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GFS-BASED MOS TEMPERATURE AND DEWPOINT GUIDANCE FOR THE UNITED STATES, PUERTO RICO, AND THE U.S. VIRGIN ISLANDS

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1. INTRODUCTION

The Meteorological Development Laboratory (MDL) of NOAA's National Weather Service (NWS) has developed regression equations to predict daytime maximum temperature (max), nighttime minimum temperature (min), and 3-h temperature and dewpoint by using the Model Output Statistics (MOS) technique (Glahn and Lowry 1972). This approach was applied to output from the National Centers for Environmental Prediction's (NCEP's) Global Forecast System (GFS) model (Kanamitsu 1989). The MOS approach correlates predictand data (surface weather observations) with combinations of predictor data (output from dynamical models, observations, and geoclimatic information). MOS max/min forecasts are generated for days 1 through 8, and temperature/dewpoint forecasts for 3-h projections from 6 to 192 hours, after the initial model time of 0000 UTC. Max/min forecasts are generated for days 1 through 3, and temperature/dewpoint forecasts for 3-h projections from 6 to 84 hours, after the initial model times of 0600, 1200, and 1800 UTC. Equations were developed for over 1,500 stations in the continental United States, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands and were last implemented in December 2003.

2. DEVELOPMENT

a. Predictand Definition

The predictands for the development of the max/min temperature guidance were values corresponding to the local daytime max and nighttime min temperatures. The daytime is defined as 7 a.m. to 7 p.m. Local Standard Time (LST); nighttime is defined from 7 p.m. to 8 a.m. LST. Because daytime max and nighttime min values are not reported in the local METAR hourly observations, we developed an algorithm to derive the daytime max and nighttime min from 6-h max/min and hourly temperature values reported in the observations. Essentially, we've attempted to specify the daytime max/nighttime min predictands as accurately as possible from available data.

The predictands for development of the 2-m temperature and dewpoint guidance were observations valid at specific hours each day, namely, 0000 UTC, 0300 UTC, 0600 UTC, etc. Certain stations, for example, part-time stations, do not report during the overnight hours; therefore, equations were not developed for these stations at certain projections. In the operational forecast product (see Section 4), missing values are put into the message for these part-time sties.

b. Predictors

Predictors used in the MOS equations primarily consisted of GFS model fields interpolated to the location of each individual station. Predictors offered to the regression procedure included temperatures, thicknesses, dewpoints, mean relative humidity, model precipitation, u- and v- wind components, wind speeds, vertical velocities, mean sea level pressure, pressure tendency, K-index, and temperature lapse rates. The predictors were offered as values at multiple projections from model run time. For example, predictor projections for a 36-h max temperature equation from 24 to 45 hours would be offered for a 36-hmax temperature equation. The large spread in projection of predictors accounts for all of the predictands used in the simultaneous development (see section 2.d).

Climatic predictors such as the sine and cosine of the day of the year (converted to radians) and twice the day of the year were also offered. These variables account for the seasonal variation of temperature throughout each 6-month season (see Section 2.c).

Finally, the observed 0300, 0900, 1500, and 2100 UTC temperature and dewpoint at a given station for the respective 0000, 0600, 1200, and 1800 UTC model run, when available, were offered as predictors at projections out to 36 hours for the 0000 and 1200 UTC cycles, and out to 33 hours for the 0600 and 1800 UTC cycles. Because observations may be unavailable operationally, secondary equations were also developed that contain no observations.

The most frequently chosen predictors were the 1000-mb temperature and dewpoint, 2-m temperature, low-level thicknesses, and the mean relative humidity. Observations were frequently chosen and improved forecasts at the 6- through 36-h projections. At the extended projections of the 0000 UTC cycle, generally considered from 96 hours onward, the climatological terms became more frequently used, accounting for the decreasing skill of the model as projection increased.

c. Seasons

Developmental data consisted of MDL's daily archive of the GFS model output from April 1997 through September 2003. The data were stratified into two, 6-month seasons: cool (October-March) and warm (April-September). Equations were developed for each season. When feasible, data from approximately 2 weeks before the start of each season and 2 weeks after the end of each season were included to smooth the transition between seasons.

d. Equation Development

Single-station equations were developed for all projections from 6 to 192 hours for the 0000 UTC cycle and from 6 to 84 hours for the 0600, 1200, and 1800 UTC cycles. In the single-station approach, surface observations from an individual station are correlated with predictors that are interpolated to that location.

To reduce the frequency of meteorological inconsistencies, forecast equations for the temperature and dewpoint are simultaneously developed with the max/min temperatures. The daytime max equation was simultaneously developed with the temperature/dewpoint equations valid at 1500, 1800, 2100, 0000, and 0300 UTC. The nighttime min equation was simultaneously developed with the temperature/dewpoint equations valid at 0300, 0600, 0900, 1200, and 1500 UTC the same night. Because of this, the forecast equations for a particular station and for each group of projections contain the same predictors, although the regression coefficients vary depending on the predictand. Note, too, as mentioned in Section 2.b, two sets of equations were derived for the 6- through 36-h projections (0000 and 1200 UTC cycles) and 6- through 33-h projections (0600 and 1800 UTC cycles). Generally, the primary temperature equations at 6 hours produced forecasts with a typical mean absolute error (MAE) that was 0.3°F less than forecasts made by the secondary equations; by 33 hours, the difference between the accuracy of the primary and secondary forecasts was negligible. Operationally, if observations are unavailable as predictors, the secondary equations are used to generate forecasts; otherwise, the primary equations are always used.

The regression process that generated equations continued until a maximum of 10 predictors was chosen or until none of the remaining predictors contributed an additional 0.5% to the reduction of variance for any one of the predictands. At the majority of stations, close to the maximum number of predictors was chosen for each equation. Note, also, that a minimum of 200 cases was required in order to develop a forecast equation.

3. POST PROCESSING

Remember that the simultaneous development, described in Section 2.3, reduces the frequency of inconsistencies. However, when applying the MOS equations operationally, meteorological inconsistencies can still arise due to the fact that each predictand has its own unique equation. Remember, however, that the simultaneous development, described in Section 2.d, reduces the frequency of inconsistencies. For example, a predicted daytime temperature might be 87°F, while the predicted daytime max is 85°F for a particular station. To ensure consistent temperature guidance, post processing of the forecasts is necessary. For instance, if the dewpoint temperature exceeds the temperature forecast at the same projection, the average of the two forecasts is used as the guidance for both temperature and dewpoint. Due to the simultaneous development, two temperature and dewpoint equations are produced for forecast projections valid at 1500 and 0300 UTC. Since the two equations may yield different forecasts, the average of the two values is used in the guidance.

As shown in the example above, the daytime max/nighttime min and temperature forecasts can also be inconsistent; that is, a particular temperature forecast may be greater (less) than the max (min) valid during that same period. In the GFS MOS system, if a temperature valid at 1500, 1800, 2100, 0000, or 0300 UTC is greater than the forecast daytime max, then the max is set to the value of the greater temperature. Similarly, if a

0300, 0600, 0900, 1200 or 1500 UTC temperature is less than the nighttime min, then the min is lowered to the lesser of the two temperatures. Finally, the daytime max and the nighttime min are compared for adjacent periods. If the max and min are inconsistent (max less than the min), the average temperature is calculated and used for both forecasts.

4. OPERATIONAL PRODUCTS

The guidance for the 6- through 60-h, and the 66-, and the 72-h projections from each forecast cycle, along with the day 1 through day 3 max/min, is issued in a set of alphanumeric messages (Dallavalle and Cosgrove 2005a,b) in the short-range GFS system. The extended-range guidance for the 12- through 192-h projections for the 0000 UTC cycle, at 12-h intervals, along with the day 1 through day 8 max/min, is available in a separate alphanumeric message (Erickson and Dallavalle 2000). The guidance for all projections and cycles is also available in both Binary Universal Format for the Representation of meteorological data (BUFR) and GRIB format. In addition, graphical plots, as well as GRIB and BUFR products, of the temperature and dewpoint guidance can be found on the internet at the following URL:

http://www.nws.noaa.gov/mdl/synop/products.shtml

5. VERIFICATION

Max/min temperature forecasts were verified for the 2003 warm season and the 2003-04 cool season. These forecasts were verified in terms of MAE for 330 stations in the continental United States and Alaska from the 0000 UTC extended-range package out to day 8. For comparison, the MAE of the NGM MOS max/min (Jacks et al. 1990) and that of climatology are shown.

Figures 1 and 2 show the MAE of the max temperature guidance in degrees Fahrenheit for the cool and warm seasons, respectively, for days 1 through 8. It can be seen that the GFS MOS improves over the NGM MOS (which is only available out to day 2), especially in the cool season, with an increase in skill of up to 0.3°F. In addition, improvements in skill over climatology is evident, as far out as day 8, where improvements of 0.5°F are seen in the warm season and almost 1.0°F in the cool season.

Similarly, Figs. 3 and 4 show the MAE of the min temperature guidance in the cool and warm seasons, respectively, for days 1.5 though 7.5. The increase in skill of the GFS MOS min temperature guidance relative to both the NGM MOS and climatology is greater than for the GFS MOS max temperature guidance. The greatest improvement is seen during the cool season, where the increase in skill over the NGM MOS is up to 0.5°F at day 2.5. The GFS MOS min system is over 1.0°F more skillful than climatology at day 7.5.

6. OPERATIONAL CONSIDERATIONS

The MOS technique accounts for certain systematic biases in the numerical model, but not erroneous model forecasts. Therefore, the forecaster should be wary of the MOS forecasts if he or she suspects an incorrect evolution of events in the dynamical model. If consistency or trends in the GFS model output indicate to the forecaster that the dynamical model should be modified, then similar reasoning should be applied to the interpretation of the MOS guidance.

The MOS temperature forecasts may be erroneous when surface conditions that impact the temperature are extremely abnormal. For example, in situations with deep snow cover, temperature forecasts may be significantly warmer than what is observed. The forecaster should recognize that MOS has difficulties in predicting extremely anomalous conditions. This is due to the fact that regression equations forecast the mean condition for a given set of predictor values. Forecasters should also be aware that MOS temperature forecasts may be erroneously warm when a shallow layer of cold air exists near the surface. An example of this phenomenon is "cold air damming" which occurs east of the Appalachians in the eastern U. S., usually during the spring. In cold air damming situations, strong high pressure sends a wedge of cold air southward down the eastern seaboard. Shallow cold air layers may also be found in the valleys in the western U.S., in the vicinity of frontal boundaries, and associated with Arctic high pressure systems.

The forecaster should be aware of a station's climatology, particularly regarding large deviations from the normal. With increasing projection, the MOS forecasts tend toward the normals because of inherent limitations in the accuracy of the GFS model. In addition, future changes to the GFS may affect the biases and characteristics of the model forecasts, which would have a direct impact on the MOS guidance.

7. REFERENCES

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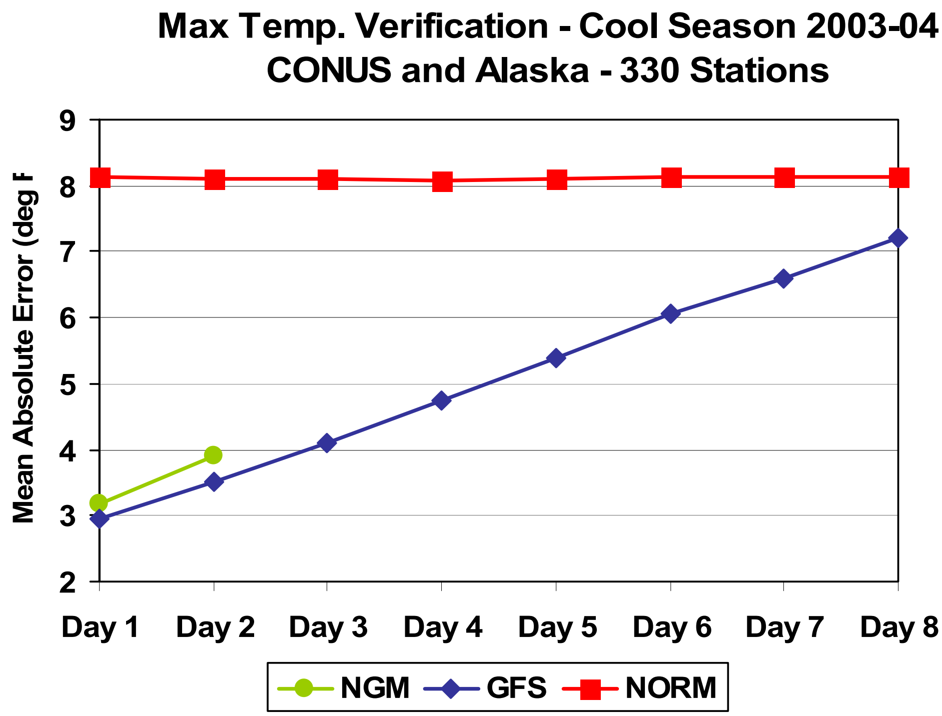

Figure 1. Mean absolute error of the GFS- and NGM-based MOS maximum temperature guidance for the 2003-04 cool season, 0000 UTC forecast cycle.

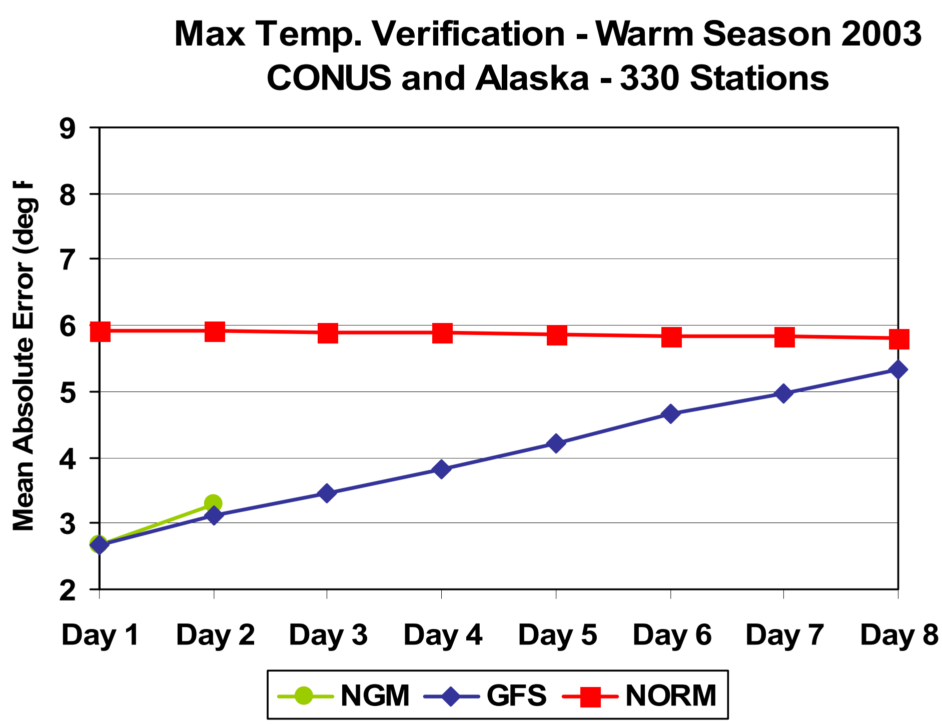

Figure 2. Mean absolute error of the GFS- and NGM-based MOS maximum temperature guidance for the 2003 warm season, 0000 UTC forecast cycle.

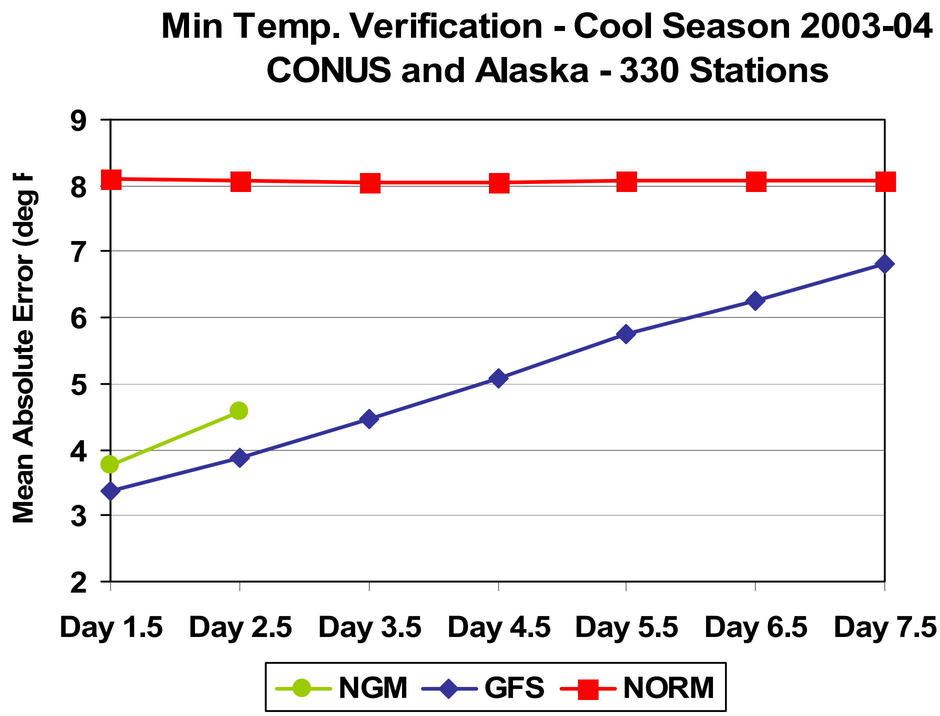

Figure 3. Same as Fig. 1, but for minimum temperature.

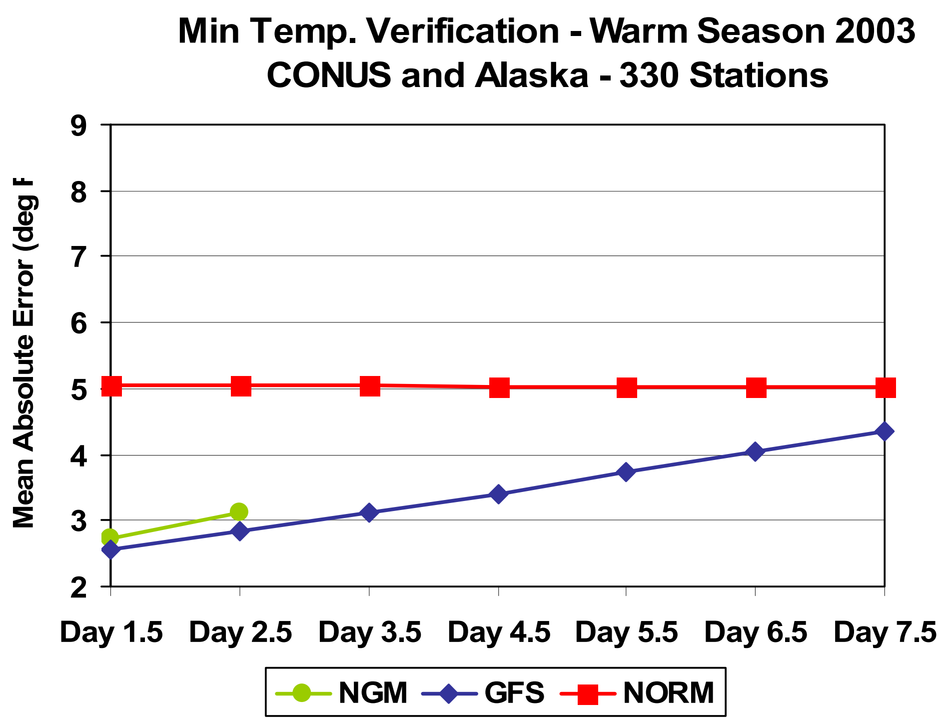

Figure 4. Same as Fig. 2, but for minimum temperature.