6A.3 THE NMM MOS REPLACEMENT FOR THE ETA MOS

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1. INTRODUCTION

In the spring of 2002, the Meteorological Development Laboratory (MDL) implemented the first operational Eta-based Model Output Statistics (MOS) guidance package. Four years later, the operational Eta model run by the National Centers for Environmental Prediction (NCEP) was replaced with the Non-hydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system, which is now the model run in the North American Mesoscale (NAM) time slot (Rogers et al. 2005). For many elements, applying the old Eta MOS equations to the new NMM output degraded forecast skill enough to warrant development of new equations. Therefore, a new suite of MOS guidance was developed for the 0000 and 1200 UTC forecast cycles of the operational WRF-NMM, to replace the previous Eta MOS. New equations were developed for 2-m temperature, 2-m dewpoint, maximum (max) and minimum (min) temperature, wind speed and direction, probability of a thunderstorm, conditional probability of a severe thunderstorm, probability of precipitation (PoP), and quantitative precipitation amount (QPF).

The equations were developed on a sample consisting of one year of output from the old Eta model, and two years of output from the new WRF-NMM. Verifications show that the NAM MOS guidance is comparable in skill to that of the Global Forecast System (GFS), and in nearly all cases is better than applying the previous Eta-based equations to the NMM output. Equations for some elements (e.g., sky cover, ceiling, visibility, etc.) are still based on the old Eta model and are applied to the NAM output. These elements showed comparable skill when the original equations were applied to the WRF-NMM output. New equations for these elements will be redeveloped at a later date. The new NAM MOS guidance was implemented operationally on 1200 UTC 9 December 2008. In this paper we discuss the new NAM MOS guidance, focusing on those elements which have been redeveloped. In Section 2, we discuss developmental details for each element, such as the predictand (observation) data used, frequently-selected predictors, and other element-specific information. In Section 3, we present verifications for these elements, covering the period of 10 December 2008 through 31 March 2009. In Section 4, we briefly outline the availability of the new NAM MOS guidance. Finally, we cover future NAM MOS work, including a gridded NAM MOS product, in Section 5.

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2. DEVELOPMENTAL DETAILS

New equations have been developed for two model cycles, 0000 UTC and 1200 UTC, for the following sets of elements: temperature, winds, precipitation, and thunderstorms. Each of these developments used two seasonal stratifications: *cool season* (01 October – 31 March) and *warm season* (01 April – 30 September). Model data were available from October 2005 through September 2008, meaning that approximately three seasons of data were available for each stratification. While a longer sample would be preferable, previous developments using three years of developmental data have yielded skillful results (Maloney 2004, Antolik and Baker 2009).

For each element except thunderstorms, equations were developed at nearly 2,300 METAR and marine (buoy and C-MAN) sites where sufficient observations were available. This represents an upgrade of over 400 stations available in the old Eta MOS. Figure 1 shows a map of the NAM MOS sites. Thunderstorm equations were developed on a grid, explained further in section 2.4.

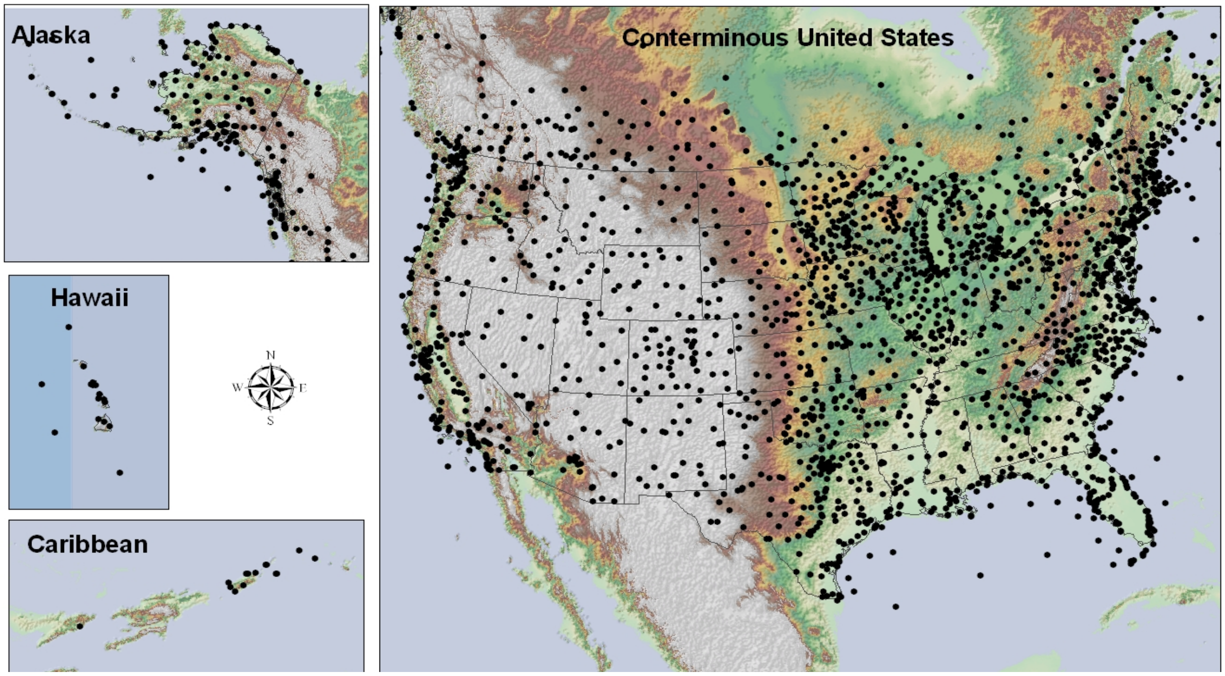

Figure 1. NAM MOS sites.

2.1. Temperature

Predictands for the development of the NAM MOS temperature elements consisted of 2-meter temperature and dewpoint observations valid at 0000 UTC and every subsequent 3 hours (i.e. 0300 UTC, 0600 UTC, 0900 UTC, etc.), as well as observations of daytime (7 a.m. to 7 p.m. Local Standard Time (LST)) max, and nighttime (7 p.m. to 8 a.m. LST) min temperatures. Because daytime max and nighttime min temperatures are not reported with the hourly temperature and dewpoint observations, they are constructed from the 6-h max/min and hourly temperature observations.

For projections ranging from 6 hours out to 36 hours, two sets of equations were developed; a *primary*, which included observations and model data as predictors, and a *secondary*, in which only model data were used. A secondary equation is used when the observations for that site are not available.

The most frequently selected predictors were typically NAM model fields of temperature, dewpoint temperature, and relative humidity fields at 1000 mb and 2-m, as well as other NAM temperature-related fields, such as the boundary layer (970 mb) temperature, 2-m temperature adjusted for elevation, and low level thicknesses. The climatic predictors (SIN DOY, COS DOY, SIN 2*DOY, and COS 2*DOY) were also selected, mainly as projections increased toward 84 hours, and to some degree for short-term projections in which no observations were submitted as predictors (secondary equations). The climatic variables account for the seasonal variation of temperature.

2.2. Winds

Observations of wind speed and direction, valid at 0000, 0300, 0600, etc., were used in the development. From wind speed and direction, we calculated the u-wind component and the v-wind component. The predictands used were these two wind components, along with the wind speed. Equations for these three predictands were developed for both the 0000 UTC and 1200 UTC cycles, for both the cool and warm seasons, and at forecast projections valid every 3 hours from 6 to 84 hours.

For the first four forecast projections (6-, 9-, 12-, and 15-h), two sets of equations were developed. The primary equations included computed u- and v- wind components and speed observations as predictors. The secondary equations used all of the same predictors as the primary equations except for the wind observations. If observations are not available in real-time, the secondary equations are used. Only one set of equations was developed after the 15-h projection, as persistence (that is, the wind observation) proved to have little skill beyond 15 hours.

The most frequently chosen predictors were the model 10-m u- and v-wind components and wind speed. The 1000- and 925-mb u- and v-wind components, wind speed, and 10-m upslope wind were also heavily selected throughout all projections. Through 15 hours, the observations (persistence) offered were the primary predictors selected. In the later projections, as model skill decreases, the harmonics of the day of the year became a prominent selection.

2.3. Precipitation

Unlike temperatures and winds, PoP and QPF (and other discontinuous and relatively rare elements) use regional equations. In a regional development, stations with similar climatologies are pooled together into regions, increasing the sample size, and equations are developed for each region. Each station in the region uses the same equation; however, predictor values will vary from station to station in the region, and thus the forecast values will also vary from station to station.

For PoP, the predictand is the occurrence of at least 0.01 inches (liquid equivalent) of precipitation in a 6-, 12-, or 24-h period. For QPF, the predictands are the *conditional* occurrence of at least 0.10, 0.25, 0.50, 1.00, and 2.00 inches (12- and 24-h forecasts only) of precipitation in a 6-, 12-, or 24-h period; that is, the occurrence of, say, 0.50 inches, given that 0.01 inches has already accumulated. All predictands are treated as binary variables – they take the value of unity should the specific precipitation amount threshold be met or exceeded, and zero otherwise. The precipitation amount data were available from METAR observations archived by MDL.

Equations for 6-h and 12-h PoP and QPF were developed every 6 hours out to 84 hours, and every 12 hours out to 84 hours for 24-h PoP and QPF. The most frequently selected predictors included 6- and 12-h precipitation amounts, mean layer relative humidities, vertical velocities, horizontal wind components, and the K index.

2.4. Thunderstorms

Equations for the probability of a thunderstorm and the conditional probability of a severe thunderstorm were developed for 3-, 6-, 12-, and 24-h periods out to 84 hours in advance. Unlike the elements above, the predictand data used to define the MOS thunderstorms are random in place and time, so thunderstorm equations were developed on a grid, rather than at actual stations. A nearest neighbor approach was used to match each of the MOS sites to the nearest grid point for the MOS alphanumeric guidance messages.

Cloud-to-ground (CG) lightning data from the National Lightning Detection Network (NLDN) were used to define the occurrence of a thunderstorm for 3-, 6-, 12-, and 24-h periods. Predictand data for severe thunderstorms were obtained from local reports of thunderstorm wind gusts, hail, and tornadoes collected by the Office of Climate, Water, and Weather Services (OCWWS). NLDN data and severe reports for April 1994 through September 2008 were available to develop observed relative frequencies for use as predictors in the MOS system.

A thunderstorm is defined as the occurrence of one or more CG flashes within a grid box during a defined period. Unlike the 47-km grid used in the previous Eta-based development (e.g., Hughes 2002), the new NAM guidance was developed on a 40-km Lambert Conformal grid, which makes the product consistent with the GFS MOS thunderstorm guidance. The lightning strikes were placed on the 40-km grid, and binary indicators were assigned to each grid cell and time period: a “1” if one or more flashes occurred or a “0” if no lightning occurred. These binary indicators served as the thunderstorm predictands in the MOS system.

To maintain consistency with severe thunderstorm probabilistic products issued by the Storm Prediction Center, the conditional severe guidance was developed on an 80-km grid, which most closely represents the probability within 25 miles of a point (NWS 2009). The severe reports were placed on the 80-km grid, and binary indicators (1 or 0) were assigned to each grid cell. Since the severe guidance is conditional on the occurrence of a thunderstorm, only cases in which a thunderstorm occurred in the cell were used in the development of the severe equations.

Predictors offered to the regression included model output fields interpolated to the 40- and 80-km grids, variables derived from those fields, as well as the observed relative frequencies of thunderstorm and conditional severe occurrence.

The predictors most often selected for the thunderstorm equations included convective precipitation amount, stability indices, the cross product of the K-index, and observed relative frequency. Important predictors in the conditional severe equations included the cross product of the SWEAT index and observed relative frequency, CAPE, best lifted index, and 500- and 700-mb wind speed. These findings are consistent with previous developments (e.g., Hughes 2002, Shafer and Gilbert 2008).

3. VERIFICATIONS

For each element, verifications were performed by comparing three systems over the time period 10 December 2008 through 31 March 2009: the newly-operational NAM MOS, the GFS MOS, and the old Eta MOS applied to NMM output. While both 0000 UTC and 1200 UTC were available, for brevity only 0000 UTC verifications are discussed here.

The NAM MOS temperature, dewpoint, and max/min forecasts show a general increase in accuracy over the previous Eta MOS, and frequently surpass the existing GFS MOS as well. Figure 2 shows the Mean Absolute Error (MAE) for 3-hourly temperature forecasts. Note that, with the exception of the 6- and 84-h projections, NAM MOS shows an increase in accuracy over both the Eta and GFS MOS forecasts. Similar performance is seen for dewpoint forecasts (Figure 3). Additionally, NAM MOS shows greater accuracy than Eta and GFS MOS for all projections of maximum temperature (Figure 4) and two of three projections of minimum temperature (Figure 5).

Mean Absolute Error (MAE) of wind speed and wind direction are plotted in Figures 6 and 7. The current operational NAM MOS shows increase in accuracy over the previous Eta MOS at all projections. Also, note the overall increase in accuracy for wind speed over the current GFS MOS except at 6-h and 84-h. The MAE of wind direction also shows an increase in accuracy over the previous Eta MOS at all projections, and is comparable to the GFS MOS.

Figure 8 compares the Brier Scores (Brier 1950) for 6-h PoP for all three systems. Unlike the winds and temperatures, there is no significant increase in accuracy from the old Eta MOS to the newer NAM MOS. However, the newer NAM MOS does perform better than the GFS MOS for the earlier forecast projections, while the GFS MOS has better scores after the 36-h projection. This result is very similar to previous MOS PoP comparisons (Maloney 2004).

Brier Scores for the three probabilistic thunderstorm systems are shown in Figure 9. It should be noted that the Eta MOS is not directly comparable to the NAM or GFS due to differences in the grids on which these products were developed (47-km vs. 40-km, respectively). The results show that the new NAM MOS is comparable to the GFS MOS at all projections, while the NAM is more accurate than the old Eta equations applied to NMM output. Comparisons for the 12- and 24-h thunderstorms (not shown) exhibit similar results. This result is very encouraging, especially considering the short sample that was available for development, for a rare element such as thunderstorms.

4. PRODUCT AVAILABILITY

The new NAM MOS has been available operationally since 1200 UTC 9 December 2008 and is currently produced twice daily at 0000 and 1200 UTC. Gilbert et al. (2008) describes details of this new guidance package and shows sample text messages. Besides the text messages, a more complete suite of NAM MOS guidance, including all of the probabilities used to generate the categorical guidance, is generated in a BUFR message (WMO 1995). Links to these text and BUFR messages, as well as graphical guidance, can be found on the Statistical Modeling Branch's MOS Products Page at http://weather.gov/mdl/synop/products.php.

5. FUTURE NAM MOS WORK

When another year of NMM data becomes available, we hope to develop new equations for elements which were not updated, such as ceiling height, sky cover, visibility, obstruction to vision, and snowfall. These rare elements generally require a longer sample. We also will work to increase the number and density of sites for which NAM MOS is available, by utilizing cooperative observer and mesonet sites, primarily for temperatures and winds. The ultimate goal is to produce Gridded NAM MOS, much like the Gridded GFS MOS (Glahn et al. 2009) currently available.

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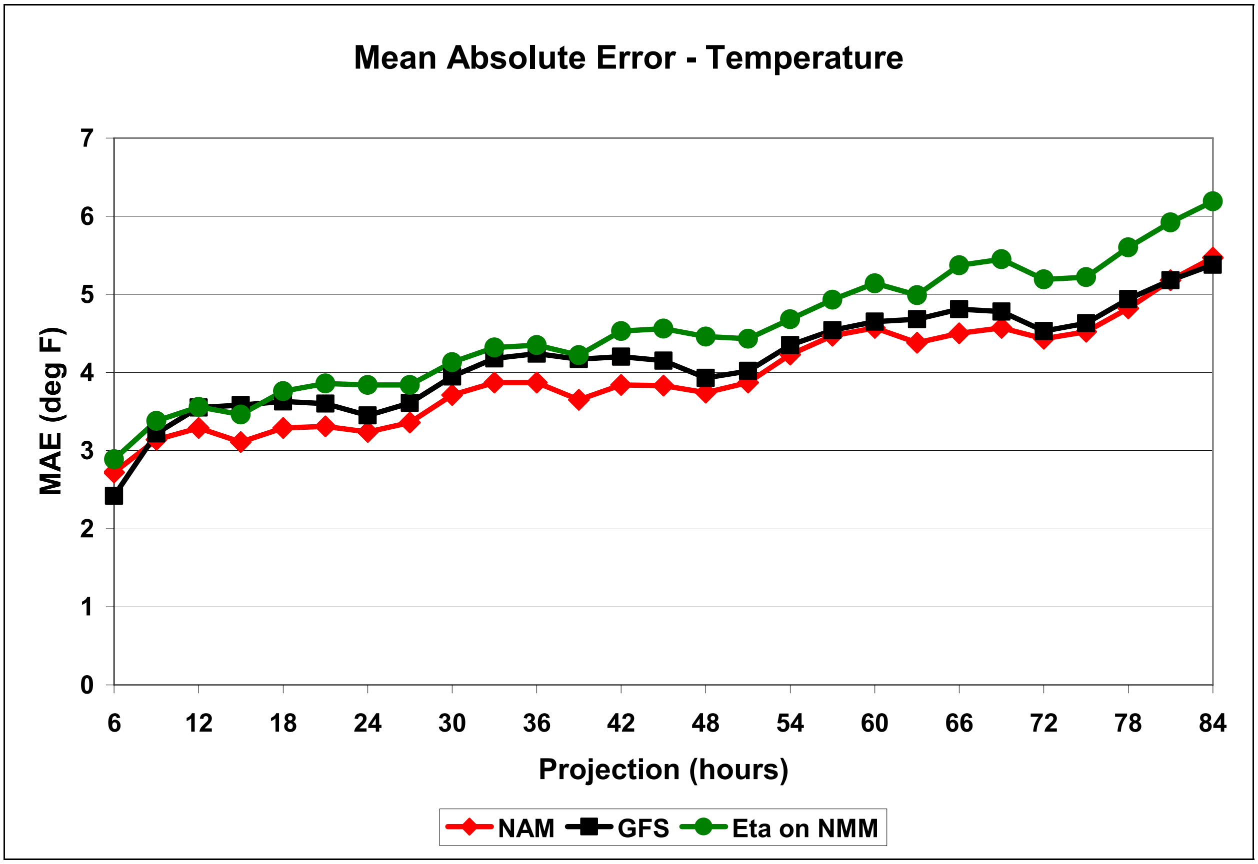

Figure 2. MAE for 0000 UTC cycle 2-m temperatures from NAM MOS, GFS MOS, and Eta MOS equations applied to NMM model output.

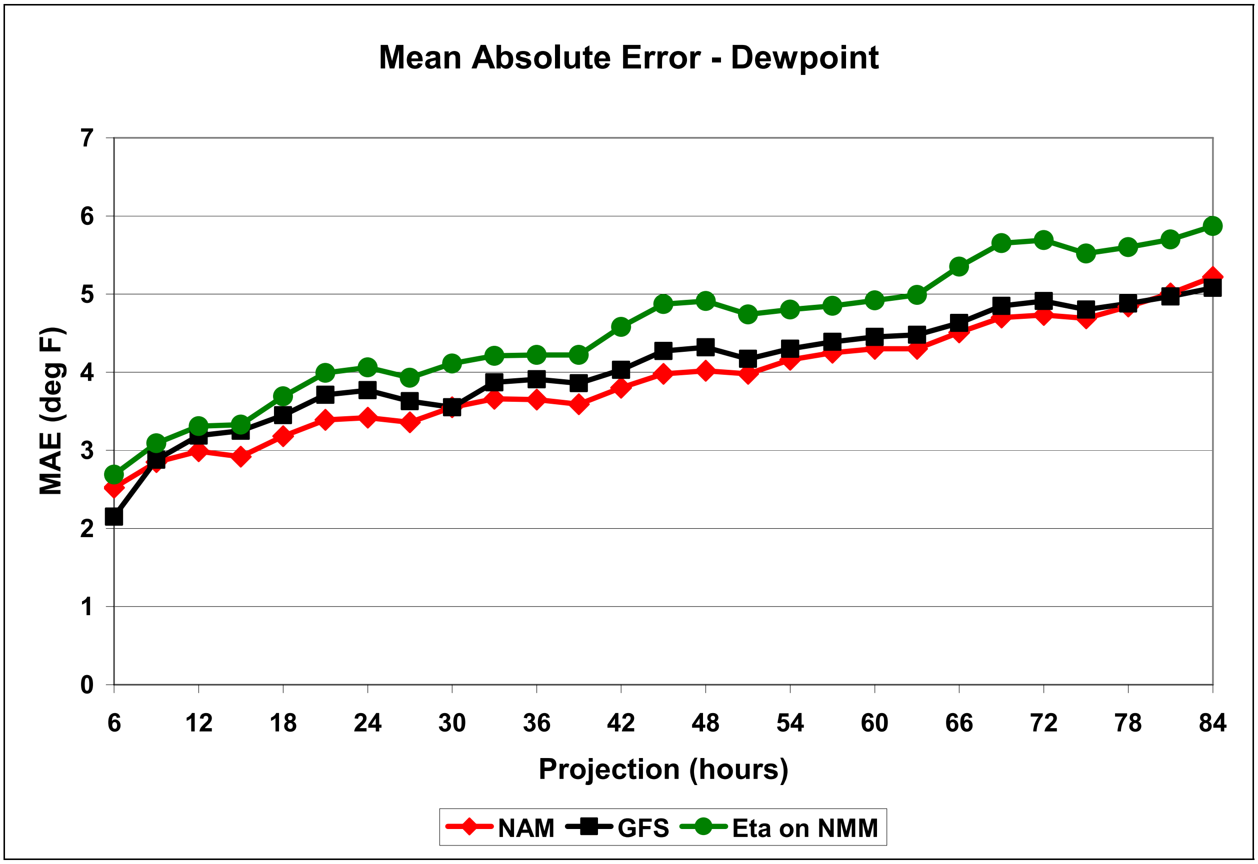

Figure 3. Same as Fig. 2, but for 2-m dewpoint.

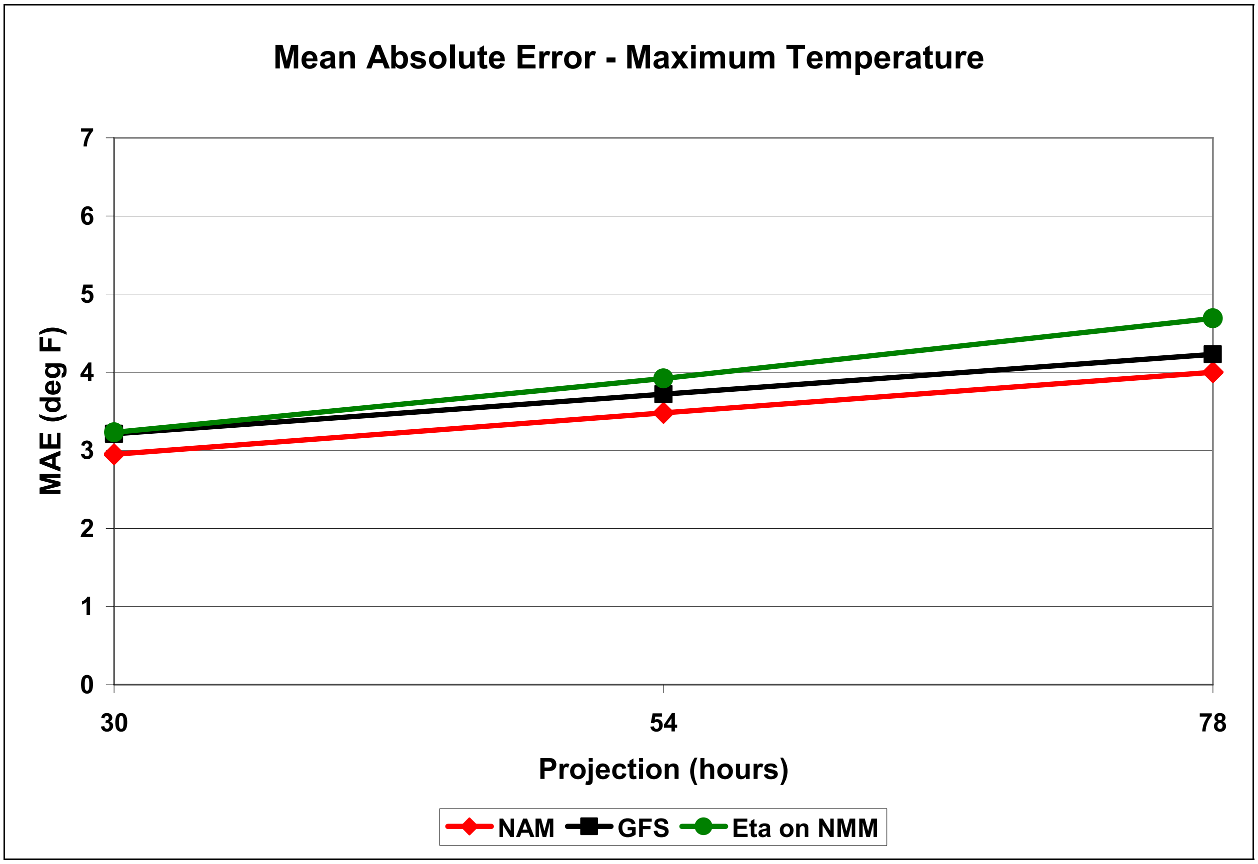

Figure 4. Same as Fig. 2, but for max temperature.

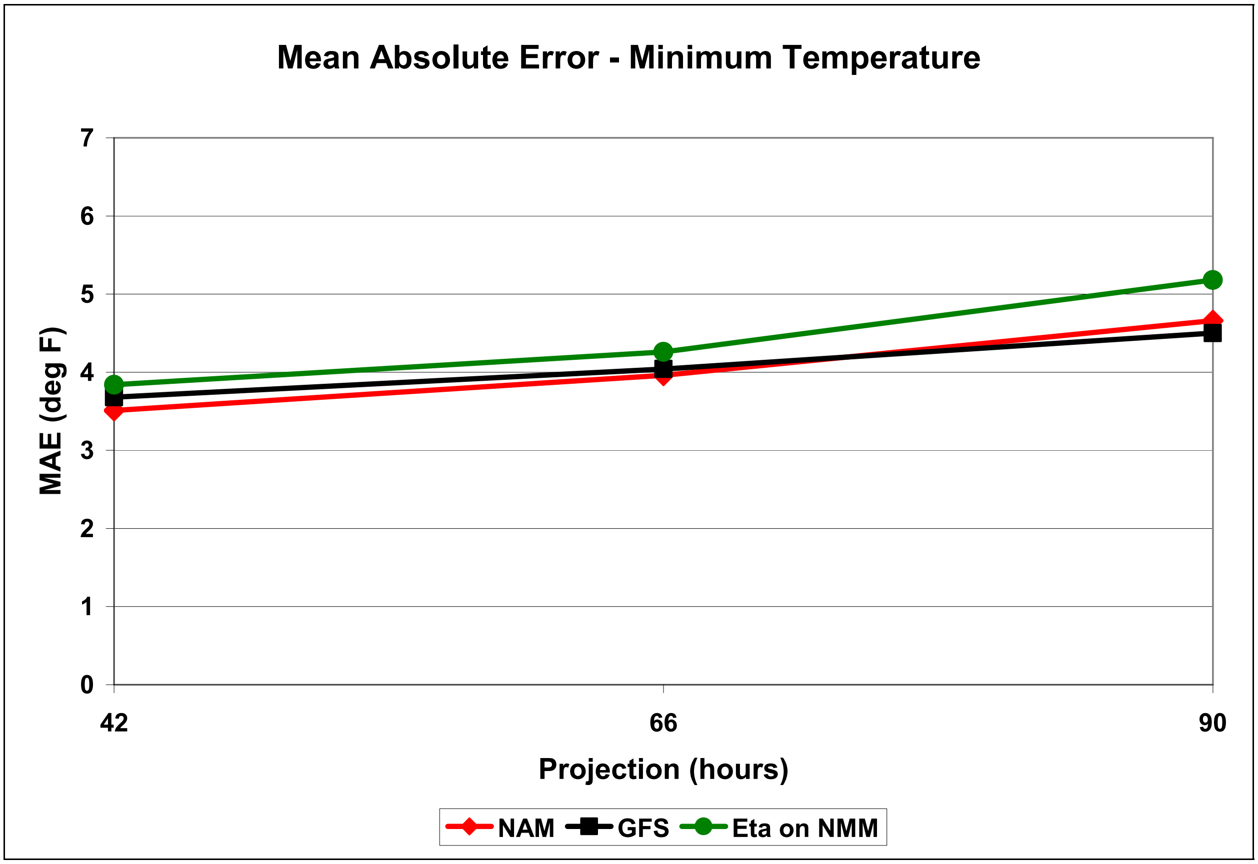

Figure 5. Same as Fig. 2, but for min temperature.

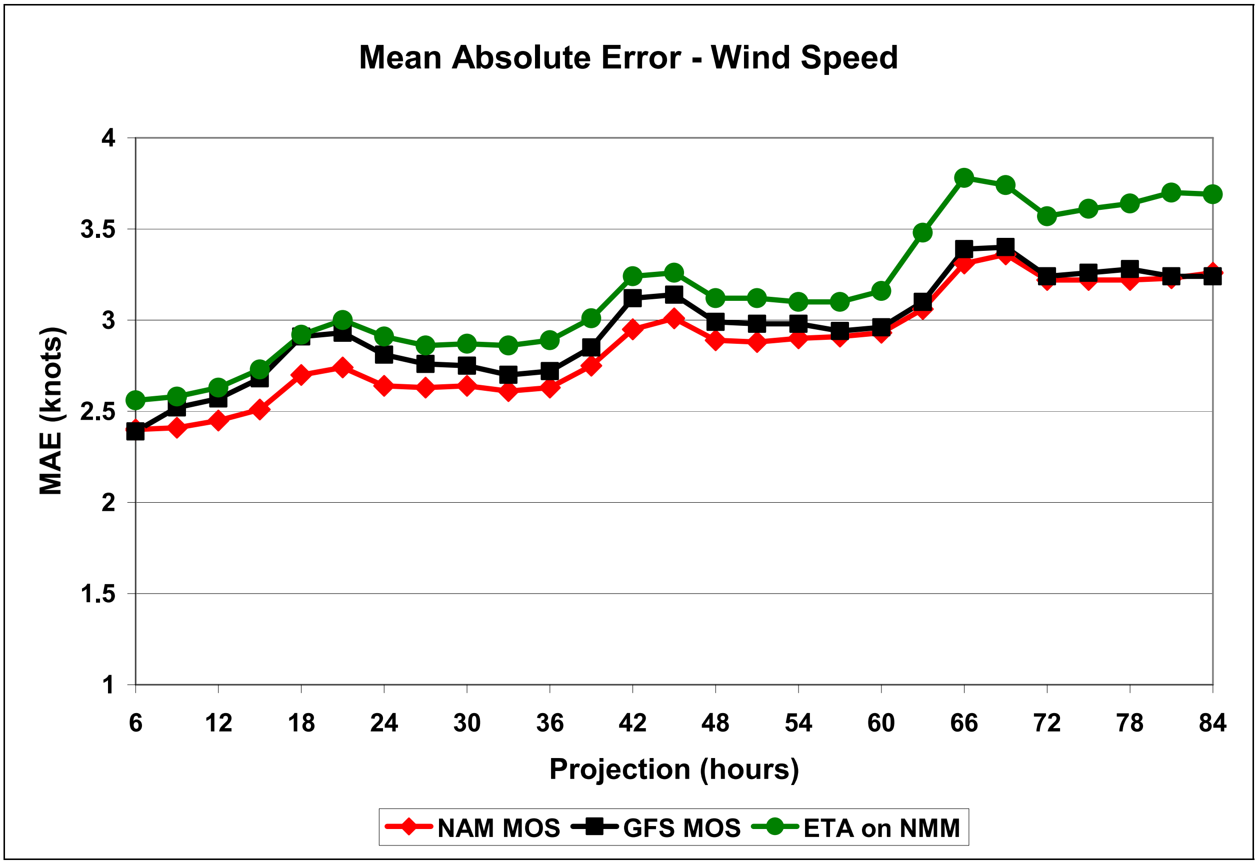

Figure 6. MAE for 0000 UTC cycle 10-m wind speed from NAM MOS, GFS MOS, and Eta MOS equations applied to NMM model output.

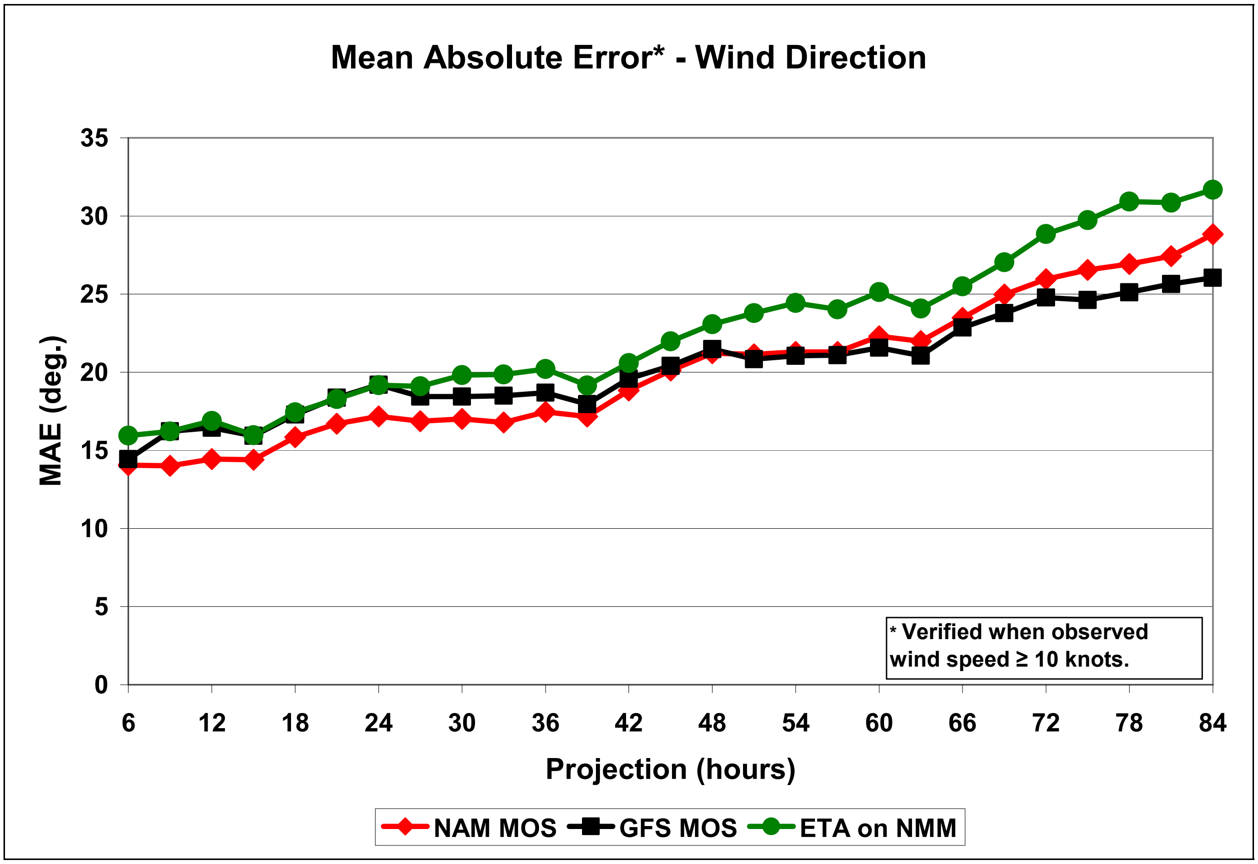

Figure 7. Same as Fig. 6, but for 10-m wind direction.

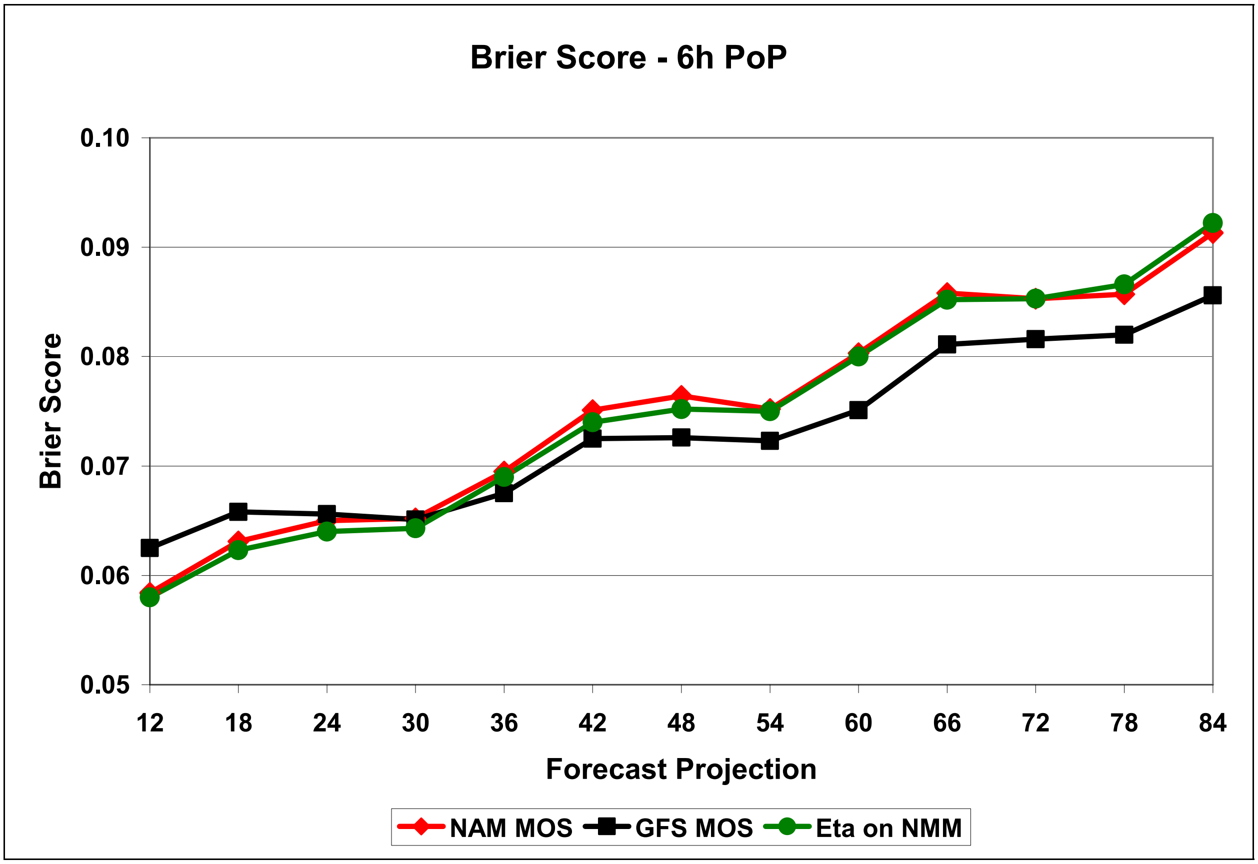

Figure 8. Brier Score for 0000 UTC cycle 6-h PoP from NAM MOS, GFS MOS, and Eta MOS equations applied to NMM model output.

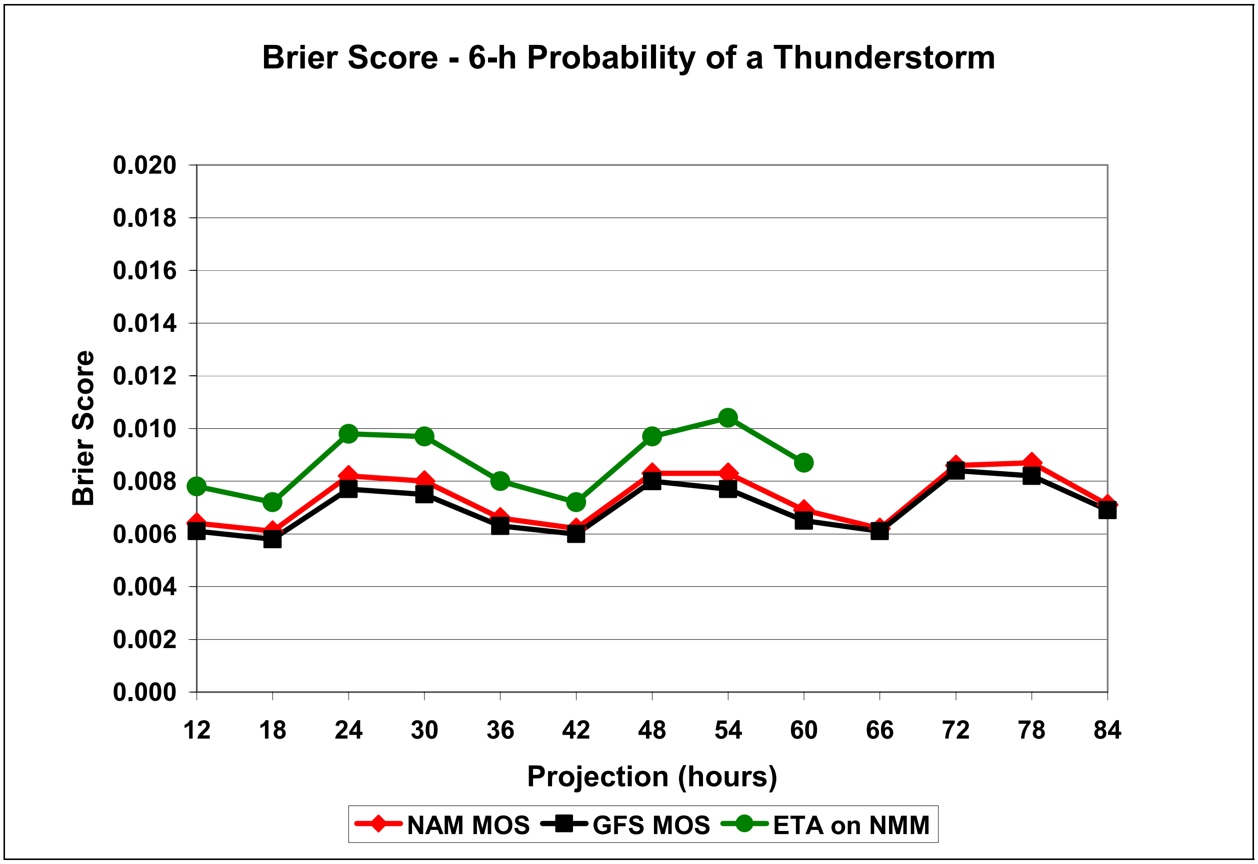

Figure 9. Same as Fig. 8, but for 6-h probability of a thunderstorm.