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MODEL OUTPUT STATISTICS (MOS) GUIDANCE FOR SHORT-RANGE PROJECTIONS

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1. INTRODUCTION

In May 2000, the Meteorological Development Laboratory (MDL) of the National Weather Service (NWS) implemented a completely new Model Output Statistics (MOS) guidance package. This new product was developed from output of the NWS Global Forecast System (GFS) (Kalnay et al. 1990). Guidance is provided for the 0000 and 1200 UTC forecast cycles at more than 1000 sites in the contiguous United States (CONUS), Alaska, Hawaii, and Puerto Rico. In addition, the new GFS-based MOS package contains guidance for forecast projections out to 72 hours. Subsequent enhancements to the GFS MOS product suite added guidance for other weather elements, provided guidance for the 0600 and 1800 UTC cycles of the GFS, and increased the number of sites with guidance to over 1500 locations, including cities in the Virgin Islands.

A second major implementation in April 2002 introduced MOS guidance based on the NWS Eta model (Black 1994) for over 1200 sites in the CONUS. Although the initial Eta-based MOS package contained only a subset of the weather element guidance provided by the GFS MOS system, the Eta-based MOS guidance gave forecasters another tool to consider in producing their final forecasts. Preliminary verifications showed that the Eta-based MOS guidance was equal to or better than the GFS-based MOS guidance at forecast projections out to approximately 36 hours.

In this paper, we review some of the details of both the GFS- and Eta-based MOS developments, with particular emphasis on the GFS-based MOS guidance package. Verifications comparing the MOS guidance with direct model output are shown, and we discuss plans to improve the guidance.

2. MOS APPROACH

In the MOS approach (Glahn and Lowry 1972), observations of the weather element to be predicted (the predictand) are related to forecasts from a dynamical weather prediction model (the predictors). At the very short-range projections (generally out to 24 hours or less), the most recent observation available in the operational environment is often added as a possible predictor to the pool of model predictors. These observation predictors act to incorporate information inherent in persistence. For example, in the GFS-based MOS system, the observations valid 3 hours after model cycle time are available as possible predictors; for the Eta-based system, observations valid 1 hour after model cycle time are available. At all projections, geoclimatic variables, such as monthly relative frequencies of the event, first and second harmonics of the day of the year, and station elevation, are also included as possible predictors. These geoclimatic variables are particularly important in the development of equations for longer-range projections or for regions.

In the application of MOS within MDL, model variables are interpolated to the location of the observing site before use as predictors. In the GFS- and Eta-based MOS systems discussed here, the statistical equations are developed by the use of multiple linear regression, specifically by the technique of forward selection. Non-linear effects are incorporated into the prediction equations by the inherent non-linearity of the GFS and Eta model predictors, as well as by various transformations of the predictor variables. Both binary and grid-binary (Jensenius 1992) transformations of the predictors are used in the regression process.

Both the GFS- and Eta-based MOS guidance systems are developed from samples of model output generated by model configurations that evolve during the collection of the developmental data. MDL recognized the difficulty of developing a MOS system in this type of environment (Dallavalle 1996, 1997), and created a new MOS development and implementation system (Glahn and Dallavalle 2002) to address some of the problems. This new MOS system is critical to the development and expansion of the GFS- and Eta-based MOS guidance.

3. MODEL ARCHIVES

The development of a MOS system requires an archive of model forecasts. Part of MDL's strategy in handling model changes was to establish an archive of the GFS or Eta model with consistent spatial and temporal resolution. In accord with this philosophy, the GFS data are saved on a polar stereographic grid, with a grid spacing of 95.25 km at 60° N. This spatial resolution has been maintained while the global spectral model used in the GFS has undergone numerous changes in both horizontal and vertical resolution. The National Centers for Environmental Prediction (NCEP) have made the MDL archive feasible by placing the model forecasts on a 1° latitude/longitude grid and providing software to interpo-

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late from that grid to any arbitrary grid. The geographical extent of the MDL archive grid is sufficient to develop guidance for the CONUS, Alaska, Hawaii, Puerto Rico, and the Virgin Islands. This archive, available for the 0000, 0600, 1200, and 1800 UTC cycles, was begun in April 1997 with 3-h resolution in the forecast fields out to the 72-h projection. In subsequent years, we've added variables at different vertical levels as well as at additional forecast projections. The availability of variables in the archive is an important factor in developing and expanding MOS guidance products.

Despite changes in the GFS from 1997 to the present, we generally include all available data for MOS development. The only exception to this is a period from June 15, 1998, to July 22, 1998, when the performance of the model was negatively affected by changes to the analysis and model physics. We've eliminated this 5-week period from our developmental samples. Erickson et al. (2002) discussed some of the issues associated with changes to the global model used in the GFS. The reader is referred to NCEP (2003a) for detailed information about the GFS, including current configuration and past changes to the model.

Requirements within the NWS for guidance to support forecast operations in Guam and the western Pacific Ocean required MDL recently to add another GFS archive, namely, a set of model variables valid on a mercator grid with 80-km resolution and covering the western Pacific. This archive was done retrospectively from NCEP run history archives and is similar to the primary GFS archive in terms of temporal and vertical resolution. Data from April 2000 to the present are now available for development of GFS-based MOS guidance for Guam.

Similar issues were encountered in developing the Eta-based MOS system. The original archive established within MDL was available on a polar stereographic grid with a resolution of 90.75 km at 60° N. The archive was available only for the CONUS and contained variables valid every 6 hours from initial cycle time to 48 hours after initial time. Data were saved only from the 0000 and 1200 UTC cycles. The first Eta-based MOS system implemented in the spring of 2002 was developed from a sample of Eta data during the period of April 1997 to September 2001.

This original Eta archive was deficient in several respects, notably, geographical coverage and both spatial and temporal resolution. Because of user requirements to enhance the Eta MOS guidance, MDL created a second-generation archive that contains a subset of the Eta model output on a 32-km Lambert conformal grid (also known as AWIPS grid 221). Like the GFS archive for the Pacific Ocean, this archive was done retrospectively from NCEP run history files. The second MDL archive of Eta data covers the CONUS, Alaska, Hawaii, Puerto Rico, and the Virgin Islands. Forecasts are available from the 0000, 0600, 1200, and 1800 UTC forecast cycles. For all four cycles, the forecasts are at 3-h resolution from initial time to the last forecast projection of the model. For development of the second-generation Eta-based MOS guidance, archive data are available from April 2000 to the present. Despite extensive changes made to the operational Eta model during the archive period, the developmental samples used in the Eta-based MOS equations incorporate the full period of record. For more extensive documentation of the Eta model changes, the reader is referred to NCEP (2003b).

4. OBSERVATIONAL SOURCES

A reliable source of observations and a clear definition of the predictand are essential to the development of the MDL MOS system. For both the GFS- and Eta-based MOS systems implemented during the last 3 years, the primary source of observations has been the nationwide aviation hourly observing network, hereafter referred to as the METAR sites. This network has also undergone extensive modifications during the last 10 years as human observers were replaced by automated sensors, as the standards for reporting weather elements in the hourly observations were modified, and as new observing sites were added to the network. Allen (2001) described the challenges faced by MDL in using these data.

While the METAR sites provide the majority of the observations, the MOS system incorporates other observing systems into the predictand data. For instance, the occurrence of thunderstorms is defined by the National Lightning Detection Network, and the occurrence of severe weather is defined by the national Storm Data logs. Hughes (1999, 2001) discussed the use of these data. Because the automated observing sites do not detect clouds above 12,000 ft, MDL uses satellite cloud estimates (Hughes 1996) to complement the automated sky cover reports. Snowfall observations are not reported by automated sites and are not a mandatory element in the METAR code. For snowfall reports, MDL obtained cooperative observer network data from the National Climatic Data Center, decoded the observations, and incorporated them into the MOS system (Cosgrove and Sfanos 2004). MDL also transferred data from the National Data Buoy Center in order to develop wind direction and speed forecasts at over 100 buoy and Coastal-Marine Automated Network sites (McAloon 2004).

5. MOS EQUATION DEVELOPMENT AND PREDICTAND DEFINITIONS

Unless noted otherwise in the following description, for both the GFS and Eta MOS systems, equations are developed for warm (April 1 - September 30) and cool (October 1 - March 31) seasons. The developmental sample for these seasons includes data between the first and last day of the season and, whenever possible, 15 days before the start of the season and after the end of the season. The use of these extra data increases the sample size and smooths the transition in the guidance as the seasons change. For the GFS MOS system, guidance is available from the four model cycles, namely, 0000, 0600, 1200, and 1800 UTC. Only two cycles of Eta-based guidance, that is, from the 0000 and 1200 UTC model runs, are currently operational. The following sections describe the definitions of most of the weather elements currently predicted by the MOS system. The interested reader is referred to Dallavalle and Erickson (2001a, 2001b, 2001c) for more detailed descriptions of the forecast projections for each weather element. Unless indicated otherwise, GFS and Eta MOS guidance are available for each of the weather elements.

Equations for all the weather elements except maximum/minimum (max/min) temperature, 2-m temperature, 2-m dewpoint, and 10-m wind direction and speed are developed from a sample of data combined for stations in relatively homogeneous regions. Region size varies from weather element to weather element. For max/min temperature, 2-m temperature, 2-m dewpoint, and wind, individual equations are developed for each station in the MOS system, provided an adequate sample of observations is available. In general, 200 cases is the minimum sample required for equation development.

5.1 *Maximum/Minimum Temperature*

For both the GFS and Eta MOS systems, the max temperature is valid for a daytime period, defined as 7 a.m. to 7 p.m. Local Standard Time (LST). The min temperature is valid for the nighttime period, defined as 7 p.m. to 8 a.m. LST. Standard METAR observations of the max/min temperature do not correspond to these definitions; hence, MDL has developed an algorithm that estimates the predictand values from the 6-h max/min observations and the hourly temperature reports.

5.2 *Hourly Temperature and Dewpoint*

Temperature and dewpoint guidance are valid at specific hours. Predictand observations are extracted directly from the METAR reports and represent the temperature and dewpoint observed at the height of the instrument, generally the 2-m level.

5.3 *Wind Direction and Speed*

Wind direction and speed guidance are valid at specific hours. Predictand observations are extracted directly from the METAR reports and represent a 2-minute average direction and speed observed at the height of the anemometer, generally the 10-m level. Because of the circular nature of the wind direction, MOS equations are derived to predict the u- and v-wind components, and the wind direction is calculated from the components. Separate equations are developed to predict the wind speed. Sfanos (2001) describes the GFS MOS wind guidance. In the development of wind guidance for buoy and C-MAN sites, the equations predict the wind speed at the height of the anemometer, which for these particular sites varies from 5 meters to nearly 50 meters.

5.4 *Total Sky Cover*

Probabilistic and categorical guidance for total sky cover (clear, scattered, broken, and overcast) are valid at specific hours. The predictand observations (that is, the category of total sky cover conditions) are obtained by combining the METAR reports with the satellite cloud product referenced earlier. Equations are developed to predict the probability of each of the following four categories:

- Clear: 0 octas,
- Scattered: > 0 to 4 octas of total sky cover,
- Broken: > 4 to < 8 octas of total sky cover,
- Overcast: 8 octas of total sky cover or totally obscured.

A post-processing scheme is used to generate categorical forecasts from the probabilistic guidance. Weiss (2001) provides more detail about the GFS MOS sky cover guidance.

5.5 *Ceiling Height*

Probabilistic and categorical guidance for ceiling height are provided for specific hours. The standard METAR observations valid at a specific hour and complemented by the satellite cloud product for ceilings over 12,000 ft are used to define the predictand. The predictand is the occurrence of a ceiling height within one of the following seven categories:

- < 200 ft,
- 200 - 400 ft,
- 500 - 900 ft,
- 1000 - 3000 ft,
- 3100 - 6500 ft,
- 6600 - 12000 ft,
- > 12000 ft, or no ceiling.

Equations are developed to predict the probability of each of these categories; pre-determined probability thresholds are used to generate a categorical forecast. Weiss (op. cit.) describes the GFS MOS system to predict ceiling height. Development of a MOS system to predict ceiling height from the 32-km Eta archive is currently underway.

5.6 *Probability of Precipitation*

The probability of $\geq$ 0.01 inches of liquid-equivalent precipitation (PoP) occurring at a specific station is provided for 6-, 12-, and 24-h periods. The predictand observation for the 6-h precipitation amount is obtained from the 6-h precipitation group in the METAR report, available at 0000, 0600, 1200, and 1800 UTC. The precipitation amounts for the 12- and 24-h predictands are calculated by summing the appropriate 6-h values.

5.7 *Quantitative Precipitation Amount*

The probabilities of $\geq$ 0.10, $\geq$ 0.25, $\geq$ 0.50, and $\geq$ 1.00 inches of liquid-equivalent precipitation (PQPF) occurring at a specific site are generated for 6-, 12-, and 24-h periods. For 12- and 24-h periods, the probability of $\geq$ 2.00 inches of liquid-equivalent precipitation is also included. The predictand observation for the various periods is obtained from the METAR reports in a manner analogous to the PoP development, with one exception, namely, that the PQPF predictand is **conditional** upon precipitation occurring. Thus, the PQPF equations produce conditional probabilities of precipitation amount. The PoP and PQPF guidance are combined to generate unconditional probabilities of precipitation amount. Subsequently, a post-processing scheme is used to generate categorical guidance from the probabilities. Maloney (2002) describes the Eta MOS system for PoP and PQPF.

5.8 *Probability of Thunderstorms*

The thunderstorm guidance is the only current MOS product dependent on observations obtained from a remote-sensing system and valid on a grid. In this case, we've used lightning strikes reported by the National Lightning Detection Network (NLDN) and provided by NASA's Global Hydrology Resource Center. Since the NLDN does not detect lightning strikes far outside the borders of the CONUS, MOS thunderstorm guidance is only available for the CONUS and adjacent coastal waters. Lightning observations are random in time and space; to handle lightning events, we established a polar stereographic grid with 47.625-km resolution at 60°N. A thunderstorm event is defined as the occurrence of one or more lightning strikes within a grid box centered on the grid points. Thunderstorm predictands are established for 6-, 12-, and 24-h intervals. The MOS system predicts the probability of a thunderstorm event for these various intervals. Equations are available for spring (March 16 - June 30), summer (July 1 - October 15), and cool (October 16 - March 15) seasons. Hughes (2001, 2002) describes the GFS and Eta MOS thunderstorm systems.

5.9 *Conditional Probability of Severe Thunderstorms*

The severe thunderstorm predictand is defined by use of Storm Data reports, and is conditional upon the occurrence of a thunderstorm event. The same grid resolution and time resolution are used for severe weather as for the thunderstorm predictand, except that severe thunderstorms are not predicted over the coastal waters. Seasons used for development of the severe thunderstorm equations are identical to those used for the thunderstorm guidance. Given that a thunderstorm has occurred, a severe thunderstorm is defined when the Storm Data reports indicate a wind speed in excess of 50 kts, hail of 0.75 inches diameter or greater, or a tornado. The MOS system predicts the conditional probability of the severe thunderstorm event. Hughes (op. cit.) provides greater detail on this system.

5.10 *Precipitation Type*

Probabilistic and categorical guidance for precipitation type (freezing, snow, or liquid) are provided for specific hours. These are **conditional** forecasts, since the predictand is defined as conditional upon the occurrence of precipitation. The standard METAR observations valid at a specific hour are used to define the predictand. All precipitating events are categorized as one of the three types described earlier. Freezing rain, freezing drizzle, sleet, or any mixture of these with snow or rain is defined as a freezing event. Only pure snow events are categorized as snow occurrence. Rain or any mixture of rain with snow is defined as a liquid precipitation event. Forecast equations are developed for one season, extending from September 1 through May 31. The categorical guidance is obtained from the probabilities by use of pre-determined threshold probabilities. Allen and Erickson (2001) describe the GFS MOS precipitation type guidance. We've not yet developed Eta MOS guidance for precipitation type.

5.11 *Precipitation Characteristics*

Probabilistic guidance for precipitation characteristics (PoPC) defined as drizzle, continuous precipitation, or showers is provided for specific hours. These are **conditional** forecasts, since the predictand is defined as conditional upon the occurrence of precipitation. The standard METAR observations valid at a specific hour are used to define the predictand. All precipitating events, including snow or freezing precipitation, are categorized as one of the three types. Categorical guidance is obtained from the probabilities by use of pre-determined threshold probabilities. The GFS MOS guidance is not available in the alphanumeric message described in Section 7, but is available in binary and gridded products. Development of the Eta MOS guidance for PoPC is underway.

5.12 *Probability of Precipitation Occurrence*

The probability of occurrence of precipitation (PoPO) is provided for specific hours. The standard METAR observation valid at a specific hour is used to define the predictand. Unlike the PoP which requires measurable precipitation ($\geq$ 0.01 inches of liquid-equivalent precipitation) over an interval of time for an event to occur, the observation of current weather at the hour is exclusively used to define the PoPO predictand. Measurable precipitation is not required. The PoPO definition corresponds to the event used to specify the conditional predictand for precipitation type and characteristics. Guidance for PoPO during 3-h intervals is also generated; the predictand for this element is defined by the occurrence of precipitation at any one of the four hourly observations defining the 3-h interval. The GFS MOS guidance is not available in the alphanumeric message described in Section 7, but is available in binary and gridded products. Development of the Eta MOS guidance for PoPO is not planned at this time.

5.13 *Visibility*

Probabilistic and categorical guidance for visibility are provided for specific hours. The standard METAR observations valid at a specific hour are used to specify the predictand. The predictand is defined as the occurrence of a visibility within one of the following categories:

- $\leq$ ¼ mile,
- $\leq$ ½ mile,
- < 1 mile,
- < 3 miles,
- $\leq$ 5 miles,
- $\leq$ 6 miles.

These breakpoints were chosen to represent significant conditions for aviation. Equations are developed to predict the probability of each of these categories; pre-determined probability thresholds are used to generate a categorical forecast specifying mutually exclusive categories, for example, 3 to 5 miles. Visibilities of 7 miles or greater are predicted when the other categories are not selected. Only a GFS MOS system is currently operational.

5.14 *Obstruction to Vision*

Probabilistic and categorical guidance for obstructions to vision (which are not themselves precipitating events) are provided for specific hours. The standard METAR observations valid at a specific hour are used to specify the predictand. The predictand is defined as the occurrence of one of the following sets of events:

- No non-precipitating obstruction to vision;
- Haze, smoke, or dust;
- Light fog or mist (fog with visibility of 5/8 mi or greater);
- Dense fog or ground fog (fog with visibility of < 5/8 mi);
- Blowing snow, dust or sand.

Equations are developed to predict the probability of each of these categories; pre-determined probability thresholds are used to generate a categorical forecast. Because of the difficulty of predicting blowing phenomenon when the characteristics of the underlying surface are unknown, we've engineered the guidance so that blowing phenomena can only be predicted during the first 24 hours of the forecast period. Only a GFS MOS system is currently operational.

5.15 *Snowfall Amount*

Starting in the 2003-04 winter, probabilistic and categorical guidance for snowfall amount during 24-h periods are provided. Developmental data for this system were obtained from the national cooperative observer network. Guidance is available for the following categories:

- No snowfall or a trace,
- > trace to < 2 inches,
- 2 inches to < 4 inches,
- 4 inches to < 6 inches,
- 6 inches to < 8 inches,
- ≥ 8 inches.

Probability forecasts for each of these categories are generated by combining probabilities from equations that predict the 24-h PoP, the conditional probability of snow occurring, and the conditional probability of categorical snowfall amounts. Pre-determined probability thresholds are used to generate a categorical forecast. Cosgrove and Sfanos (2004) describe the snowfall amount system. Only the GFS MOS system was developed at the time of this paper; development of the Eta MOS system was underway.

6. POST-PROCESSING USED IN THE MOS SYSTEM

Extensive post-processing of the raw MOS guidance occurs before any products are issued to the forecast community. As indicated in Section 5, post-processing is used to obtain categorical forecasts from the probabilities. Prior to calculating a categorical forecast, the probabilities are checked, as feasible, to be sure that the statistical properties of the guidance are reasonable. Thus, for instance, probabilities are constrained to be non-negative and not exceed 100%. Probabilities of multi-category, exclusive events (for instance, ceiling height) are normalized so that the probabilities of the categories are non-negative and sum to 100%. Probabilities of multi-category, cumulative events (for instance, precipitation amount) are examined for monotonicity, that is, the probability of the rarer event should not exceed the probability of the more common event. For the probability of precipitation or thunderstorms over a 12-h interval, the 12-h probability is checked to be sure that it is, at least, as large as the 6-h probabilities for the subintervals.

Post-processing is also done for the temperature, dewpoint, and wind guidance, though the checks are, in some sense, more meteorological than statistical. Thus, wind speeds are inflated to generate a more realistic distribution of the higher wind speeds (Sfanos 2001). Wind speeds are constrained to be non-negative; when the speed is zero, the wind direction is set to indicate a calm wind. Temperatures and dewpoint forecasts valid at the same time are checked for meteorological consistency. If the dewpoint exceeds the temperature, then the temperature and dewpoint are set equal to the average of the original two values. The max temperatures are compared to some of the 3-h temperatures forecast during the daytime hours; if the max temperature is less than a 3-h value, then the max temperature is raised to equal the highest of the 3-h values. An analogous check is made to compare the nighttime min temperature forecast to some of the 3-h temperatures predicted during the night.

We do not check for meteorological consistency among the various element forecasts, except for those mentioned above. Thus, for example, the conditional guidance for precipitation type could indicate snow while the temperature guidance predicts a max in the mid 50's. The total sky cover guidance could indicate scattered conditions while the ceiling height guidance indicates a ceiling, implying broken or overcast conditions. The post-processing checks we've implemented are those that we can make with reasonable confidence that the guidance is not degraded. Other inconsistencies will occur; these must be reconciled by the user.

7. SAMPLE PRODUCTS

Figures 1 and 2, respectively, show examples of the GFS and Eta MOS alphanumeric guidance messages. Dallavalle and Erickson (op. cit) describe the format of these messages in detail. Note that the limitations of alphanumeric messages constrain the projections and weather elements contained in these messages. Thus, for instance, even though probability forecasts are generated for most of the weather elements, generally, the alphanu-

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KDCA   AVN MOS GUIDANCE    1/29/2003  0000 UTC
DT /JAN  29            /JAN  30                /JAN  31          /
HR   06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 18 00
X/N                    41          25          38          26    42
TMP  34 34 34 34 38 38 36 33 29 28 27 31 36 36 33 31 29 28 27 40 38
DPT  27 30 31 31 30 28 25 24 23 21 20 21 21 21 22 23 23 23 24 27 29
CLD  OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV BK OV OV
WDR  19 21 22 19 05 35 35 36 36 01 01 02 02 03 04 02 01 02 03 06 10
WSP  04 04 04 04 03 05 08 12 10 09 08 07 05 05 06 05 04 05 06 03 04
P06        76    81    57    19    10     2     9     7     4  0  3
P12                    88          29          10          11     4
Q06         1     2     1     0     0     0     0     0     0  0  0
Q12                     3           0           0           0     0
SNW                                 0                       0
T06      0/ 0  1/ 0  2/ 0  0/ 0  0/ 0  0/ 0  0/ 0  0/ 0  0/ 0  0/ 0
T12            2/ 0        3/ 0        1/ 0        0/ 0     0/ 0
POZ  12 15 13  7  4  4  6  5  9  8 11 10  8 10 16 10 13 13 14  5  8
POS  43 29 14 19 14 18 28 47 55 60 68 50 50 55 60 47 43 60 36 44 24
TYP   S  R  R  R  R  R  R  S  S  S  S  S  S  S  S  S  S  S  S  S  R
CIG   5  5  4  4  3  3  4  5  6  7  7  5  6  5  4  7  6  7  5  5  4
VIS   7  7  5  4  5  4  6  7  7  7  7  7  7  7  7  7  7  7  7  7  7
OBV   N  N BR BR BR BR  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
```

Figure 1. GFS MOS guidance message for KDCA for 0000 UTC cycle, January 29, 2003.

meric messages contain only the categorical forecasts. As a second example, note that the GFS temperature and dewpoint guidance is currently valid every 3 hours from 6 to 72 hours after 0000 UTC, yet the message shown in Fig. 1 does not contain all the projections. All of the MOS guidance is available in digital format (MDL 2003), either in gridded analyses or in binary messages for each station.

8. ACCURACY AND SKILL OF THE GUIDANCE

Figures 3 through 12 provide a sample of the accuracy and skill of the GFS MOS guidance compared to the older NGM MOS guidance and to the GFS direct model output (DMO), when possible. We've chosen to concentrate on the 2002-03 cool season results for max/min temperature, 3-h temperature, 3-h dewpoint, PoP, surface wind speed and direction, total sky cover, and precipitation type. For purposes of comparison, we've restricted these verifications to 300 stations in the CONUS. Because the Eta-based system will be revised extensively in early 2004, we've omitted Eta MOS results from this discussion.

```
KDCA   ETA MOS GUIDANCE    1/29/2003  0000 UTC
DT /JAN  29            /JAN  30                /JAN  31
HR   06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12
X/N                    40          29          42          30
TMP  38 38 37 38 38 37 36 34 32 31 30 35 40 40 37 34 32 32 31
DPT  27 29 29 29 30 30 29 27 26 24 24 24 24 24 24 26 27 27 26
CLD  OV OV OV OV OV OV OV OV OV OV BK BK BK OV OV OV OV OV BK
WDR  18 17 15 12 03 01 36 35 36 01 01 04 06 06 02 03 01 36 01
WSP  05 04 02 02 02 06 08 08 06 08 09 05 05 04 07 07 04 05 07
P06        31    48    74    45     5     0     1     8    19
P12                    88          45           1          19
Q06         0     1     1     1     0     0     0     0     0
Q12                     2           1           0           0
T06      2/ 0  1/ 0  1/ 0  0/ 0  0/ 0  0/ 0  0/ 0  0/ 0  1/ 0
T12            3/ 0        1/ 0        1/ 0        0/ 0
```

Figure 2. Eta MOS guidance message for KDCA, 0000 UTC cycle, January 29, 2003.

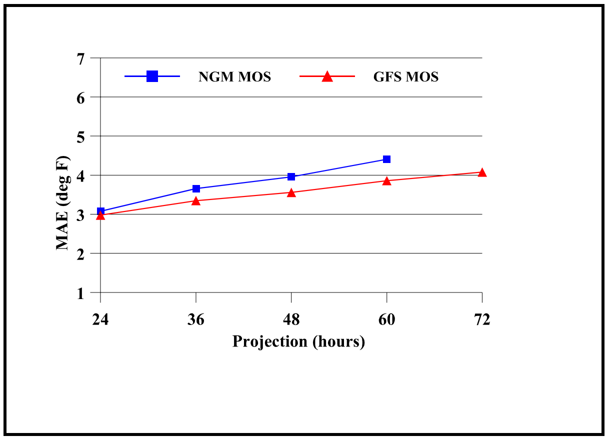

Figure 3. Mean absolute error (° F) for the NGM and AVN MOS guidance for the 2002-03 cool season.

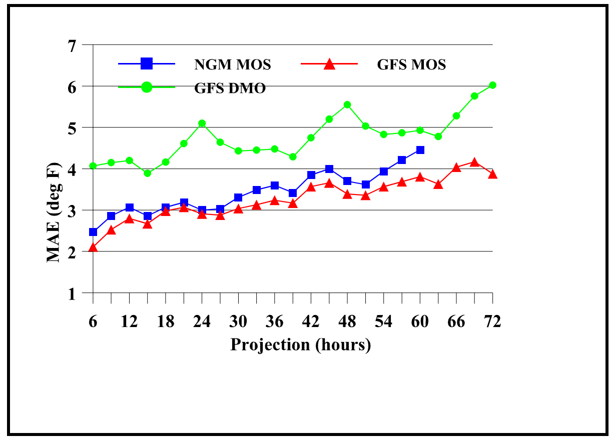

Figure 5. Mean absolute error (°F) of NGM MOS, GFS MOS, and GFS DMO temperature forecasts for the 2002-03 cool season, 0000 UTC cycle.

Figures 3 and 4 show the mean absolute error for the NGM and GFS MOS max and min temperature guidance, respectively. Note that both diagrams are a combination of forecast projections from the 0000 and 1200 UTC cycles. For example, the errors of the max temperature guidance for the first, third, and fifth periods from 0000 UTC are plotted at 24, 48, and 72 hours, respectively. The second and fourth period errors, plotted at 36 and 60 hours, respectively, are from the 1200 UTC guidance. The plotting convention for the min temperature guidance is similar, except that the first period forecast is from the 1200 UTC cycle. Note that the NGM MOS guidance is only available for four periods, while the AVN MOS guidance is available for five periods. Except for the first period max temperature, the GFS MOS is more accurate than the NGM MOS by 0.2 to 0.5° F. Note, also, that the accuracy of the GFS MOS decreases by approximately 0.5° F per 24-h period during the cool season.

Figures 5 and 6 show the mean absolute errors of the temperature and dewpoint forecasts, respectively, generated by the NGM MOS, GFS MOS, and the GFS direct model output interpolated to the stations. Both MOS systems improve significantly over the GFS DMO. The GFS MOS is more accurate than the NGM MOS, and the improvement increases with increasing projection.

Brier scores (Brier 1950) are shown in Fig. 7 for the 12-h PoPs from the 0000 UTC forecast cycle, ending at the indicated projections. Note that the GFS MOS is consistently more accurate than the NGM MOS and that this improvment increases with increasing projection. Note, too, that the Brier score of the GFS MOS increases at a rate of approximately 0.01 in a 24-h period, a smaller increase than for the NGM MOS. Maloney (2004) provides additional verifications comparing the NGM, GFS, and Eta MOS for both PoP and quantitative precipitation amount.

Verification scores for wind speed and direction are shown in Figs. 8 and 9, respectively. Figure 8 gives the Heidke skill score (HSS) (Wilks 1995) for wind speed forecasts, based on dividing the wind speed into the following categories: 0 - 12, 13 - 17, 18 - 22, 23 - 27, 27 - 32, and > 32 kts. The DMO forecasts were obtained by interpolating grid point values to the stations. Note that the GFS MOS guidance is superior to the DMO at all

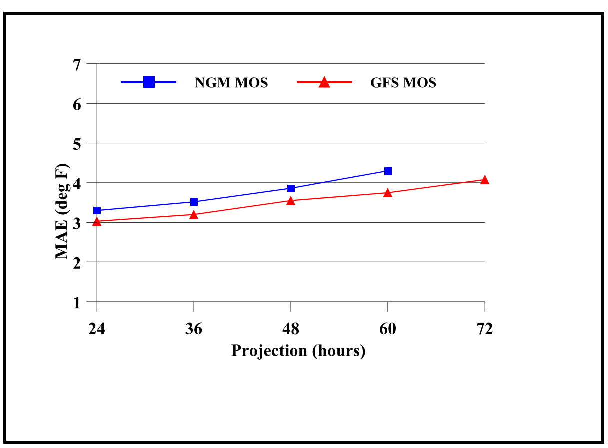

Figure 4. Same as Fig. 3, except for the min temperature guidance.

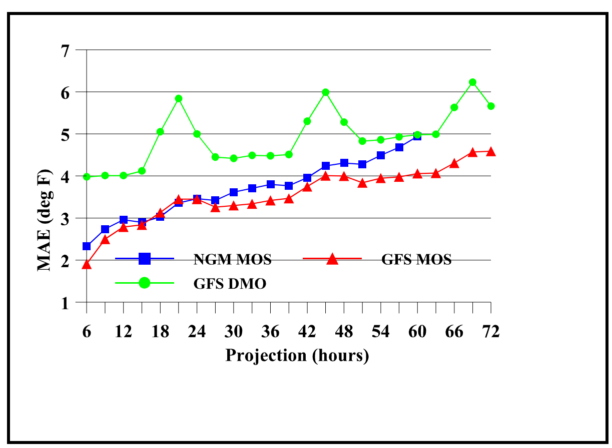

Figure 6. Same as Fig. 5, except for dewpoint forecasts.

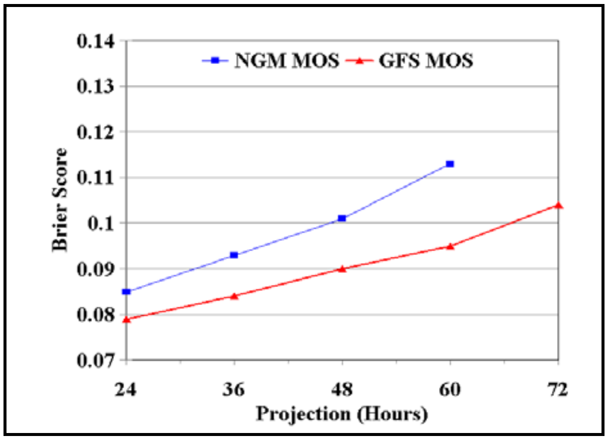

Figure 7. Brier scores for 12-h PoP's ending at the indicated projections and generated from the 0000 UTC forecast cycle, 2002-03 cool season.

projections, indicating that the MOS guidance is producing a more accurate representation of the wind speed distribution than the DMO. Even the NGM MOS guidance has higher skill scores for all projections out to 51 hours. For forecast projections of 51- through 60-h, the NGM MOS only uses 48-h forecasts from the NGM as model variables. Figure 9 shows the relative frequency of wind direction errors of $\leq$ 30°, given that the observed wind speed is 10 kts or greater. The results indicate that the GFS MOS guidance is providing more accurate wind direction forecasts than either the NGM MOS or the DMO. The relative benefits of the NGM MOS and GFS DMO wind direction forecasts parallel those seen in the wind speed forecasts. These results are not surprising; one of the benefits of the MOS approach is to relate the observations at specific locations to model forecasts.

Figure 10 shows the HSS for the total sky cover for the GFS and NGM MOS systems. Four categories of sky cover were used to compute the HSS, namely, clear, scattered, broken, and overcast. The GFS MOS system is consistently more skillful than the NGM MOS guidance. Since the latter system was developed from observations

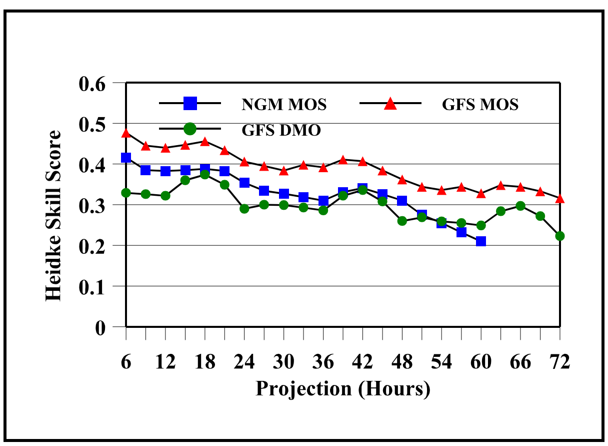

Figure 8. Heidke skill scores for wind speed forecasts for the 0000 UTC forecast cycle, 2002-03 cool season.

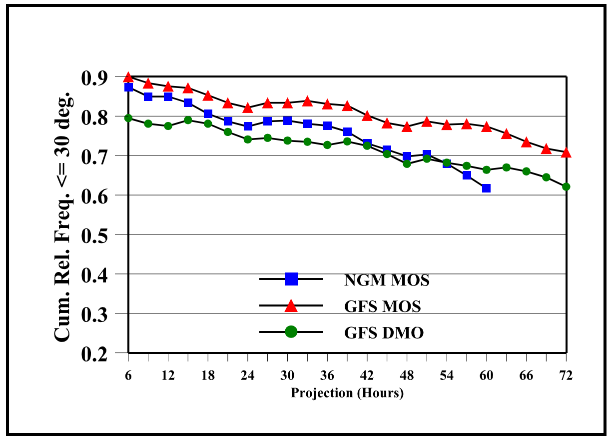

Figure 9. Same as Fig. 8, except for cumulative relative frequency of wind direction forecasts. Only cases in which the observed wind speed is 10 kts or greater are verified.

of opaque cloud cover, and the GFS system was developed from observations of total sky cover, these differences are not surprising.

Heidke skill scores for precipitation type and threat scores for freezing precipitation are shown in Figs. 11 and 12, respectively. Note that the NGM MOS system only produces guidance for the projections shown. The HSS of the GFS MOS is slightly higher overall than the HSS for the NGM MOS, and the threat scores for freezing precipitation indicate that the GFS MOS is better able to discriminate cases of freezing precipitation than the NGM MOS.

9. FUTURE PLANS

The current MOS system will undergo extensive revisions, beginning in December 2003 and continuing until the fall of 2004. Thus, the GFS MOS system will be expanded to over 1500 sites in the U.S., starting in December 2003. At that time, new equations to predict max/min temperature, temperature, dewpoint, wind direction and speed, PoP, PQPF, total sky cover, ceiling

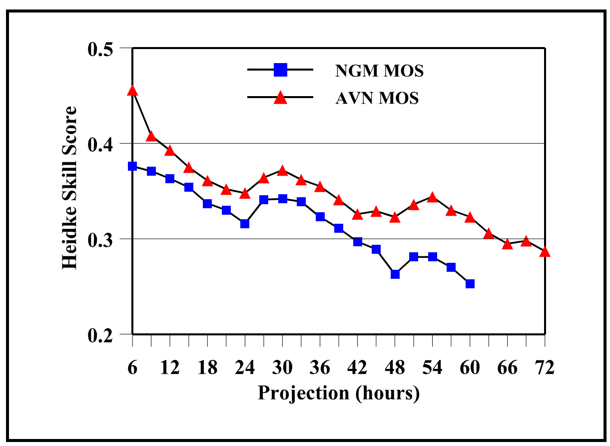

Figure 10. Same as Fig. 8, except for Heidke skill score for total sky cover.

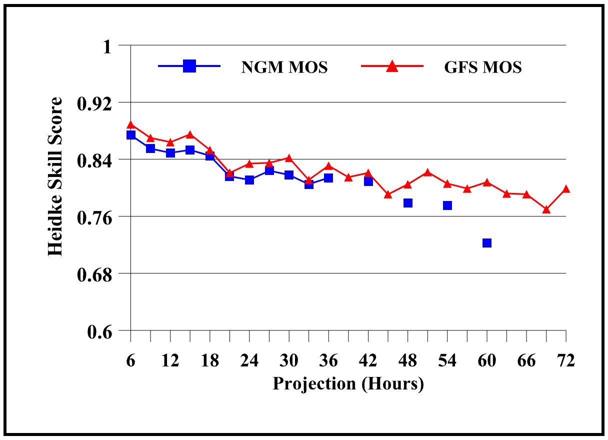

Figure 11. Same as Fig. 8, except Heidke skill score for precipitation type forecasts.

height, precipitation characteristics, thunderstorms, severe weather, and snowfall will be implemented. The GFS MOS system is also being expanded to provide guidance out to the 84-h projection for all four model cycles. An entirely new MOS system based on the 32-km Eta archive described in Section 3 is scheduled to be implemented in late January 2004. This system will contain forecasts for the same set of stations included in the GFS MOS guidance. The new Eta MOS system will initially provide guidance for max/min temperature, temperature, dewpoint, wind direction and speed, PoP, PQPF, total sky cover, ceiling height, precipitation characteristics, thunderstorms, severe weather, and snowfall amount. Guidance for other weather elements will be added as resources permit. By April 2004, we plan to modify the sky cover guidance to predict five categories (clear, few, scattered, broken, and overcast), to subdivide the 1000 - 3000 ft ceiling height category into two categories, and to revamp the visibility categories to conform to modified NWS requirements.

As Glahn and Ruth (2003) indicate, a new era now exists in which the demand for high-resolution digital guidance must be met. To accommodate this need, we've initiated a project to create a MOS system for a grid with 2.5- to 5-km horizontal resolution. As mentioned in Section 5.8, the thunderstorm guidance is the sole MOS product developed from remotely-sensed data and valid for a grid. Hughes and Trimarco (2004) discuss changes in the characteristics of the thunderstorm guidance as the spatial resolution of the predictand grid is modified. Use of other remotely-sensed observations as predictands in the MOS development process will allow us to develop gridded products for such elements as precipitation (Antolik 2004) or sky cover. However, we don't have comparable remotely-sensed observations for weather elements such as temperature, dewpoint, wind direction, wind speed, visibility, and so forth. For these elements, our plan is to obtain as much observational data as possible from available observing networks and to incorporate those additional sites into the MOS system. For that reason, we've used the cooperative observer network reports of max/min temperature to increase the sites at which we can produce max/min temperature guidance by approximately 5,000 locations. As mentioned in Section 4, wind guidance for over 120 marine sites has been recently added to the MOS system. We're now working with researchers at the University of Utah to obtain an archive of mesonet observations. Data from other networks will be incorporated into the MOS system as resources permit. Our goal is to use all available observational data with high-resolution geophysical data such as terrain elevation, aspect, and slope; vegetation type; urbanization factors; land/sea mask; and so forth to develop regionalized prediction equations that can generate MOS guidance at the desired spatial resolution.

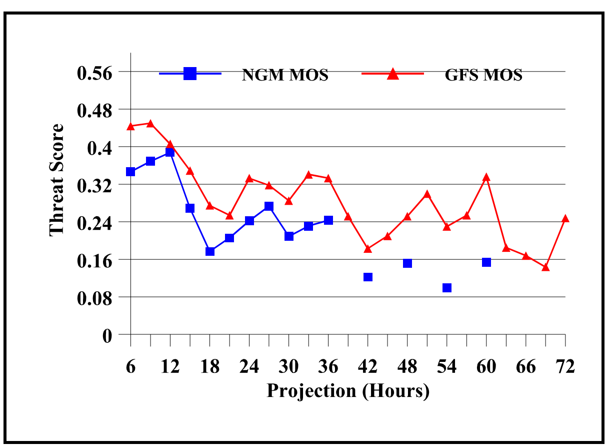

Figure 12. Same as Fig. 11, except threat score of the freezing precipitation event.

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