MDL TPB 05 – 02
February 25, 2005

GFS-BASED MOS WIND FORECAST GUIDANCE FOR THE WESTERN PACIFIC ISLANDS

by
James C. Su

1. INTRODUCTION

This Technical Procedures Bulletin (TPB) describes the new Global Forecast System (GFS)-based Model Output Statistics (MOS) wind guidance for island locations in the western Pacific Ocean. The forecast equations used to generate the guidance are linear regression equations that relate observed wind data at stations (predictands) to predictors, which include NWP model output of various meteorological variables interpolated to stations, observed weather elements, and geoclimatic variables. MOS guidance for these islands has not been developed for any meteorological element before. This new guidance is focused on tropical locations and provides forecasts for a station in the Southern Hemisphere, which is unique among the MOS guidance packages.

The Model Output Statistics (MOS) technique (Glahn and Lowry 1972), specifically, multiple linear regression with forward selection, is used in the development of the guidance equations. Other MOS wind guidance packages for the contiguous United States (CONUS), Alaska, and Hawaii have been developed by the staff of Meteorological Development Laboratory (MDL); see, for example, Miller 1993 and Sfanos 2001. The GFS (see Alpert et al. 1991) is an improved version of the National Centers for Environmental Prediction (NCEP) aviation model (AVN) (Kanamitsu 1989).

This document describes development of the forecast equations, post-processing procedures, operational products, and verification results.

2. DEVELOPMENT

a. Stations

This new MOS wind guidance package has been developed for 15 island sites in the western Pacific Ocean within the area from 15 S to 30 N and from 130 E to 170 W. Two sites are located in the Western Hemisphere and 13 sites in the Eastern Hemisphere. The list of stations can be found at the following URL:
http://www.nws.noaa.gov/mdl/synop/stadrg.html

b. Predictands

The developmental sample for wind predictands includes earth-oriented u- and v-wind components, as well as wind speed observed at the 10-m level above the earth's surface. All predictands are continuous variables. The u and v components are computed from hourly observed wind direction and speed. The predictand variables have a unit of nautical miles per hour (knots). The observed data for 0000, 0300, 0600, …, and 2100 UTC are used in the development for projections every 3 hours from 6 to 84 hours after initial model time. Forecast wind directions are computed from the MOS forecast of u and v components.

c. Predictors

Meteorological variables that could impact surface wind forecasts were used as potential predictors. In this development, the potential predictors included variables derived from the GFS model output, observed speed and wind components, and sinusoidal functions of the first and second harmonics of the day of the year.

Potential predictor variables derived from the GFS model output consisted of earth-oriented wind components (u and v) on isobaric levels and at 10-m height. Also on isobaric levels were vertical velocity, relative vorticity, and mass divergence. Variables that are related to the atmospheric stability included temperature difference between two isobaric levels and K index. In addition, mean relative humidity computed by integration through an isobaric layer was included in the list of potential predictors.

In order to reduce the amount of small-scale noise inherent in the NWP model output, a 25-point smoother was applied to the GFS model data. Grid point data were then interpolated to the location of stations for which MOS wind forecast equations were developed.

The sinusoidal functions of the first and second harmonics of the day of the year are used as potential predictors to account for annual and semi-annual variations of the wind pattern.

d. Meteorological Data

An archive system was established for the collection of GFS model data to be used for the development of MOS guidance for island sites in the western Pacific Ocean. A Mercator grid was designed to cover the area from 129.9 degrees E to 149.7 degrees W longitude and from 19.3 degrees S to 32.7 degrees N latitude. The GFS model output was extracted and stored on this grid. The GFS model data for this development are available for April 2000 through the present, for 0000 and 1200 UTC cycles, and for projections from 0 to 84 hours at a 3-h increment. The MDL archive of observed hourly data provides observations for every 3 hours from 0000 to 2100 UTC for the same period as the model data.

All the data used in the development were grouped in two seasons: monsoon season (June through September) and dry season (October through May), and forecast equations were developed for each station and each season. The data for five monsoon seasons (in 2000 through 2004) and four dry seasons (2000-01, 2001-02, 2002-03, and 2003-04) were used in the development of final equations.

e. Equation Characteristics

Multiple linear regression equations are developed for wind components (u and v) and wind speed simultaneously. Individual equations are developed for each station, season (monsoon or dry), cycle (0000 or 1200 UTC), and projection (06, 09, 12, …, 78, 81, or 84 hours). Several limitations are imposed on the development of forecast equations. The maximum number of predictors to select is 12. The minimum number of cases (when both predictand and predictor data are available) required for an equation to be developed is 190. The necessary reduction of variance by a predictor is 0.5%, for the predictor to be added to the forecast equation. Some stations have part-time observed data; thus, forecast equations for several projections cannot be developed for these stations.

Potential predictors derived from observed wind data are generally not used in the development of forecast equations except for short-range projections. For 6-, 9-, and 12-h projections, this kind of potential predictor from 0300 UTC and 1500 UTC is used in the development of equations for the 0000 UTC and 1200 UTC forecast cycles, respectively (primary equations). For corresponding projections, a set of equations that do not involve potential predictors derived from observed data is also developed (secondary equations). For projections beyond 12 hours, only one set of equations which use no observed predictors are developed.

The selection of potential predictors by the screening regression procedure varies between seasons and forecast cycles. Observed wind components and speed are predominantly selected to be used in equations, for both seasons and both cycles valid at the 6-, 9-, and 12-h projections. This is an indication of persistency in the tropics.

GFS model output variables for potential predictors include wind components and speed at 10-m height and at various isobaric levels up to 500 mb. Predictors on isobaric levels also include relative vorticity, vertical velocity, and mass divergence. The 10-m wind components and speed are used frequently in the forecast equations for both seasons and cycles. Predictors at 925 mb and below are frequently used in dry season equations, and those at all isobaric levels are frequently used in monsoon season equations. In addition, vertical velocity and mass divergence are used in equations more often for the monsoon season than for the dry season. Other GFS model output predictors include temperature difference between isobaric surfaces, the K index, and mean relative humidity. These predictors are used in the forecast equations more often during the monsoon season than during the dry season.
In particular, the difference between seasons in the use of K index is substantial.

The mean relative humidity used in the forecast equations is mainly from the 1000-850 mb layer. This indicates that the relationship between predictors and predictands is governed by variables in a shallow layer near the earth's surface during the dry season whereas predictors in a much deeper layer in the lower troposphere are influential during the monsoon season.

Sinusoidal functions of the first and second harmonics of the day of the year are more frequently used in the forecast equations for the dry season and the 0000 UTC cycle. More first harmonic functions are used in the dry season, and more second harmonic functions are used in the monsoon season.

3. POST-PROCESSING

MOS wind forecast equations provide estimates of wind components (u and v) and wind speed while the wind forecast guidance to be disseminated provides wind direction and speed. Post-processing procedures are required to ensure that the wind guidance is meteorologically and statistically sound. The wind speed directly computed from forecast equations tends to have few cases of high speed. To enhance the skill of wind speed forecasts for high winds, an "inflation" technique is applied to the wind speed (Schwartz and Carter 1985). The inflation process increases the magnitude of wind speeds above the developmental mean wind speed. This process also increases the variance of wind speed forecasts to approach that of the observed wind speeds. Verification (Dallavalle et al. 1979) indicates that the inflation technique increases the number of high wind speed forecasts with a small decrease in the overall accuracy of MOS wind forecasts.

The next step is to compute wind directions from wind components obtained from forecast equations and to ensure that all wind speeds are non-negative. The negative wind speeds are changed to zero. Subsequently, a check is made to set wind direction to calm (zero) whenever the speed is zero.

4. OPERATIONAL PRODUCTS

The MOS guidance produced from the forecast equations will be disseminated in two groups. The guidance for two stations located on the east side of the international dateline (NSTU and PMDY) will be added to the existing Hawaiian products, whose WMO headers are FOPA20 KWNO for the text message and JSML30 KWNO for the binary (BUFR) message. The guidance for 13 stations located on the west side of the international dateline will be disseminated in two new packages, whose WMO headers are FOPA21 KWNO for the text message and JSML38 KWNO for the BUFR message. The addition to the Hawaiian products will be effective April 19, 2005, and the new packages will be operational June 7, 2005. Both sets of the new guidance are initially available for the 0000 and 1200 UTC cycles only.

Although wind guidance is available for projections of 6 to 84 hours at 3-h increments, the alphanumeric message (text) provides predictions to 72 hours only

(Dallavalle and Su 2005). The BUFR messages contain predictions for projections up to 84 hours. The wind direction is given in tens of degrees and varies from 10 to 360 degrees (from 1 to 36), according to the normal meteorological convention for specifying wind directions. The wind speed is given in knots. Both wind direction and speed are denoted by 00 for calm wind.

When the real-time observed data for 0300 UTC or 1500 UTC are available to produce wind guidance for 0000 UTC or 1200 UTC, respectively, the observed data are used in the primary equations for 6-, 9-, and 12-h projections. Otherwise, secondary equations requiring no observed predictors are used.

5. VERIFICATION

Before final MOS wind forecast equations were produced, test equations were developed by using data for three dry seasons (2000-01, 2001-02, and 2002-03) and four monsoon seasons (2000 through 2003). Data for the 2003-04 dry season and 2004 monsoon season were used as test data. Verification of MOS forecast wind directions and speeds were done for the 0000 UTC cycle only. The MOS wind forecasts were compared to the GFS model output wind directions and speeds. The overall performance of the forecasts for 15 island sites is discussed in this TPB.

Mean absolute errors (MAE) of wind speeds are shown in Fig. 1 (for dry season) and Fig. 2 (for monsoon season). The MAE of the MOS forecasts are between 2 and 3 kts and increase from 2 kts at the 6-h projection to 3 kts at the 84-h projection, for both seasons. The increase for the dry season is gradual (almost monotonic) while that for the monsoon season shows a diurnal variation with small amplitude. The MAE of the GFS model output wind speeds range from about 4 to 6 kts for the dry season and from 3 to about 4.5 kts for the monsoon season. The diurnal variation of the MAE of GFS output is very prominent for both seasons.

Figures 3 and 4 show the comparison of overall MAE of wind directions, for dry and monsoon seasons, respectively. For the dry season, the MAE of MOS forecasts are between about 21 and 30 degrees while that of GFS forecasts are between about 22 and 32 degrees. For the monsoon season, the MAE of MOS forecasts range from about 23 to 39 degrees while that of GFS forecasts range from about 24 to 41 degrees. The MAE for both seasons increase slightly toward longer projections with little diurnal variation. The MOS forecasts of wind direction are slightly better than the GFS forecasts for all projections.

The MAE of wind direction forecasts for cases with observed wind speeds greater than or equal to 10 kts are shown in Figs. 5 and 6, for dry and monsoon seasons, respectively. For the dry season, the MAE of MOS forecasts are between about 12 and. 20 degrees while that of GFS forecasts are between about 13 and 22 degrees. For the monsoon season, the MAE of MOS forecasts range from about 13 to 24 degrees while that of GFS forecasts range between 15 and 28 degrees. Comparing Figs. 5 and 6 with Figs. 3 and 4, we see that both MOS and the GFS predict strong winds better than all winds. For strong winds, MOS also predicts directions better than the GFS for all projections.

Figures 7 and 8 show the cumulative relative frequencies (CRF) of wind direction forecast errors of less than or equal to 10 degrees for cases when observed wind speeds are greater than or equal to 10 kts. For the dry season, the CRF of MOS are between about 0.41 and 0.58 while that of GFS are between 0.35 and 0.51. For the monsoon season, the CRF of MOS are between about 0.36 and 0.54 while that of GFS are between 0.30 and 0.44. The CRF decrease with increasing projection; the decrease is more rapid for the monsoon season. The graphs also show that the CRF of MOS are greater than that of GFS for all projections; the differences are larger for the monsoon season. This verification also indicates that MOS forecasts of wind directions are better than that of GFS for strong winds.

Based on this investigation, the MOS wind speed forecasts are better than the GFS direct model output. It is very obvious that the MOS wind guidance can predict the local diurnal variations in wind speed, especially well for the dry season, while the GFS model can not. The improvement of the MOS wind direction forecasts over the GFS model output wind directions is small but consistent.

6. OPERATIONAL CONSIDERATIONS

Robust MOS forecast equations rely on stable NWP model output and consistent historical observed data. If the parent NWP model on which the MOS forecast equations are based undergoes major modifications in the model dynamics, physics, computational scheme, or initialization process, the MOS equations would have to be re-developed. If a station does not have adequate historical observed data, MOS forecast equations cannot be developed for the station. This is the case for three island sites in the western Pacific Ocean (PGRO, PGWT and PTSA), for which equations for many projections are missing.

Strong winds and gusts that are associated with thunderstorms, typhoons, and other severe weather phenomena are not predicted well by the MOS wind guidance. The current MDL archive data do not contain sufficient samples of severe weather phenomena and typhoons in order to warrant any skill for strong wind and gust forecasts; moreover, these phenomena are often too small in scale to be adequately represented in the GFS model.

If a field forecaster has any reason to believe that the GFS model output is in error, especially in those predictors mentioned in Section 2.e, the forecaster should correct the MOS forecast according to his or her experience. By the same token, if ground-based or satellite observations indicate thunderstorm, typhoon, or other severe weather phenomena in the local area, the MOS forecasts should also be modified accordingly.

7. REFERENCES

Alpert, J. C., K. A. Campana, P. M. Caplan, D. G. Deaven, M. Iredell, B. Katz, H.-L. Pan, J. Sela, and G. H. White, 1991: Recent changes implemented into the global forecast system at NMC. Wea. Forecasting, **6,** 425-435.

Dallavalle, J. P., G. M. Carter, D. B. Gilhousen, K. F. Hebenstreit, G. W. Hollenbaugh, J. E. Janowiak, and D. J. Vercelli, 1979: Comparative verification of guidance and local aviation/public weather forecasts – No. 6. TDL Office Note 79-11, National Weather Service, NOAA, U.S. Department of Commerce, 61 pp.

Dallavalle, J. P., and J. C. Su, 2005: GFS-based MOS guidance for the western Pacific – The short-range alphanumeric message from the 0000/1200 UTC forecast cycles. MDL Technical Procedures Bulletin No. 05-01, Meteorological Development Laboratory, National Weather Service, NOAA, U.S. Department of Commerce, 4 pp.

Glahn, H. R., and D. A. Lowry, 1972: The use of Model Output Statistics (MOS) in objective weather forecasting. J. Appl. Meteor., **11**, 1203-1211.

Kanamitsu, M., 1989: Description of the NMC global data assimilation and forecast system. Wea. Forecasting, **4**, 335-343.

Miller, D. T., 1993: NGM-based MOS wind guidance for the contiguous United States, NWS Technical Procedures Bulletin No. 399, NOAA, U. S. Department of Commerce, 19 pp.

Schwartz, B. E. and G. M. Carter, 1985: The use of Model Output Statistics for predicting surface wind. NWS Technical Procedures Bulletin No. 347, NOAA, U. S. Department of Commerce, 11 pp.

Sfanos, B., 2001: AVN-based MOS wind guidance for the United States and Puerto Rico. NWS Technical Procedures Bulletin No. 475, NOAA, U.S. Department of Commerce, 6 pp.

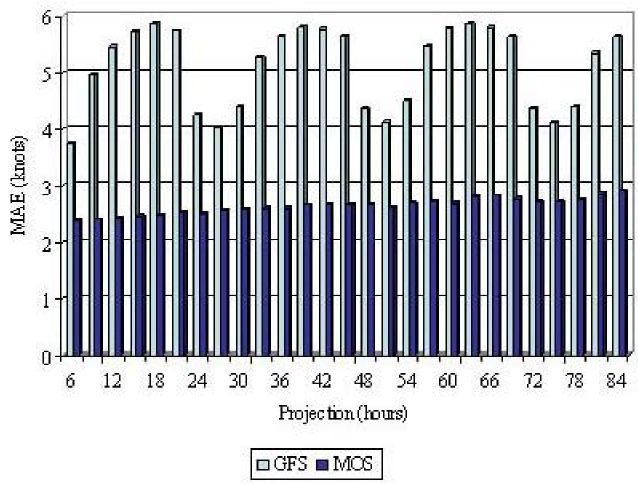

Figure 1. Overall mean absolute errors (MAE) in MOS and GFS wind speed forecasts, dry season, 0000 UTC, for 15 stations.

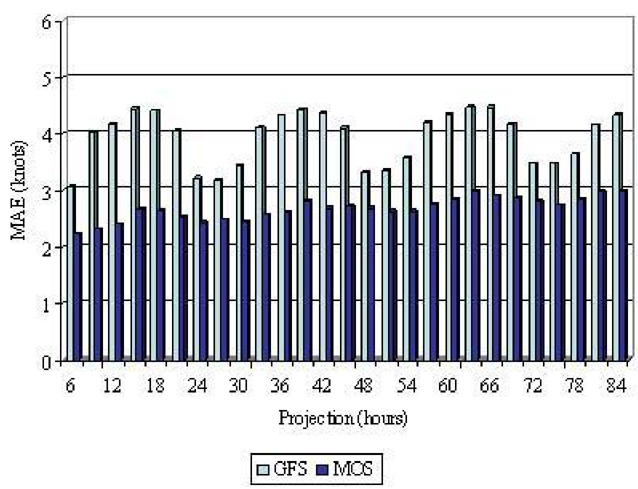

Figure 2. Same as Fig. 1, except for the monsoon season.

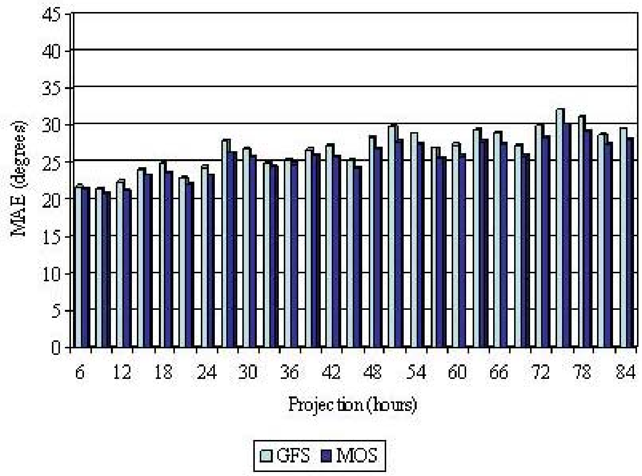

Figure 3. Same as Fig. 1, except for the MAE for wind direction forecasts.

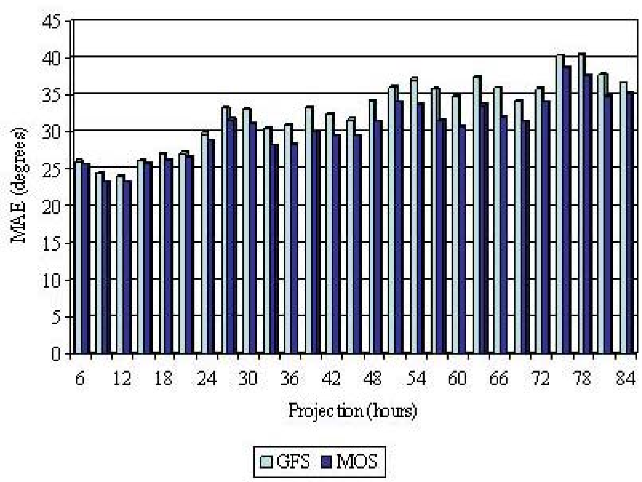

Figure 4. Same as Fig. 3, except for the monsoon season.

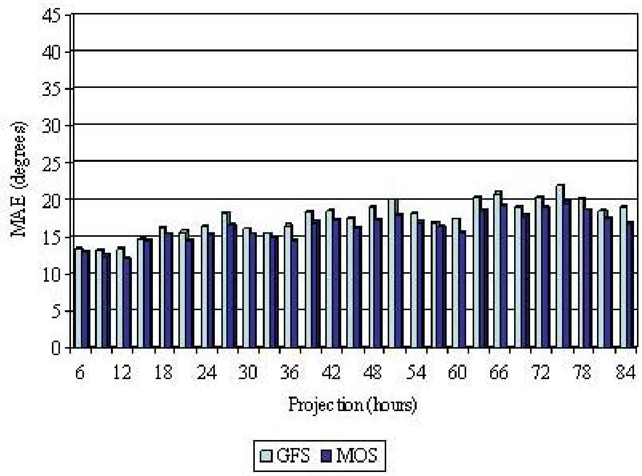

Figure 5. Mean absolute errors (MAE) in wind directions when observed wind speeds are greater than or equal to 10 kts, MOS versus GFS forecasts, dry season, 0000 UTC, for 15 stations.

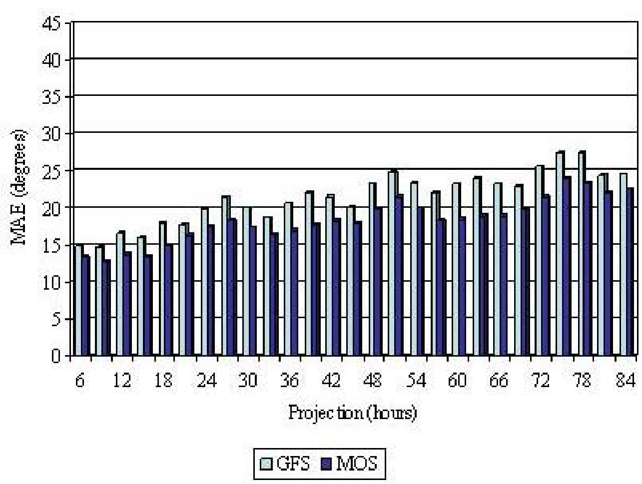

Figure 6. Same as Fig. 5, except for the monsoon season.

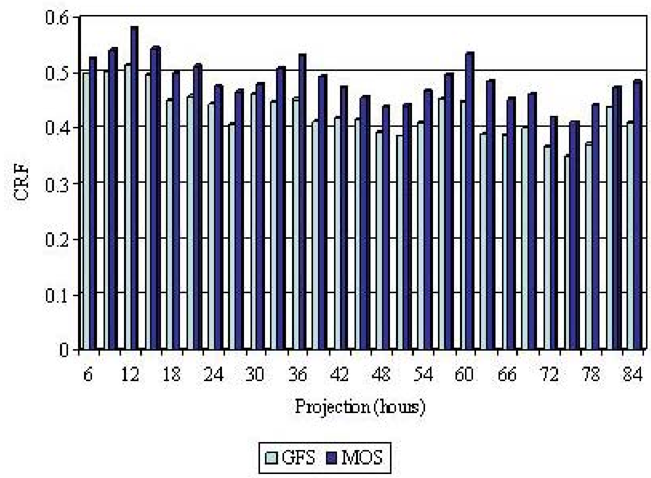

Figure 7. Cumulative relative frequencies (CRF) of wind direction forecast errors of less than or equal to 10 degrees when observed speeds are greater than or equal to 10 kts, MOS versus GFS forecasts, dry season, 0000 UTC, for 15 stations.

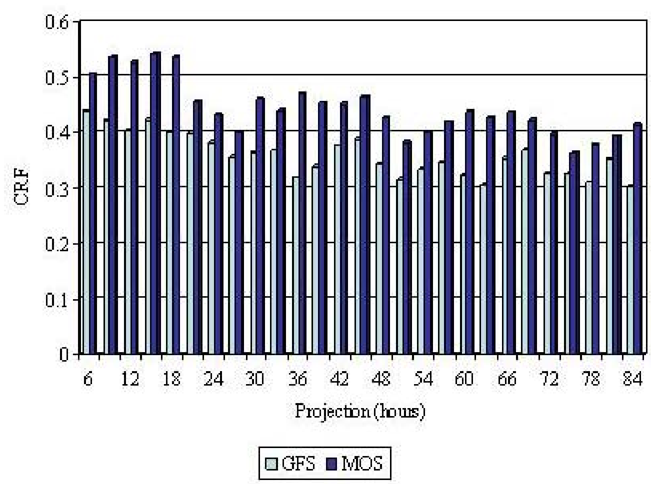

Figure 8. Same as Fig. 7, except for the monsoon season.