2B.6 ANALYSIS OF MODEL FORECASTS OF MAXIMUM TEMPERATURE BEFORE AND AFTER COLD FRONT PASSAGES IN THE SOUTHERN PLAINS

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1. INTRODUCTION

Forecasting maximum temperatures before and after the passage of significant cold fronts can be quite a challenge. The speed at which the numerical weather prediction models move the cold air is one important factor. Another is the magnitude of the warming predicted ahead of the front and the cooling behind the front. The temperature forecasts produced by the National Centers for Environmental Prediction Global Forecast System (GFS) and the North American Mesoscale (NAM) model, and that of the European Centre for Medium-Range Weather Forecasts (ECMWF) were analyzed. The analyses used Model Output Statistics (MOS) as proxies for the GFS and NAM. Direct model output was from the ECMWF. For the purpose of this investigation, a significant cold front was defined as one in which the maximum surface temperature change from one day to the next was 15 or more Fahrenheit degrees.

Strong cold fronts generally result in weather that has a significant impact to the public and commerce. The impact may be strictly one of interest or it may actually have an impact on actions before or after the frontal passage. Also, the optimal lead time to providing meaningful and reasonably accurate information to the customer may vary, depending on the operation or interest. However, the importance to the National Weather Service (NWS) and the private weather enterprise is simple: make the forecast as accurate as possible as early as possible.

An analysis of thirty-eight short term forecasts (periods one through five) and thirty-five extended period forecasts (period six through thirteen) found that the models forecast insufficient warming immediately ahead of significant cold fronts and insufficient cooling immediately behind those same cold fronts. An awareness of these biases should allow forecasters to add value to the numerical guidance of significant frontal passages and may help modelers identify and correct issues on how models handle these fronts.

2. DATA

Data at Tulsa International Airport between October 2007 and February 2009 were compiled for significant frontal passages through the Southern Plains. Maximum temperature forecasts from the GFS MOS (MAV and MEX), NAM MOS (MET) and ECMWF three-hour guidance were used as proxies to analyze errors and biases in the underlying numerical weather prediction models. All forecasts were analyzed for maximum daytime temperatures (highs) using the thirteen standard forecast projections issued by NWS forecast offices. Therefore, the second period forecast was generated from the previous 1200 UTC model run, the previous 0000 UTC model run for the third period forecast and so on, creating a series of thirteen separate high temperature forecasts on the day before and the day after the passage of a significant cold front.

Periods 1 through 5 were analyzed from the GFS MAV MOS forecasts and the NAM MET MOS forecasts. There were 38 cases. Periods 6 through 13 were analyzed from the GFS MEX MOS and the highest daytime temperature forecast from the three-hour ECMWF temperature output. Only 35 cases were available for the extended periods due to missing ECMWF data. No ECMWF forecasts were analyzed for periods 1 through 5.

Again, a significant cold front was defined as a maximum observed temperature change of 15°F or more from one daytime high to the next. The site used in the study was Tulsa International Airport (TUL) which uses the standard Automated Surface Observing System. Data were analyzed separately for the maximum temperature errors on the day before frontal passage and again for the maximum temperature errors on the day after the frontal passage

3. SHORT TERM MEAN ERRORS, BIASES AND COUNTS

Mean Absolute Errors (MAEs) and biases were computed for all periods and segmented for days before and after cold front passages. Counts of positive errors and negative errors were also computed to help define the randomness of the errors.

For maximum temperatures the day before frontal passage, the MAV had an MAE of just less than 4°F in the first period and increased to a 5th period MAE of over 7°F. The MET was slightly better with an average first period error of just over 4°F which increased to a 5th period error of just less than 7°F. The data in Table 1 are rounded to the nearest tenth of a degree. It is notable that the average biases were almost as large as the mean absolute.

Pre-front errors by category for the MAV and MET are shown in Figures 1 and 2, respectively. As expected, the number of large errors increased as the time to the event increased. The counts of forecasts that were too cool and too warm are shown in Figures 3 and 4 for the MAV and MET, respectively. The discrepancy of the counts is quite remarkable. Over 80% of the MAV errors in periods one through 5 were too cool ahead of the fronts.

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	Period 1	Period 2	Period 3	Period 4	Period 5
MAV	4.0 / -3.3	5.5 / -5.1	6.0 / -5.5	6.9 / -6.4	7.5 / -7.1
MET	4.1 / -2.8	4.1 / -3.4	4.6 / 3.7	4.8 / -4.1	6.8 / -6.0

Table 1. Mean absolute temperature errors and biases (degrees Fahrenheit) for MAV (GFS MOS) and MET (NAM MOS) the day before a significant cold front (in the warm sector) at TUL.

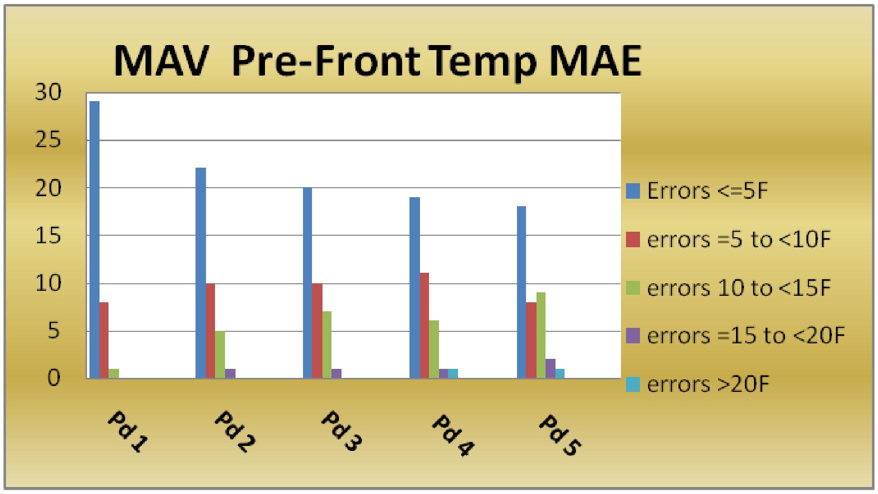

Figure 1. Numbers of maximum temperature errors by category for the GFS MAV MOS for the days before a cold front passage at TUL.

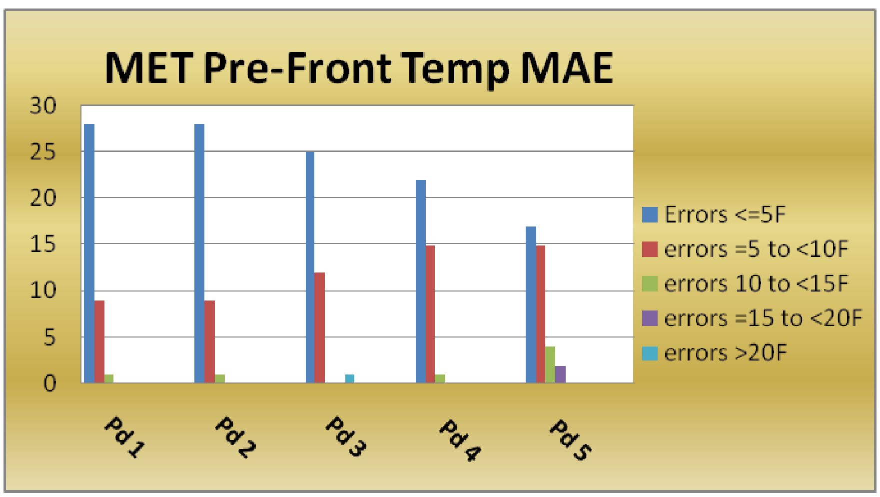

Figure 2. Numbers of maximum temperature errors by category for the NAM MET MOS for the days before a cold frontal passage.

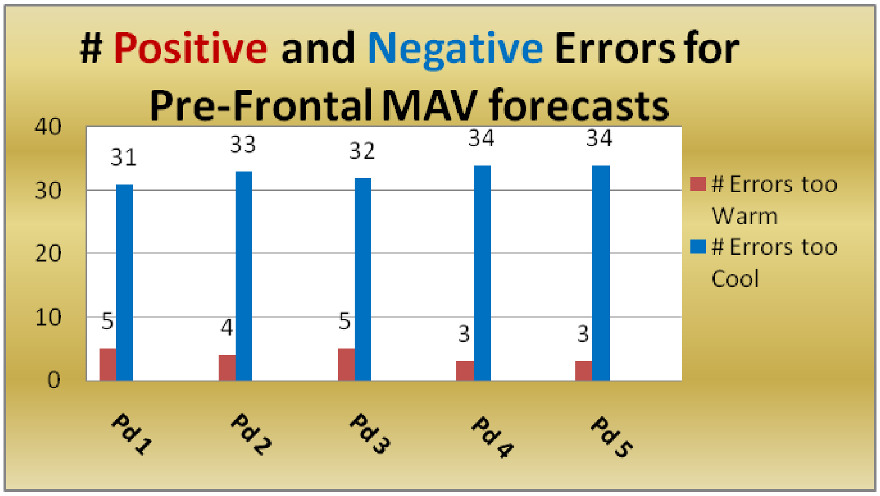

Figure 3. Count of positive and negative GFS MAV MOS high temperature errors for the days before a cold front passage. Errors of zero are not shown.

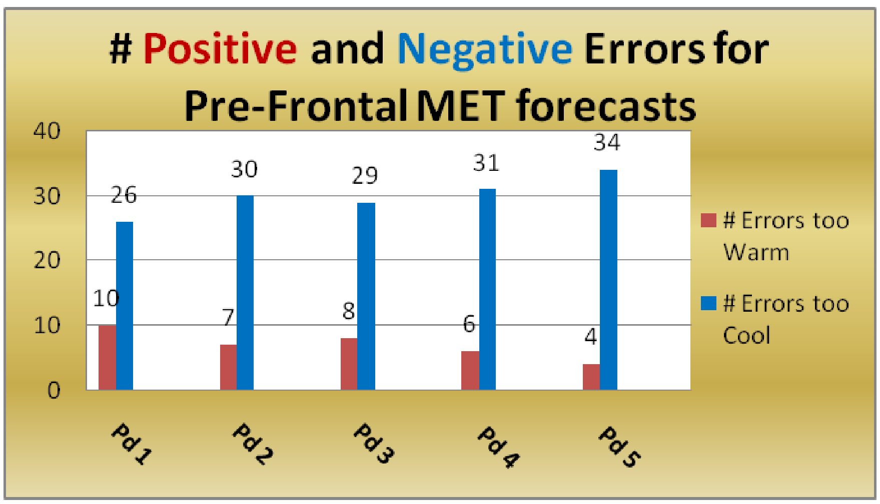

Figure 4. Count of positive and negative GFS MAV MOS high temperature errors for the days before the passage of a cold front. Errors of zero are not shown.

Table 2 shows that for maximum temperatures on the day after frontal passages, the MAV had an average MAE of just over 4°F consistently for periods 1 through 5. The MET was slightly better with an average first period error of just over 3°F in period 1 which trended up to over 4°F by period 5. Biases were similar, where neither the MAV nor MET forecast highs cold enough on the day after significant cold front passages. The data in Table 2 are rounded to the nearest tenth of a degree.

Post-frontal high temperature errors by category are shown for the MAV and MET in Figures 5 and 6, respectively. The counts of forecasts that were too cool and too warm are shown in Figures 7 and 8 for the MAV and MET. The MAV forecast were warmer than observed in over 80% of the events after frontal passage. Again, the MET forecasts were not quite as poor, but showed considerable bias.

	Period 1	Period 2	Period 3	Period 4	Period 5
MAV	4.1 / 2.4	4.2 / 3.6	4.3 / 2.9	4.3 / 4.0	4.3 / 4.2
MET	3.2 / 2.6	3.4 / 3.1	4.2 / 2.5	4.5 / 3.9	4.3 / 2.9

Table 2. Mean absolute temperature errors and biases (degrees Fahrenheit) of high temperatures for MAV and MET the day after cold front passage.

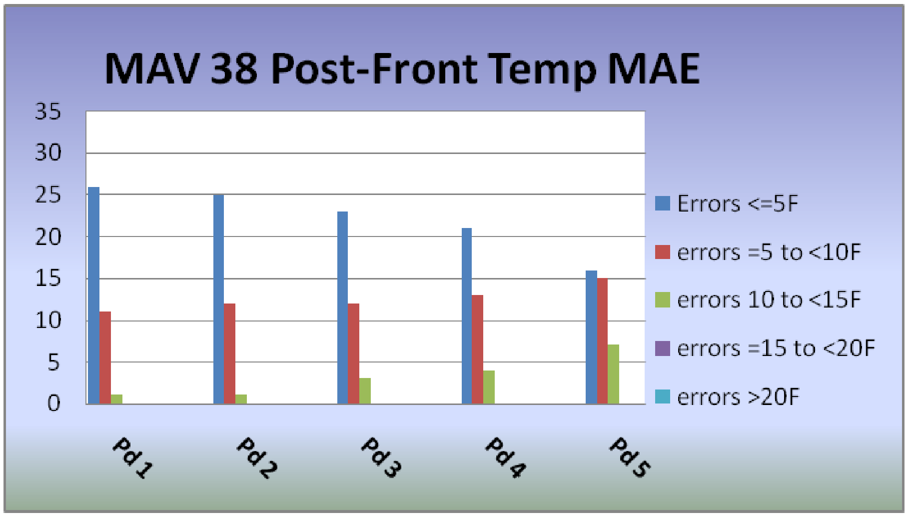

Figure 5. Numbers of absolute errors by category for GFS MAV MOS for post-frontal high temperature forecasts at TUL.

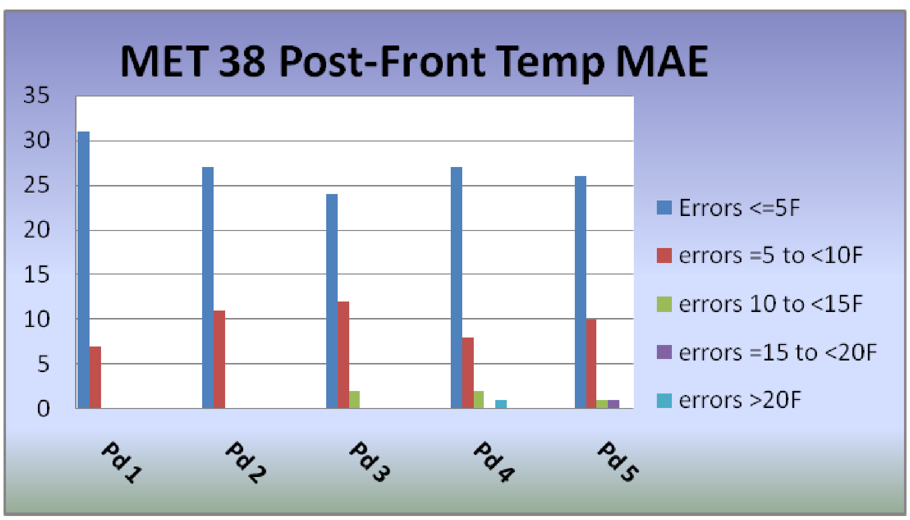

Figure 6. Numbers absolute of errors by category for the NAM MET MOS for post-frontal high temperature forecasts at TUL.

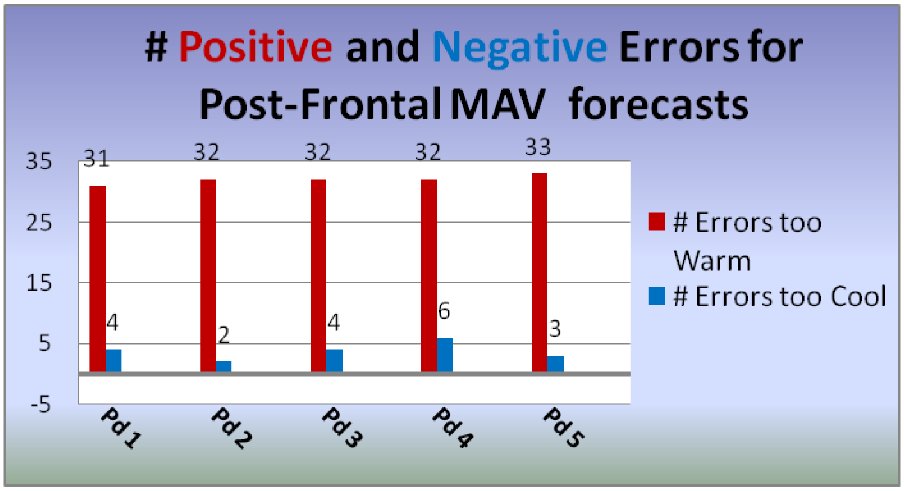

Figure 7. Count of GFS MAV MOS forecasts that were too warm (red) or too cold (blue) for the day after a significant cold frontal passage at TUL.

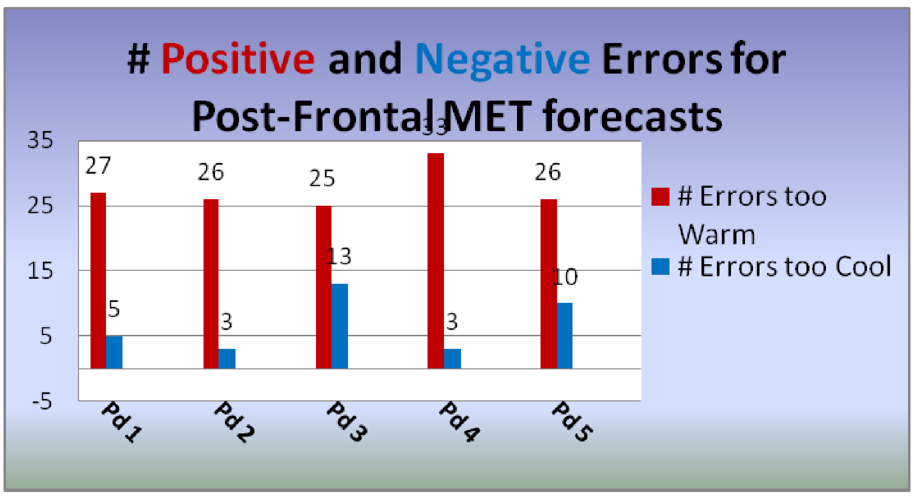

Figure 8. Count of NAM MET MOS forecasts were too warm (red) or too cold (blue) for the day after a significant cold frontal passage at TUL.

These errors and biases confirmed forecasters' perceptions that the guidance rarely forecast high temperatures warm enough ahead of cold fronts and, in contrast, rarely forecast high temperatures cool enough immediately behind the fronts. Note the negative biases in Table 1 and positive biases in Table 2.

4. LONG TERM MEAN ERRORS, BIASES AND COUNTS

Mean absolute errors and biases were also computed for periods 6 through 13, using the GFS MEX MOS and the ECMWF maximum/minimum three-hour forecasts. Counts of positive errors and negative errors were computed as in section three to help define the randomness of the errors. Here again, it was found that the GFS MEX MOS was consistently too cool in its forecasts for daytime high temperatures ahead of significant cold fronts in nearly all cases. The MAEs for forecast maximum daytime temperatures from the MEX and ECMWF prior to frontal passages are shown in Table 3.

Pre-front errors by category are shown for the MEX and ECMWF in Figures 9 and 10, respectively. The counts of forecasts that were too cool and too warm are shown in Figures 11 and 12. As with periods 1-5, the bias of the count is quite significant. The MEX forecast high temperatures ahead of the fronts were too cool in over 85% of the events. The ECMWF was just as poor.

	Pd 6	Pd 7	Pd 8	Pd 9	Pd 10	Pd 11	Pd 12	Pd 13
MEX	7.7 / -6.6	8.8 / -7.7	9.0 / -7.8	8.9 / -7.3	11.1 / -11.1	11.7 / -11.3	11.6 / -11.6	11.5 / -11.2
ECMWF	7.7 / -6.4	8.7 / -7.4	8.9 / -7.7	10.5 / -9.5	10.5 / -9.6	11.3 / -10.1	10.2 / -9.2	9.7 / -9.3

Table 3. Mean absolute temperature errors and biases (degrees Fahrenheit) for the GFS MEX and ECMWF for daytime high temperatures on the last day prior to the passing of a significant cold front.

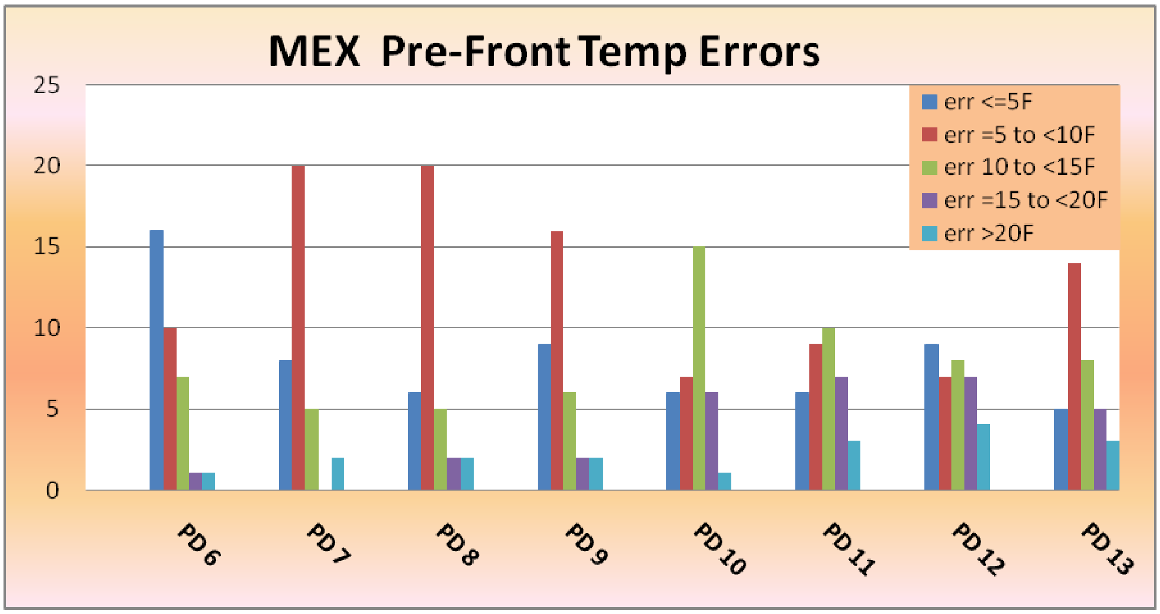

Figure 9. Numbers of absolute errors by category for pre-frontal MEX high temperature forecast for periods 6 through 13.

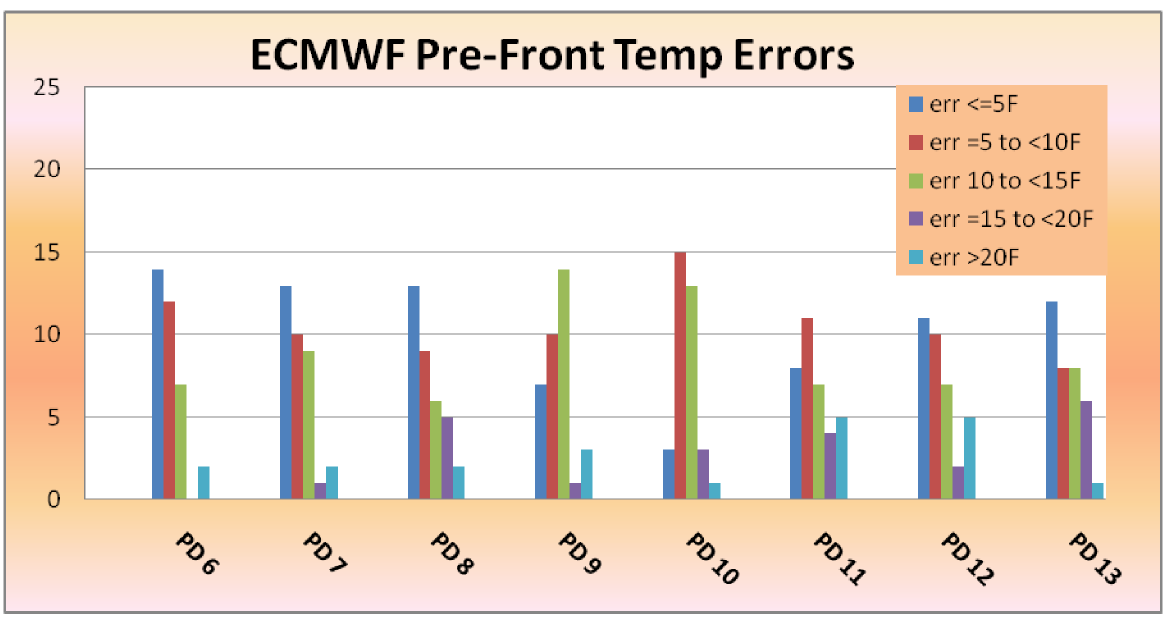

Figure 10. Numbers of absolute errors by category for pre-frontal ECMWF high temperature forecasts for periods 6 through 13.

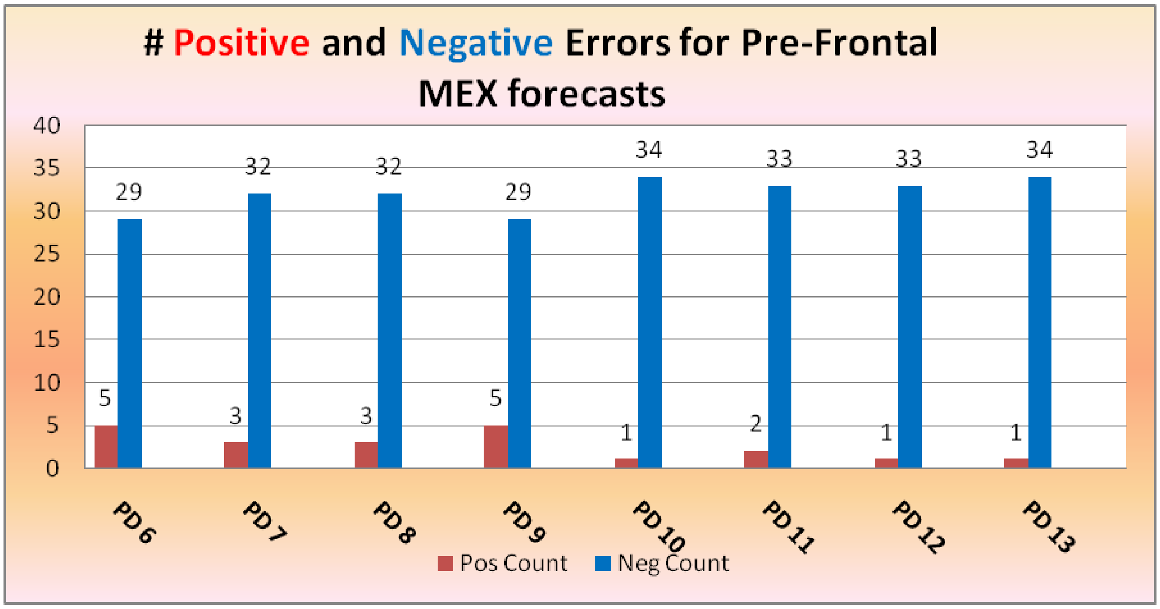

Figure 11. Counts of MEX forecast highs that were too warm (red) and too cold (blue) the day before a cold front passage at TUL.

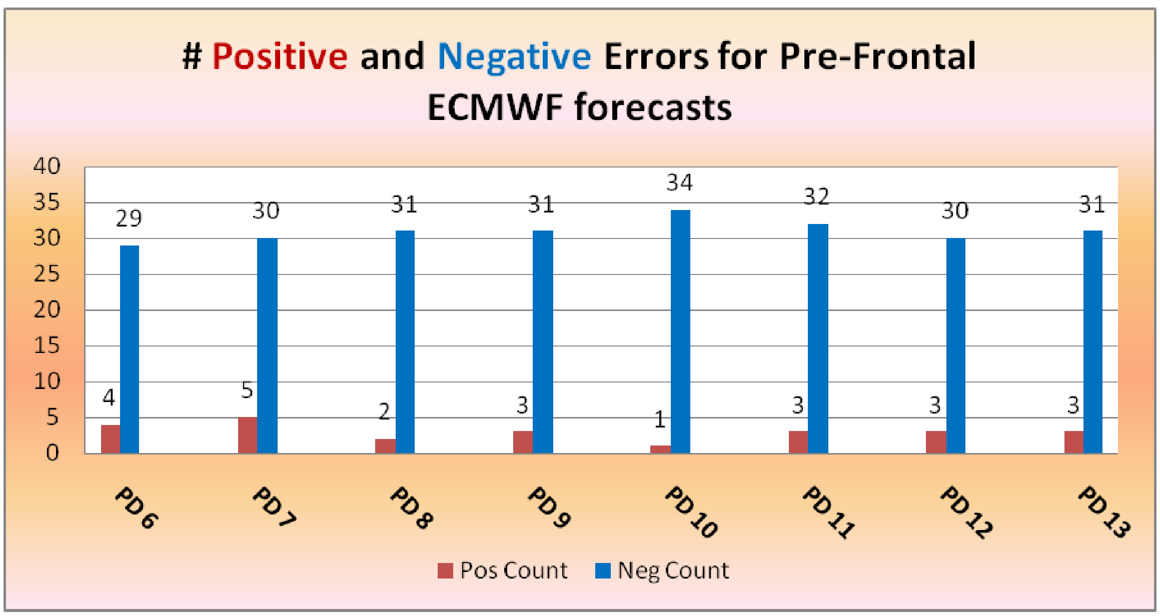

Figure 12. Counts of ECMWF forecast highs that were too warm (red) and too cold (blue) the day before a cold front passage at TUL.

Table 4 shows MAEs and biases for MEX and ECMWF forecast daytime highs on the day following the same significant cold frontal passage as shown in Table 3. The MEX was consistently warm on the day after cold front passages with biases from 6°F to nearly 10°F. It is curious that the ECMWF biases for daytime high temperature after frontal passages were considerably lower than those for the MEX.

Post-front errors by category are shown for the MEX and ECMWF in Figures 13 and 14, respectively. The counts of forecasts that were too warm or too cool are shown in Figures 15 and 16 for the MEX and ECMWF. As with periods 1-5, the discrepancy of the count is quite significant for the MEX, with over 80% of the errors too warm. Surprisingly, the ECMWF missed too warm and too cold about the same number of times.

	Pd 6	Pd 7	Pd 8	Pd 9	Pd 10	Pd 11	Pd 12	Pd 13
MEX	6.6 / 6.11	6.9 / 6.2	8.2 / 6.3	7.4 / 7.1	8.6 / 8.0	7.8 / 7.5	10.2 / 9.9	9.0 / 8.2
ECMWF	5.0 / 0.1	4.7 / -0.9	4.8 / -0.2	5.3 / -0.2	6.5 / 1.1	7.5 / 1.3	6.51 / 2.6	8.0 / 3.29

Table 4. Mean absolute errors and biases (degrees Fahrenheit) for the GFS MEX and ECMWF for daytime high temperature on the first day after the passage of a significant cold front.

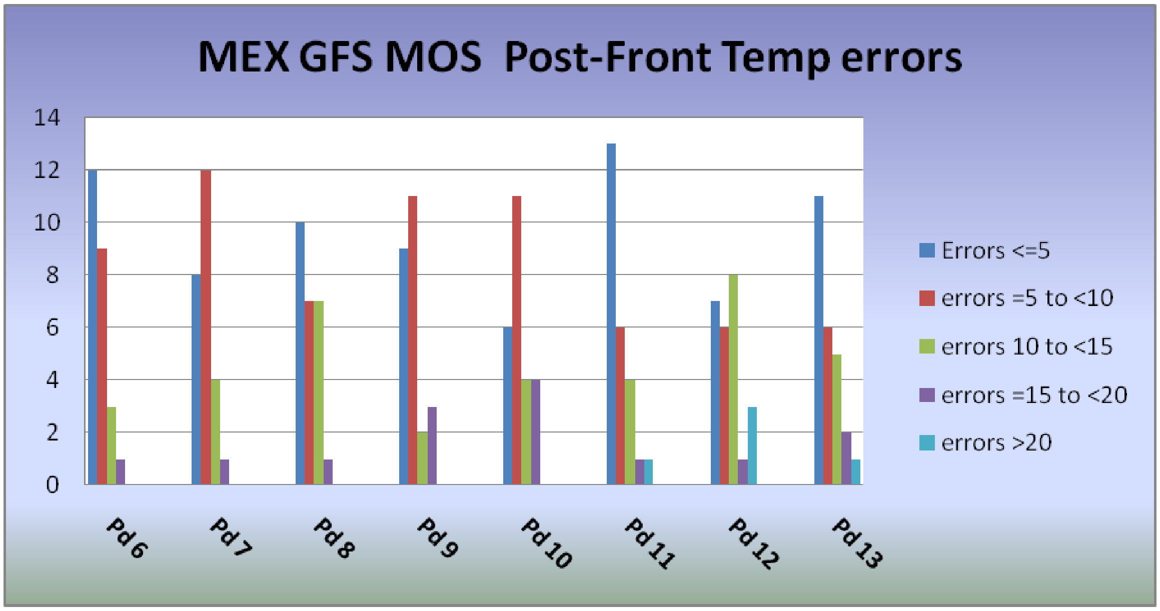

Figure 13. Number of MEX MAE errors by category for high temperatures on the day after a significant cold front passage at TUL.

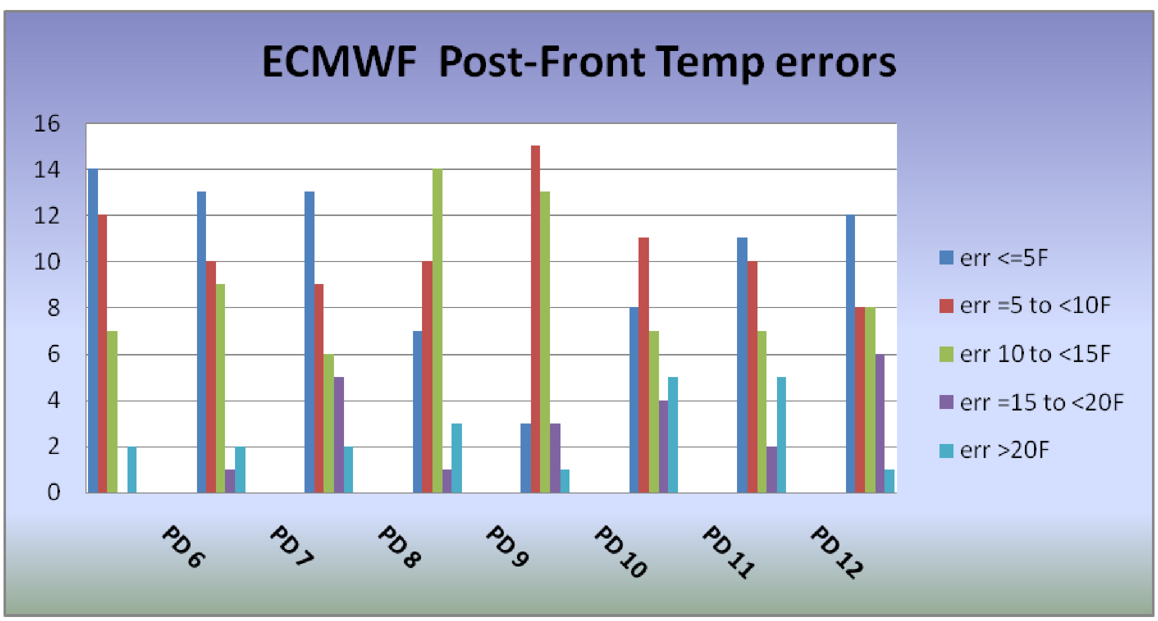

Figure 14. Number of ECMWF MAE errors by category for high temperature forecasts on the day after a significant cold front passage at TUL.

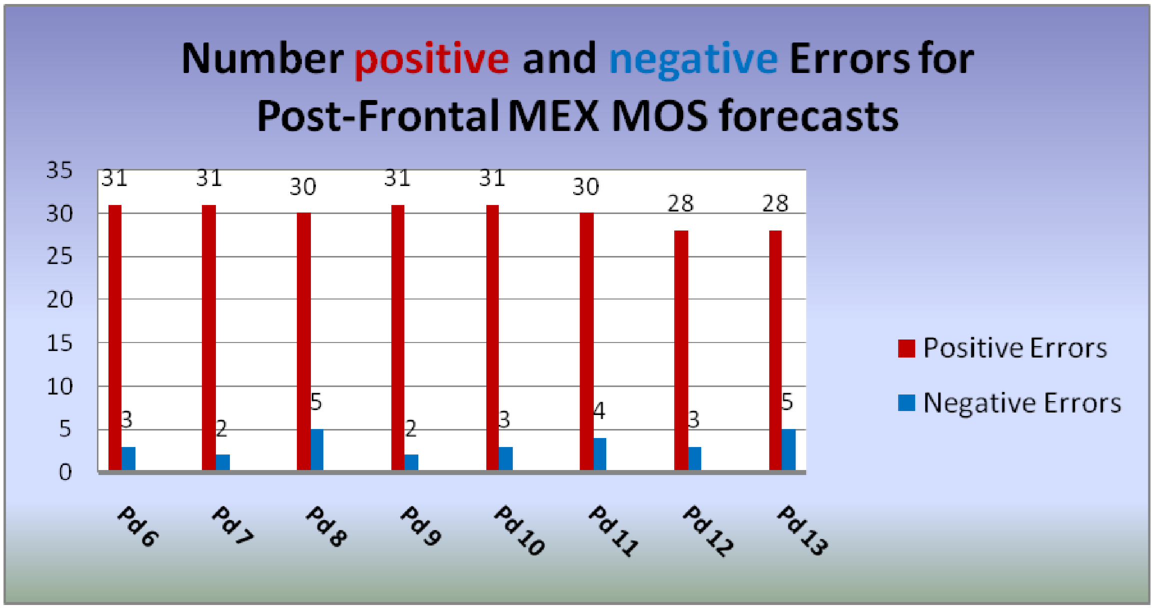

Figure 15. Counts of MEX forecast highs that were too warm (red) and too cold (blue) the day following a cold front passage at TUL.

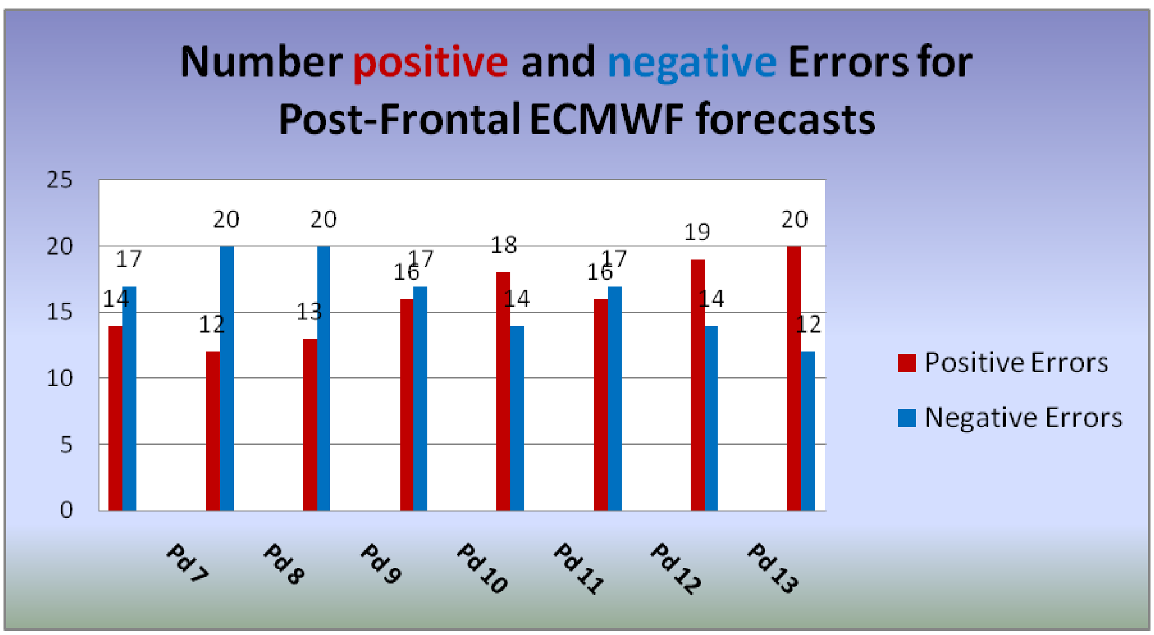

Figure 16. Counts of ECMWF forecast highs that were too warm (red) and too cold (blue) the day following a cold front passage at TUL.

5. CONCLUSIONS

Forecaster discussions and speculations at WFO Tulsa since about 2005 indicated that model forecasts and the MOS derived from those models had significant daytime high temperature biases just before and just after significant cold frontal passages. A dominant cool bias was identified on the day before a significant front moved through the forecast area, with a significant warm bias on the day after that same front. This was investigated for 38 short-term forecasts (periods 1-5) and 35 long-term forecasts (period 6-13) at TUL and found to be true.

As indicated by their associated short-range MAV and MET products, the GFS and NAM failed to generate sufficient warming in nearly all pre-frontal events and insufficient cooling in nearly all post-frontal events. The MEX and ECMWF long-range forecasts also failed to produce sufficiently warm high temperatures on the day before frontal passages. And although the MEX guidance had a strong warm bias the day after fronts passed TUL, the ECMWF guidance was about evenly mixed too warm and too cool. But even though the ECMWF biases were smaller than those of the MEX, the ECMWF MAEs were still significantly large.

Reasons for these model biases would be speculative on the part of this author. However, some thoughts include model smoothing that might diminish gradients, model timing of the fronts, and cloud development either ahead of or behind the fronts. One forecaster rule-of-thumb is that the GFS and NAM typically fail to develop a narrow band of clearing just ahead of cold fronts in eastern Oklahoma. This “dry slot” is often between passage of the dry line and the cold front, and allows temperatures to climb significantly above what the “cloudier” model suggests.

For whatever reason, knowing these model biases should be helpful to forecasters as they try to make the best forecasts possible. In the case of significant cold fronts, improvements to model/MOS forecasts could be significant for the discerning forecaster.

6. ACKNOWLEDGEMENTS

The author would like to acknowledge James Frederick for making the data available for this research. Also, thanks are extended to Diana Riddle and Karen Trammel of WFO Tulsa for suggestions and corrections to this paper.