P2.8 FORECASTING COOL SEASON DAILY PEAK WINDS AT KENNEDY SPACE CENTER (KSC) AND CAPE CANAVERAL AIR FORCE STATION (CCAFS)

Joe H. Barrett III* and David A. Short
NASA Applied Meteorology Unit / ENSCO, Inc. / Cape Canaveral Air Force Station, Florida

William Roeder
45th Weather Squadron, Patrick Air Force Base, Florida

1. INTRODUCTION

The 45th Weather Squadron (45 WS) provides comprehensive weather support to America's space program at KSC/CCAFS (Harms et al. 1999). Part of this support includes daily 24-Hour and Weekly Planning Forecasts, which are used for planning operations at KSC/CCAFS. The 24-Hour Forecast is valid from 8:00 am to 8:00 am the next day in local time, and it is broken into six 4-hour time blocks. The Weekly Forecast is for the next 6 days starting with the next day and is broken into 12-hour time blocks. One of the elements in the planning forecasts is the expected peak wind speed for the day. Forecasting this element has proven challenging during the cool season months at KSC/CCAFS (October-April).

To improve their peak wind forecasting capability, the 45 WS tasked the Applied Meteorology Unit (AMU) (Bauman et al. 2004) to develop a tool to forecast the speed and timing of the daily peak and its associated average wind occurring between the surface and 300 ft on KSC/CCAFS during the cool season. The tool uses data available by 1200 UTC to meet the deadlines for issuing the Planning Forecasts. Because the 45 WS issues wind warnings for wind gusts ≥ 35 kt, ≥ 50 kt, and ≥ 60 kt, the AMU tool also provides the probability that the expected peak speed will meet each of these warning thresholds.

2. DATA

Weather observations were collected for the cool season months from October 2002 to February 2007. The data sources included:

- 5-minute average and peak wind observations from the KSC/CCAFS tower network to be used as predictors and predictands,
- Hourly and special observations from the Shuttle Landing Facility (SLF) to verify the occurrence of precipitation at or near the SLF, and
- CCAFS morning upper-air soundings to determine wind speeds at different levels and the existence of temperature inversions.

Table 1 shows the sensor levels at each tower used in this task, and Figure 1 shows the location of the towers in the KSC/CCAFS area.

Table 1

Wind levels for each tower used in the task.

Tower #	Tower Wind Levels (ft)	Tower #	Tower Wind Levels (ft)	Tower #	Tower Wind Levels (ft)	Tower #	Tower Wind Levels (ft)
0001	12, 54	0108	12, 54	0397	60	0511	30
0002	12, 54, 90, 145, 204	0110	12, 54, 162, 204	0398	60	0512	30
0003	12, 54	0211	12, 54	0403	12, 54	0513	30
0006	12, 54, 162, 204	0300	54	0412	12, 54	0714	12, 54
0019	54	0303	12, 54	0415	12, 54	0803	12, 54
0022	54	0311	12, 54	0418	54	0805	12, 54
0036	90	0313	12, 54, 162, 204, 295	0421	54		
0040	54	0393	60	0506	12, 54		
0041	230	0394	60	0509	12, 54		

* *Corresponding author address:* Joe H. Barrett III, ENSCO, Inc., 1980 North Atlantic Ave, Suite 230, Cocoa Beach, FL 32931; e-mail: barrett.joe@ensco.com

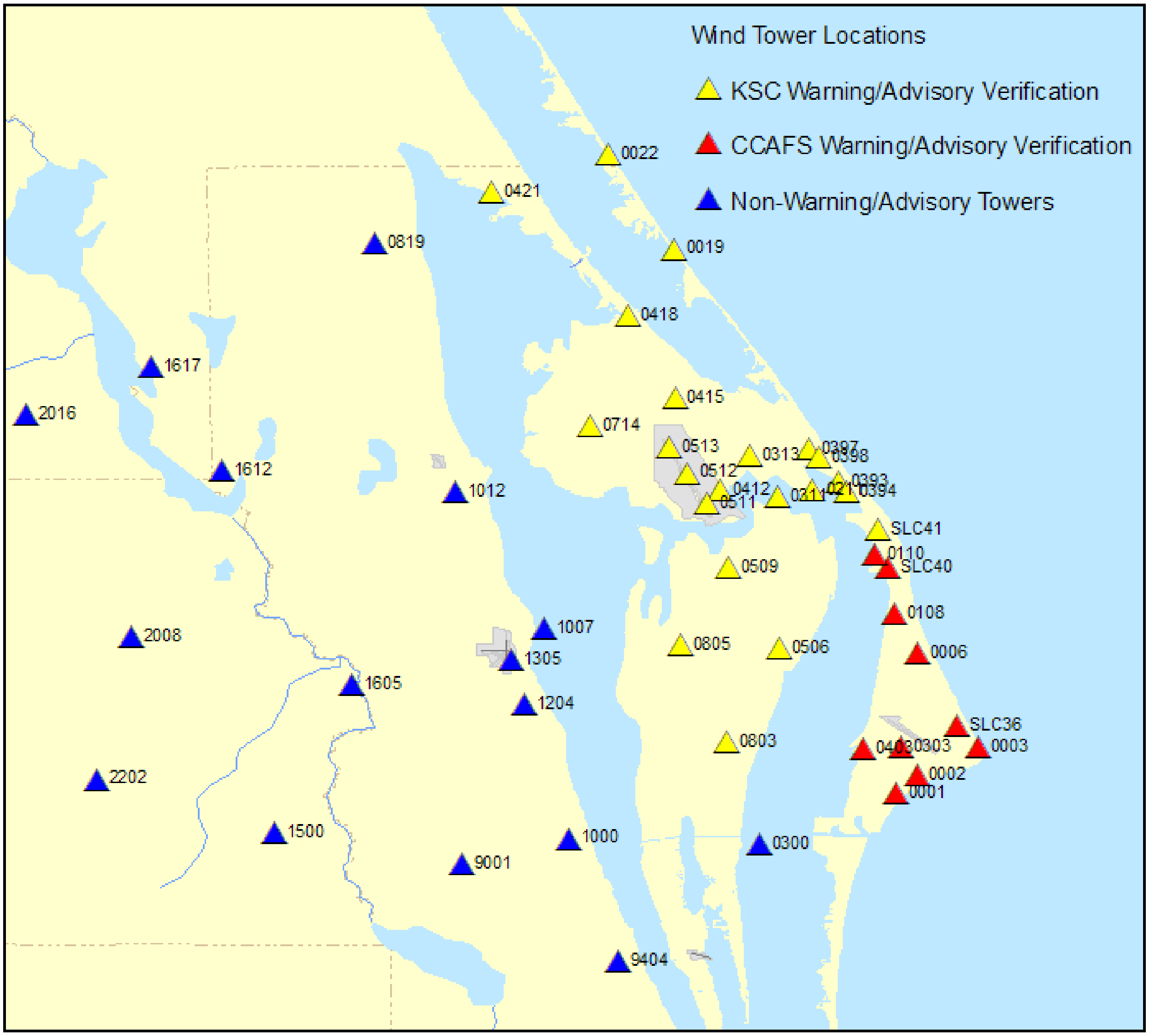

Figure 1. A map of the KSC/CCAFS area showing the locations of the towers in the network. The towers used in the task for verifying wind warnings and advisories on KSC are shown in yellow and for CCAFS are shown in red. One other tower used is just south of the southern end of KSC, Tower 0300.

3. PEAK WIND SPEED OF THE DAY

The following candidate predictors were evaluated to predict the daily peak wind speed:

- Strongest wind in the lowest 3000, 4000, and 5000 ft,
- Persistence,
- Inversion depth and strength, and
- The wind speed at the top of the surface-based temperature inversion.

If no inversion was observed in the sounding, the surface wind was used for the wind speed at the top of the inversion and the inversion depth and strength were set to 0. Figures 2-6 show scatter plots for persistence, strongest wind in the lowest 5000, 4000, and 3000 ft, and the surface wind at the top of the inversion.

The multiple linear regression equation that combined the strongest wind in the lowest 3000 ft with the inversion depth and strength showed the lowest mean absolute error and highest R^2 (coefficient of determination) values, therefore showing the greatest skill. The strongest wind in the lowest 3000 ft showed the best skill as a single predictor, followed closely by the strongest wind in the 4000 ft and 5000 ft. Figure 7 is a bar graph comparing the mean absolute error from several regression equations. In regards to mean absolute error, the worst predictors were persistence and the wind speed at the top of the inversion. The differences in mean absolute error were small among the strongest wind in the lowest 3000, 4000, and 5000 ft predictors.

A second prediction equation was created by stratifying each day into one of four categories, based on the existence or non-existence of a temperature inversion and the occurrence or non-occurrence of precipitation at the SLF. A temperature inversion was defined as an increase in temperature from the surface to 500 ft, in order to ignore very shallow and weak inversions that often occur in the morning sounding.

Figures 8 and 9 show vertical profiles of wind speed and temperature for the four categories. The lightest winds occurred on days with an inversion and no precipitation. On days with an inversion, wind speeds tended to increase rapidly from the surface to around 500 ft, increase slowly between 500 ft and 1500 ft, and then remain nearly steady above 1500 ft. On days without an inversion, winds tended to increase rapidly from the surface to around 1000 ft, increase slowly between 1000 ft and 2000 ft, and then remain steady or decrease slowly above 2000 ft. Days with no inversion and no precipitation had the coolest temperature aloft, which indicates the possibility of post-frontal cold-air advection. Days with precipitation had the warmest temperatures. On days with an inversion, the top of the inversion tended to occur around 500 ft.

Figures 10-13 show scatter plots of the strongest wind in the lowest 3000 ft for each category. The category with an inversion and no precipitation shows the least amount of scatter across the linear regression line, indicating the best linear relationship between observed peak wind speed and strongest wind speed in the lowest 3000 ft, among the four categories.

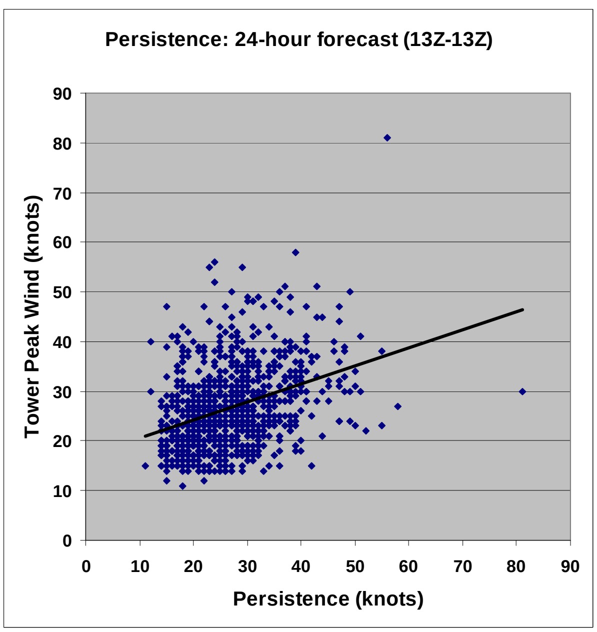

Figure 2. Observed peak wind speed versus persistence.

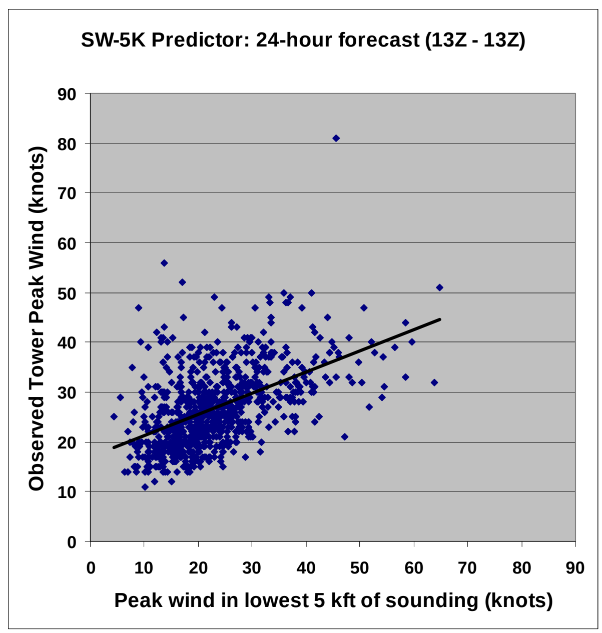

Figure 3. Observed peak wind speed versus strongest wind in the lowest 5000 ft.

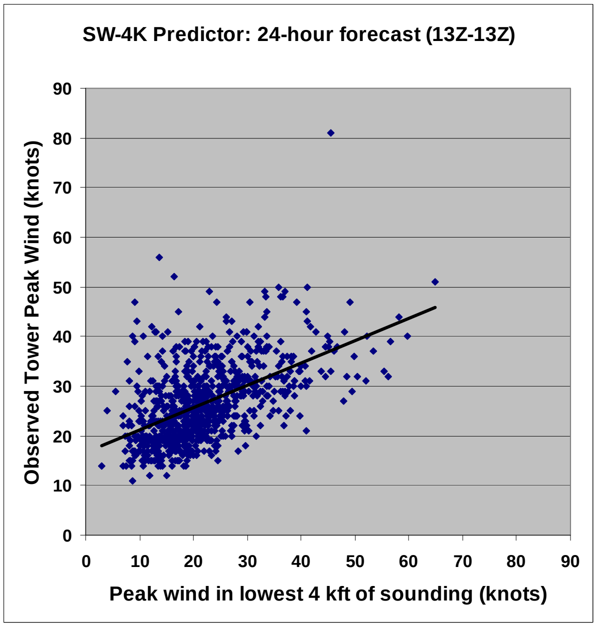

Figure 4. Observed peak wind speed versus strongest wind in the lowest 4000 ft.

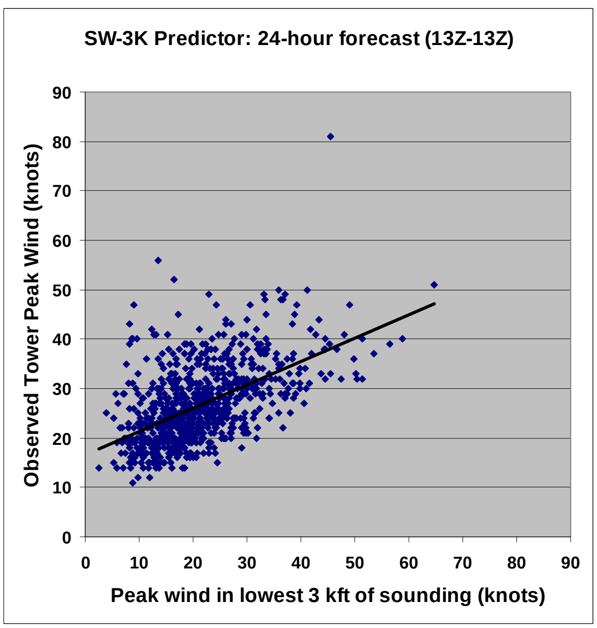

Figure 5. Observed peak wind speed versus strongest wind in the lowest 3000 ft.

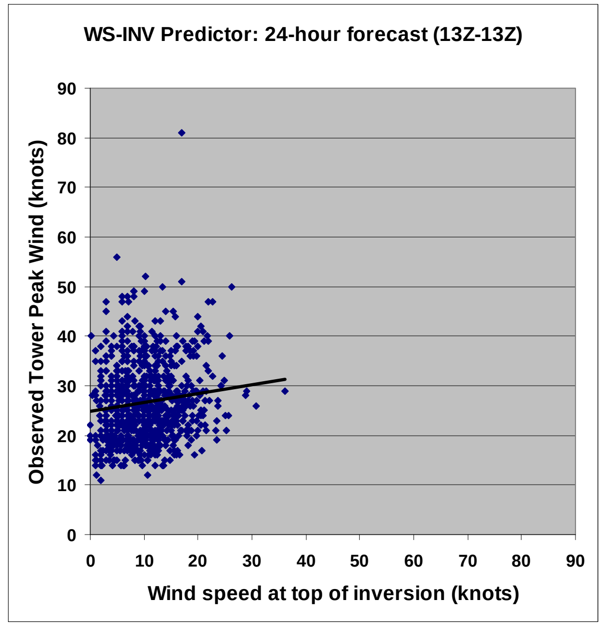

Figure 6. Observed peak wind speed versus wind speed at the top of the inversion.

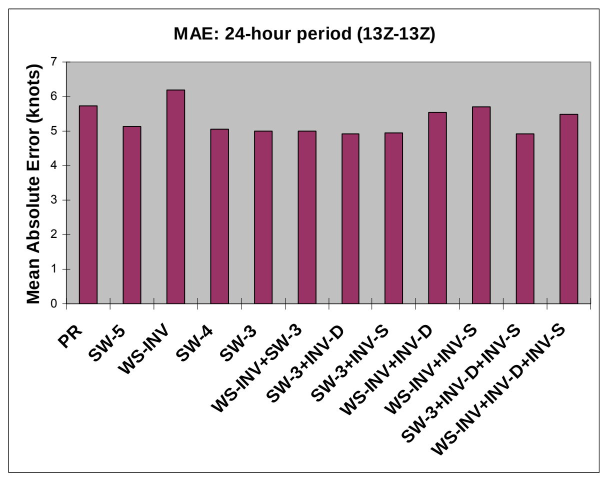

Figure 7. Mean absolute error from several regression equations to predict the daily peak wind speed. PR is persistence, SW-5 to SW-3 is the strongest wind in the lowest 5000 ft to 3000 ft, WS-INV is the wind speed at the top of the inversion, INV-D is inversion depth (in ft), and INV-S is inversion strength (in degrees Celsius).

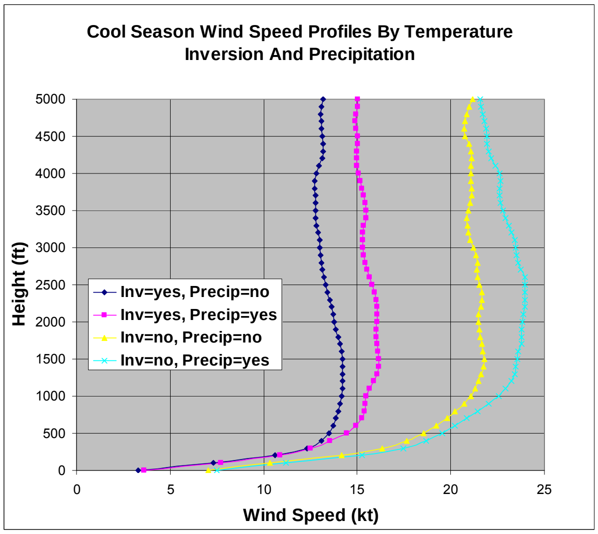

Figure 8. Observed wind profiles of speed for the four inversion/precipitation categories.

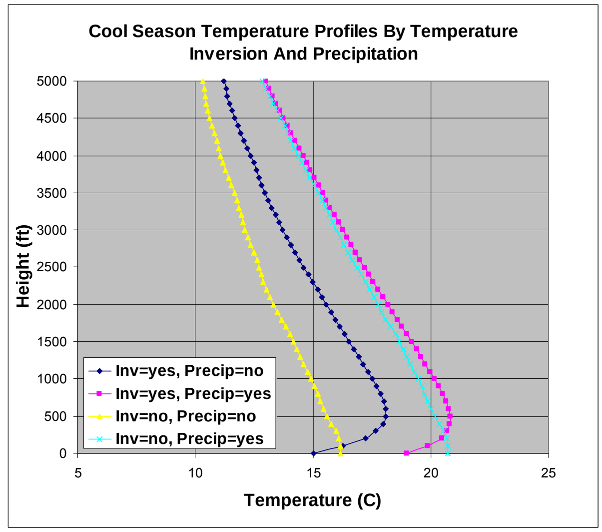

Figure 9. Observed temperature profiles for the four inversion/precipitation categories.

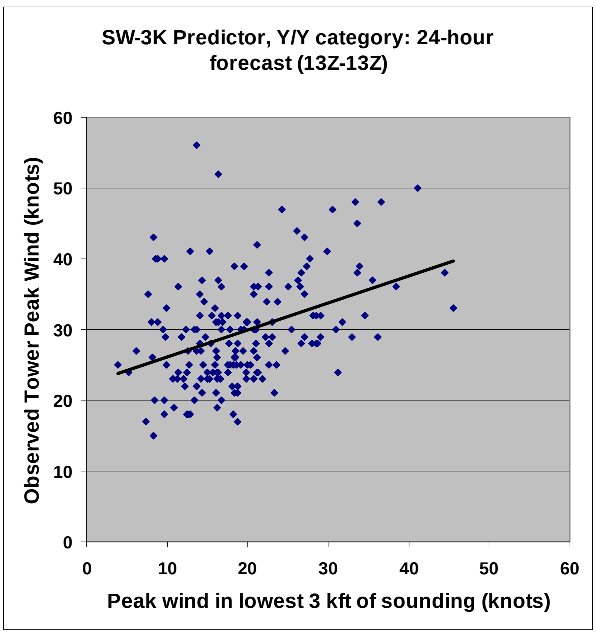

Figure 10. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when both an inversion and precipitation are observed.

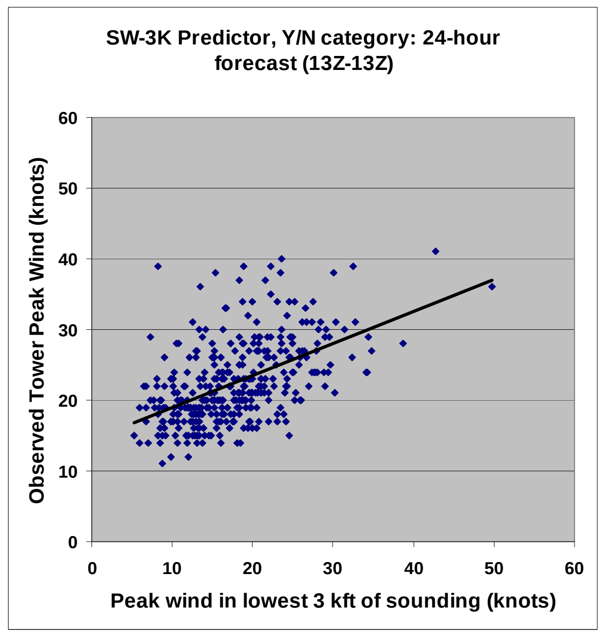

Figure 11. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when an inversion and no precipitation are observed.

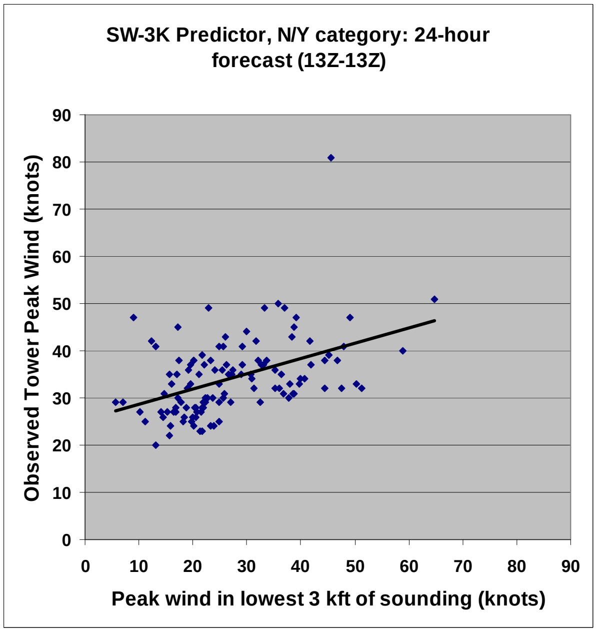

Figure 12. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when precipitation and no inversion are observed.

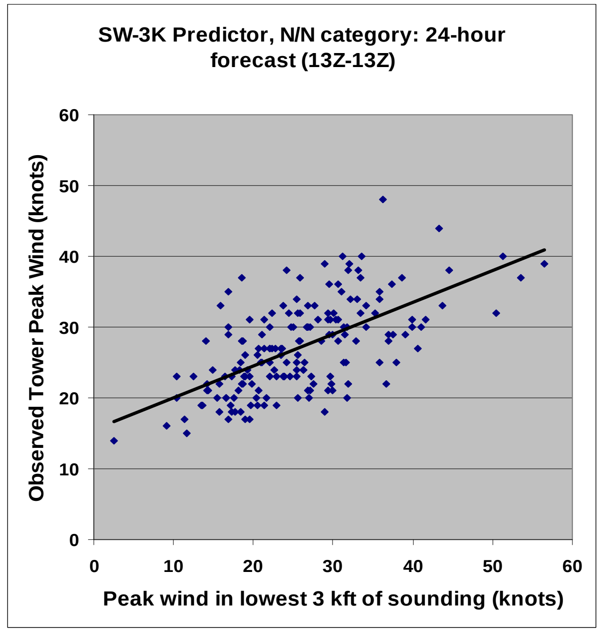

Figure 13. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when no inversion and no precipitation are observed.

A third prediction equation was created by stratifying each day into one of six categories, based on the synoptic weather pattern at 1200 UTC (category name in parentheses):

- Surface high pressure over or near Florida with variable winds across central Florida (P1),
- Surface high pressure north or east of Florida with east winds across central Florida (P2),
- Surface high pressure south or west of Florida with west winds across central Florida (P3),
- Front approaching Florida from the north (P4),
- Front across central Florida (P5), and
- Front to the south of central Florida (P5).

Figures 14 and 15 show vertical profiles of wind speed and temperature for the six categories. Wind speeds aloft are similar for days with surface fronts approaching or across Florida. Winds are weakest aloft when surface high pressure is over or near Florida. Each weather pattern contains a surface-based temperature inversion, although the inversion is strongest when surface high pressure is across Florida.

Figures 16-21 show scatter plots of the strongest wind in the lowest 3000 ft for each category. The best linear relationship between observed peak wind speed and strongest wind in the lowest 3000 ft occurs when surface high pressure is north or east of Florida. The worst linear relationship occurs when surface high pressure is south or west of Florida.

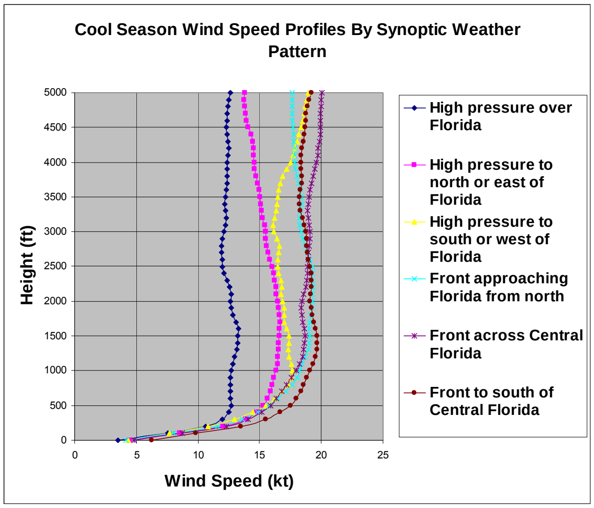

Figure 14. Vertical profiles of observed wind speed for each of the six synoptic pattern categories.

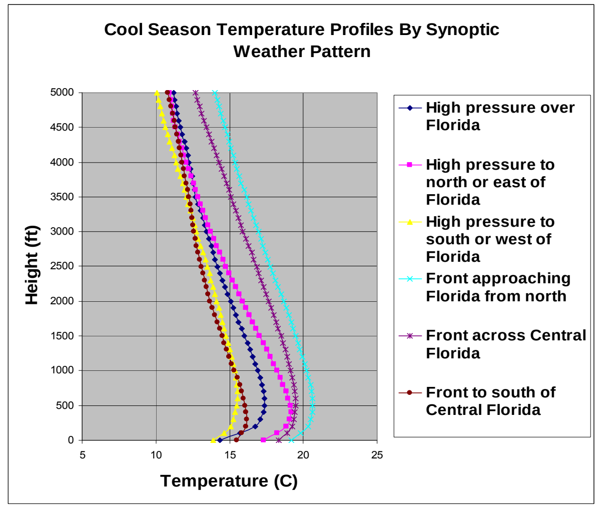

Figure 15. Vertical profiles of observed temperature for each of the six synoptic pattern categories.

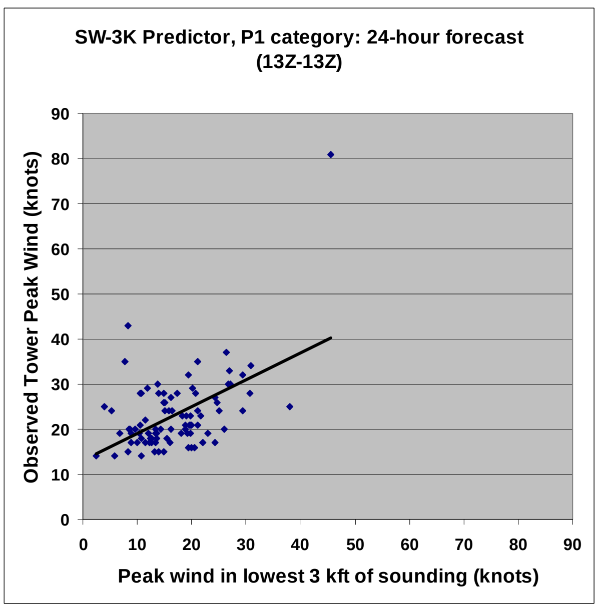

Figure 16. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when surface high pressure is across Florida.

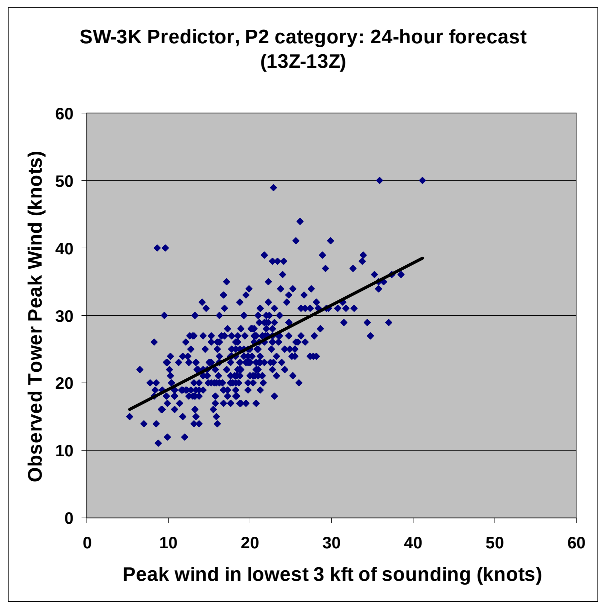

Figure 17. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when surface high pressure is north or east of Florida.

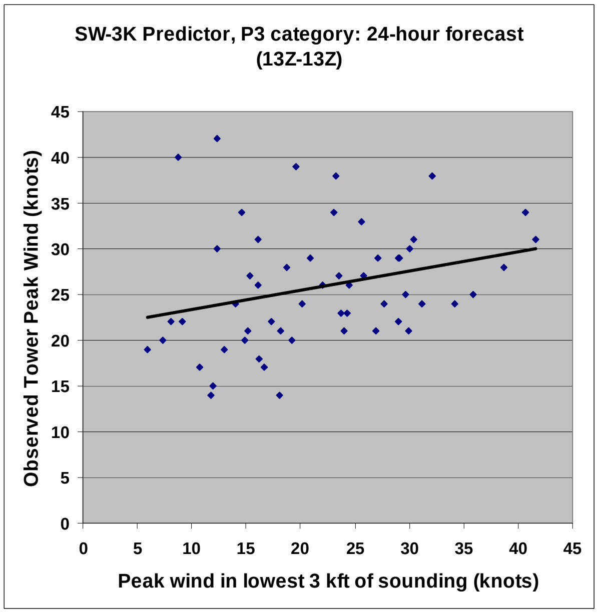

Figure 18. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when surface high pressure is south or west of Florida.

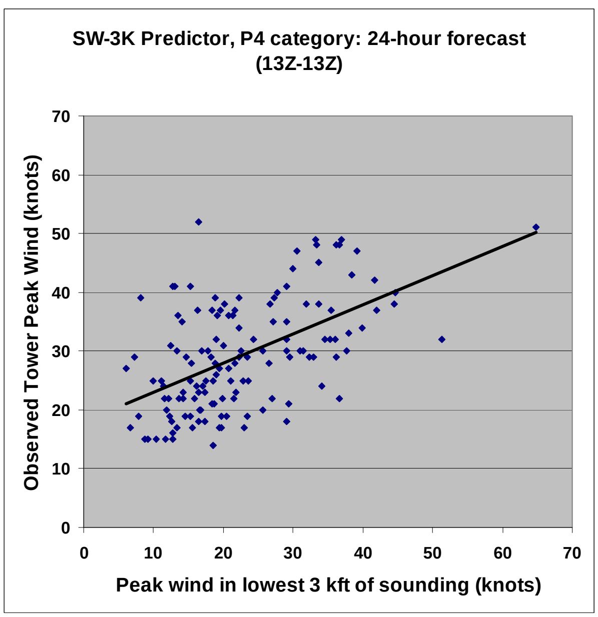

Figure 19. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when a front is approaching Florida from the north.

4. AVERAGE WIND SPEED DURING PEAK WIND SPEED OCCURRENCE

The following candidate predictors were evaluated to predict the 5-minute average wind speed at the time of the peak wind:

- Observed peak wind speed,

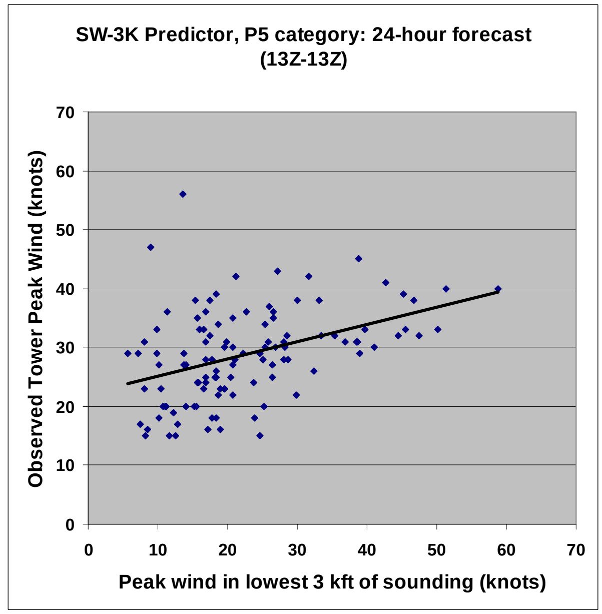

Figure 20. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when a front is across central Florida.

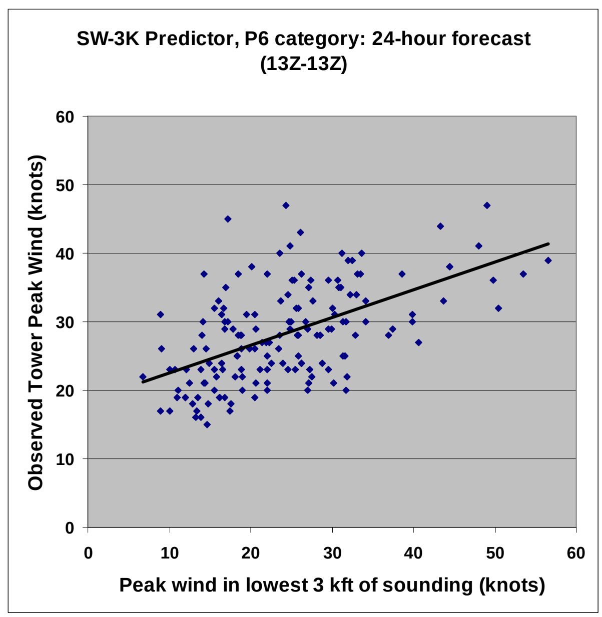

Figure 21. Observed peak wind speed versus strongest wind in the lowest 3000 ft, when a front is to the south of central Florida.

- Gust factor, and
- Wind sensor height.

The gust factor is the ratio of the peak to average wind speed over a given time period (5 minutes in this case). Figure 22 shows a scatter plot of peak wind as a predictor. Figures 23 and 24 are scatter plots of gust factor versus observed peak wind and sensor height. As shown by figures 22-24, only the observed peak wind speed showed useful skill as a predictor.

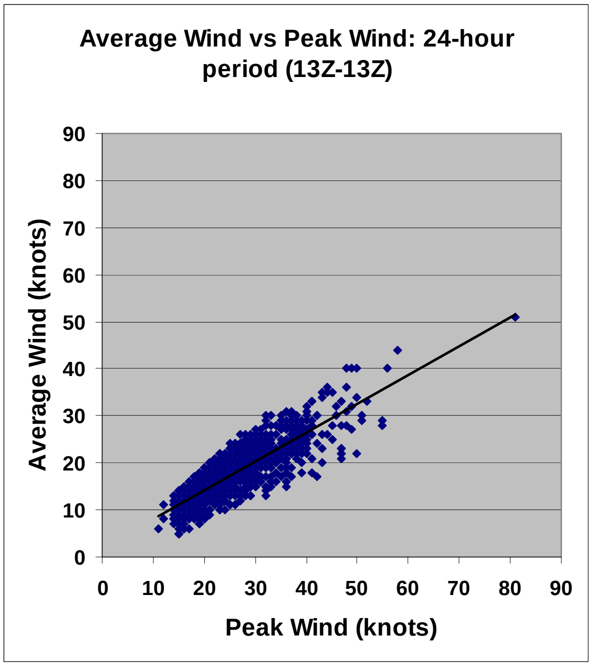

Figure 22. Observed 5-minute average wind speed versus observed peak wind speed.

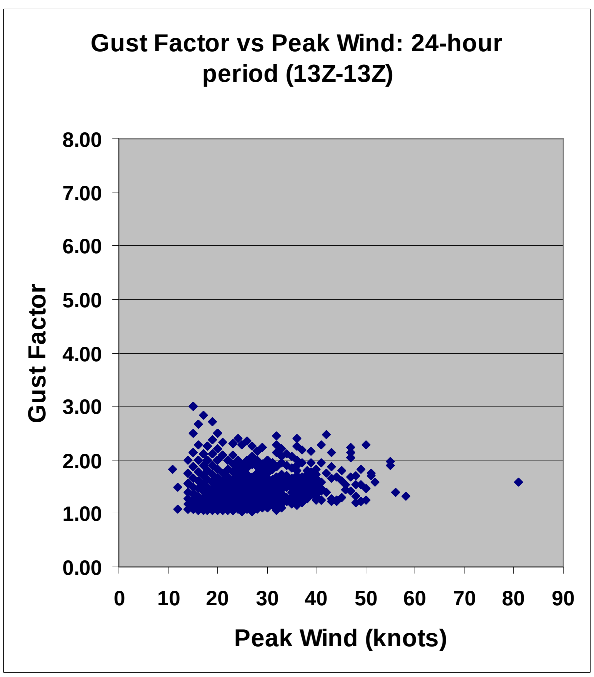

Figure 23. Observed gust factor versus observed peak wind speed.

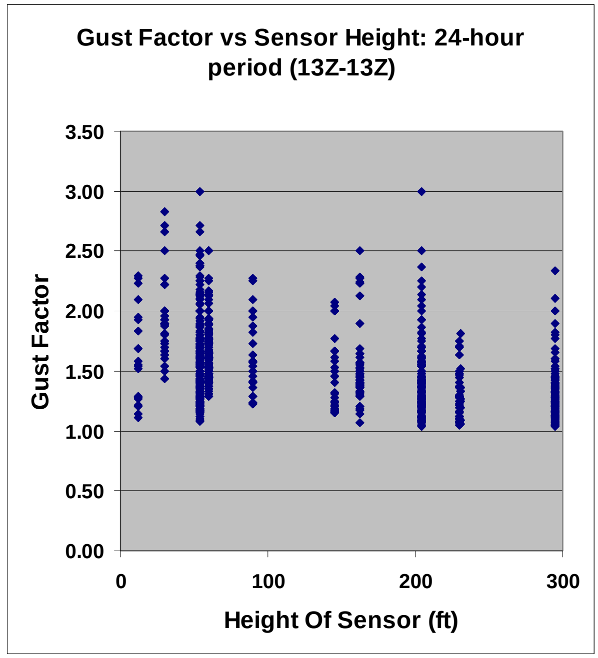

Figure 24. Observed gust factor versus height of wind sensor.

5. TIMING OF THE PEAK WIND SPEED OF THE DAY

Like the peak wind speed forecast, three separate prediction methods were created to predict the timing of the peak wind speed of the day. The first was a multiple linear regression equation, with inversion depth and strength as predictors. A strong and deep inversion tended to delay the occurrence of the peak wind speed of the day, most likely since it takes longer for higher level winds to mix down to the surface layer. The second method used the average time of peak wind occurrence based on the synoptic weather pattern. The peak wind tended to occur the earliest when there was either a front to the south of central Florida, or high pressure to the south or west of Florida. The peak wind tended to occur the latest when there was either a front approaching Florida from the north, or high pressure across Florida. The third method used the average time of peak wind occurrence based on the inversion/precipitation stratification. The peak wind occurred earliest on days with no inversion or precipitation.

6. PEAK WIND FORECAST TOOL

The forecast tool was created in Microsoft Excel, using the Visual Basic for Applications programming language. In addition to the speed and timing of the daily peak and average wind speed, the tool also predicts the probability of exceeding the warning thresholds for peak wind speeds of 35 kt, 50 kt, and 60 kt. When the forecaster runs the tool, the input Graphical User Interface (GUI) is displayed (Figure 25). After the forecaster has finished entering data, the output GUI displays the predicted values (Figure 26).

The GUI was developed for accuracy, speed, and ease of use. The GUI provides:

- The peak wind speed, timing of the peak wind speed, and 5-minute average speed associated with the peak wind speed calculated from the values input by the forecaster to the GUI in Figure 25. The first and second parameters are calculated from the average of three prediction equations, weighted by each equation's mean absolute error. The average speed is calculated from the predicted peak wind speed.
- The probability of exceeding the three warning thresholds using the 1-σ error estimates from the linear regression using the following equation (Wilks 2006):

$$1-\left[0.5*\left(1\pm\sqrt{1-e^{\left(-2/\pi*\left((x-y)/z\right)^{2}\right)}}\right)\right]$$

  where x is the threshold value (35, 50, or 60), y is the predicted peak wind speed, and z is the predicted sigma (estimated error of the linear regression equation).

- Internal consistency checks for the input data. For example, if there is a surface-based temperature inversion, then the temperature at the top of the inversion must be warmer than the surface.

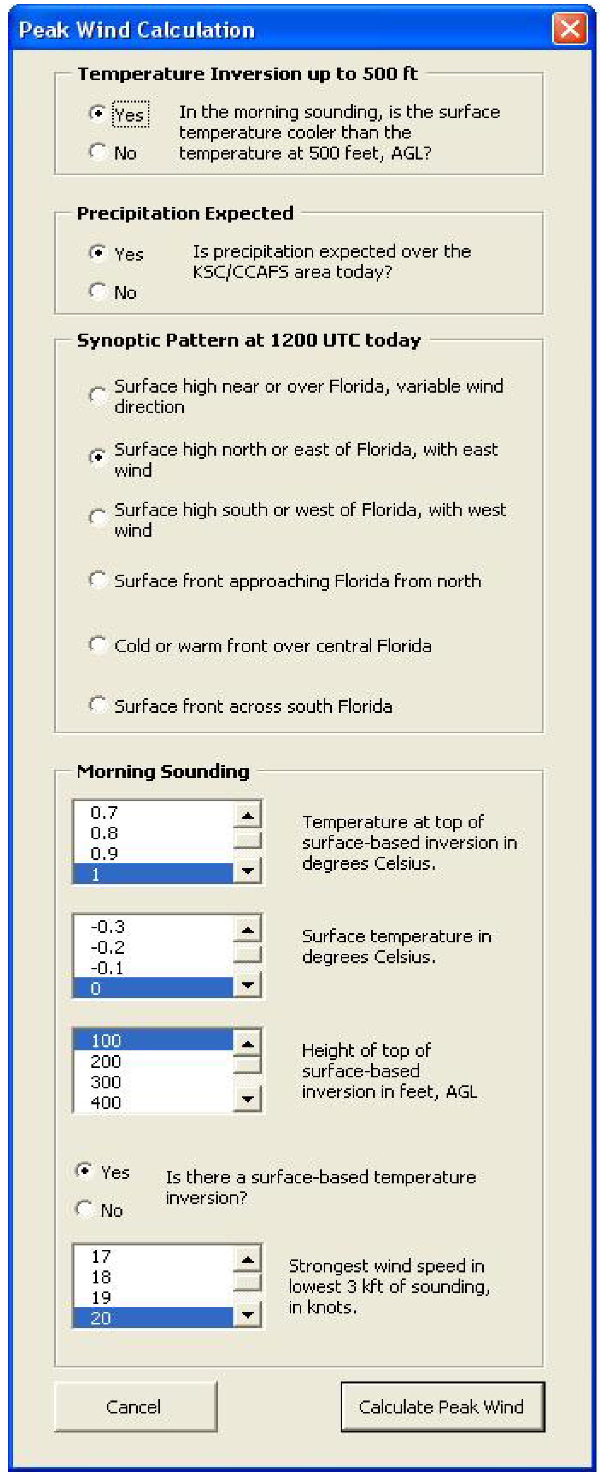

Figure 25. Input GUI showing the default input values.

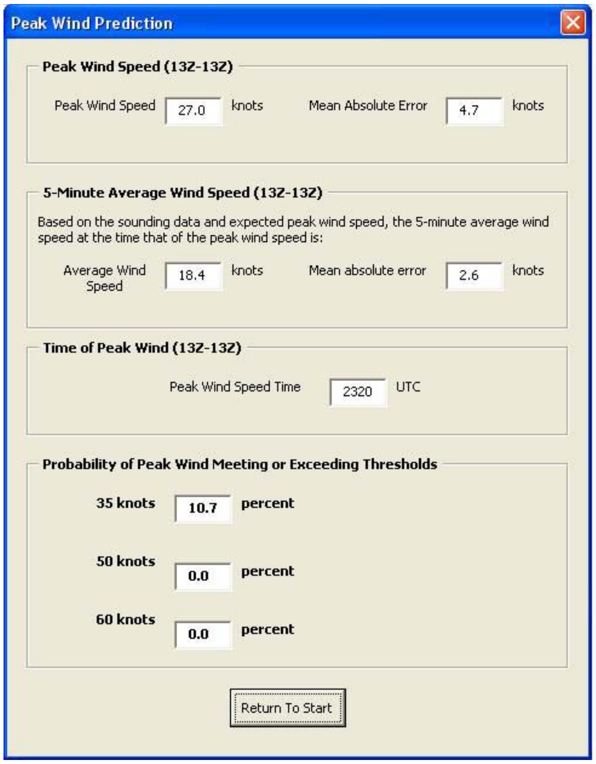

Figure 26. Output GUI showing the predicted peak wind speed, average wind speed, timing of the peak wind, and the probability that the peak wind speed will meet or exceed the warning thresholds.

7. SUMMARY

The AMU developed a new tool to help the 45 WS improve their forecasts of peak winds during their cool season (October-April). The tool forecasts the speed and timing of the daily peak wind and its associated average wind.

Several possible predictors were evaluated for each forecast value. Three separate linear regression equations were developed for the peak wind forecast. The first equation used three predictors: strongest wind in the lowest 3000 ft of the sounding, inversion depth, and inversion depth. The second equation used the strongest wind in the lowest 3000 ft as a predictor, and stratified the data into four categories:

- Inversion and no precipitation,
- Inversion and precipitation,
- No inversion and precipitation, and
- No inversion and no precipitation

The third equation also used the strongest wind in the lowest 3000 ft as a predictor, and stratified the data into six categories:

- Surface high pressure near or over Florida,
- Surface high north or east of Florida,
- Surface high south or west of Florida,
- Surface front approaching Florida from the north,
- Surface front over central Florida, and
- Surface front over south Florida.

The predicted peak wind speed used the average of the three equations, weighted by each equation's mean absolute error.

Three predictors were evaluated for predicting the average wind speed: observed peak wind speed, gust factor, and wind sensor height. Only the observed peak wind speed showed useful skill as a predictor.

The timing of the peak wind speed used three prediction methods. The first was a multiple linear regression with inversion depth and strength as predictors. The second method used the synoptic weather pattern as its only predictor, while the third method used the inversion/precipitation stratification as the predictor. The predicted timing of the peak wind speed used the average of the three methods.

A GUI was developed to manage the inputs, calculations, and display of final results. The GUI displays the expected peak wind speed, its timing, and the mean wind speed associated with the peak wind. The GUI also provides the probability of meeting the three wind warnings issued by 45 WS: ≥ 35 kt, ≥ 50 kt, and ≥ 60 kt. The probabilities are based on the estimated error of the linear regression equations.

8. REFERENCES

Bauman, W. H., W. P. Roeder, R. A. Lafosse, D. W. Sharp, and F. J. Merceret, 2004: The Applied Meteorology Unit – Operational Contributions to Spaceport Canaveral. *11th Conf. on Aviation, Range and Aerospace Meteorology.* Amer. Meteor. Soc., 24 pp.

Harms, D. E., A. A. Guiffrida, B. F. Boyd, L. H. Gross, G. D. Strohm, R. M. Lucci, J. W. Weems, E. D. Priselac, K. Lammers, H. C. Herring and F. J. Merceret, 1999: The Many Lives Of A Meteorologist In Support Of Space Launch, *Eighth Conf. on Aviation, Range and Aerospace Meteorology.* Amer. Meteor. Soc., 5 pp.

Wilks, D. S., 2006: Statistical Methods in the Atmospheric Sciences, 2nd Edition, Academic Press, Boston, MA, 627 pp.

NOTICE

Mention of a copyrighted, trademarked or proprietary product, service, or document does not constitute endorsement thereof by the authors, ENSCO Inc., the AMU, the National Aeronautics and Space Administration, or the United States Government. Any such mention is solely for the purpose of fully informing the reader of the resources used to conduct the work reported herein.