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# GFS-BASED MOS WIND GUST GUIDANCE FOR THE UNITED STATES, PUERTO RICO, AND THE U.S. VIRGIN ISLANDS

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## 1. INTRODUCTION

The National Weather Service has recently decided to include wind gust forecasts on an experimental basis in the National Digital Forecast Database (NDFD) (Glahn and Ruth 2003). To provide guidance for wind gusts, the Meteorological Development Laboratory (MDL) has developed a station-based Model Output Statistics (MOS) wind gust guidance product utilizing the National Centers for Environmental Prediction's (NCEP) Global Forecast System (GFS) Model (Kanamitsu 1989). The station-based MOS guidance will then be processed and analyzed onto the NDFD 5-km grid (Glahn and Dallavalle 2005).

MOS regression equations were developed for approximately 1,800 stations in the continental United States, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Buoys as well as Coastal-Marine Automated Network (C-MAN) sites were also included in the development. Equations were developed for all four cycles (0000, 0600, 1200, and 1800 UTC) off the GFS. For the 0000 and 1200 UTC forecast cycles, MOS guidance is generated for projections valid every 3 hours from 6 to 192 hours after initial model time. For the 0600 and 1800 UTC cycles, guidance is valid for projections of 6 to 84 hours in advance.

## 2. DEVELOPMENT

### a. Predictand Definition

Two predictands were defined in developing the GFS MOS wind gust equations. The first predictand was a binary value indicating whether or not a 10-m wind gust of 14 knots or greater was observed at the hour. A gust event was set to a value of one. All observed wind gusts less than 14 knots and all non-gust events were set to a value of zero indicating a non-gust event. Using 14 knots as the threshold for a gust event was decided upon after performing a detailed analysis of the observed wind gust data in which we noticed that a vast majority of the observed wind gusts was greater than or equal to 14 knots. This type of stratification yielded a more consistent definition of a gust event that was adhered to throughout the developmental process. This predictand definition was also used in the decision-making process of generating a wind gust forecast (see Section 4).

The second predictand was defined as the observed 10-m wind gust speed in knots reported at the hour. To maintain consistency with the strict definition of an observed wind gust given above, all wind gust observations below 14 knots and all non-gust observations were set to a value of 9999., indicating a non-gust event which would not be included in the development of prediction equations for the second predictand. In other words, the second predictand in the wind gust system is the wind gust speed, conditional upon the occurrence of a wind gust of 14 knots or greater. In this manner, categorical forecasts (1=Yes, 0=No) obtained by using the forecast equations for the first predictand could then be used in the decision process of issuing a wind gust forecast (see Section 4).

### b. Predictors

The majority of predictors used in this MOS wind gust development were identical to those used in the GFS MOS wind speed and wind direction development (Sfanos 2001). To refresh the reader, some of those predictors included the model u- and v-wind components and the model wind speeds at the 10-m, 925-mb, 850-mb, 700-mb, and 500-mb levels. Relative vorticity and relative humidity were also used as predictors. Wind speed observations in the early projections (6- to15-h projections) were also offered to the regression program. Climatic predictors such as the first and second harmonics of the day were included to account for the seasonal variation of wind gusts throughout each 6-month season (see Section 2c).

Aside from the standard set of predictors used in the MOS wind speed development, four additional predictors were also used. These predictors included: (1) the wind gust speed observed 3 hours after initial model time, (2) the difference between the GFS 850-mb temperature forecast valid at a specific projection time and 12 hours later, (3) an empirically derived predictor that describes the mixing potential in the planetary boundary layer (PBL), and (4) the ratio between the 925-mb and the 10-m model wind speeds. The rationale behind this last predictor is that large momentum values (i.e., large 925-mb wind speeds) found in the PBL (as indicated by large ratios) may mix down to the surface in favorable thermodynamic environments.

The most frequently chosen type of predictors (for both predictands) varied as a function of projection. In general, the wind gust observations along with the 10-m, 925-mb, and 850-mb model wind speeds were the most favored predictors in the 6-15 h projections. The continuous wind gust predictand heavily relied upon the model wind speeds and relative vorticity as predictors for all forecast projections. For the binary wind gust predictand, the first and second harmonics of the day were chosen quite frequently as predictors from approximately the 114-h through the 192-h projection. These results were generally true for all cycles and both seasons.

### c. Seasons

The developmental data sample consisted of data archived from the GFS model from April 2002 through September 2005. The data were stratified into two, 6-month seasons: cool (October-March) and warm (April-September). Consequently, the warm season equations were comprised of a 4-year sample while the cool season equations were comprised of a 3-year sample. To mitigate possible forecast fluctuations at the time when seasonal equations are switched, data for a 2-week overlap between the beginning and end of each season were included in the developmental sample.

### d. Stations

To address the spatial variability of wind gust events, a non-conventional MOS approach was employed in the development of continuous wind gust equations. Early testing indicated that a wind gust system based on single-station equations was superior to a wind gust system dependent on regionalized equations. However, depending upon projection time, the number of cases available to develop the equations for any single-station varied considerably. This resulted in a station having an equation at some projections but not at others. To solve this problem, both single-station and regionalized equations were developed (where possible) for all stations. The rationale behind this approach is as follows: If the regression program was unable to generate an equation for any of the stations found in the single-station list, an equation for that station would then be generated from the regionalized station list**.** (see Section e).

Most MOS products that are generated through regionalized equations have the same general geographic borders. Consequently, creating new regions for wind gusts would have added little to the wind gust forecast system. As such, we used the same regions used in the cool season development of the GFS MOS probability of precipitation occurrence and applied them to the wind gust development. The regions used for both the cool and warm season wind gust developments were not altered because the underlying meteorology associated with wind gusts does not vary seasonally.

**e. Equation Development**

Primary equations for each predictand were developed at 3-h intervals from 6 to 192 hours after 0000 and 1200 UTC initial time and 6 to 84 hours after 0600 and 1800 UTC initial time. GFS model values, climatic data, and observations were used as predictors in the regression development. The observational predictors were restricted to the 6-, 9-, 12-, and 15-h projections because the effects of persistence were negligible by the 18-h projection. Secondary equations (i.e., equations containing no observational predictors) were also developed for the 6-15 h projections to accommodate those instances when observations are not available in the operational environment.

The maximum number of possible predictors used in the regression equation for the “binary” predictand of gust or no gust was restricted to nine. An equation was generated when at least 200 cases were present in the developmental sample. Similarly, an equation containing a maximum number of 5 predictors was developed for the predictand of wind gust speed when at least 50 wind gust cases were present. The number of possible predictors for the latter predictand was halved in order to prevent over-fitting of the dependent data which could yield an unrealistic forecast on independent data. As noted above, if the minimum number of cases was not available for a particular station (for either predictand), the resulting equation for that station was regionalized, not single-station.

**f. Threshold Development**

The probabilistic forecast values of gust/no gust from the equations (applied to independent data) were used in generating single-station threshold values of gust/no gust events. We found that station-based threshold values as opposed to regionalized based thresholds provided better skill in determining wind gust events. The threshold values were generated by maximizing the threat score within the bias range of .80 - 1.20. These threshold values were generated for each 3-h projection and each station.

## 3. GENERATING FORECASTS

When generating MOS wind forecasts, the forecast values are "inflated." Inflation is one way to alter the distribution of forecasts as to increase the frequency of the extremes of the forecast distribution. According to Glahn et al. (1991), inflation allows the system to generate wind speed forecast values that may considerably deviate from the mean of the predictand. Recently, we found that by restricting the inflation process to the wind speed forecast values exceeding or equaling the mean of the predictand, higher wind speed forecasts were improved without degrading the forecasts of lower wind speeds. This desirable result was applied to the MOS wind gust forecast system as well. In short, wind gust forecasts that were greater than the mean of the development predictand were increased, while those less than the mean were unchanged. This method preserved the lower wind gust values by not permitting them to drop below 14 knots while inflating the higher wind gust speeds. The probabilistic forecasts of gust/no gust were generated in their usual manner without any manipulation.

## 4. POST-PROCESSING FORECASTS

After the probabilistic forecasts of gust/no gust were massaged to restrict values within the range of 0-1, inclusively, a wind gust forecast could now be generated. What follows is the rationale and the steps taken in making a wind gust forecast: At an ASOS observing site, a wind gust is not reported if the gust speed is less than 3 knots greater than the reported wind speed (National Weather Service 1998). Consequently, we decided that if the difference between the MOS wind speed and MOS wind gust forecast is less than three knots (despite the fact that the binary wind gust predictand indicates that a gust will occur), a wind gust forecast will not be generated. If the forecast difference exceeds 3 knots, the wind gust speed forecast value is accepted. When a wind gust is forecast to occur, its associated wind gust forecast speed (provided it is less than or equal to 40 knots) is quality checked so it never exceeds a value 2.5 times greater than the forecasted MOS wind speed. Similarly, all wind gust forecasts greater than 40 knots are quality checked to ensure that the gust speed never exceeds a value 2.0 times greater than the MOS wind forecast. If a wind gust forecast exceeds its respective maximum tolerance value, it is truncated to its maximum tolerance value. These tolerance values were empirically derived from an analysis of the observed wind gust data as a function of the observed wind speed. MOS gust speed forecasts also have to be 14 knots or greater. Finally, it should be noted that MOS wind gust forecasts are only produced for stations that have MOS wind speed forecasts.

## 5. FORECAST VERIFICATION

The 0000 UTC MOS wind gust forecasts were verified for 1797 stations during October 2005-January 2006. Since a crucial portion in the decision-making process of generating a wind gust forecast involves the forecasting of a gust/no gust event, it is especially important to demonstrate accuracy with this predictand. Figure 1 shows the threat score of a gust/no gust event for projections of 6 through 192 hours. Two features are evident from this graph: (1) the diurnal trend of wind gust behavior, and (2) the overall forecast accuracy of the system from the 6-h projection to approximately the 138-h projection, where the maximum threat score during a 24-h period never drops below 0.23. It is interesting to note that the peak values along the threat score curve for the first three diurnal cycles (days) exceed values of 0.43.

Plotting the probability of detection (POD) and the false alarm ratio (FAR) is another way to evaluate the accuracy of the system. Figure 2 shows such a plot for the 6-h through the 192-h projections. The POD curve remains above the FAR curve through the 72-h projection, once again attesting to the robustness of the system.

Figure 3 shows the Heidke skill score for predicting a wind gust of a specific gust intensity. The gust speed intensity was parsed into categories that are aligned with the National Weather Service's verification program (STATS on Demand) binning of wind gust Terminal Aerodrome Forecasts (Table 1). Once again, the diurnal cycle is evident from the forecast skill values shown in the plot (e.g, 0.42 at 18-h and 0.27 at 90-h). Although the Heidke skill score is highly dependent on those forecasts where a no gust event was predicted (yielding a gust value of zero), the values on the diagonals of the contingency tables (not shown), indicate that this system has skill in forecasting wind gust intensities across most categories.

While the verification scores of wind gust intensities (Fig. 3) indicate skill to 192 hours, it is evident that the forecast of a wind gust occurrence and its intensity beyond 4 or 5 days is not very good. This is primarily due to the ineffectiveness of the GFS model in predicting the wind at later projections and, to a lesser extent, to not utilizing MOS predictors in a more effective manner (e.g., performing non-linear transformations). While the first issue cannot be easily resolved, we will address the second issue in future developments.

Figure 4 shows the threat score for wind gust forecasts exceeding 37 knots. The forecast accuracy tends to decline rather quickly but maintains score values above 0.20 to the 48-h projection. As one might expect, capturing the rare wind gust above 37 knots beyond the 48-h projection posses quite a challenge.

Table 1. Wind gust category as a function of wind gust intensity.

| Category Number | Wind Gust Speed Range (Knots) |
|---|---|
| 1 (No gust) | 0 – 13 |
| 2 | 14 - 17 |
| 3 | 18 - 22 |
| 4 | 23 – 27 |
| 5 | 28 - 32 |
| 6 | 33 - 37 |
| 7 | 38 - 42 |
| 8 | 43 - 47 |
| 9 | $\geq$ 48 |

## 6. OPERATIONAL PRODUCTS

The MOS wind gust guidance will be used in generating gridded MOS wind gust forecasts at a 5-km resolution over the United States, Puerto Rico, and the U.S. Virgin Islands. This product will be disseminated in GRIB2 to all interested users and will be graphically displayed on the NDFD web site. Plans for the dissemination of the gust guidance in alphanumeric (Dallavalle and Cosgrove 2005a, 2005b; Cosgrove and Dallavalle 2005) or Binary Universal Format for the Representation of meteorological data (BUFR) products are not yet finalized.

## 7. OPERATIONAL CONSIDERATIONS

The forecaster must be aware of the limitations within the MOS system, namely, that the MOS product cannot correct for incorrect GFS model forecasts and/or all systematic GFS model biases. Forecasters also need to understand that although MOS forecasts are quite good, the MOS package is still a guidance product and may not always be accurate. Care must be taken during the forecasting process to evaluate both the recent (or historical) performance of the GFS and GFS MOS in specific synoptic situations. Also, it is important to be mindful that wind gusts are not always synoptically induced. Mesoscale phenomena such as lake breezes and the eroding of an inversion layer in the PBL may also cause wind gusts. Such phenomena are not forecasted by the GFS model and GFS MOS very well. Consequently, the forecaster should not solely rely on the MOS guidance product when generating wind gust forecasts. The forecaster must also recognize that a station's local climatology is a vital component in creating reliable forecasts.

## 8. REFERENCES

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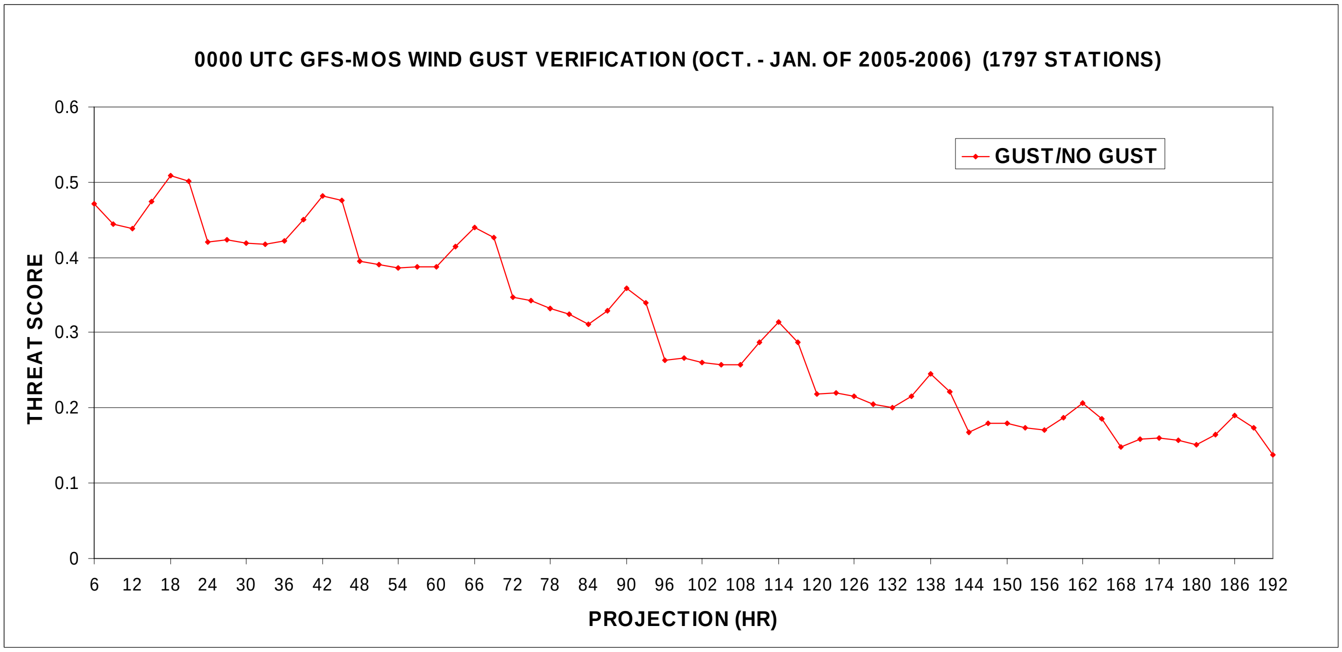


**Figure 1. Threat scores verifying a wind gust event using 1797 stations for the months of October-January during the 2005-2006 cool season.**

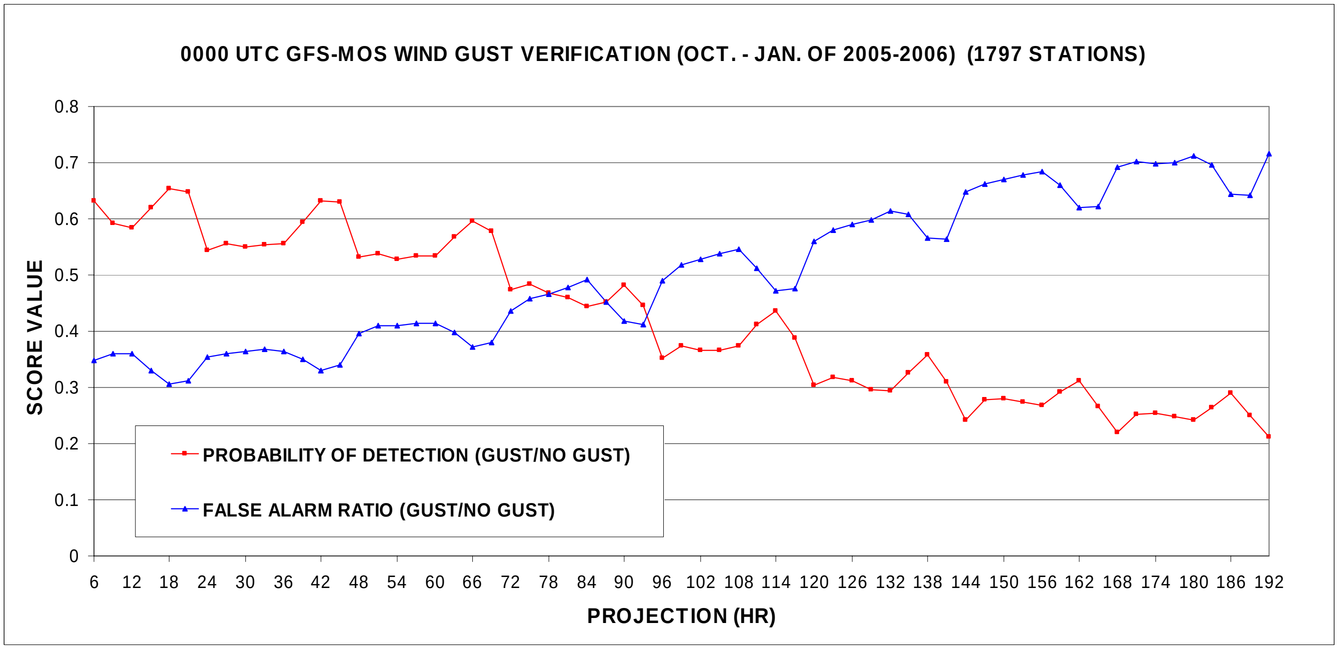


**Figure 2. The comparison of the probability of detection versus the false alarm ratio in detecting a wind gust event using 1797 stations for the months of October-January during the 2005-2006 cool season.**

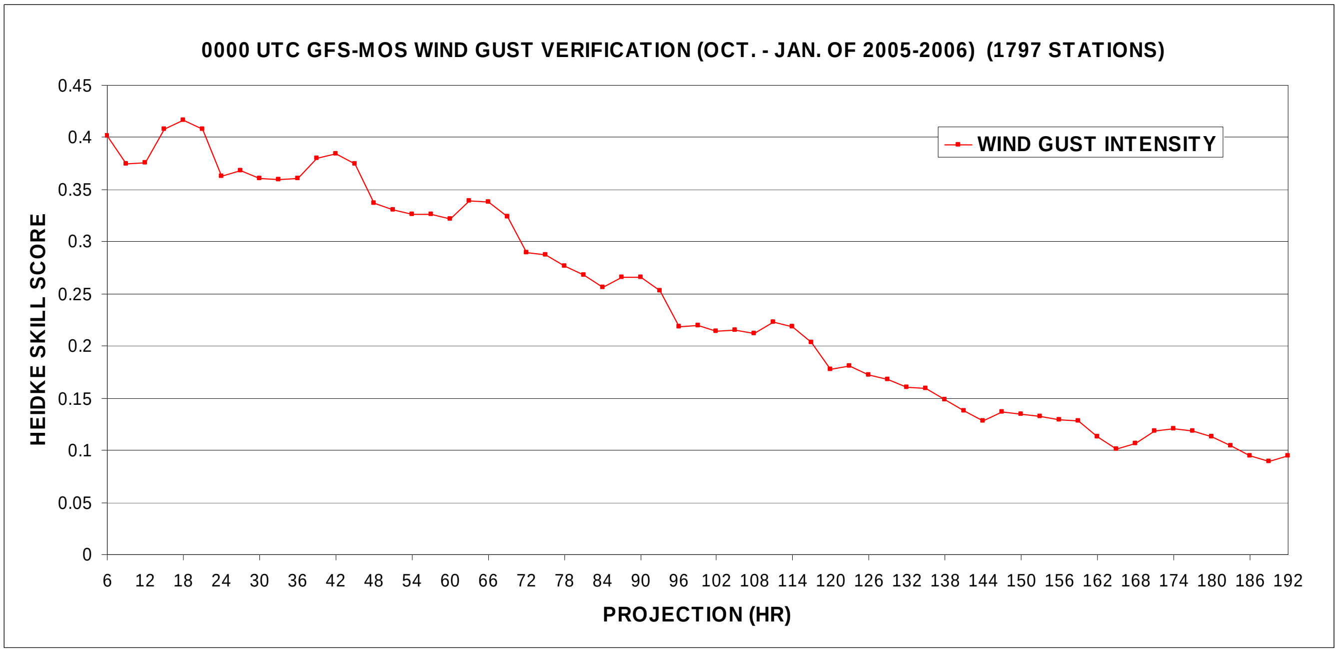


**Figure 3. The Heidke skill score for detecting specific categories of wind gust intensities (as outlined in Table 1) using 1797 stations for the months of October-January during the 2005-2006 cool season.**

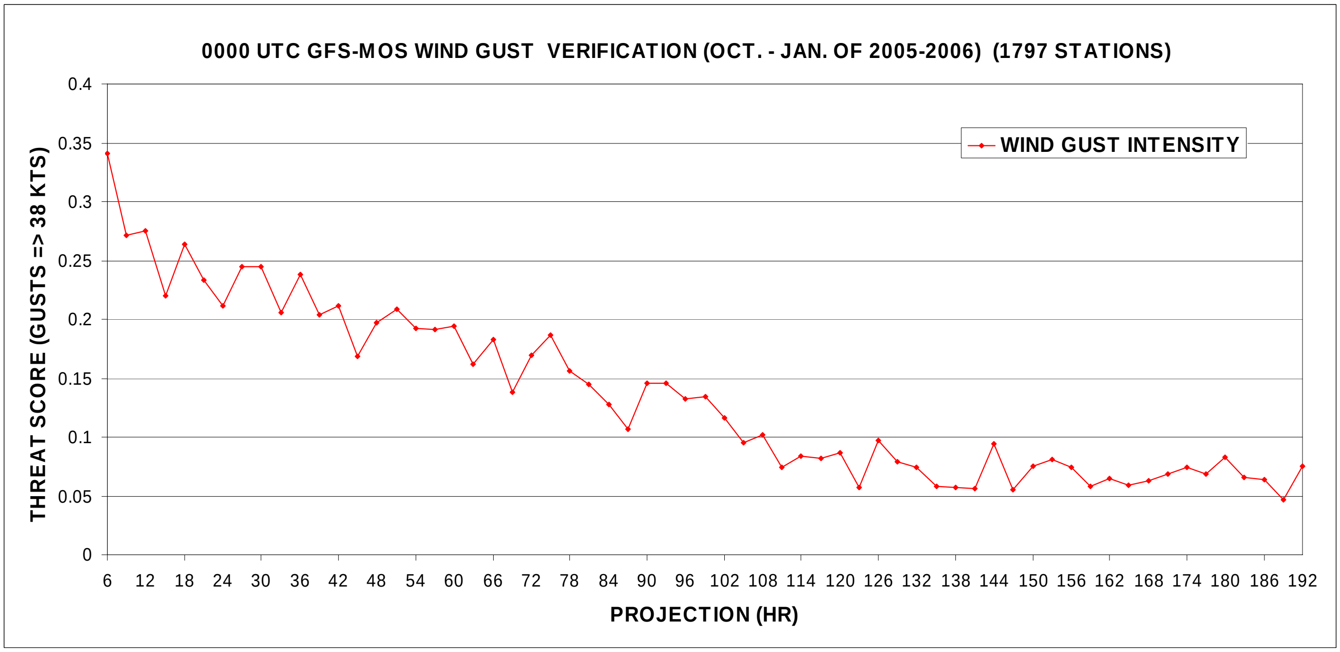


**Figure 4. The Threat score of a wind gust above 37 knots using 1797 stations for the months of October-January during the 2005-2006 cool season.**