3)$$

where $G\ell$ is the scale factor to convert map coordinates to km
$\Delta E_{i,x}$ is the absolute difference in elevation in 1000 M between stations X and i
Fe is the elevation difference weighting factor

When either all $\Delta E_{i,x}$ values are zero or Fe is zero, Equation 3 becomes equivalent to the weight function used in Equation 2.

The temperature estimation equation for mountainous areas is obtained by the substitution of Equation 3 into Equation 1. This substitution yields:

$$\cdot = \frac{\sum_{=}^{=} \left(\cdot + \ \cdot \ - \cdot \quad * \frac{}{\cdot \ \ell * \quad + \cdot \quad * \Delta} \right)}{\sum_{=}^{=} \left(\frac{}{\cdot \ \ell * \quad + \cdot \quad * \Delta} \right)} \qquad (4)$$

Rather than merely using the long-term mean maximum and minimum temperatures in Equation 4, the estimation procedure uses mean monthly values to account for seasonal variations in the temperature differences between stations. Such seasonal variations are significant in many mountainous areas because of large seasonal changes in climatic conditions.

[Next] [Previous] [Bookmarks] [Top]

Elevation Weighting Factor (Fe)

It can be readily seen from Equation 4 that Fe affects the station weight of each station being used to estimate the temperature at point X. Increasing Fe will give more weight to stations with the smallest values of $\Delta E_{i,x}$ and less weight to stations with the largest values of $\Delta E_{i,x}$. The estimate of temperature at point X is computed using the station within each quadrant with the largest station weight.

Thus, as Fe is increased, the stations used to estimate the temperature at point X may change. Changes will occur if the station weight of more distant stations in each quadrant becomes greater than the station weight of stations which are closer to point X. This will occur as Fe increases if the distant stations have a smaller value of $\Delta E_{i,x}$. The dominant effect of Fe in most cases is the effect it has on the selection of the stations used to estimate the temperature at point X.

Fe has units of KM of distance per 1000 M of elevation. Thus one physical way to think of Fe is as follows: how many km further, in terms of distance, would you be willing to go in order to find an estimator which is 1000 M closer to point X in terms of elevation. Such a physical interpretation should be helpful in the arbitrary selection of Fe values. In the temperature estimation procedure a separate Fe value is used for maximum and minimum temperature at each station.

Optimum values of Fe for a given station can be determined through an iterative technique, utilizing the available valid data from the station. Program MAT described in Chapter III.8-MAT [Hyperlink] contains a provision for the iterative determination of optimum values of Fe. It is probably necessary to determine optimum values of Fe only for stations that have a considerable weight in the computation of mean areal temperature and, in addition, have a significant amount of missing data.

[Next] [Previous] [Bookmarks] [Top]

Computation of MAT from Max-Min Temperature Data

The previous section describes the method of estimating missing maximum or minimum temperature data. The estimation method is an integral part of the mean areal temperature computational procedure. This section describes each of the other main parts of this procedure.

[Next] [Previous] [Bookmarks] [Top]

Use of Synthetic Stations

By definition, in a non-mountainous area, both the mean maximum and minimum temperatures can be considered the same for all stations. If the mean areal temperature is computed by assigning normalized areal weights to each station, the mean temperature for the area will be essentially the same as the mean temperature for any given station. Thus in a non-mountainous area only the existing temperature stations are needed to compute an unbiased estimate of the mean areal temperature.

In a mountainous area, it may be possible to compute an unbiased estimate of the mean areal temperature using only existing stations. This would be possible if the stations were adequately distributed over the area, especially with regard to elevation. However, such a distribution is not found in many mountainous areas. In many cases, the coldest of the existing stations may still be warmer than the mean temperature for the area. For this reason, the MAT procedure allows for the use of synthetic or 'dummy' stations. A synthetic station is a hypothetical station with all missing data. Max-min temperature data are estimated for each synthetic station by using Equation 4. In order to use Equation 4 to estimate data at a synthetic station, x and y coordinates, an elevation and mean monthly maximum and minimum temperatures must be assigned to the synthetic station.

Since the temperature estimate at each synthetic station is based solely on the existing max-min temperature data network, the use of synthetic stations does not have a significant effect on the standard error of the MAT estimate. However, the correct use of synthetic stations will reduce the bias of the MAT estimate. Thus, the purpose of using synthetic stations is to produce both a seasonally and long-term unbiased MAT estimate.

[Next] [Previous] [Bookmarks] [Top]

Max-Min Temperature Time Series

The observed max-min temperature data are positioned in the time series according to the observation time of the station. For stations with AM observation times, the observed maximum temperature is assumed to have occurred on the previous day and the minimum temperature on the current day. For stations with PM observation times, both the maximum and minimum temperatures are assumed to have occurred on the current day. Equation 2 or Equation 4 is then used to estimate all of the missing max-min temperature data (both real and synthetic stations) depending on whether the area is classified as non-mountainous or mountainous.

[Next] [Previous] [Bookmarks] [Top]

Conversion of Max-Min Temperature Data to 6 Hour Time Series

Once the max-min temperature time series for each station are completed, they must be converted to mean 6 hour temperature time series. 6 hour time series are required because the basic computational time interval of the calibration programs is 6 hours.

The MAT procedure uses a fixed diurnal temperature pattern since the exact time of occurrence of the maximum and minimum temperatures is unknown. The maximum temperature is assumed to occur in the afternoon and the minimum near sunrise. The relationship between each 6 hour period and the maximum or minimum temperature varies throughout the year because of variations in the number of daylight hours. In terms of snow computations, the most important time of the year is the spring melt period. The relationships used in the MAT procedure were derived from max-min and hourly air temperature data available for the spring snowmelt period from the Central Sierra Snow Laboratory near Donner Summit, California and the NOAA-ARS Cooperative Snow Research Station near Danville, Vermont. The relationship used in the MAT procedure are:

$$= \quad * \quad + \quad * \tag{5}$$

$$= \quad * \quad + \quad * \tag{6}$$

$$= \quad * \quad + \quad * \quad + \quad * \quad + \tag{7}$$

$$= \quad * \quad + \quad * \quad + \tag{8}$$

where T6 is the mean 6 hour temperature
Tmax is the maximum temperature
Tmin is the minimum temperature
n is the current day

[Next] [Previous] [Bookmarks] [Top]

Computation of Areal Means

The computation of 6 hour mean areal temperature is simply a matter of multiplying the 6 hour temperature time series for each station by the areal weight for that station. The areal weights assigned to the stations can be either predetermined weights or grid-point weights.

Predetermined station areal weights are usually based on an analysis of the temperature variation over the area, especially with regard to elevation and on the area-elevation curve for the area. Predetermined weights are used primarily in mountainous areas.

Grid-point weights are normally used only in non-mountainous areas and are computed by first superimposing a grid over the area. Then for each grid-point falling within the area, the non-mountainous area station weight ($1.0/d_{i,x}$) is computed for the closest station in each quadrant. This weight is then assigned to the appropriate station. The summation of the weights assigned to each station, after being normalized, becomes the areal weight for that station.

[Next] [Previous] [Bookmarks] [Top]

Checking the Consistency of Max-Min Temperature Data

Before hydrologic data is used, it should be checked for consistency. Thus, one of the early steps in the mean areal temperature computational process is checking the consistency of the maximum and minimum temperature time series. The method described in this section is included in the MAT program (Chapter II.8 [Hyperlink]).

The mean temperature at one station tends to differ from that of other stations by an absolute amount. A different situation exists for precipitation. Precipitation values at one station are, on the average, proportional to the corresponding values at other stations. Thus, the 'double-mass plotting' method of checking the consistency of precipitation data is not directly applicable to temperature data. However, a slightly different type of double-mass plot can be used for temperature data. In the case of temperature data, the accumulated deviation of the mean monthly temperature at an individual station from the average mean monthly temperature at a base group of stations is plotted against the accumulation of time in months. If an individual station deviates from the base group by a constant temperature, then such a plot will be a straight line. In some cases the deviation of an individual station from the base group will exhibit seasonal variations. This occurs when variations in climatic conditions cause seasonal changes in the mean lapse rate. In these situations the plot for a consistent station will not be a perfectly straight line, but will show a seasonal fluctuation about a straight line. The consistency of the maximum temperature time series is checked separately from the consistency of the minimum temperature time series.

Inconsistencies in temperature data show up as distinct breaks on the consistency plots. If there is an inconsistency in one of the stations which comprise a base group of stations, there will not only be a break in the plot for that station, but smaller breaks in the opposite direction will also show up for all other stations which either comprise that base group or are plotted against that particular base group. If two stations in a base group develop an inconsistency at about the same time, even more investigation is needed to determine which stations are inconsistent, plus the magnitude and timing of the inconsistencies. Thus, the base group should contain as many stations as possible. When the size of the base group is large, inconsistencies in any given station will have only a minor effect on the consistency plots for the other stations.

Inconsistencies in temperature data are usually associated with changes in the location of a station. Even minor location changes can sometimes affect the consistency of the data if the local environment near the instrument shelter is significantly altered. Inconsistencies can be corrected by adding or subtracting a constant temperature adjustment to a portion of the data record.

Figure 1. Station location and quadrant designation for the estimation of air temperature at station X