**Frequency Examination of 24-hour POP Forecasts and Verification for July and August 2006 across North and Central New Mexico**

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## Introduction

The summer of 2006 was one for the records books for North and Central New Mexico as several exceptional monsoonal surges set up across the Southwestern United States. Many locations across New Mexico received over 200% of their average rainfall for July and August. Given such an extraordinary event it seems prudent to analyze the probability of precipitation forecasts and the subsequent verification. This study examines the frequency distribution of 12- and 24-hour POP forecasts issued by the Albuquerque WFO for July and August 2006 at several forecast points. The 24-hour POP frequencies are then verified using daily 24-hour precipitation reports obtained from National Weather Service cooperative (COOP) observers.

## Methodology

The dataset used for this study was compiled using the preliminary point temperature and POP matrix obtained from the area forecast discussions. Data for all 30 forecast points are available in this single product making it an efficient reference for gathering information. The 12-hour POP fields were extracted from the table beginning 00Z July 1, 2006 and ending 12Z August 31, 2006 for the first two periods of the appropriate 00Z and 12Z forecasts. The 12-hour POP frequency was defined for each forecast point by counting each 0, 5, 10, 20, …, 80, 90, 100 POP then dividing by the total number of 12-hour forecast POPs issued for the two month period. The 12-hour POPs were then converted to 24-hour POPs using the addition rule for two independent events. This is defined as:

$$P(A \cup B) = P(A) + P(B) - P(A) \cap P(B) = P(A) + P(B) - P(A) * P(B)$$

For example, if the $P(A) = 0.20$ and the $P(B) = 0.30$, then the $P(A) + P(B) - P(A) * P(B) = 0.50 - 0.06 = 0.44$. The 24-hour POP frequency was defined in the same manner as the 12-hour POP frequency. Since two forecast packages are issued each 24-hour period and the first two 12-hour periods are extracted from each forecast package, the 12 and 24-hour frequency calculations include the most recent forecast cycle.

COOP rainfall reports were then extracted for each corresponding 24-hour period. COOP sites that reported 24-hour rainfall around 12Z were compared to the 12Z forecast 24-hour POP and respectively for the 00Z COOP reports. Next, 24-hour POPs were sorted from 0 to 100 and placed into 10 equal bins. POPs with a value of 5 were rounded to the 0 bin since precipitation uncertainty is not mentioned below 8 percent. The occurrence of rainfall greater than or equal to 0.01 inches in each 24-hour POP bin was marked as a verifiable event. The total number of events was divided by the total number of 24-hour POPs in each bin to define a rainfall frequency.

Finally, the 24-hour POPs were plotted against the rainfall frequency. Linear regression was used to plot the best fit line between the points. The best fit line was compared with the ideal 24-hour POP frequency of $y = x$. The standard deviation and Pearson correlation were calculated to measure how well the 24-hour POPs represented the actual rainfall frequency. Furthermore, a subjective bias was assumed depending on where the best fit line laid in reference to the ideal distribution of $y = x$. If the entire best fit line lies below (above) $y = x$ then the forecast is said to contain a wet (dry) bias. If the best fit line crosses $y = x$ for $0 < x > 100$ then the $x$ value was calculated and the 24-hour forecast is said to contain both a wet and a dry bias with respect to $x$. After several quality control steps a total of 13 stations were retained for this study.

**Discussion**

The actual rainfall and percent of normal from July and August 2006 for all 13 stations is summarized in table 1. Rainfall ranged from slightly below normal at Raton to nearly 300% of normal at Glenwood. Several stations were close to 200% of normal. The percent of normal precipitation can also be examined using the National Weather Service precipitation analysis based on radar-derived precipitation, rain gauges, satellite estimates, and (west of the Continental Divide) PRISM climate data. Figures 1 and 2 illustrate the percent of normal rainfall for July

| LOCATION | JULY | AUGUST | TOTAL | NORMAL | PON |
|---|---|---|---|---|---|
| Farmington ASOS | 2.38 | 0.18 | 2.46 | 1.18 | 217% |
| Grants ASOS | 2.21 | 4.08 | 6.29 | 3.80 | 166% |
| Glenwood | 6.77 | 7.62 | 14.39 | 5.13 | 281% |
| Chama | 3.04 | 5.44 | 8.48 | 4.98 | 170% |
| Santa Fe ASOS | 3.84 | 3.76 | 7.60 | 4.02 | 189% |
| Albuquerque ASOS | 3.55 | 3.74 | 7.29 | 3.82 | 191% |
| Albuquerque Foothills | 4.46 | 9.23 | 13.69 | 5.12 | 267% |
| Ruidoso | 6.41 | 9.74 | 16.15 | 8.19 | 197% |
| Raton ASOS | 2.40 | 3.13 | 5.53 | 6.00 | 92% |
| Roy | 2.35 | 7.24 | 9.59 | 5.38 | 178% |
| Tucumcari ASOS | 7.55 | 4.24 | 11.79 | 5.37 | 220% |
| Portales | 1.14 | 8.41 | 9.55 | 5.55 | 172% |
| Roswell ASOS | 1.05 | 3.34 | 4.39 | 4.02 | 109% |

Table 1. COOP and ASOS 24-hour rainfall and percent of normal for July and August 2006.

and August respectively. It is worthy to note that radar coverage is limited across parts of New Mexico, especially over the Northwest Plateau and the Gila region resulting in decreased spatial resolution in these areas. The greatest above normal values for July occurred from the Rio

Grande Valley westward to the Continental Divide, and parts of the Northeast Highlands and Plains. The focus expanded eastward during August to include most of the Eastern Plains. Note the dramatic drying trend over the Northwest Plateau during August. Also note the radar beam blockage east of the Sandia Mountains over southern Santa Fe and western San Miguel counties in both figures. Despite shortcomings in radar coverage, the radar estimated percent of normal compares favorably with values obtained from station observations.

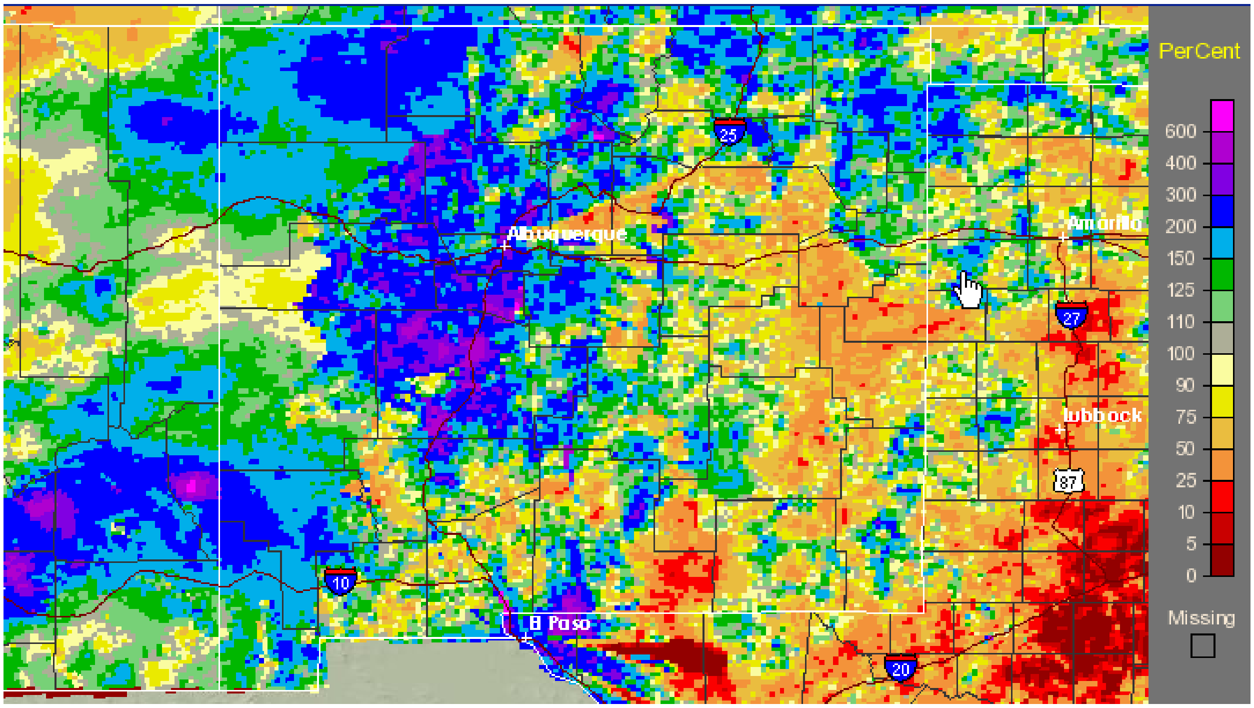


Figure 1. Multi-sensor estimated percent of normal precipitation for July 2006 across New Mexico.

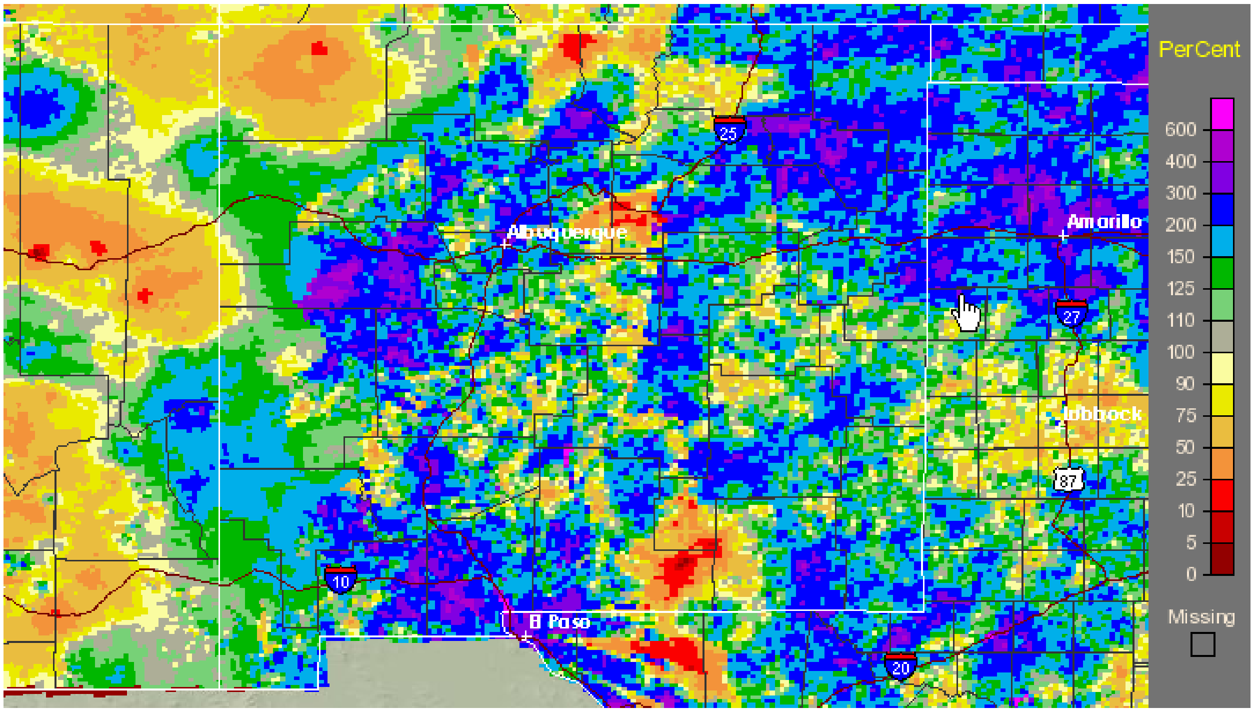


Figure 2. Multi-sensor estimated percent of normal precipitation for August 2006 across New Mexico.

The position and strength of mid and upper level height features during the summer months is an important component of the moisture advection processes into the southwest United States. Since southerly transport of moisture along the western periphery of mid and upper level high pressure is an important feature of the resulting precipitation distribution, it is advantageous to examine the mean mid and upper level geopotential height fields for the period to perhaps better understand the eastward shift in anomalous precipitation. Figures 3 and 4 show the NCEP/NCAR reanalysis composite mean 700mb and 500mb geopotential height fields over North America for July and figures 5 and 6 illustrate the same for August. The main axes of 700mb and 500mb high pressure over the desert southwest during July shifted eastward into the south central United States during August. Hence, southerly moisture transport into the western half of the state shifted eastward into the eastern half of New Mexico as the western periphery of the ridge migrated eastward. This corresponds well with the eastward migration of positive anomalous percent of normal precipitation from the western half of the state in July to the eastern half in August.

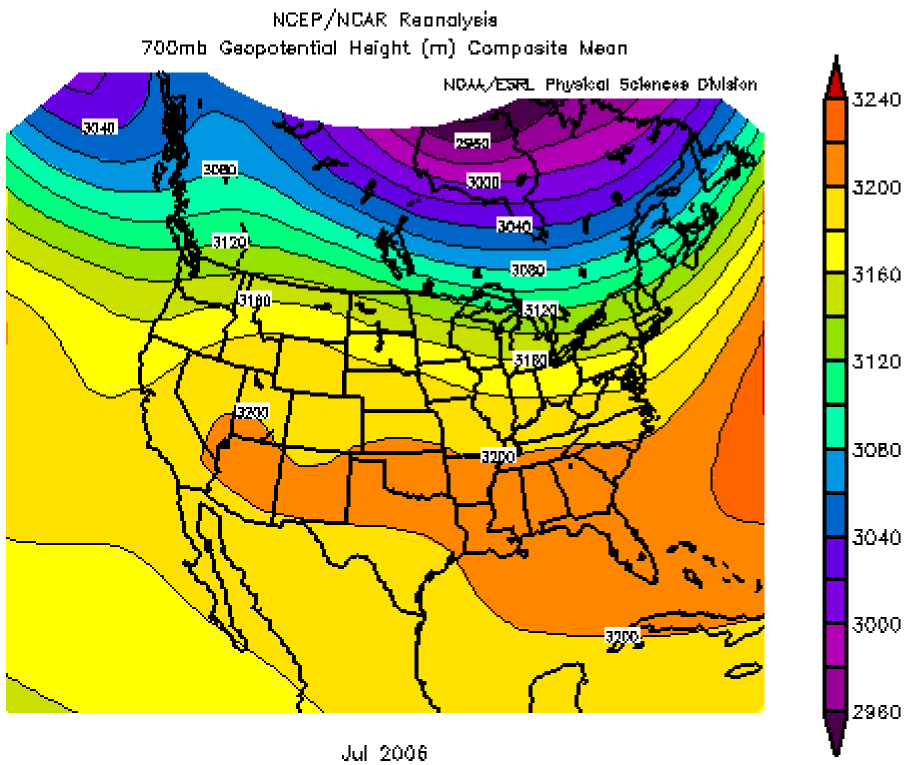



Figure 3. 700mb composite mean geopotential height July 2006. A ridge of high pressure stretches across the southern United States from the central Atlantic west to the desert southwest.

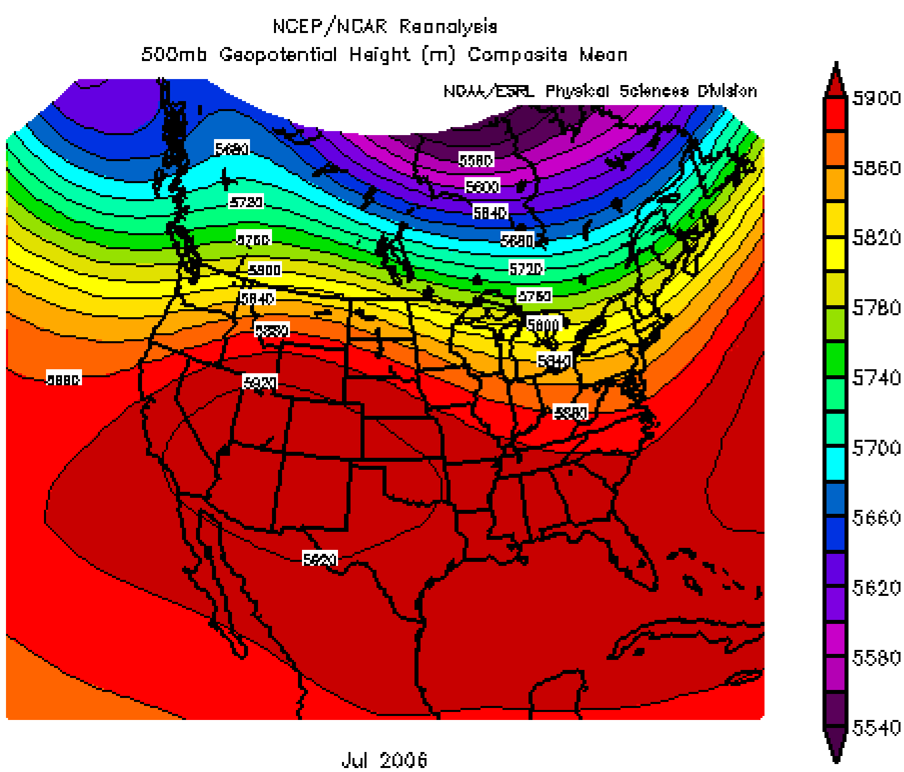



Figure 4. 500mb composite mean geopotential height August 2006. A ridge of high pressure stretches across the southern United States with the main dome over the desert southwest.

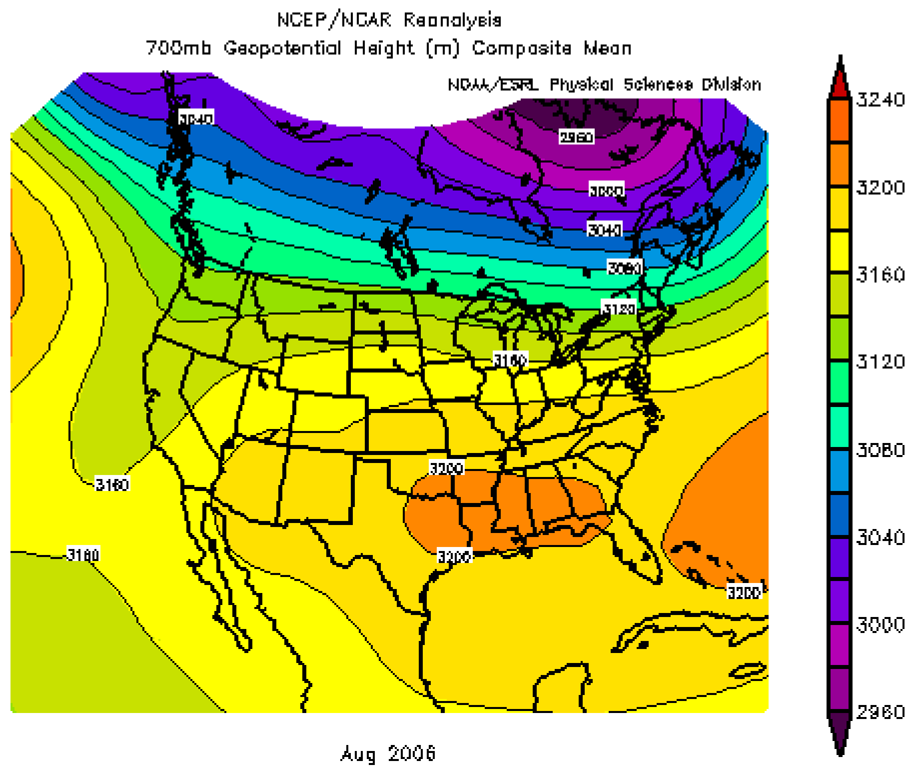



Figure 5. 700mb composite mean geopotential height August 2006. A ridge of high pressure stretches across the southern United States with the main dome shifted east over the southeastern United States.

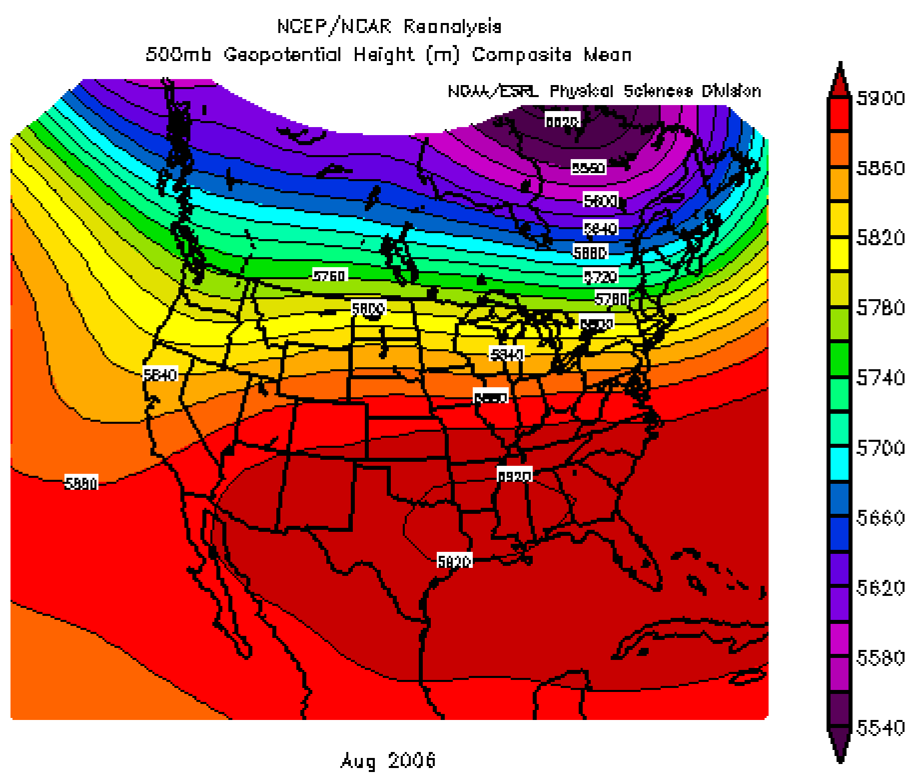



Figure 6. 500mb composite mean geopotential height August 2006. A ridge of high pressure stretches across the southern United States with the main dome shifted east over the southeastern United States.

Given such above normal rainfall for the season it seems prudent to analyze the POP forecasts and the subsequent verification to determine whether any station biases were present. The 12- and 24-hour POP forecast versus forecast frequency at the Farmington ASOS for July and August 2006 is illustrated in figure 7a. The 12-hour POP is represented by the blue line and the 24-hour POP by the green line. Twenty POPs were issued 35.5% of the time for the two month period resulting in a maximum 24-hour POP frequency of 42.7% at the 40 POP. Figure 7b compares the 24-hour POP forecast to the actual rainfall frequency. The bold green line is the linear regression line, or the best fit line, and the grey line is the ideal POP distribution of $y = x$. The regression line does not include weight for points where POP values do not exist. The linear regression equation is shown in the upper left hand corner. The y-intercept represents the average bias of the distribution and the slope is a subjective measure of the bias. If the slope is close to 1 then the best fit distribution lies close to the ideal distribution, in other words a perfectly reliable forecast. In this case, the y-intercept is -15.895 and the slope is 1.1810. This is interpreted as a wet bias of around 15% at Farmington that occurs for nearly all values. The value where the best fit line crosses the ideal distribution can be found in the lower right hand corner (x), along with the standard deviation (s), and the Pearson correlation (corr). The table below figure 7b details the number of total verifiable events and the actual number of forecasts made within the corresponding POP category.

The remaining figures 8-19 (see end of paper) are similar charts for the 12 additional stations examined in this study. Several interesting features can be noted at these other stations. There was no station that displayed a dry bias for the entire spectrum of possible POPs. There were a few stations that showed both a wet and a dry bias (Santa Fe ASOS, Albuquerque Foothills, Ruidoso, and Tucumcari ASOS). For all four stations that exhibited both biases, the wet bias occurred for lower grade POPs (i.e., less than 50) and the dry bias for higher grade POPs (i.e., more than 50). Perhaps the most interesting results were at Ruidoso, figure 14b. The correlation between forecast POP and actual rainfall frequency was 0.92, however, the y-intercept was exceptionally high at -30.69 with the slope = 1.5121, and x = 59.93. This suggests that while the forecast correlation is high, there are strong wet biases in the forecast POP below about 60% and equally strong dry biases in the forecast POP above 60%.

Since the sample size of the study is relatively small there will be artifacts in the wet and dry biases that are purely subjective and limited to this short period of study. For example, the 10, 20, and 30 POPs are often unverified by a rainfall event since the forecaster likely believes there is only a slight chance for measurable precipitation at the station. In these types of cases the linear regression line is skewed to the wet bias for the lower grade POPs thus resulting in the appearance of a wet bias for the entire range of 24-hour POPs. Figure 20 illustrates the same results as figure 14b except the 10, 20, and 30 POPs have been removed from the linear regression equation. Notice how the verified distribution is much closer to the ideal POP distribution and there is little bias present. This shows to what degree non-zero low grade POPs have on the overall forecast verification. It is important to note that while attempting to reduce the number of low grade POPs may help improve overall verification, forecasting POPs during the convective season can be very difficult since thunderstorms often fire at a moments notice and drop significant amounts of rainfall.

**Conclusion**

Despite the well-above normal rainfall during the summer of 2006, the greatest frequency of 12-hour POP forecasts averaged only 20 to 30 percent. A few stations displayed two local maximums in the 24-hour POP frequency, one favoring the 20 and 30 POP range, and the other the 70 and 80 POP range. While charts of the 24-hour POP versus actual rainfall were not shown for July and August discretely, table 1 indicates that precipitation totals in August were much greater than July at many sites and contribute more to the above normal rainfall for the season. The local maximum at 70 and 80 percent may represent the increase in convective activity from one month to the next, with a significant contribution of the POPs from July masking the lesser contribution of higher POPs from August. This may also represent the diurnal convective cycle typical during strong monsoonal surges.

Since model output statistics represent a significant contribution to the decision making process for determining the chance of precipitation for a given forecast period, the forecast 24-hour POPs (CCF) were compared with the statistical guidance available from the NAM, GFS, and NGM models (METMOS, MAVMOS, and FWCMOS, respectively). In order to illustrate this comparison the average Brier Score for the 1$^{st}$ and 2$^{nd}$ periods for the period of study was calculated using the NWS SOOVER program. The Brier Score is essentially the squared difference between the forecast probability and the binary occurrence or non-occurrence of the event (i.e., 1 or 0). Hence, the lower the Brier Score the better. For example, if the forecast probability was 0.70 and the event occurred, 1, then the Brier Score is 0.09, which is excellent. Figure 21 compares the average Brier Scores from the MET, MAV, FWC, and CCF for six stations. Figure 22 is similar to figure 21 by illustrating the percent improvement over statistical guidance. It is clear that for a majority of the six stations the best forecast improvements are over the FWC and the least improvement is over the MAV.

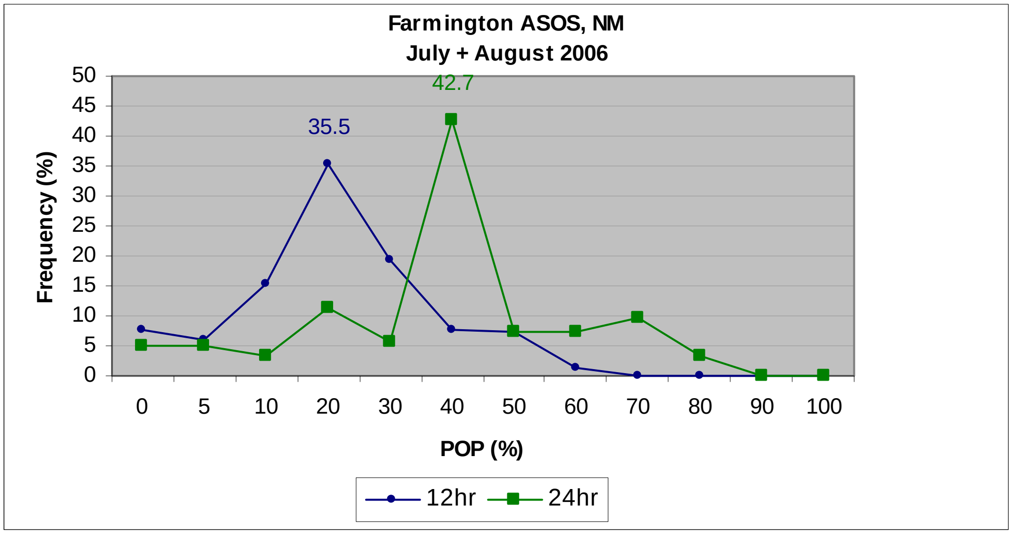
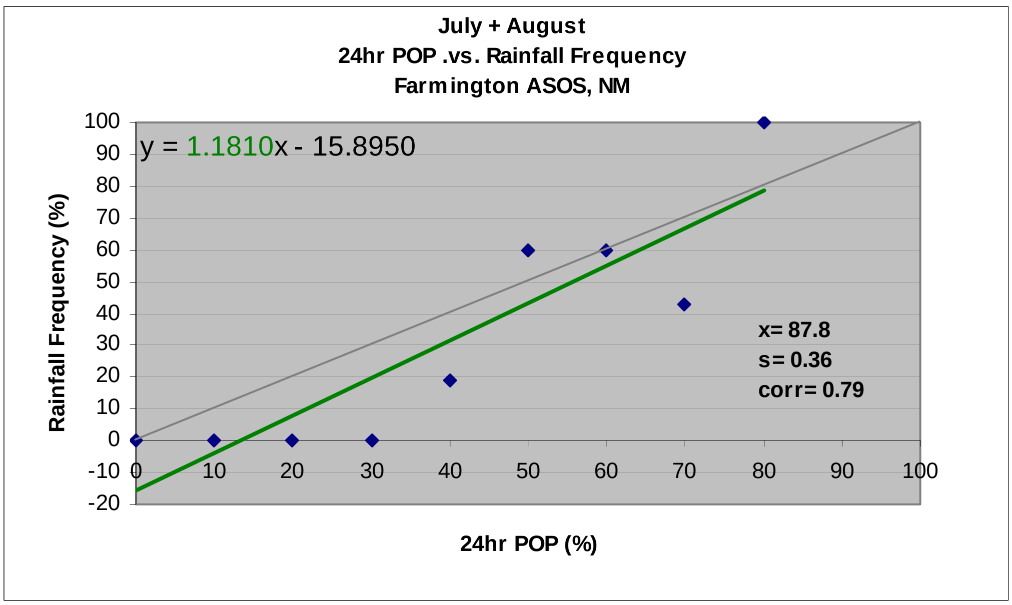



Figure 7a. 12 and 24-hour POP vs frequency at the Farmington ASOS for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 0 | 0 | 5 | 3 | 3 | 3 | 1 | 0 | 0 |
| # of forecasts | 6 | 2 | 6 | 4 | 26 | 5 | 5 | 7 | 1 | 0 | 0 |

Figure 7b. 24-hour POP vs actual rainfall frequency at the Farmington ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

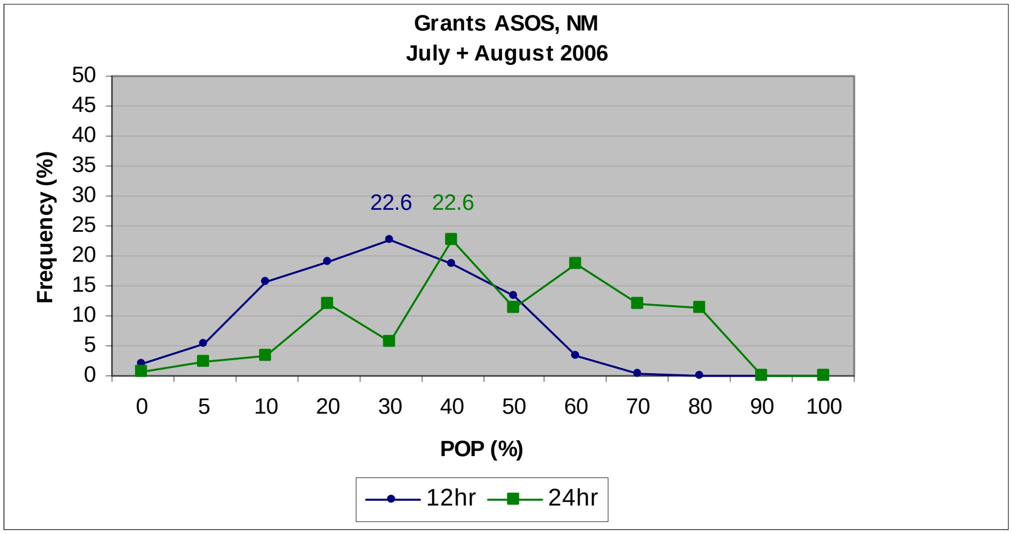
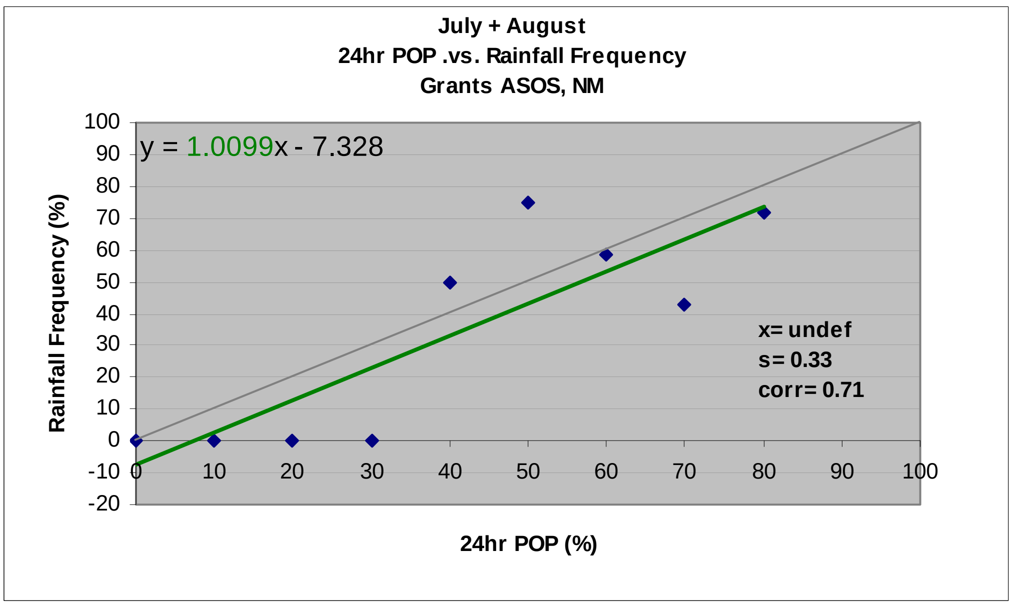



Figure 8a. 12 and 24-hour POP vs frequency at the Grants ASOS for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 0 | 0 | 7 | 6 | 7 | 3 | 5 | 0 | 0 |
| # of forecasts | 3 | 1 | 7 | 3 | 14 | 8 | 12 | 7 | 7 | 0 | 0 |

Figure 8b. 24-hour POP vs actual rainfall frequency at the Grants ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

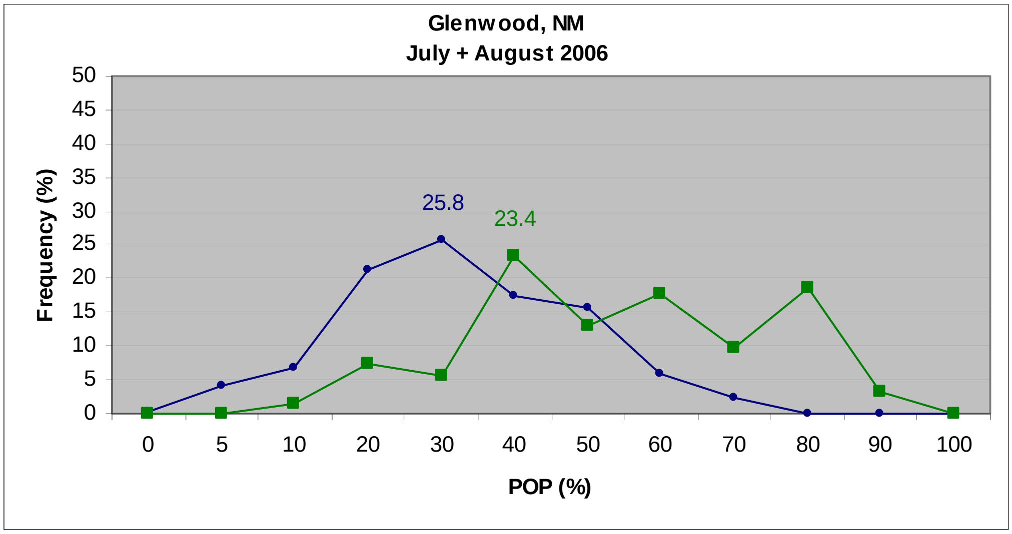
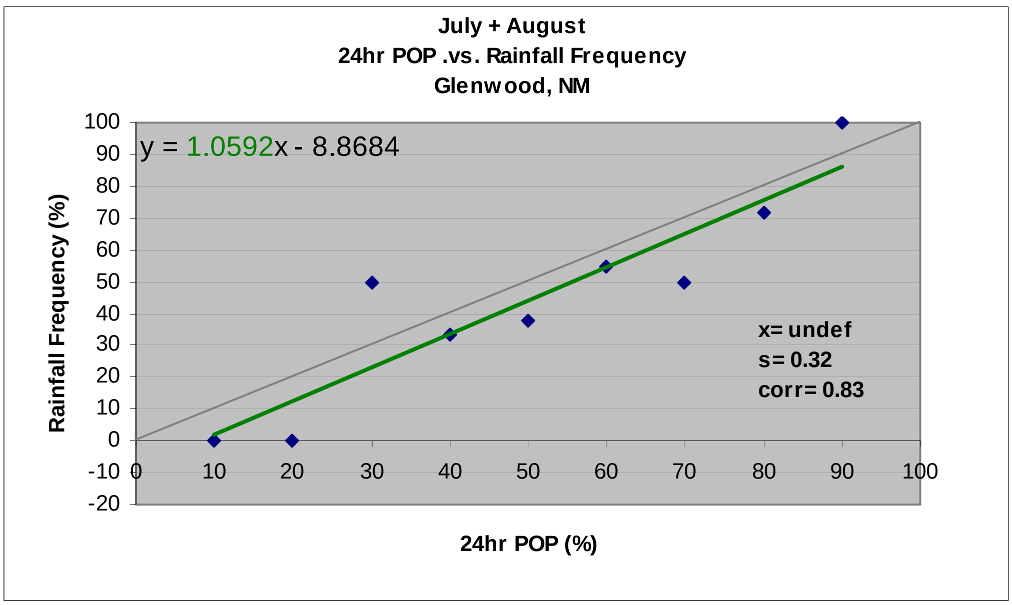



Figure 9a. 12 and 24-hour POP vs frequency at Glenwood for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 0 | 2 | 4 | 3 | 6 | 3 | 10 | 1 | 0 |
| # of forecasts | 0 | 1 | 5 | 4 | 12 | 8 | 11 | 6 | 14 | 1 | 0 |

Figure 9b. 24-hour POP vs actual rainfall frequency at Glenwood for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

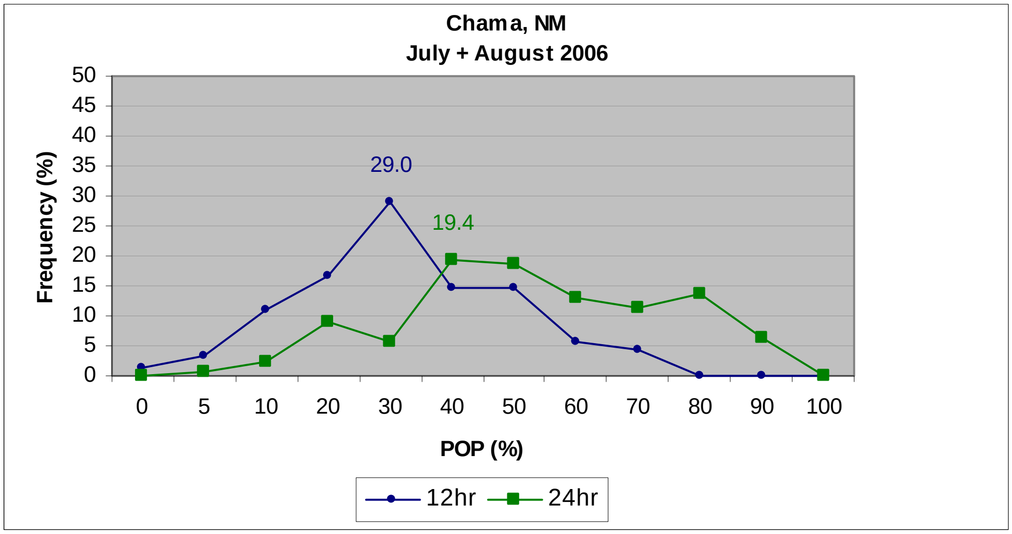
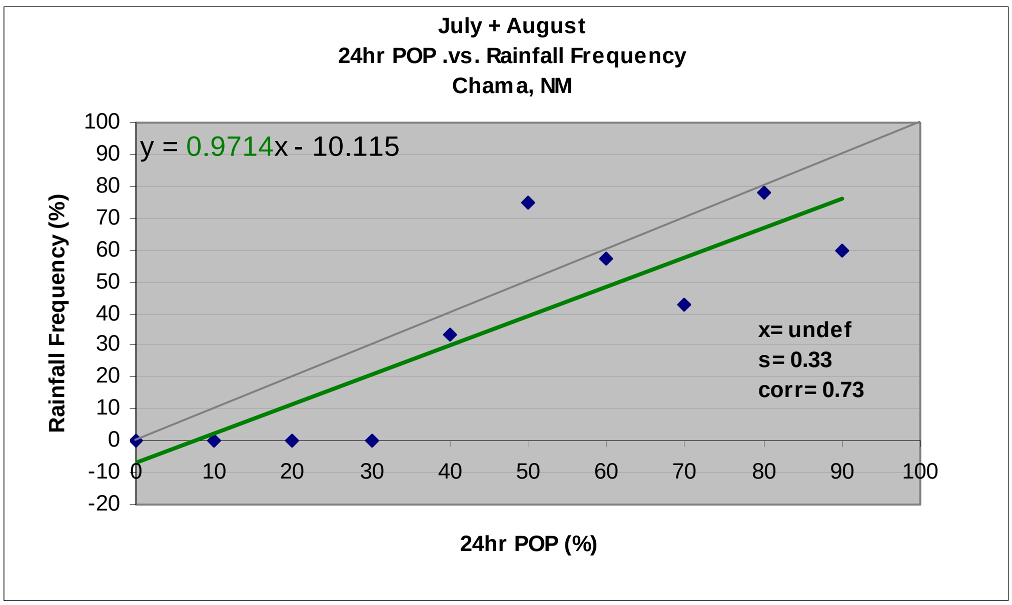



Figure 10a. 12 and 24-hour POP vs frequency at Chama for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 0 | 0 | 4 | 9 | 4 | 3 | 7 | 3 | 0 |
| # of forecasts | 1 | 2 | 5 | 2 | 12 | 12 | 7 | 7 | 9 | 5 | 0 |

Figure 10b. 24-hour POP vs actual rainfall frequency at Chama for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

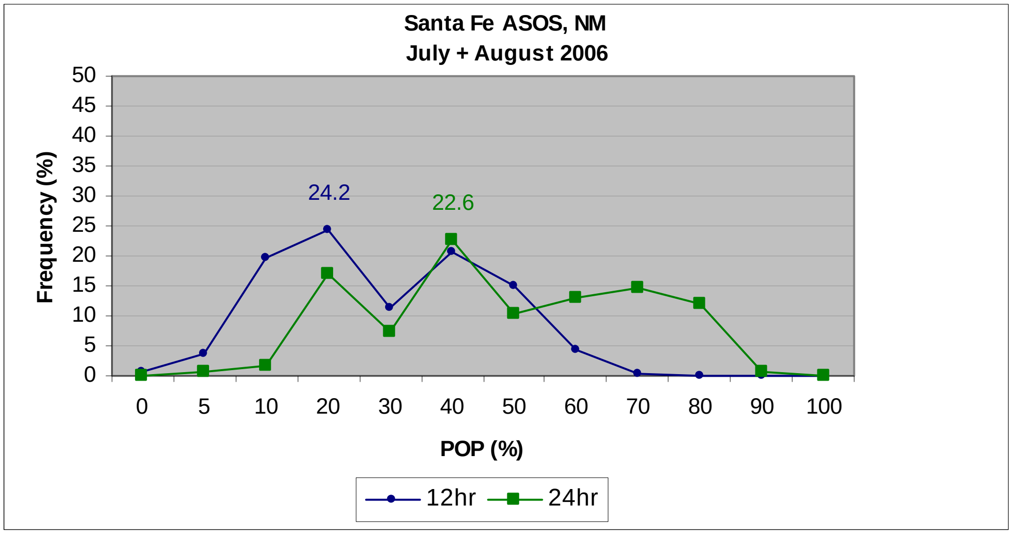
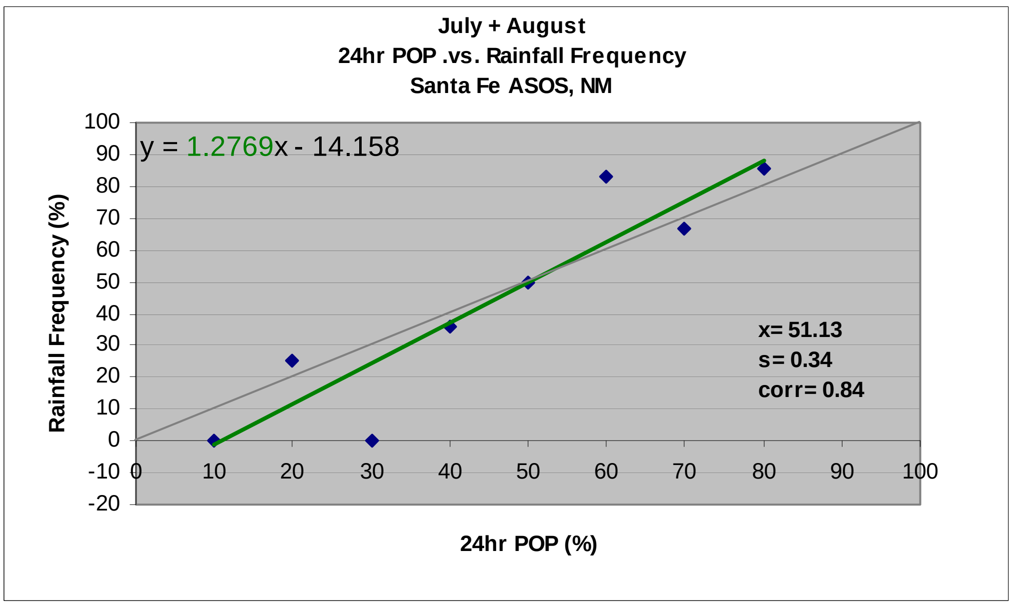



Figure 11a. 12 and 24-hour POP vs frequency at the Santa Fe ASOS for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 3 | 0 | 5 | 3 | 5 | 8 | 6 | 0 | 0 |
| # of forecasts | 0 | 1 | 12 | 4 | 14 | 6 | 6 | 12 | 7 | 0 | 0 |

Figure 11b. 24-hour POP vs actual rainfall frequency at the Santa Fe ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

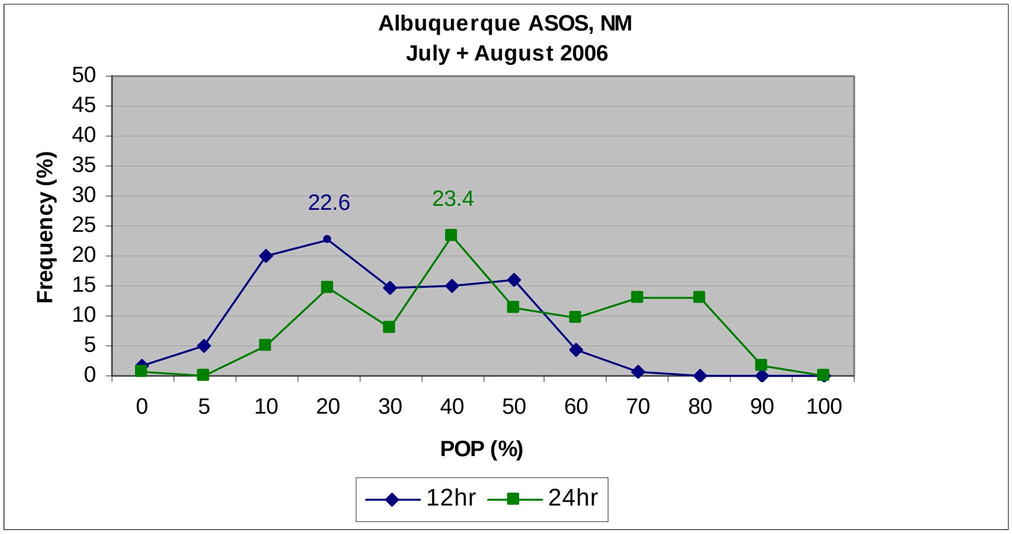
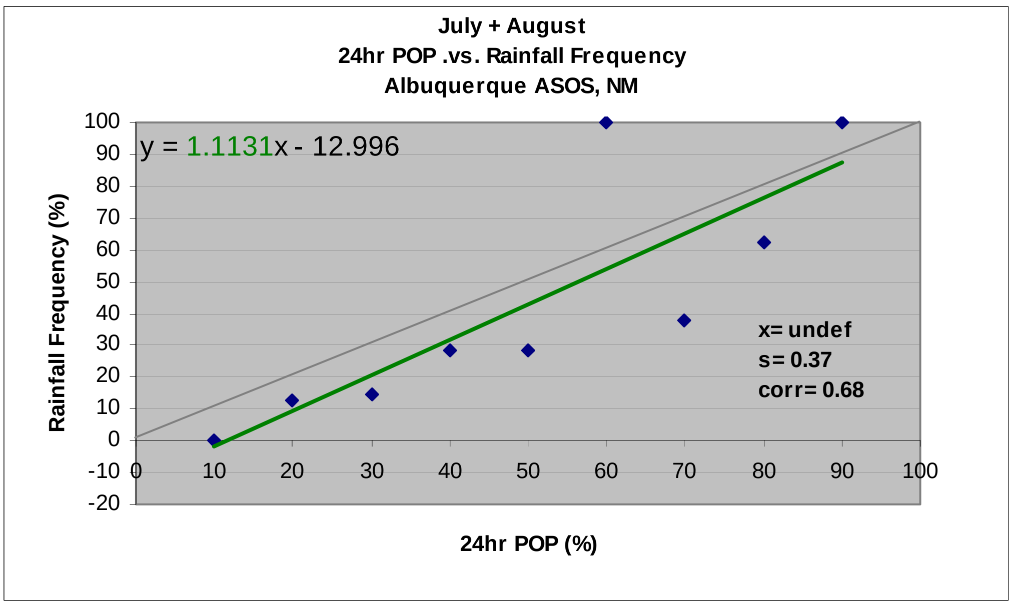



Figure 12a. 12 and 24-hour POP vs frequency at the Albuquerque ASOS for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 1 | 1 | 4 | 2 | 5 | 3 | 5 | 1 | 0 |
| # of forecasts | 0 | 4 | 8 | 7 | 14 | 7 | 5 | 8 | 8 | 1 | 0 |

Figure 12b. 24-hour POP vs actual rainfall frequency at the Albuquerque ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

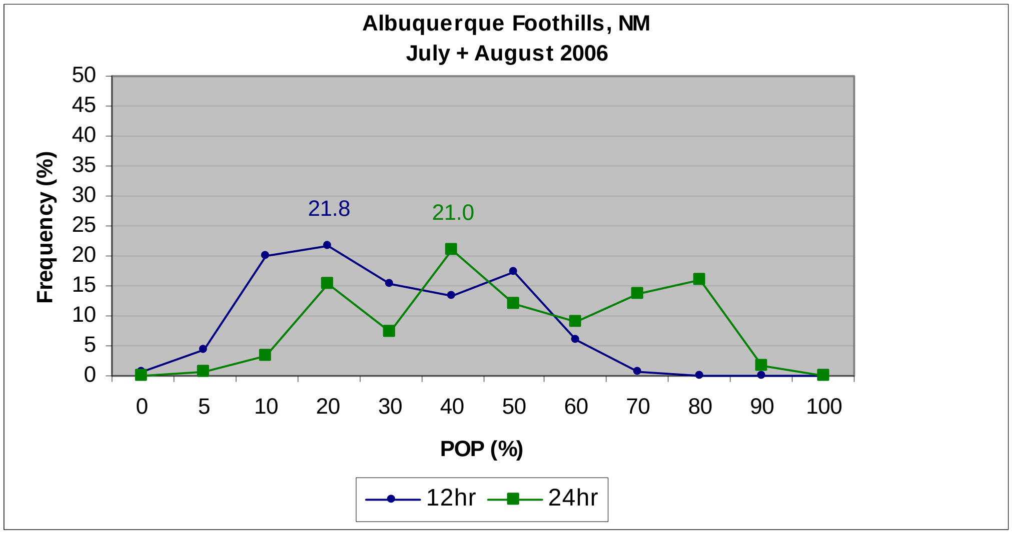
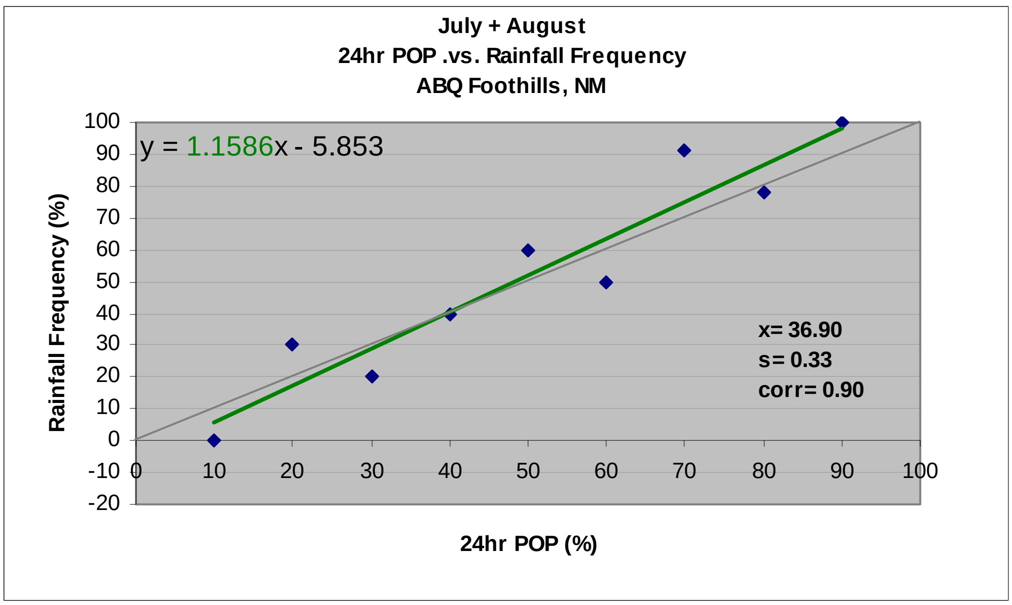



Figure 13a. 12 and 24-hour POP vs frequency at the Albuquerque Foothills for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 3 | 1 | 6 | 3 | 2 | 10 | 7 | 1 | 0 |
| # of forecasts | 0 | 2 | 10 | 5 | 15 | 5 | 4 | 11 | 9 | 1 | 0 |

Figure 13b. 24-hour POP vs actual rainfall frequency at the Albuquerque Foothills for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

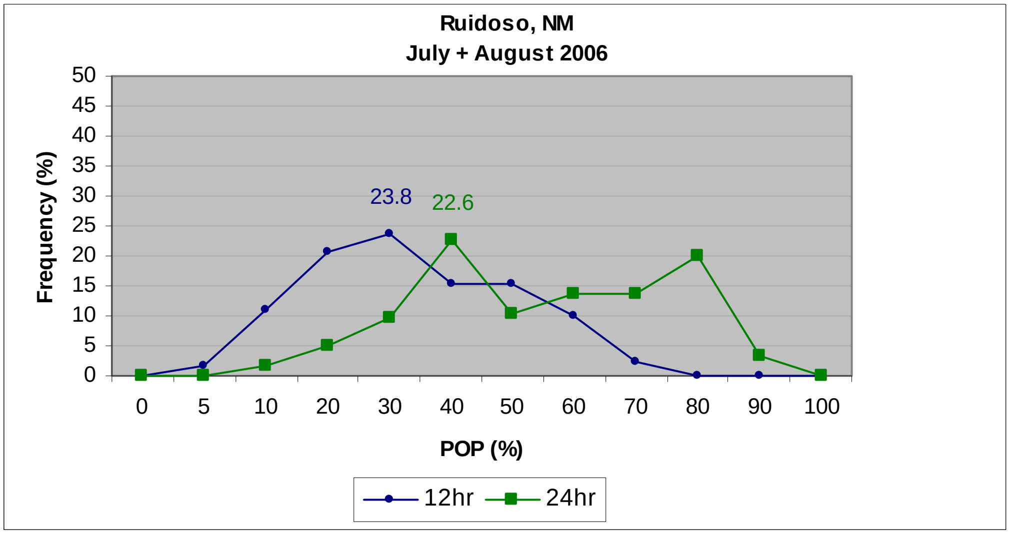
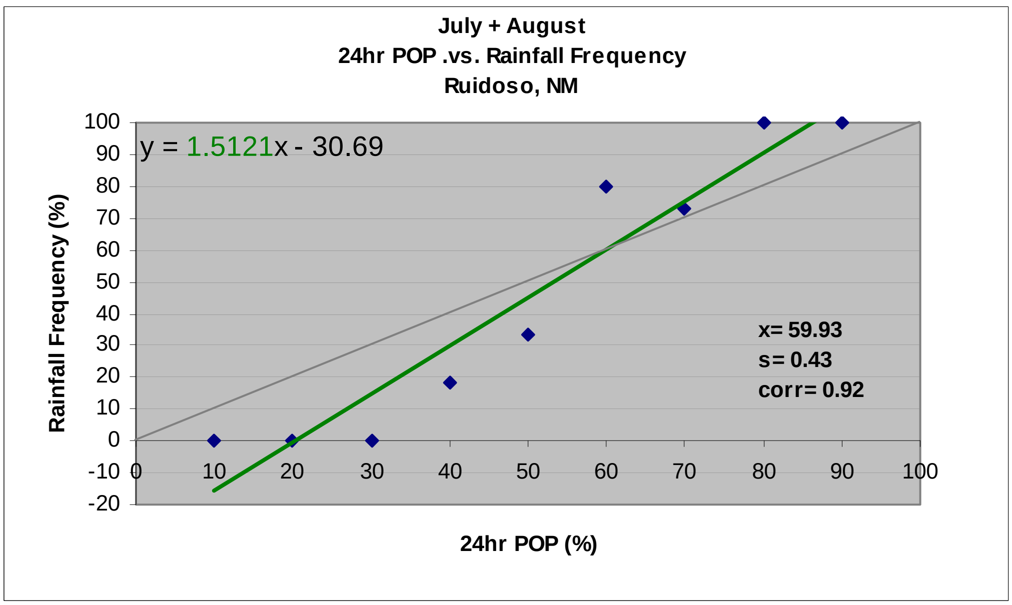



Figure 14a.  12 and 24-hour POP vs frequency at Ruidoso for July and August 2006.




| **24hr POP** | **0** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **# of hits** | 0 | 0 | 0 | 0 | 2 | 2 | 8 | 8 | 10 | 3 | 0 |
| **# of forecasts** | 0 | 1 | 2 | 8 | 11 | 6 | 10 | 11 | 10 | 3 | 0 |

Figure 14b.  24-hour POP vs actual rainfall frequency at Ruidoso for July and August 2006.  The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

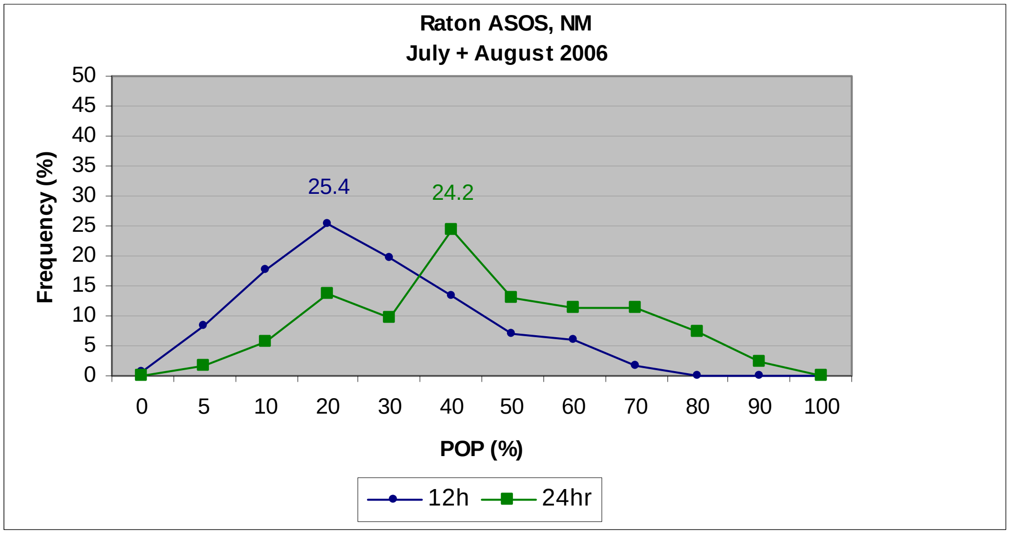
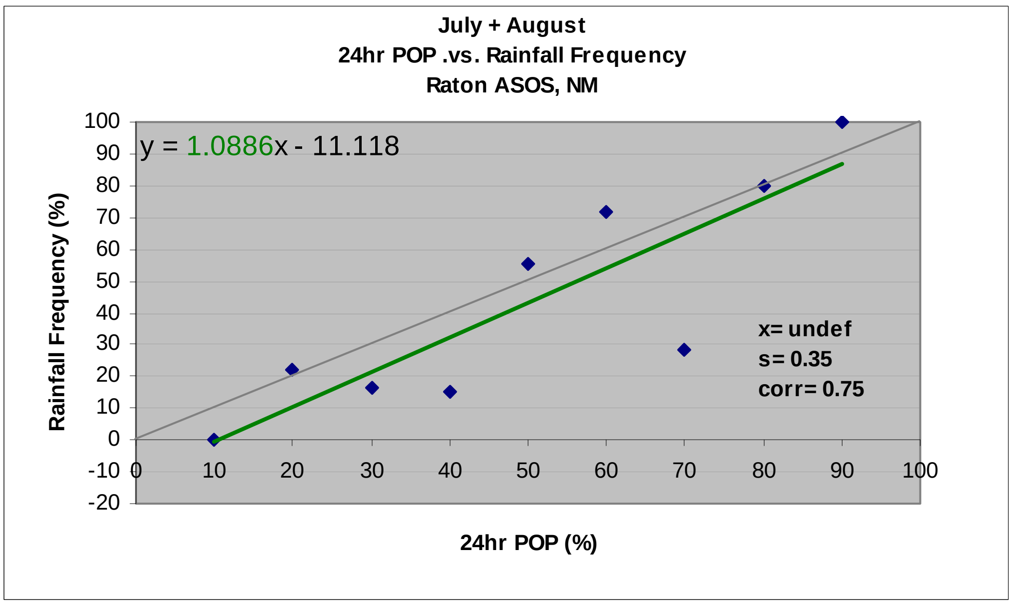



Figure 15a. 12 and 24-hour POP vs frequency at the Raton ASOS for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 2 | 1 | 2 | 5 | 5 | 2 | 4 | 1 | 0 |
| # of forecasts | 0 | 5 | 9 | 6 | 13 | 9 | 7 | 7 | 5 | 1 | 0 |

Figure 15b. 24-hour POP vs actual rainfall frequency at the Raton ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

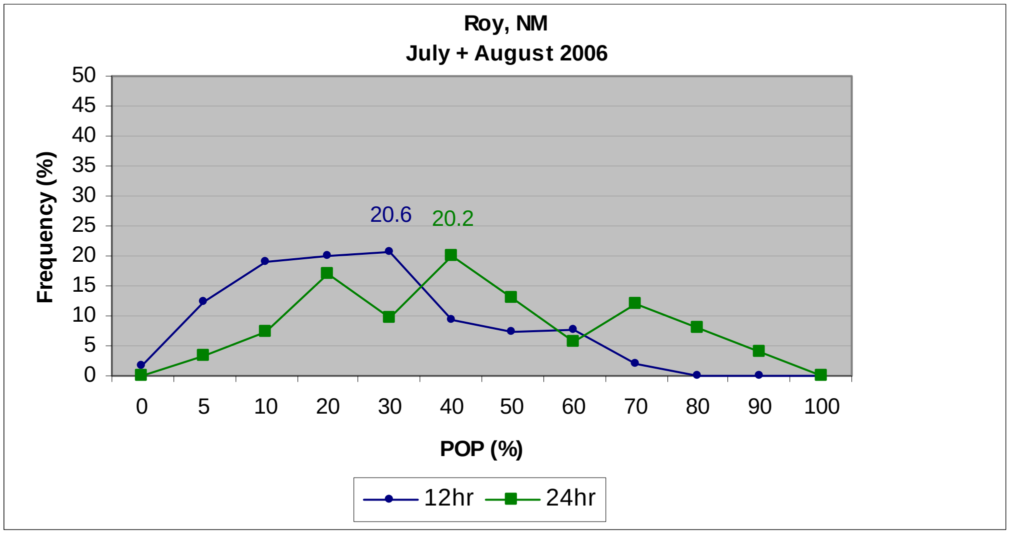
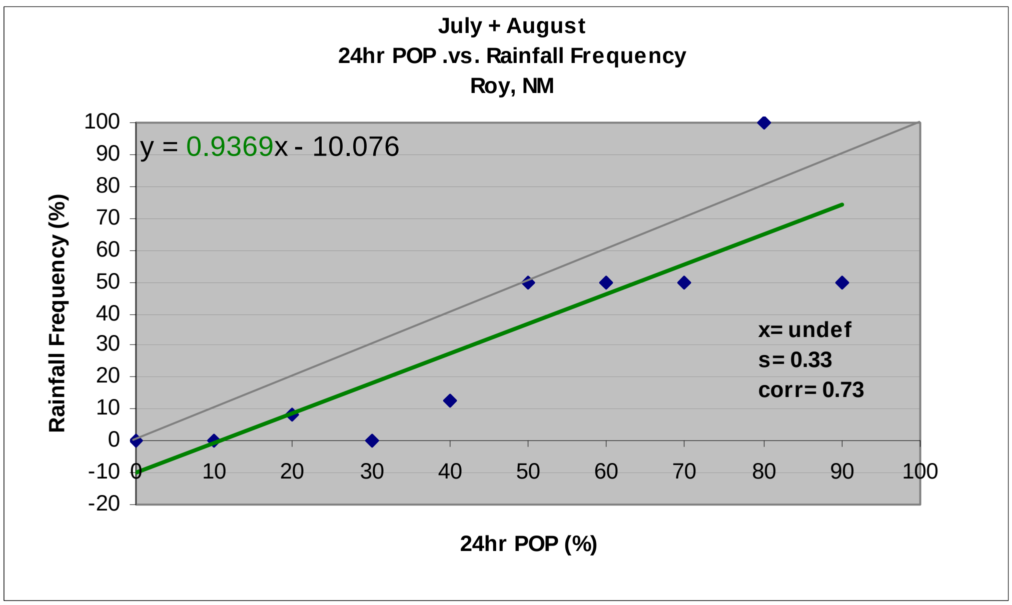



Figure 16a. 12 and 24-hour POP vs frequency at Roy for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 1 | 0 | 2 | 3 | 3 | 3 | 6 | 1 | 0 |
| # of forecasts | 3 | 1 | 12 | 4 | 16 | 6 | 6 | 6 | 6 | 2 | 0 |

Figure 16b. 24-hour POP vs actual rainfall frequency at Roy for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

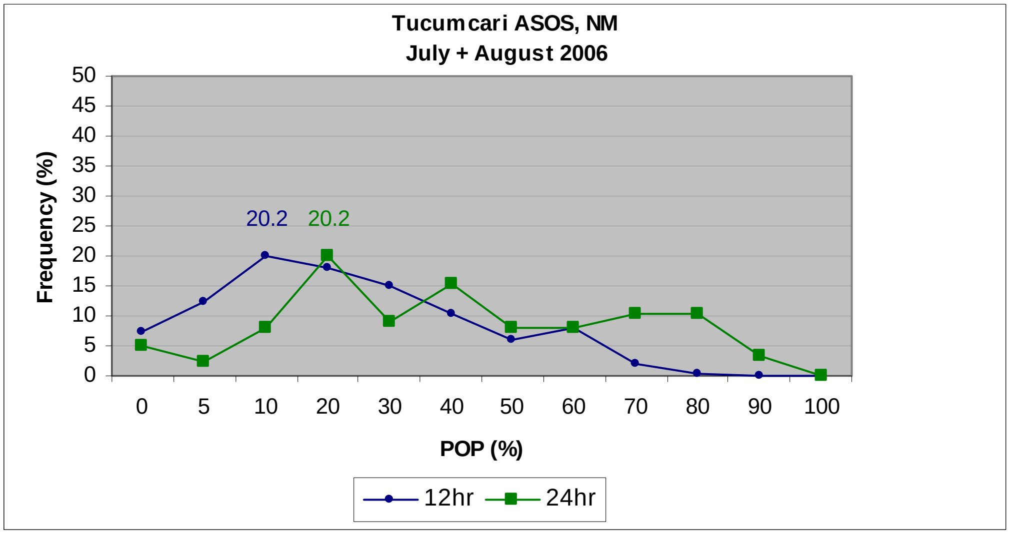
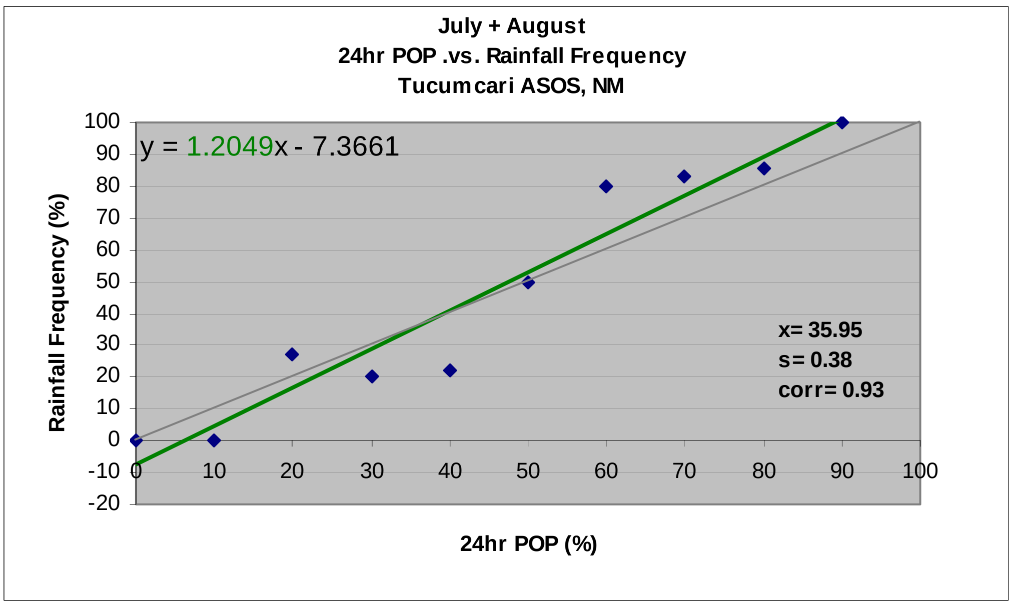



Figure 17a. 12 and 24-hour POP vs frequency at the Tucumcari ASOS for July and August 2006.




| **24hr POP** | **0** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **# of hits** | 0 | 0 | 3 | 1 | 2 | 3 | 4 | 5 | 6 | 2 | 0 |
| **# of forecasts** | 5 | 6 | 11 | 5 | 9 | 6 | 5 | 6 | 7 | 2 | 0 |

Figure 17b. 24-hour POP vs actual rainfall frequency at the Tucumcari ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

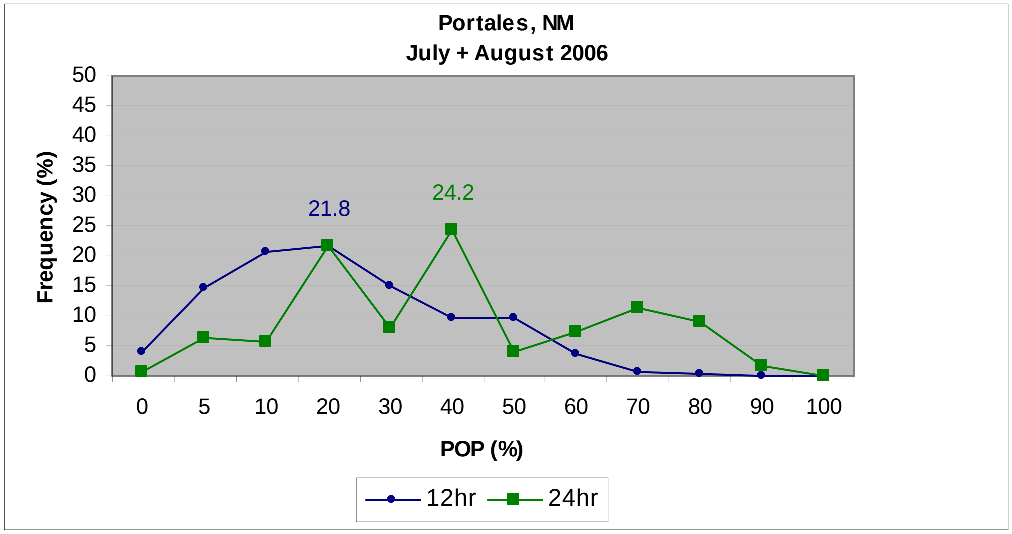
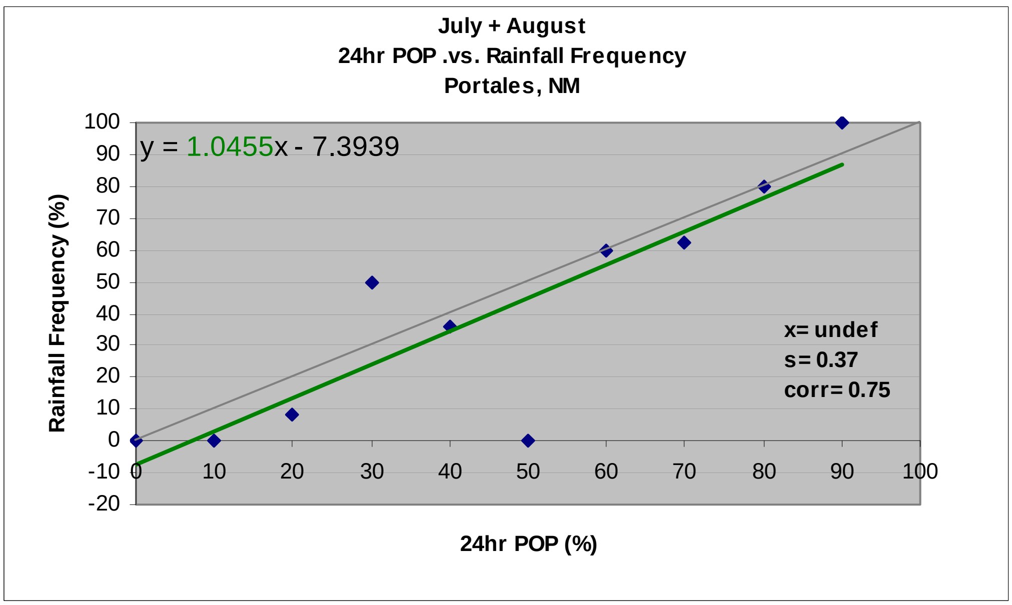



Figure 18a. 12 and 24-hour POP vs frequency at Portales for July and August 2006.




| 24hr POP | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| # of hits | 0 | 0 | 1 | 2 | 5 | 0 | 3 | 5 | 4 | 1 | 0 |
| # of forecasts | 3 | 7 | 12 | 4 | 14 | 3 | 5 | 8 | 5 | 1 | 0 |

Figure 18b. 24-hour POP vs actual rainfall frequency at Portales for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

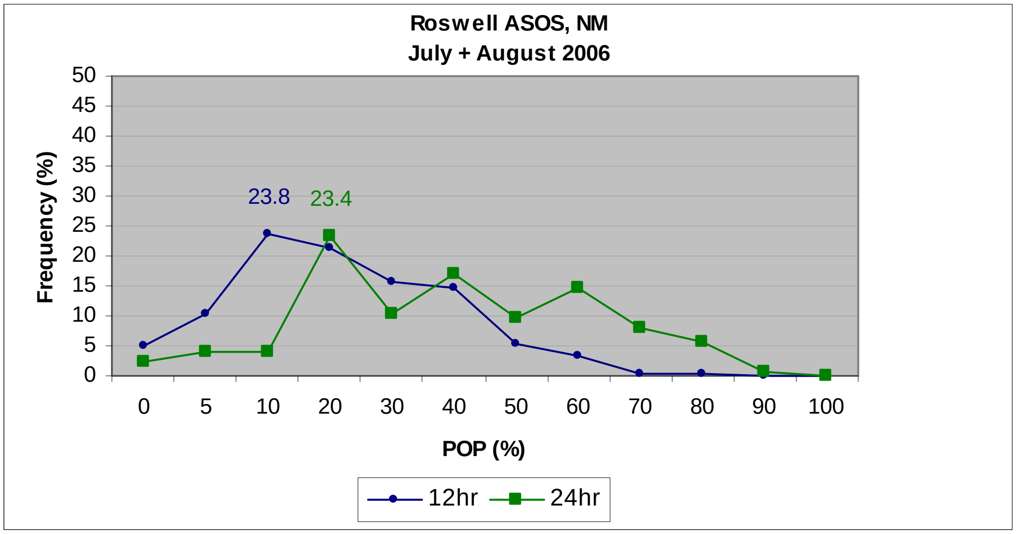
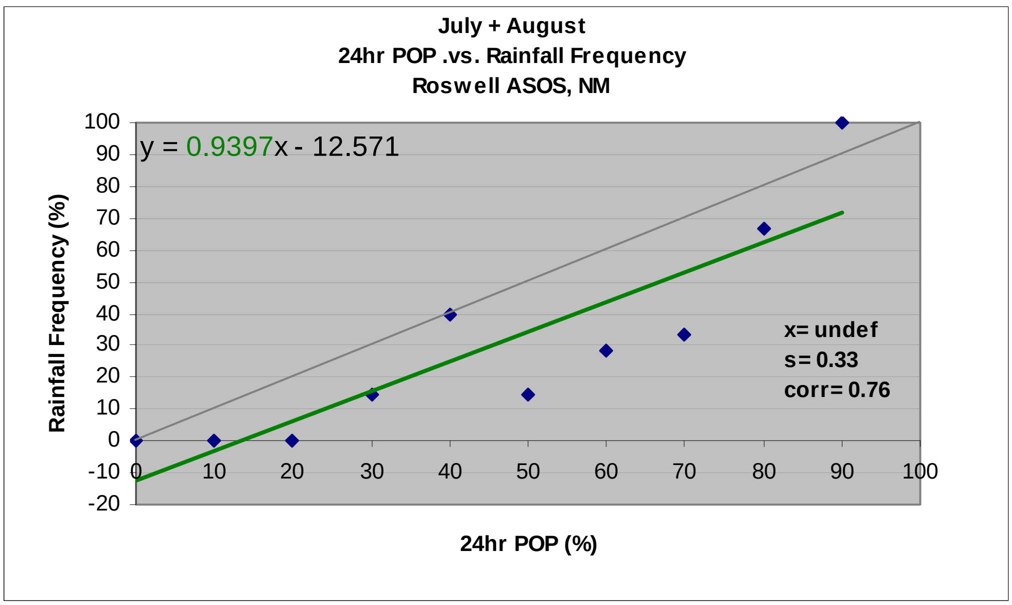



Figure 19a. 12 and 24-hour POP vs frequency at the Roswell ASOS for July and August 2006.




| **24hr POP** | **0** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** | **100** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **# of hits** | 0 | 0 | 0 | 1 | 4 | 1 | 2 | 2 | 2 | 1 | 0 |
| **# of forecasts** | 4 | 4 | 13 | 7 | 10 | 7 | 7 | 6 | 3 | 1 | 0 |

Figure 19b. 24-hour POP vs actual rainfall frequency at the Roswell ASOS for July and August 2006. The table details the number of actual precipitation events versus the total number of 24 hour POP forecasts for the corresponding POP category.

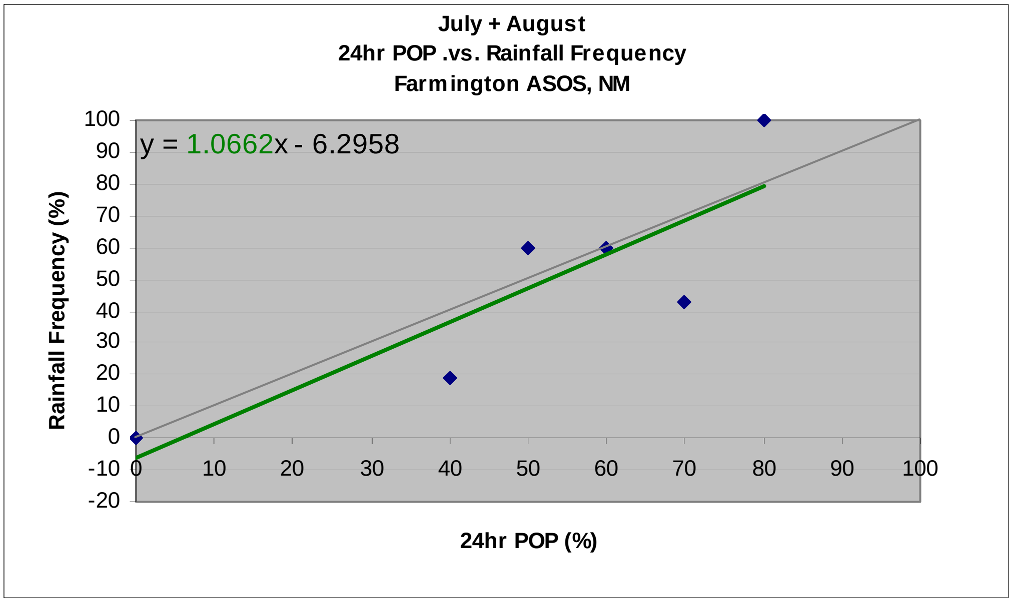
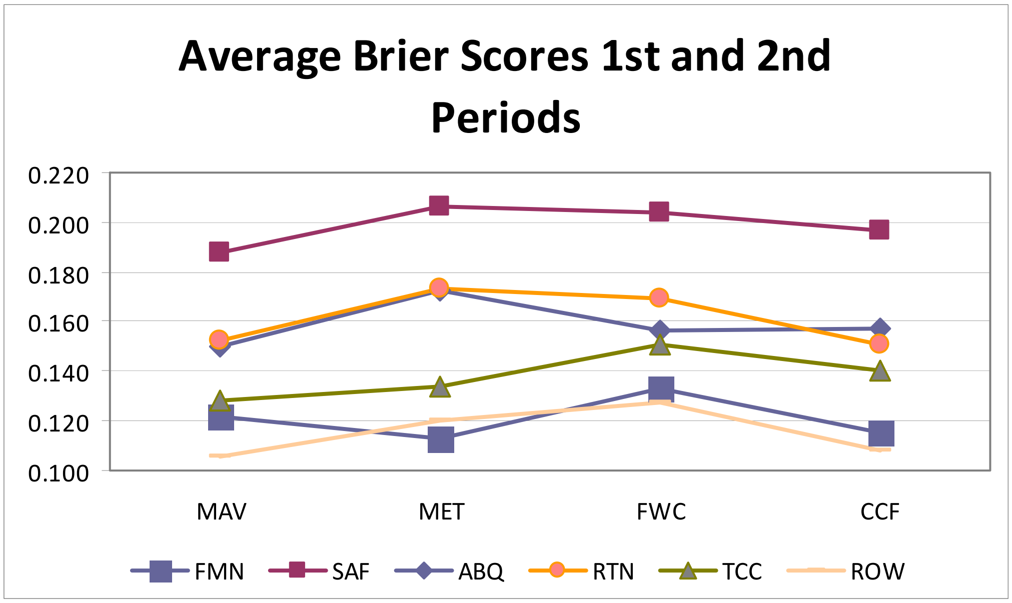
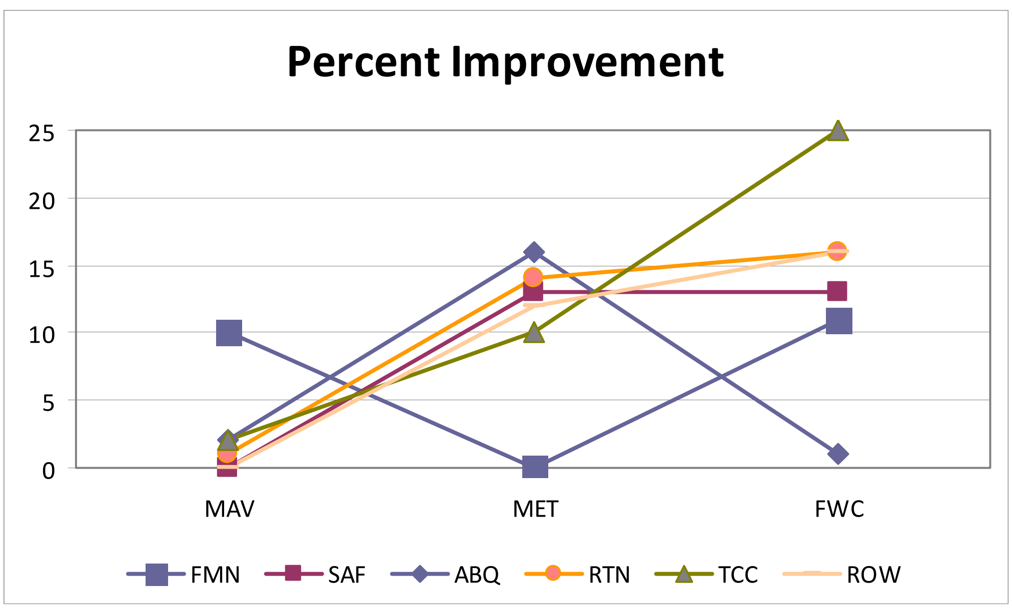



Figure 20. 24-hour POP vs actual rainfall frequency at the Farmington ASOS for July and August 2006 without the 10, 20, and 30 24-hour POPs.




| Product | FMN | SAF | ABQ | RTN | TCC | ROW |
|---|---|---|---|---|---|---|
| **MAV** | 0.122 | 0.188 | 0.150 | 0.152 | 0.129 | 0.106 |
| **MET** | 0.113 | 0.207 | 0.173 | 0.173 | 0.134 | 0.121 |
| **FWC** | 0.133 | 0.204 | 0.157 | 0.169 | 0.151 | 0.127 |
| **CCF** | 0.116 | 0.197 | 0.158 | 0.151 | 0.140 | 0.108 |

Figure 21. Average Brier Scores for the 1st and 2nd periods from the MAV, MET, FWC, and CCF products.




| Product | FMN | SAF | ABQ | RTN | TCC | ROW |
|---|---|---|---|---|---|---|
| **MAV** | 10 | 0 | 2 | 1 | 2 | 0 |
| **MET** | 0 | 13 | 16 | 14 | 10 | 12 |
| **FWC** | 11 | 13 | 1 | 16 | 25 | 16 |

Figure 22. Forecast percent improvement for the 1st and 2nd periods over the MAV, MET, and FWC products.