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

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1. INTRODUCTION

A new Global Forecast System (GFS)-based Model Output Statistics (MOS) wind forecast guidance package has been developed for island locations in the tropical western Pacific Ocean. The forecast equations used to generate the guidance are linear regression equations that relate the observed wind data at stations (predictands) to predictors, which include GFS 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 15 stations, including the one and only station in the Southern Hemisphere for which MOS guidance has ever been developed by the Meteorological Development Laboratory (MDL).

The MOS technique (Glahn and Lowry 1972), specifically, multiple linear regression with forward selection, is used in the development of the forecast equations for this guidance. Other MOS wind guidance packages for the contiguous United States (CONUS), Alaska, and Hawaii have been developed by the MDL staff; 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 article describes the development of forecast equations, post-processing procedures, operational products, and verification results.

2. DEVELOPMENT

2.1 *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, one of which is in the Southern Hemisphere, and 13 sites are in the Eastern Hemisphere. Table 1 lists these stations with their call letters and affiliations. The list of stations with their respective latitudes and longitudes can be found at URL: http://www.nws.noaa.gov/mdl/synop/stadrg.html

Table 1. Island stations in the tropical western Pacific Ocean for which GFS MOS wind guidance is provided.

CALL LETTER	STATION NAME	AFFILIATION
NSTU	Pago Pago	American Samoa
PGRO	Rota	Micronesia
PGSN	Saipan	Micronesia
PGUA	Andersen AFB,Guam	Micronesia
PGUM	Agana, Guam	Micronesia
PGWT	West Tinian	Micronesia
PKMR	Majuro Atoll, WSO	Micronesia
PKWA	Bucholz AFB	Marshall Islands
PMDY	Midway Islands, NAS	US Territory
PTKK	Truk	Micronesia
PTKR	Koror WSO, Palau	Micronesia
PTSA	Kosrae	Micronesia
PTTP	Pohnpei WSO	Micronesia
PTYA	Yap	Micronesia
PWAK	Wake Island	US Territory

2.2 *Predictands*

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

2.3 *Predictors*

Meteorological variables that could impact surface wind forecasts were used as potential predictors. In this development, potential predictors consisted of variables derived from GFS model output, observed wind speed

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and components, as well as 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 related to atmospheric stability were temperature difference between two isobaric levels and K index. In addition, mean relative humidity computed by integrating 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 GFS model output, a 25-point smoother was applied to the model data. The model gridpoint data were then interpolated to the locations of stations for which MOS wind forecast equations were developed.

Potential predictors derived from observed wind data were used only in the development of forecast equations for short-range projections. For 6-, 9-, and 12-h projections, observed wind speed and components from 0300 and 1500 UTC were used in the development of equations for the 0000 and 1200 UTC forecast cycles, respectively (primary equations). For corresponding projections, a set of equations that did not require observed data was also developed (secondary equations). For projections beyond 12 hours, only one set of equations which use no observed predictors was developed.

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

2.4 *Meteorological Data*

An archive system was established for the collection of GFS model data to be used in this development. A Mercator grid was designed to cover the area from 129.9° E to 149.7° W longitude and from 19.3° S to 32.7° N latitude. The GFS model output data were extracted and stored on this grid. Data for this development were available for April 2000 through September 2004, for 0000 and 1200 UTC cycles, and for projections from 0 to 84 hours at a 3-h increment. The MDL archives of observed hourly data provided 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: dry season (October through May) and monsoon season (June through September), and forecast equations were developed for each station and each season. The data for four dry seasons (2000-01, 2001-02, 2002-03, and 2003-04) and five monsoon seasons (2000 through 2004) were used in the development of final equations.

2.5 *Equation Characteristics*

Multiple linear regression equations were developed for wind components (u and v) and wind speed in such a way that same predictors were used in all three equations, but the equation coefficients for those predictors differed. Individual equations were developed for each station, season (monsoon or dry), cycle (0000 or 1200 UTC), and projection (06, 09, 12, …, 75, 78, 81, or 84 hours). Several limitations were imposed on the development of forecast equations. The maximum number of predictors to select was 12. The minimum number of cases (when both predictand and predictor data were available) required for an equation to be developed was 190. The necessary reduction of variance by a predictor was 0.5%, for the predictor to be added to the forecast equation. Some stations were part-time observing sites; thus, forecast equations for several projections could not be developed for these stations.

The selection of potential predictors by the screening regression procedure varied between seasons and forecast cycles. Observed wind components and speed were 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 included wind components and speed at 10-m height, and at various isobaric levels up to 500 mb. The 10-m wind components and speed were used frequently in the forecast equations for both seasons and cycles. Predictors at 925 mb and below were frequently used in the dry season equations, and those at all isobaric levels were frequently used in monsoon season equations. In addition, vertical velocity and mass divergence were used in equations more often for the monsoon season than for the dry season. Other GFS model output predictors included temperature difference between isobaric surfaces, the K index, and mean relative humidity. These predictors were used in the forecast equations more frequently during the monsoon season than during the dry season. In particular, the difference between seasons in the use of K index was notable. The mean relative humidity used in the forecast equations was 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 were more frequently used in the forecast equations for the dry season and the 0000 UTC cycle. More first harmonic functions were used in the dry season, and more second harmonic functions were 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 were required to ensure that the wind guidance was meteorologically and statistically sound. The wind speed directly computed from forecast equations tended to have few cases of high speed. To enhance the skill of wind speed forecasts for high winds, an “inflation” technique was applied to the wind speed (Schwartz and Carter 1985). The inflation process increased the magnitude of wind speeds above the developmental mean wind speed. This process also increased the variance of wind speed forecasts to approach that of the observed wind speeds. A verification study conducted by Dallavalle et al. (1979) indicated that the inflation technique increased the number of high wind speed forecasts with a small decrease in the overall accuracy of MOS wind forecasts.

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

4. OPERATIONAL PRODUCTS

The MOS guidance produced from the forecast equations is disseminated in two groups. The guidance for two stations located on the east side of the international dateline (NSTU and PMDY) was 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 was 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 became effective on April 19, 2005, and the new packages became operational on 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 through 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 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 (kts). Both wind direction and speed are denoted by 00 for calm wind.

When the real-time observed data for 0300 or 1500 UTC are available to produce wind guidance for 0000 or 1200 UTC, respectively, they 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 was done for the 0000 UTC cycle only. The MOS wind forecasts were compared to the GFS model output wind directions and speeds at the 10-m level. The overall performance of the forecasts for 15 island sites is discussed here.

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 about 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.

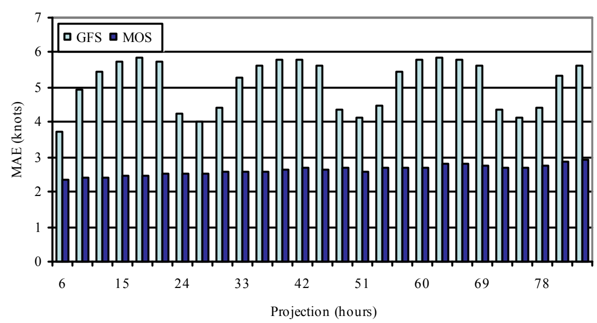

Figure 1. Comparison of overall mean absolute errors (MAE) in wind speed, MOS versus GFS forecasts, dry season, 0000 UTC, for 15 stations.

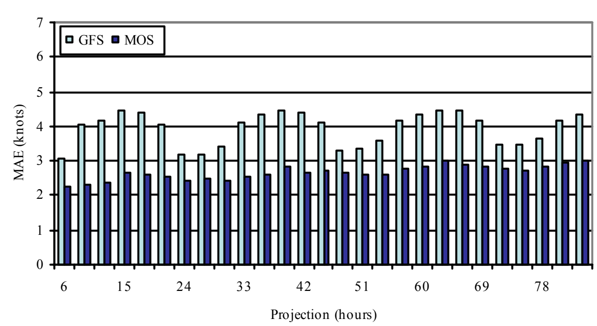

Figure 2. Same as Fig. 1, except for the monsoon season.

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

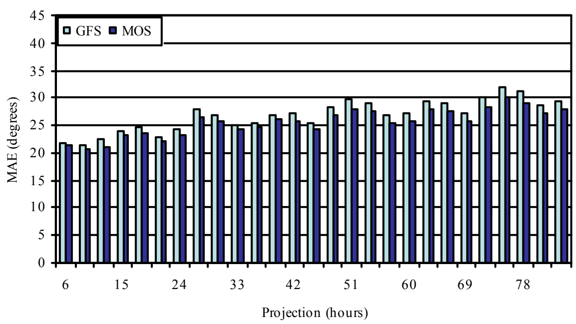

Figure 3. Same as Fig. 1, except for the MAE for wind direction forecasts.

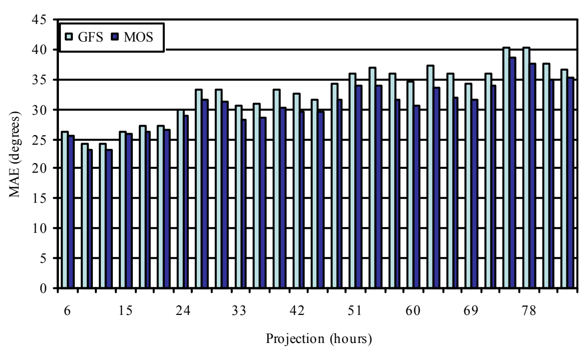

Figure 4. Same as Fig. 3, except for the monsoon season.

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° while those of GFS forecasts are between about 13° and 22°. For the monsoon season, the MAE of MOS forecasts range from about 13° to 24° while that of GFS forecasts range between 15° and 28°. 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.

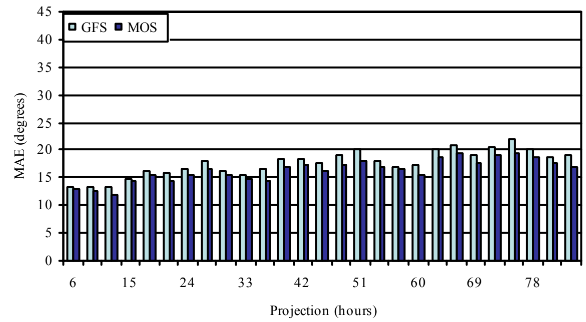

Figure 5. Comparison of mean absolute errors (MAE) in wind directions when observed wind speeds are greater than or equal to 10 kts, MOS versus GFS forecasts, dry season, 0000 UTC, for 15 stations.

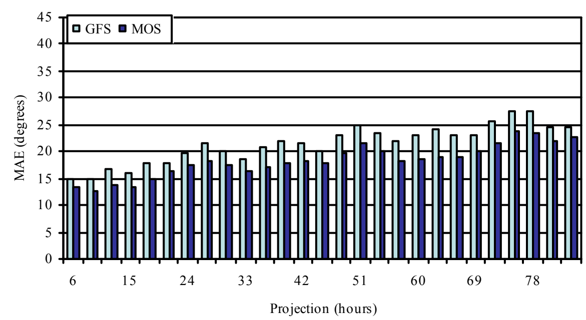

Figure 6. Same as Fig. 5, except for the monsoon season.

Figures 7 and 8 show the relative frequencies (RF) of wind direction forecast errors of less than or equal to 10°, for cases when observed wind speeds are greater than or equal to 10 kts. For the dry season, the RF of MOS are between about 0.41 and 0.58 while those of GFS are between 0.35 and 0.51. For the monsoon season, the RF of MOS are between about 0.36 and 0.54 while those of GFS are between 0.30 and 0.44. The RF decrease with increasing projection; the decrease is more rapid for the monsoon season. These graphs also show that the RF of MOS are greater than those 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 those of GFS for strong winds.

Based on this investigation, the MOS wind speed forecasts are more accurate than the GFS direct model output. 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 can not be developed for the station. This is the case for three island sites in the tropical western Pacific Ocean (PGRO, PGWT and PTSA), for which equations for many projections are missing.

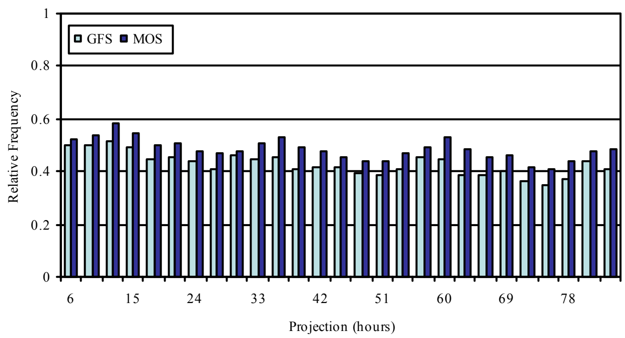

Figure 7. Comparison of overall relative frequencies (RF) of wind direction forecast MAE, when observed speeds are greater than or equal to 10 kts and direction errors are less than or equal to 10°, MOS versus GFS forecasts, dry season, 0000 UTC, for 15 stations.

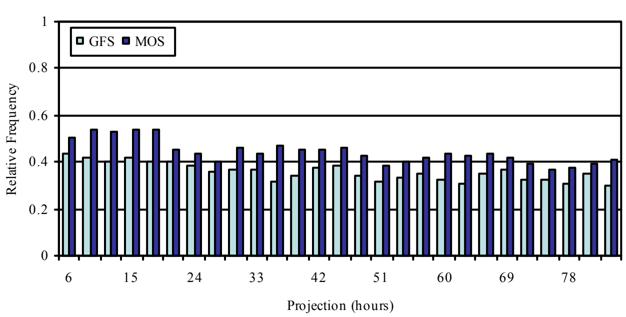

Figure 8. Same as Fig. 7, except for the monsoon season.

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 2.5, the forecaster should correct the MOS forecasts 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.

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