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AN ANALYSIS OF ETA MODEL FORECAST SOUNDINGS IN RADIATION FOG FORECASTING

Steven A. Amburn*
National Weather Service Forecast Office, Tulsa, Oklahoma

1. INTRODUCTION

Forecasting radiation fog for TAFs (Terminal Aerodrome Forecasts) continues to be a significant challenge for aviation meteorologists. General rules about clear skies, calm winds and recent rainfall are still used by most meteorologists. Sverre Petterssen (1940) concluded that fog is more likely when mixing ratios increase with height in the boundary layer. Petterssen's rule could be applied if upper air observations were available for each TAF across the United States. Observations of the vertical profile of moisture might be helpful, but they are not cost effective. However, Eta model forecast soundings (National Center for Environmental Prediction, 2004) are available for virtually all TAF sites. This study was conducted to determine the value of those Eta soundings.

Meteorologists at United Parcel Service (Baker, et. al.) developed a fog forecasting technique based on assumptions about the vertical profile of moisture. Their technique assumes that the lowest dew point temperature during the warmest part of the afternoon ("crossover temperature") represents the vertical profile of moisture in the boundary layer through the following night when no advection takes place. As surface temperatures cool, the air temperature near the ground may fall below the "assumed" dew point temperature aloft, signaling a possible fog event. If the nighttime temperature drops well below the crossover temperature, fog can be expected to become more probable and more dense.

Combining the United Parcel Service technique with model forecast soundings should provide better visibility forecast guidance since the forecast soundings can predict advection and changes in wind during the night that might enhance or deter fog development. For this study, Eta model BUFR soundings were used with an abbreviated UPS technique to create forecast visibility categories equivalent to the MAV MOS or Model Output Statistics (Meteorological Development Lab, 2004). Statistical comparisons were made to determine the usefulness of Eta model soundings in fog forecasting.

2. BACKGROUND

Meteorologists continue to use the same forecast techniques that have been available for many years. MAV MOS (from the NWS's Global Forecast System) and FWC MOS (from the NWS's Nested Grid Model) generally provide the best guidance to forecasters at this time. However, both MOS products could do much better. The MOS products frequently miss significant events and frequently forecast dense fog when no significant fog occurs. Eta model forecast soundings have been observed to show the typical fog soundings during significant events and could be used as an independent source of guidance.

2.1 MOS and TAF Verification

Table 1 shows the MAV MOS categories and their equivalent FWC MOS categories. These categories have been used by the Weather Forecast Office in Tulsa for many years to verify MOS and TAF forecasts. Table 2 is a contingency table that shows the MAV MOS visibility verification for a one-year period (April 2003 through March 2004), for the combined TAF sites of TUL, MLC, FSM and FYV. Table 2 shows the forecast category down the left side and the observed visibility across the top. (The total hours that a category was forecast can be obtained by summing across a row.) The final column is the average category observed for the given forecast category, weighted by the number of hours of occurrence in that category. For example, the MAV forecast a total of 182 hours of category 1 visibility (< ½ mi) during the year. However, category 1 visibility was only observed for 40 of those 182 hours, or about 22% of the time. Also, it can be seen that when the MAV forecast was category 5 (> 5 mi), category 1 visibility was observed for 236 hours, or about 0.5% of the time.

For comparison purposes, Figure 1 shows the MAV, FWC and TAF weighted average observed visibility category converted to each of the five 5 FWC forecast categories. The figure shows the average category of fog observed, down the left side, corresponding to the forecast fog category across the bottom. For example, when the MAV MOS forecast visibility category was 1 (less than ½ mile), the average observed visibility was 3.23 miles (left side of figure). For a MAV forecast category between 3 and 5 miles, the average observed visibility was 4.35. In fact, <u>for almost any MAV forecast visibility category, the most probable observed value was either category 4 or 5</u>.

Corresponding author address: Steven A. Amburn, NWS Tulsa, OK, 10159 E. 11th Street, Suite 300, Tulsa, OK, 74128; e-mail: Steve.Amburn@noaa.gov

FWC Ctgry	Vsby (mi)	MAV Ctgry
1	<1/2	1 & 2
2	1/2 to 7/8	3
3	1 to 2 3/4	4
4	3 to 5	5
5	> 5	6 & 7

Table 1. FWC MOS visibility categories are shown with corresponding visibility ranges and associated MAV MOS categories.

MAV	1	2	3	4	5	Wtd Avg
1	40	15	39	39	49	3.2
2	8	1	12	15	23	4.8
3	19	16	148	249	337	4.2
4	79	42	229	527	1328	4.4
5	236	95	482	2135	37104	4.9

Table 2. MAV MOS forecast contingency table from April 2004 through March 2004. The forecast category is shown down the left side. The observed category is across the top. The number of hours a category was forecast is shown in the table. The weighted average of a row is shown in the far right column. For example, 40 hours of category 1 were forecast and observed, but category 5 was observed more often (49 hours). Finally, 3.23 in the last column was the weighted average category observed when the MAV MOS forecast category 1 (<½ mile).

2.2 Typical Fog and No-Fog Soundings

Indications of fog are generally recognizable on a Skew T/log P diagram. An example is shown in Figure 2, which is quite similar to the fog sounding shown by Bluestein (1992, p. 65). Note that near the surface, the air temperature crosses below the dew point temperature aloft. This agrees with Petterssen, and fits well with the UPS fog forecasting technique. Soundings where no fog is occurring vary widely, but clearly maintain a significant spread between the air temperature and dew point temperature at the lowest levels as shown in Figure 3, and again by Bluestein (1992, p. 66).

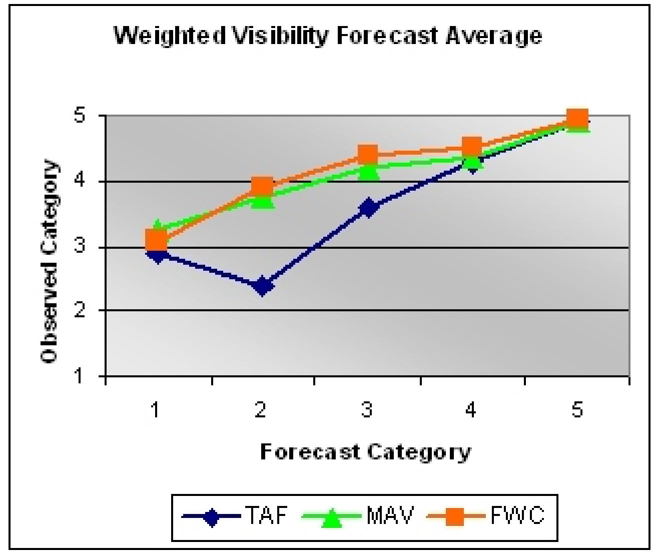

Figure 1. April 2003 through March 2004 average observed visibility categories for the TAF sites of TUL, MLC, FSM, and FYV combined.

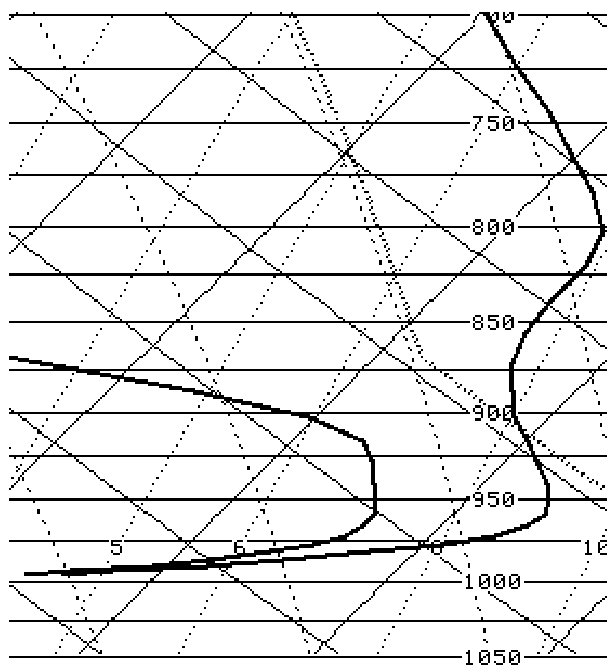

Figure 2. Example of a forecast fog sounding (14 Jan 2004) on a standar Skew T/log P diagram. Visibility at this forecast time was less than 1/4 mile.

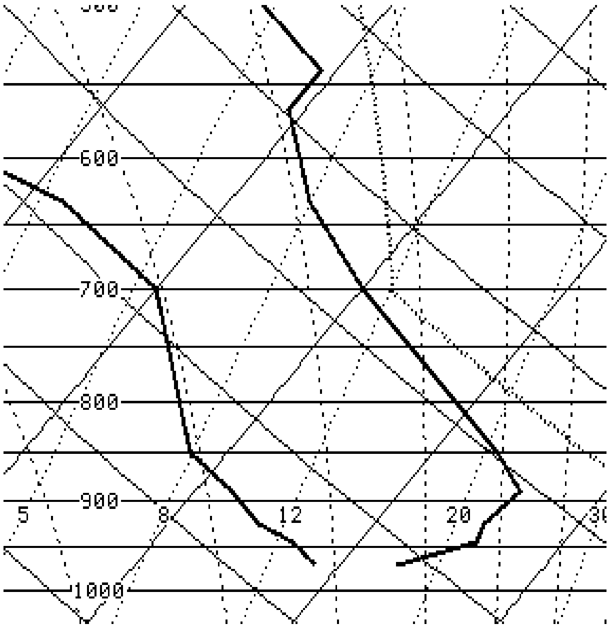

Figure 3. Example of a “no-fog” sounding at 12 UTC. Note the dew point temperature decreases with height.

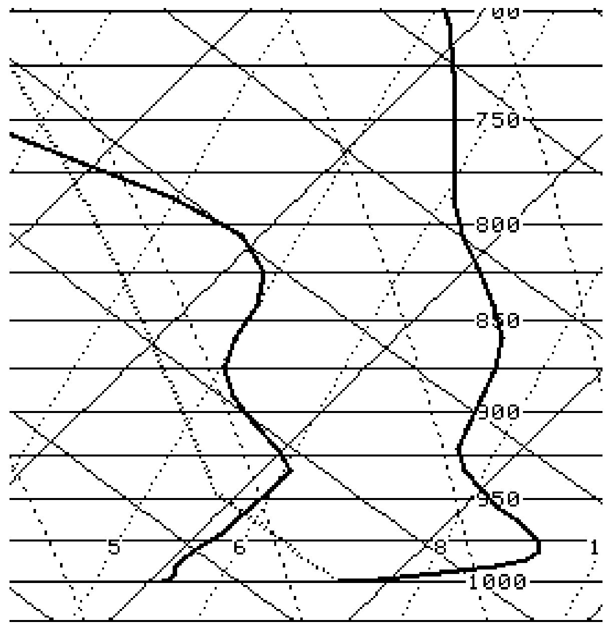

Figure 4. 13 Jan 2004, 12 UTC Eta run cycle forecast sounding, valid at 03Z, 14 Jan 2004, for TUL. Visibility at the time was 4 miles.

3. Eta Model Soundings

The Eta model is run at a higher resolution (32km for the operational Eta) than the GFS (0.5 x 0.5 degree latitude/longitude) from which the MAV MOS guidance is generated. For that reason, it seemed reasonable to expect better performance at individual TAF sites. The Eta forecast soundings are also available for each forecast hour and provide very detailed vertical resolution in the lowest levels. All this makes it possible for meteorologists to sample data very near the ground to see when and if a crossover temperature has been reached. Eta model forecast soundings have been observed to show the typical fog characteristics on many occasions, with an example shown below. However, the forecast soundings have also missed a number of events, also shown below.

3.1 Accurate Eta Forecast for Fog

A series of Eta model forecast soundings are shown in Figures 4 through 7 in which dense fog occurred at TUL in January 2004. The progression from 03 UTC through 12 UTC shows the surface temperature gradually cooling to less than the dew point temperature aloft. By 06 UTC, TUL was reporting a visibility of 0.25 mile, with a forecast to exceed the crossover temperature of 1ºF from the previous 12 UTC run cycle and 0ºF from the 18 UTC run cycle. By 12 UTC, visibility was 0.13 mile, with the surface air temperature forecast 9ºF cooler than the crossover temperature (the highest dew point temperature forecast aloft).

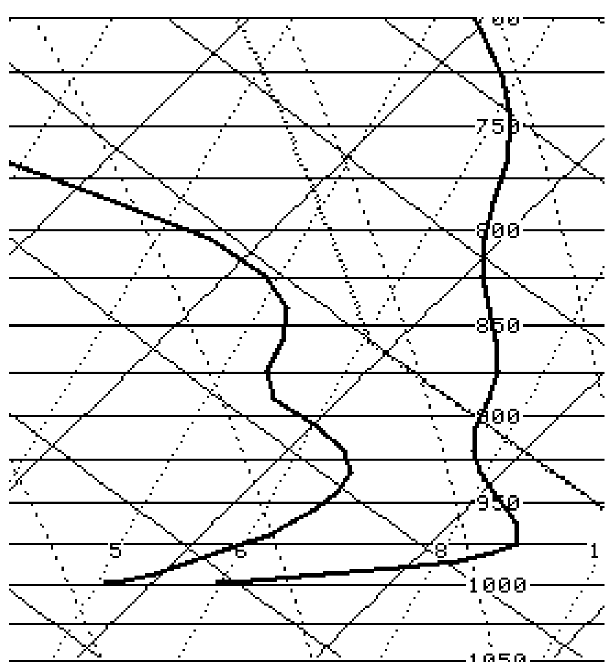

Figure 5. 13 Jan 2004, 12 UTC Eta forecast sounding, valid 06 UTC, 14 Jan 2004, for TUL . Visibility 0.25 miles.

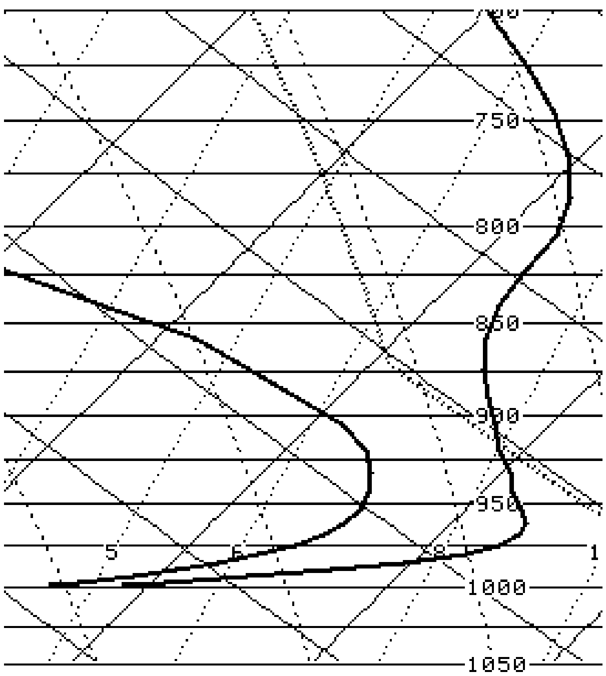

Figure 6. 13 Jan 2004, 12 UTC Eta forecast sounding, valid 09 UTC, 14 Jan 2004, for TUL. Visibility at the time was 0.13 miles.

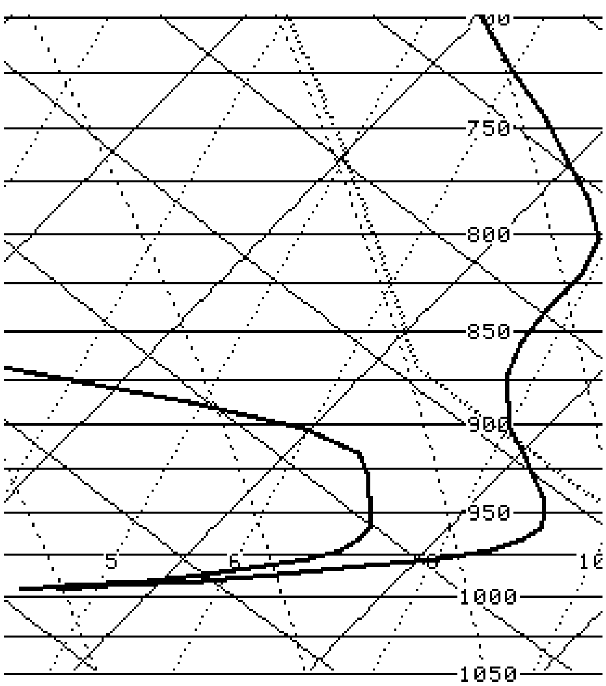

Figure 7. 13 January 2004, 12 UTC Eta forecast sounding, valid 12 UTC, 14 January 2004, for TUL. Visibility at the time was 0.13 mile.

3.2 Eta Forecasts for a Missed Event

The following series of Eta forecasts are for a fog event at FYV (Fayetteville, AR, in northwest Arkansas). At 03 UTC, visibility at FYV had just lowered to 6 miles. By 06 UTC, visibility dropped to 0.25 miles and remained there through 12 UTC (7 am Local Daylight Time). The Eta forecast soundings from both the 12 UTC and 18 UTC run cycles never indicated that surface temperature would drop below the crossover temperature (maximum dew point temperature aloft). The series of forecast soundings from the 18 UTC Eta run are shown in Figures 8 through 11.

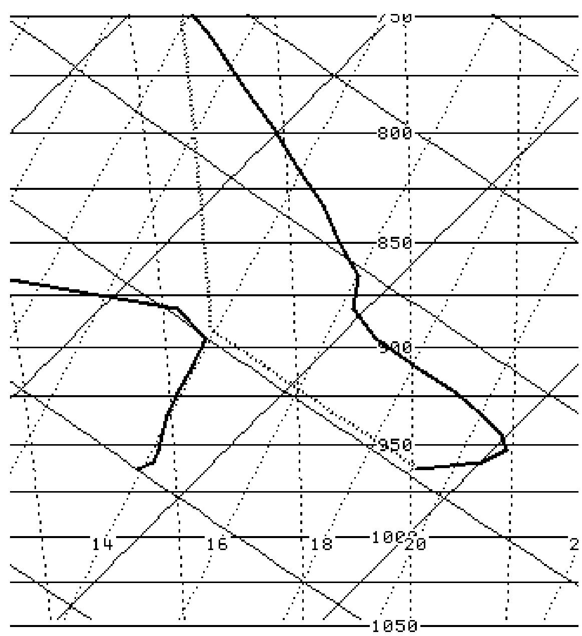

Figure 8. 30 July 2004, 18 UTC Eta run cycle sounding forecast, valid at 03 UTC, 31 July 2004, for FYV. Visibility at the time was 6 miles.

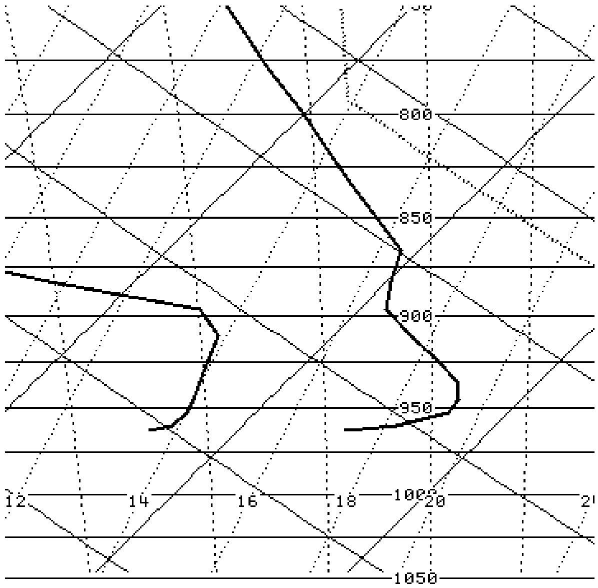

Figure 9. 30 July 2004, 18 UTC Eta forecast sounding, valid at 06 UTC, 31 July 2004, for FYV. Visibility at the time was 0.25 miles.

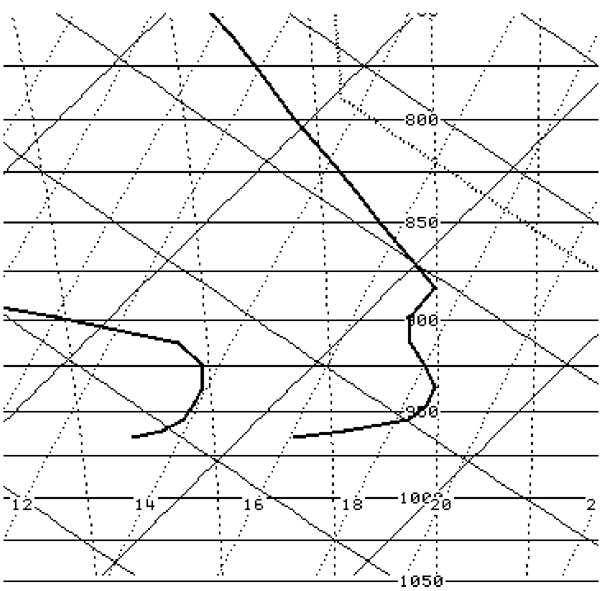

Figure 10. 30 July 2004, 18 UTC Eta forecast sounding, valid at 09 UTC, 31 July 2004, for FYV. Visibility at the time was 0.25 miles.

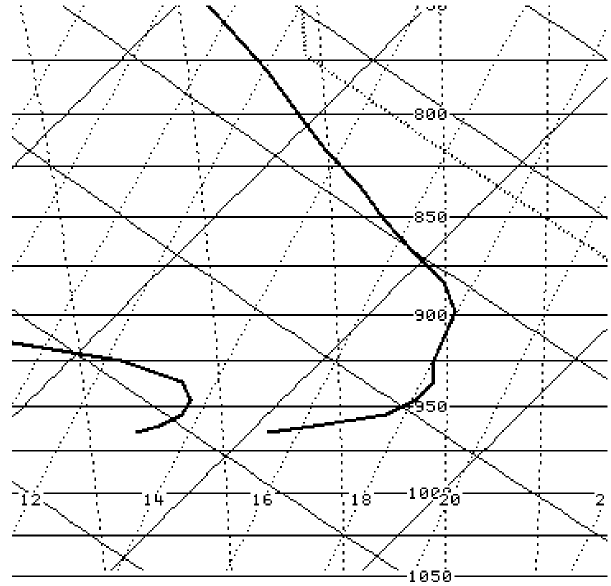

Figure 11. 30 July 2004, 18 UTC Eta forecast sounding, valid at 12 UTC 31 July 2004, for FYV. Visibility at the time was 0.25 miles.

4. DATA and PROCEDURES

Data were gathered for eight random fog events in the Tulsa forecast area. Of these events, one occurred in the winter, one in the spring, four were in the summer, and two were in the fall. Few or no clouds were present during the events and wind speeds were light or calm. Hourly forecasts and observations were collected at three-hour intervals (03, 06, 09, 12, 15 UTC) to match the seven MAV MOS guidance categories shown in Table 3.

MAV Category	Visibility (mi)
1	≤1/4
2	1/4 to 1/2
3	1/2 to 7/8
4	1 to 2 3/4
5	3 to 5
6	6
7	> 6

Table 3. MAV MOS categories and corresponding visibility ranges.

Corresponding categories were obtained from the Eta model soundings, based on the UPS fog forecasting technique for crossover temperatures alone. According to the authors, a forecaster can expect visibilities of about 3 to 5 miles with a crossover temperature of 0 F (surface temperature equivalent to dew point temperature aloft). Where the surface air temperature is equal to or greater than 3 F, the expected visibility is less than ¼ mile. From these criteria, interpolation was used to create the Eta model fog conversions shown in Table 4.

Eta Vsby Ctgry	Visibility (mi)	Tsfc - Td aloft
1	≤ 1/4	≤ -4° F
2	1/4 to 1/2	-3 F
3	1/2 to 7/8	-2° F
4	1 to 2 3/4	-1° F
5	3 to 5	±0° F
6	6	1° F
7	≥7	2° F

Table 4. Eta model visibility forecast categories, based on crossover temperature (Tsfc – Td aloft).

Four TAF sites were used in the study: TUL, MLC, FSM, FYV. Each site supplied five data points per event, corresponding to the data collection times listed above, for the upcoming night. First, the surface temperature was obtained (Tsfc). Then, the forecast sounding was searched in the vertical to find the highest dew point temperature aloft (Td aloft) up to 900 mb. The difference in those temperatures (Tsfc – Td aloft) was used to assign the category for the expected density of the fog at that time, using Table 4.

Sites and events were selected only if there was fog on that night, so not all sites were used for each event. In total, there were 125 data samples collected from both the Eta model and the MAV MOS off the 12UTC forecast cycle, and 125 data samples collected off the 18UTC forecast cycle. This provided 250 sets of data for comparing the MAV MOS and Eta forecast soundings.

5. RESULTS

Results of the study were disappointing. It was expected that the Eta model forecast soundings would be an excellent indicator of fog. Figure 3 shows the biases, average category errors and standard deviations for the MAV and Eta model forecasts. In both forecast cycles, the MAV MOS showed lower average errors, lower biases and lower standard deviations.

From the 12 UTC forecast cycle, the forecasts were valid for the upcoming night. Therefore, the first forecast time to be verified was 03 UTC, or 15 hours after the 12 UTC forecast cycle. Model runs from the 18 UTC forecast cycle became valid 9 hours into the forecast. It is interesting to note that the MAV MOS mean average category error (MAE) improved slightly with the later forecast cycle. However, the 18 UTC Eta technique actually performed worse than the earlier run.

As indicated in the table at the bottom of Figure 3, the 12 UTC MAV bias was 1.30, compared to 1.52 for the 12 UTC Eta technique. This would indicate that the MAV MOS either had fewer missed events, or was closer to the correct category. For that same run cycle, the MAV MOS also had a slightly lower MAE (by category). The lower standard deviation in the MAV MOS implies fewer large misses. The 18 UTC forecast cycle was very similar to the 12 UTC forecast cycle, with only minor differences in the specific values.

Forecast Cycle	Bias	Abs Error/MAE	Standard Deviation
12 UTC MAV	1.30	1.53	1.74
12 UTC Eta	1.52	1.57	1.84
18 UTC MAV	1.36	1.49	1.75
18 UTC Eta	1.54	1.70	1.83

Table 5. Verification statistics for the 12UTC and 18UTC forecast cycles, for eight random fog events for the upcoming night. Bias, mean absolute category error and standard deviation are included. Forecasts were valid for the upcoming night.

6. CONCLUSIONS

Clearly, the application of crossover temperature categories to the Eta forecast soundings did not provide improved forecast skill over the MAV MOS. The average MAV bias was lower, the average absolute category error from the MAV was lower and the standard deviation of the error was lower. However, it was observed that when both the Eta BUFR and MAV MOS agreed there would be fog, the fog generally did occurr. However, on several occasions both the MAV MOS and the Eta sounding technique failed to recognize fog events and timing, particularly in the summer.

It is not clear why the Eta soundings did not outperform the MAV MOS. Perhaps the model initial conditions were incorrect. Perhaps the model does not have the necessary grid resolution to be used at TAF sites. It may also be that the physics of fog development are still too compex for the Eta model to resolve.

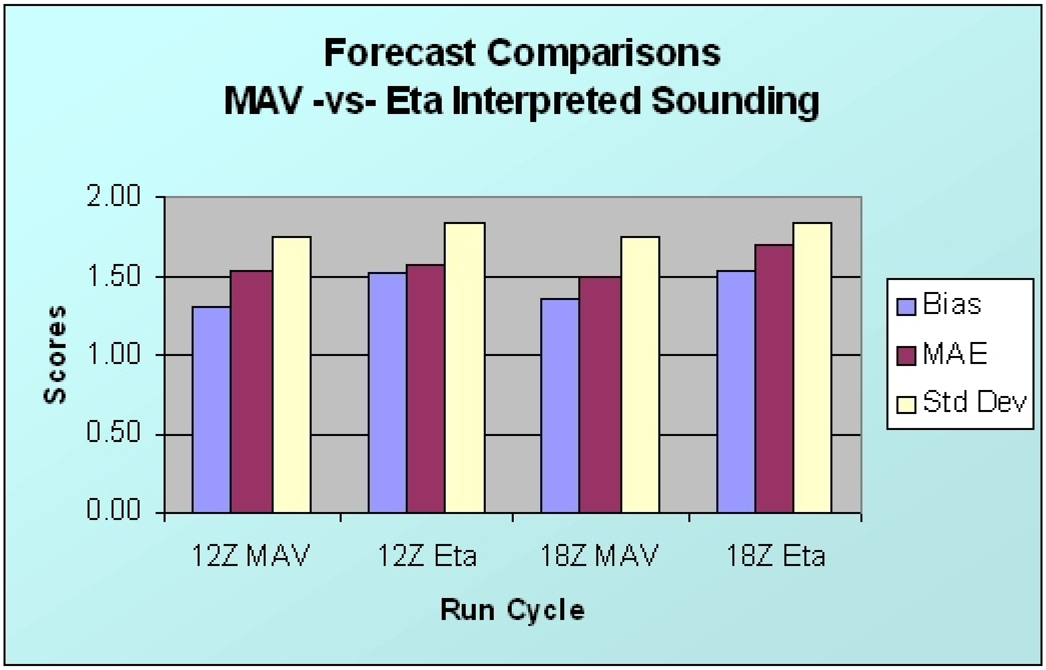

Figure 12. Verification statistics for the 12 UTC and 18 UTC forecast cycles, for eight random radiation fog events, for the upcoming night. Biases, mean absolute errors of the forecast category and standard deviations are included.

This study suggests that if model soundings are to be used in forecasting fog, a unique model will probably be needed. The model may also require some degree of customization to each TAF site to account for the specific physical characteristics of each site, including terrain, vegetation and soil type.

7. REFERENCES

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