WESTERN REGION TECHNICAL ATTACHMENT
NO. 99-28
DECEMBER 21, 1999

REGRESSION EQUATIONS FOR FORECASTING TEMPERATURES FOR HARDIN AND BROADUS, MONTANA

David Spector - NWSO Billings

Introduction

Big Horn County in south central Montana is one of the most challenging areas to forecast in the Billings County Warning Area (CWA). The topography varies from rolling hills in the northern part of the county to the Pryor and Big Horn Mountains in the southern portion. The county has over 11,000 residents, many of which live in or around Hardin, its largest city. Temperature forecasting is often difficult for Hardin since its daytime high temperatures are usually several degrees warmer than those of nearby cities such as Billings, Miles City, and Sheridan; and no objective guidance is available. However, from comparing maximum and minimum temperatures for Hardin with those from Billings, equations were derived to help forecast temperatures for Hardin for at least part of the year. Using a similar method, equations were also derived to help forecast temperatures for Broadus by comparing their maximum and minimum temperatures with those from Miles City.

Methodology

The average mean monthly high and low temperatures (climatological monthly averages) were compared for Billings and Hardin. Because Hardin is more prone to shallow arctic air mass influence than Billings is during the winter months, the four coldest months of the year, November through February were discarded from the study. For the other months, the coefficients of the average maximum temperatures and the coefficients of the average minimum temperatures for Billings and Hardin were computed and averaged. The calculated coefficient for maximum temperatures was 1.06 while the calculated coefficient for minimum temperatures was 0.91. From these coefficients, simple regression equations were obtained for making temperature forecasts for Hardin from the forecasted temperatures for Billings.

For maximum temperatures, the equation would be

(1) *Hardin Temp. = Billings Temp. X 1.06*

while for minimum temperatures, the equation would be

(2) *Hardin Temp. = Billings Temp. X 0.91.*

Likewise, the average mean monthly high and low temperatures (climatological averages) were compared for Miles City and Broadus. Since Miles City is more prone to shallow arctic air mass influence than Broadus is during the winter months, November through February were also discarded from this comparison. From averaging the other months, the calculated coefficient for maximum temperatures was 1.01 while the calculated coefficient for minimum temperatures was 0.89. Similar regression equations were then derived for making temperature forecasts for Broadus from the forecasted temperatures for Miles City.

For maximum temperatures, the equation would be

(3) *Broadus Temp. = Miles City Temp. X 1.01*

while for minimum temperatures, the equation would be

(4) *Broadus Temp. = Miles City Temp. X 0.89.*

From data obtained from the National Climatic Data Center (Climatological Data), the derived maximum and minimum temperatures for Hardin were calculated by comparing the observed Billings temperatures with the observed maximum and minimum temperatures for Hardin each day from 1996 to 1998. For each month included in the study the average error was determined for both the maximum and minimum temperatures and monthly correction factors were derived. The monthly correction factors were added to the derived temperatures. The same process was done comparing the derived maximum and minimum temperatures for Broadus from the Miles City temperatures with the observed maximum and minimum temperatures for Broadus each day from 1996 to 1998, and again monthly correction factors were derived. These correction factors substantially reduced the average error for both maximum and minimum temperatures. These equations were then tested for the first half of 1999. It should be noted that since Hardin and Broadus only take their observations once each day in the afternoon, carry-over maximum temperatures often occur. Maximum temperatures which were determined to be carry-over maximums were discarded from the study. It should also be noted that there were a few days in which the contract observers in Hardin and Broadus did not take an observation, or did not reset their thermometer. Those dates as well as dates in which there was an air mass variation or an evening cold front passage over the region were also discarded from the study.

Results

Table 1 shows the correction factors used for each month of the study which were determined by smoothing out the average error by month during the period of study.

Table 2 lists the actual equations for determining the Hardin maximum and minimum temperatures from the Billings maximum and minimum temperatures with the monthly correction factors included.

Table 3 lists the actual equations for determining the Broadus maximum and minimum temperatures from the Miles City maximum and minimum temperatures with the monthly correction factors included.

Table 4 shows the total number of forecasts for maximum temperatures, the sum of the average errors and the average error for the derived maximum temperatures from the actual maximum Hardin temperatures without and with the correction factors.

Table 5 shows the total number of forecasts for minimum temperatures, the sum of the errors and the average error for the derived minimum temperatures from the actual minimum Hardin temperatures without and with the correction factors.

Table 6 shows the total number of forecasts for maximum temperatures, the sum of the errors and the average error for the derived maximum temperatures from the actual maximum Broadus temperatures without and with the correction factors.

Table 7 shows the total number of forecasts for minimum temperatures, the sum of the errors and the average error for the derived minimum temperatures from the actual minimum Broadus temperatures without and with the correction factors. Without the correction factors included the average error for the uncorrected regression maximum temperature for Hardin was around + 0.75°F, and for Broadus the average error was around + 2.35°F, indicating a warm bias. For minimum temperatures the average error for the uncorrected regression minimum temperature for Hardin was around - 3°F, and for Broadus - 2.5°F, indicating a significant cold bias. These errors were more significant during the summer months. Correction factors were then tested for each month to determine the best correction factor for both maximum and minimum temperatures.

Tables 8-11 show the results for the time period (March 1999 through June 1999) when these formulas were applied to a real-time data set. When the monthly regression equations were applied, the error for the Broadus minimum temperatures was nearly reduced to zero. Meanwhile, the errors for the Hardin minimum temperatures and the Broadus maximum temperatures were reduced to around 1°F while there was actually a deterioration in the skill of the Hardin maximum temperature even through the error turned out to be less than 1°F. One possible reason for this is that southern Montana was under

the influence of an unseasonably warm air mass for much of March 1999, which had a substantial error of nearly 3°F for the Hardin maximum temperature. Had the equation for April been used instead, the error for March would have not been nearly as large as it turned out to be.

Suggestions

The purpose of this study was to formulate a simple approach for obtaining first guess maximum and minimum temperature forecasts for Hardin, Montana utilizing the temperature forecasts for Billings; and for Broadus, Montana from the temperature forecasts for Miles City. It should be noted that this method will not work properly when the region is under the influence of an arctic airmass since widespread temperature fluctuations can occur. It should also be noted that even though correction factors were not determined for November through February, the average error for this period (using the regression method) turned out to be within one degree Fahrenheit. This suggests that the regression method will work on days throughout the year without significant airmass variation across these locations. One possible idea for future study is to incorporate the results of this study with those of Rasch et al. (1999), which utilizes Eta 2-meter temperature biases to forecast temperatures for Billings and Miles City. Another would be to use these formulas operationally in a real time environment over an extended period of time.

References

Rasch, et al., 1999: Bias-Corrected Temperature Guidance from the Eta Model, WR *Technical Attachment 99-04.*

Climatological Data, 1996-1998: Montana, January 1996-December 1998, National Climatic Data Center, Asheville, NC.

Table 1

Average Monthly Correction Factors For Hardin and Broadus; 1996-1998

Month	Hardin Correction Factor Max. Temp. / Min Temp.	Broadus Correction Factor Max. Temp. / Min Temp.
March	**-1 / +1**	**0 / +2**
April	**0 / +2**	**-1 / +1**
May	**0 / +4**	**-2 / +2**
June	**-1 / +5**	**-3 / +3**
July	**-2 / +4**	**-3 / +4**
August	**-1 / +3**	**-4 / +3**
September	**-1 / +4**	**-3 / +3**
October	**0 / +1**	**-1 / +2**

Table 2

Equations Used for Determining the Hardin Maximum and Minimum Temperatures from the Billings Maximum and Minimum Temperatures with the Monthly Correction Factors

HDN=Forecasted Hardin Temperature
BIL=Forecasted Billings Temperature

Month	Maximum Temperature	Minimum Temperature
March	**HDN=(BIL X 1.06)-1**	**HDN=(BIL X 0.91)+1**
April	**HDN=(BIL X 1.06)**	**HDN=(BIL X 0.91)+2**
May	**HDN=(BIL X 1.06)**	**HDN=(BIL X 0.91)+4**
June	**HDN=(BIL X 1.06)-1**	**HDN=(BIL X 0.91)+5**
July	**HDN=(BIL X 1.06)-3**	**HDN=(BIL X 0.91)+4**
August	**HDN=(BIL X 1.06)-4**	**HDN=(BIL X 0.91)+3**
September	**HDN=(BIL X 1.06)-3**	**HDN=(BIL X 0.91)+4**
October	**HDN=(BIL X 1.06)-1**	**HDN=(BIL X 0.91)+1**

Table 3

Equations Used for Determining the Broadus Maximum and Minimum Temperatures from the Miles City Maximum and Minimum Temperatures with the Monthly Correction Factors

4BQ=Forecasted Hardin Temperature
MLS=Forecasted Billings Temperature

Month	Maximum Temperature	Minimum Temperature
March	**4BQ=(MLS X 1.01)**	**4BQ=(MLS X 0.89)+2**
April	**4BQ=(MLS X 1.01)-1**	**4BQ=(MLS X 0.89)+1**
May	**4BQ=(MLS X 1.01)-2**	**4BQ=(MLS X 0.89)+2**
June	**4BQ=(MLS X 1.01)-3**	**4BQ=(MLS X 0.89)+3**
July	**4BQ=(MLS X 1.01)-2**	**4BQ=(MLS X 0.89)+4**
August	**4BQ=(MLS X 1.01)-1**	**4BQ=(MLS X 0.89)+3**
September	**4BQ=(MLS X 1.01)-1**	**4BQ=(MLS X 0.89)+3**
October	**4BQ=(MLS X 1.01)**	**4BQ=(MLS X 0.89)+2**

Table 4

Number of Forecasts for Maximum Temperatures, Total Sum of the Errors and True Average Error for the Derived Maximum Temperatures from the Actual Maximum Hardin Temperatures Without and With the Correction Factors for 1996 through 1998

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**614**	**+459**	**+0.75**
With Correction	**614**	**-34**	**-0.06**

Table 5

Number of Forecasts for Minimum Temperatures, Total Sum of the Errors and True Average Error for the Derived Minimum Temperatures from the Actual Minimum Hardin Temperatures Without and With the Correction Factors for 1996 through 1998

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**671**	**-1980**	**-2.95**
With Correction	**671**	**+105**	**+0.16**

Table 6

Number of Forecasts for Maximum Temperatures, Total Sum of the Errors and True Average Error for the Derived Maximum Temperatures from the Actual Maximum Broadus Temperatures Without and With the Correction Factors for 1996 through 1998

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**694**	**+1634**	**+2.35**
With Correction	**694**	**+28**	**+0.04**

Table 7

Number of Forecasts for Minimum Temperatures, Total Sum of the Errors and True Average Error for the Derived Minimum Temperatures from the Actual Minimum Broadus Temperatures Without and With the Correction Factors for 1996 through 1998

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**666**	**-1682**	**-2.53**
With Correction	**666**	**+7**	**+0.01**

Table 8

Number of Forecasts for Maximum Temperatures, Total Sum of the Errors and True Average Error for the Derived Maximum Temperatures from the Actual Maximum Hardin Temperatures Without and With the Correction Factors for March 1999 through June 1999

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**94**	**-41**	**-0.44**
With Correction	**94**	**-87**	**-0.93**

Table 9

Number of Forecasts for Minimum Temperatures, Total Sum of the Errors and True Average Error for the Derived Minimum Temperatures from the Actual Minimum Hardin Temperatures Without and With the Correction Factors for March 1999 through June 1999

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**99**	**-252**	**-2.55**
With Correction	**99**	**+102**	**+1.03**

Table 10

Number of Forecasts for Maximum Temperatures, Total Sum of the Errors and True Average Error for the Derived Maximum Temperatures from the Actual Maximum Broadus Temperatures Without and With the Correction Factors for March 1999 through June 1999

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**111**	**+264**	**+2.38**
With Correction	**111**	**+98**	**+0.88**

Table 11

Number of Forecasts for Minimum Temperatures, Total Sum of the Errors and True Average Error for the Derived Minimum Temperatures from the Actual Minimum Broadus Temperatures Without and With the Correction Factors for March 1999 through June 1999

	# of Forecasts	Sum of Errors	Average Error
Without Correction	**104**	**-186**	**-1.79**
With Correction	**104**	**+14**	**+0.13**