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Peak Wind Tool for General Forecasting

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April 2008

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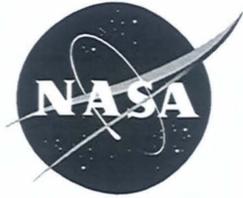
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Executive Summary

The expected peak wind speed of the day is an important forecast element in the 45th Weather Squadron's (45 WS) daily 24-Hour and Weekly Planning Forecasts. The forecasts are used for ground and space launch operations at the Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). The 45 WS also issues wind warnings for KSC/CCAFS when they expect peak gusts to meet or exceed 35 kts, 50 kts, and 60 kts thresholds at any level from the surface to 300 ft. The 45 WS forecasters indicate peak wind speeds are challenging to forecast, regardless of their value. They requested the Applied Meteorology Unit (AMU) develop a tool to help them forecast the average wind speed and the speed and timing of the daily peak wind, from the surface to 300 ft on KSC/CCAFS for the cool season (October – April). They also requested the tool provide the probability that the expected peak speed will meet or exceed each of the wind warning thresholds.

Three data types were used in this task: 5-minute observations from the KSC/CCAFS tower network, hourly and special surface observations from the Shuttle Landing Facility (SLF), and CCAFS soundings (XMR). The period of record for this task included the 2002/2003 to 2005/2006 cool seasons, as well as October 2006 to February 2007. The SLF observations were used to determine if precipitation occurred at or within 5 n mi of the SLF. Wind speed and direction data were collected from all of the 32 towers used to verify wind warnings and advisories issued by the 45 WS. An additional tower was used to provide better coverage of the southern portion of KSC. The AMU ran an automated quality control (QC) algorithm to flag bad tower data. After comparing the QC'd tower data to the sounding data, several outliers in the tower data were identified. The AMU performed a manual QC check on the outliers, and several of the days were eliminated as a result. The XMR observations were used to create predictors for the peak and average winds. Only soundings between 0930 UTC and 1230 UTC were used, since soundings outside this time period may be unrepresentative of the temperature and wind profiles at 1200 UTC.

The AMU evaluated several candidate predictors from the morning sounding for the peak wind speed: whether or not a surface-based temperature inversion was observed, wind speed at the top of the temperature inversion, strength and depth of the temperature inversion, and strongest wind speed in the lowest 3000, 4000, and 5000 ft. Persistence, precipitation, and synoptic weather pattern were also evaluated as predictors. The AMU developed three prediction methods for the peak wind speed forecast. The first method used a multiple linear regression with three predictors: strongest wind in the lowest 3000 ft of the sounding, inversion strength, and inversion depth. The second method used the strongest wind in the lowest 3000 ft as the predictor, and uses one of four linear regression equations based on the occurrence or non-occurrence of a surface-based temperature inversion and precipitation. The third method also used the strongest wind in the lowest 3000 ft as the predictor, and uses one of six linear regression equations based on the synoptic weather pattern: surface high pressure near or over Florida, surface high pressure north or east of Florida, surface high pressure south or west of Florida, surface front approaching Florida from the north, surface front over central Florida, and surface front over south Florida. The final predicted peak wind speed was the average of the three methods, weighted by each method's mean absolute error.

The AMU evaluated three predictors for the average wind speed: observed peak wind speed, gust factor as a function of peak wind speed, and gust factor as a function of 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 strength and depth 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.

The AMU developed a Graphical User Interface (GUI) to manage the inputs and calculations, and display the forecast parameters. The GUI displays the expected peak wind speed, its timing, and the 5-minute average wind speed associated with the peak wind. The GUI also provides the probability of meeting or exceeding the three wind warnings issued by the 45 WS. The probabilities were based on the estimated error of the linear regression equations for the peak wind speed.

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1. Introduction

The expected peak wind speed of the day is an important forecast element in the 45th Weather Squadron's (45 WS) daily 24-Hour and Weekly Planning Forecasts. The forecasts are used for ground and space launch operations at the Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). The 24-Hour Forecast is valid from 0800 to 0800 local time the next day, and is broken into six 4-hour time blocks. The Weekly Forecast is for the next six days starting with the next day and is broken into 12-hour time blocks. The 45 WS also issues wind warnings for KSC/CCAFS when they expect peak gusts to meet or exceed 35 kts, 50 kts, and 60 kts thresholds at any level from the surface to 300 ft.

The 45 WS forecasters have indicated that peak wind speeds are challenging to forecast regardless of their value, particularly in the cool season months of October – April. They requested that the Applied Meteorology Unit (AMU) develop a tool to help them forecast non-convective winds. The tool outputs the average wind speed and the speed and timing of the daily peak wind, from the surface to 300 ft on KSC/CCAFS for the cool season. The tool uses data available by 1200 UTC (0700 local time) to meet the deadlines for issuing the Planning Forecasts. In addition, the tool provides the probability that the expected peak speed will meet or exceed each of the wind warning thresholds.

1.1 Previous Work

According to Arya (1988), several factors influence the wind distribution in the atmospheric boundary layer (ABL):

- Large scale horizontal pressure and temperature gradients,
- Surface roughness characteristics,
- Earth's rotation,
- Diurnal cycle of heating and cooling,
- Depth of the ABL,
- Entrainment of air from the free atmosphere,
- Horizontal advections of momentum and heat,
- Large scale horizontal divergence and the resulting mean vertical motion in the ABL,
- Presence of clouds and precipitation in the ABL, and
- Surface topography.

Several studies have addressed some of these factors in order to forecast peak winds, as discussed in Sections 1.1.1 through 1.1.4.

1.1.1 Studies on Gust Factor

McVehil and Camnitz (1969) used one year of data from several levels on a 150-m tower in the KSC/CCAFS network to determine the gust factor for different stratifications of average wind speed and atmospheric stability. The largest observed gust factor was at the lowest observation level. It was also largest during unstable to neutral conditions, and smallest during stable conditions. The observed gust factor was proportional to the ratio of the standard deviation of the peak wind speed to the mean speed, indicating that that gust factors were largest when wind speeds were highly variable.

Paulsen and Schroeder (2004) compared the gust factors from landfalling tropical cyclones and extratropical cyclones. The gust factor in the study was defined as the ratio of the peak 2-second gust to mean wind speed during a 10-minute period. The gust factor increased with increasing roughness. The gust factors showed increasing variability with decreasing average wind speed. The authors stated that environments with lower average wind speeds were more conducive to free convection, which can introduce additional turbulence and increase deviations from the mean wind speed.

1.1.2 Studies on Predicting Peak Winds With Neural Networks

Storch (1999) developed a neural network model to predict a time series of peak winds at KSC and CCAFS launch pads. The neural network was trained to forecast 15 parameters 15 minutes into the future, and then an ensemble of slightly perturbed neural network forecasts was generated. The neural network's peak wind forecasts were skillful compared to persistence when the number of tower locations was limited and the time interval of the prediction was increased. The ensemble portion did not increase the skill of the model.

Clays (2000) developed neural networks to predict wintertime (November – March) peak wind speeds at the Atlas launch pad on CCAFS. The networks produced 16 30-minute forecasts of peak wind speed, from 30 minutes beyond the start time to eight hours beyond the start time. The neural networks generally performed worse than persistence. The forecasts by the neural networks, persistence, and climatology worsened later in the forecast period. When the neural networks were trained with observations nearer in time to the forecast period, they showed skill against persistence beyond six hours.

1.1.3 Climatological Studies of Peak Winds

Coleman (2000) used a climatology of wintertime (November – March) wind observations from the KSC/CCAFS tower network to forecast the conditional probabilities of meeting or exceeding the maximum allowable wind speeds for each launch pad at KSC and CCAFS. The study concluded that the method showed very little skill in forecasting peak wind speeds.

Lambert (2002) calculated cool season climatologies and distributions of 5-minute average and peak winds for each of the towers on KSC/CCAFS used in making launch decisions. The climatologies are used to determine the average behavior of the wind for each month, hour and direction sector. The distributions are used to determine the probability of meeting or exceeding certain peak speeds based on the average speed.

1.1.4 Studies on Predicting Peak Winds With Numerical Weather Prediction Models

Hart and Forbes (1999) used hourly soundings from the operational Eta and Meso Eta Models to forecast non-convective wind gusts. The wind speed in the model best correlated to the observed wind gust was identified as the source layer. Probabilities of surface wind gusts reaching several speed thresholds (30 mph, 40 mph, and 50 mph) were determined from the source layer wind. The study showed skill in forecasting strong to damaging surface wind gusts, though the accuracy depended on the model's boundary layer stability forecast.

Brasseur (2001) developed a wind gust estimate (WGE) method based on vertical mixing by turbulent eddies that deflect air parcels higher up in the boundary layer down to the surface. The method calculates a bounding interval of the gust estimate, providing a range of likely wind gusts. The lower bound of the interval is based on the assumption that the local vertical turbulent kinetic energy is the only mechanism that triggers the deflection of air parcels. The upper bound is given by the maximum wind speed in the boundary layer.

Brasseur (2001) compared the WGE method with two other wind gust forecasting methods: the surface-roughness-based (SR) method and the surface-layer deflection (SL) method. The SR method uses the ratio of maximum gust to hourly average wind speed. The SR method was compared to the WGE method for five observation sites using the output of medium-range weather models. Except for one site, the SR method had larger average errors than the WGE method.

The SL method assumes that surface gusts result from the deflection of air parcels at the top of the surface layer. The calculation of wind gusts depends on three stability classes. In a neutral atmosphere, the predicted wind gust is the wind speed at the top of the surface layer. In a stable atmosphere, the predicted wind gust is the wind velocity at the top of the surface layer, corrected by the effect of atmospheric stability. In an unstable atmosphere, the predicted wind gust is the wind speed in the layer where equivalent potential temperature decreases with height. The average error in the SL method was slightly lower than the average error in the WGE method.

1.2 Current Operational Products to Forecast Peak Winds

There are very few existing tools and data sources forecasters can use to predict peak winds. In the National Weather Service's (NWS) National Digital Forecast Database (NDFD) (2006), wind gust forecasts have been available operationally since 20 September 2007. They are available in graphical and tabular format (as well as GRIB2 and XML formats) on the Internet for every three hours, out to 72 hours into the future. In the NDFD, a wind

gust is defined as the maximum 3-second wind speed forecast to occur within a 2-minute interval at a height of 10 m (NWS 2006).

There is only one numerical weather prediction model product for peak winds or wind gusts available over NOAAPORT, a broadcast system that provides National Oceanic and Atmospheric Administration environmental data in near real-time. The gridded data from the 40-km resolution output of the Rapid Update Cycle (RUC) model includes surface wind gusts for the following forecast hours: 0, 1, 2, 3, 4, 5, 6, 9, and 12.

The tool that resulted from Lambert (2002) is in the form of Excel Pivot Charts and Tables. There are files for each of the towers used to make forecast decisions for the shuttle and the Atlas and Delta expendable launch vehicles. The files contain the monthly, hourly, and directional wind mean and peak speed averages and standard deviations; and the empirical and modeled probability density functions for peak wind speed based on mean speed.

1.3 AMU Study

The current operational products and previous peak wind studies did not meet the requirements of the 45 WS for a tool to forecast peak winds during the cool season. The AMU needed to predict the speed and timing of the daily peak wind, the average wind speed at the time of the peak wind, and the probability that the peak wind speed will meet or exceed 35 kts, 50 kts, and 60 kts. The 45 WS were only interested in the peak wind on KSC and CCAFS, from the surface to 300 ft. Several predictors were evaluated for each method, and the most skillful predictors were used in the forecast tool. The predictors for peak wind speed, average wind speed, timing of the peak wind speed, and probabilities are discussed in Sections 3 and 3.4.

The tool provides guidance for the 45 WS's 24-Hour Planning Forecast valid from 0800 to 0800 the next day, local time. Since standard time is in effect for most of the cool season, observations from 0800 to 0800 EST were used during the development of the tool.

2. Data

Three data types were used in this task: 5-minute observations from the KSC/CCAFS tower network, hourly and special surface observations from the Shuttle Landing Facility (SLF), and CCAFS soundings (XMR). The tower and XMR data were obtained from the Range Technical Services Contractor, Computer Sciences Raytheon. Most surface observations were obtained from the Air Force Combat Climatology Center (AFCCC). Surface observations for January and February 2007 were obtained from the Plymouth State University Weather Center (<http://vortex.plymouth.edu/statlog-u.html>). Only data from the cool season months of October to April in the years 2002-2006, and January and February of 2007 were used. This is because very few XMR soundings with 100-ft vertical resolution data were available before October 2002.

2.1 Tower Data

Data were collected from all 32 towers used to verify wind warnings and advisories issued by the 45 WS, as shown in Figure 1. Tower 0300 was also used to provide better coverage of the southern portion of KSC. Table 1 shows the wind sensor levels on each tower. The meteorological variables in the tower dataset include: temperature and relative humidity, 5-minute average and peak wind speeds, 5-minute average and peak wind directions, and the standard deviation of the 5-minute average wind direction over a 30-minute period. In order to report a wind average or directional deviation, at least 20 percent of the samples must be available in the averaging period (CSR 2006). Wind speed and direction data are sampled every second. The peak wind is the maximum 1-second speed in the 5-minute period. Case and Bauman (2004) provides a detailed description of the KSC/CCAFS tower network instrumentation.

The AMU ran an automated quality control (QC) algorithm to flag bad tower data (Lambert 2002) prior to analysis. Since 45 WS wind advisories and warnings apply to winds up to 300 ft, only tower wind observations up to 300 ft were used in this study. For each day with tower data, the peak wind speed of the day (PWSD) was determined from the 33 towers at all levels up to 300 ft. After comparing the quality-controlled tower data to XMR data, several outliers in the tower data were identified. Any wind gusts over 60 kts were considered outliers, due to a past study of convective wind gusts using the tower network (Koermer 2007). A manual QC check was performed on the outliers, and several of the days were eliminated as a result. It is possible that other non-outlying tower observations were bad, but not flagged by the automated QC program or manual QC. Most of the bad PWSD observations were from towers 0040 or 0511-0513.

There was one extreme outlier that passed both automated and manual QC checks. On 24 October 2005, a peak wind of 81 kts from 345° was observed at 60 ft AGL from Tower 397 at 1645 UTC. The 5-minute average wind speed at the time of the gust was 51 kts from 334°. The strong wind occurred while Hurricane Wilma moved northeastward offshore the eastern seaboard, as seen in the 1200 UTC surface analyses in Figure 2 and Figure 3. These figures were obtained from the NWS Hydrometeorological Prediction Center's Daily Weather Maps webpage (<http://www.hpc.ncep.noaa.gov/dailywxmap/>).

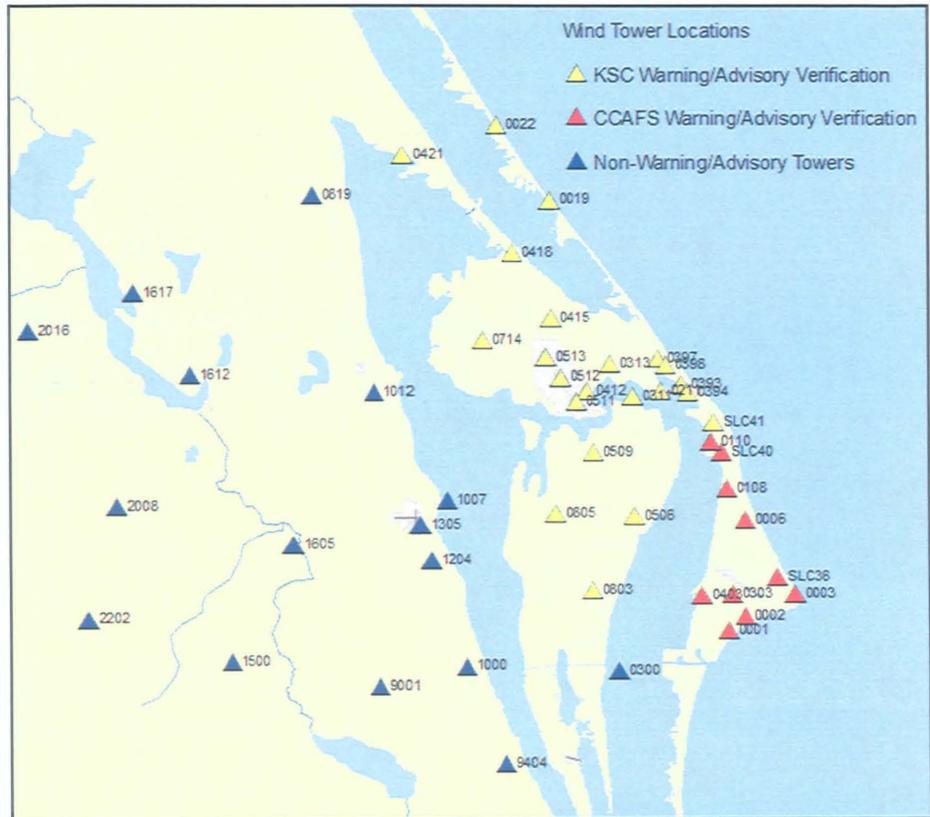


Figure 1. A map showing the towers used in the task. Except for tower 0300, only the yellow- and red-colored towers were used.

Table 1. KSC and CCAFS wind towers used in this study.

<i>Tower Number</i>	<i>Tower Wind Levels (ft)</i>	<i>Tower Number</i>	<i>Tower Wind Levels (ft)</i>
0001	12, 54	0394	60
0002	12, 54, 90, 145, 204	0397	60
0003	12,54	0398	60
0006	12, 54, 162, 204	0403	12, 54
0019	54	0412	12, 54
0022	54	0415	12, 54
0036	90	0418	54
0040	54	0421	54
0041	230	0506	12, 54
0108	12, 54	0509	12, 54
0110	12, 54, 162, 204	0511	30
0211	12, 54	0512	30
0300	54	0513	30
0303	12, 54	0714	12, 54
0311	12, 54	0803	12, 54
0313	12, 54, 162, 204, 295, 394, 492	0805	12, 54
0393	60		

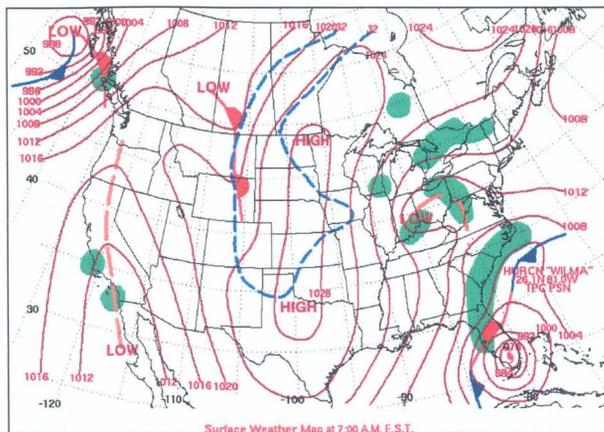


Figure 2. Hurricane Wilma was centered over south Florida at 1200 UTC on 24 October, 2005. Strong winds were occurring across south and central Florida as a result.

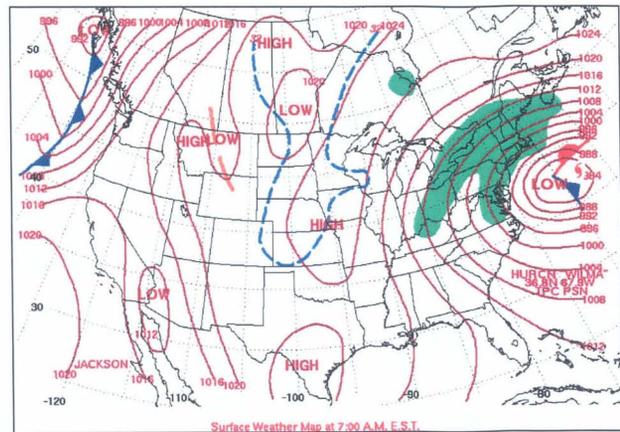


Figure 3. By 1200 UTC on 25 October, 2005, Hurricane Wilma had moved quickly northeastward offshore the mid-Atlantic region.

2.2 Surface Observations

The SLF hourly and special observations were used to determine if precipitation occurred at or within 5 n mi (the vicinity) of the SLF.

2.3 Upper-Air Sounding Data

The predictors for the PWS were created from the XMR data. Only soundings between 0930 UTC and 1230 UTC were used, since soundings outside this time period may be unrepresentative due to diurnal changes in temperature, relative humidity, and wind velocity. The soundings included wind speed and direction, pressure, temperature, and dew point. Soundings were only used if data were available to at least 15,000 ft. There were 155 possible January soundings (2003-2007), 141 possible February soundings (2003-2007), 124 possible March soundings (2003-2006), 120 possible April soundings (2003 – 2006), 155 possible October soundings (2002 – 2006), 150 possible November soundings (years 2002 – 2006), and 155 possible December soundings (2002 –

2006). This gave a total of 1000 possible soundings. Out of the 1000 soundings, there were 855 soundings available between 930 and 1230 UTC with data up to 15,000 ft.

3. Development of Prediction Equations

After the observation data were gathered and QC'd, prediction equations were developed for each forecast parameter in the tool.

3.1 Peak Wind Speed of the Day

The AMU created several candidate predictors from the surface and XMR observations. The Air Force Weather Agency (AFWA) publication on Meteorological Techniques (Chapter1, Section III of AFWA 2006) provides general guidelines on forecasting surface wind speed. The guidelines suggest that low-level temperature inversions can prevent high winds aloft from reaching the surface until the inversion breaks due to surface heating. One guideline states "If winds increase above the inversion (and the inversion is below 5000 feet), expect maximum gusts during maximum heating to be 80 percent of the 5000 feet wind speed." As a result, the AMU used the maximum wind speed from the surface to 5000 ft in the sounding as a candidate predictor. In addition, the maximum wind speeds from the surface to 3000 ft and 4000 ft were used as candidate predictors. Another candidate predictor was the wind speed at the top of the surface-based temperature inversion. If the inversion breaks, then the observed peak wind may be correlated to this predictor. Two more candidate predictors were investigated: the inversion depth and inversion strength. A strong and deep inversion may act to weaken the peak wind speed, as well as delay its occurrence during the day.

Each day was stratified into one of four categories based on the existence or non-existence of a temperature inversion in the XMR data and the occurrence or non-occurrence of precipitation at the SLF. A temperature inversion was defined as an increase in temperature between the surface and 500 feet, in order to ignore very shallow and weak inversions that frequently occur in morning soundings during the cool season. Since the 24-hour planning forecast by the 45 WS is valid from 0800 to 0800 local time, surface and tower observations between 1300 UTC (0800 local time) the current day and 1300 UTC the following day were used. Out of the 855 days with valid soundings, there were 852 days with SLF surface observations 1300 UTC - 1300 UTC and 847 days with SLF surface observations 1300 UTC - 0000 UTC. The reason for fewer days with surface observations between 1300 UTC and 0000 UTC is that only one observation of precipitation was needed to count the day as having a complete set of surface observations. For example, suppose that surface observations for one day were missing between 2000 UTC and 0100 UTC, and rain was observed at 0300 UTC. The surface observations between 1300 UTC and 0000 UTC were considered to be missing. However, the surface observations between 1300 UTC and 1300 UTC were not missing, because precipitation occurred during the period. However, if no rain was observed between 1300 UTC and 1300 UTC, both periods (1300 UTC - 0000 UTC and 1300 UTC - 1300 UTC) were considered to be missing.

Each day was also stratified into one of six categories based on the synoptic weather pattern at 1200 UTC (the number of days is in parentheses):

- Surface high pressure over or near Florida with variable winds across central Florida (110),
- Surface high pressure north or east of Florida with east winds across central Florida (348),
- Surface high pressure south or west of Florida with west winds across central Florida (66),
- Front approaching Florida from the north (163),
- Front across central Florida (132), and
- Front south of central Florida (181).

This gave a total of 1000 days in the period stratified by synoptic pattern. The days were then filtered to include only those that had both an XMR morning sounding and SLF surface observations.

3.1.1 Peak Wind Speed Forecast Using All Days

The AMU evaluated the following candidate predictors for peak wind speed: persistence (PR), strongest wind in the lowest 5000 ft of the sounding (SW-5K), strongest wind in the lowest 4000 ft of the sounding (SW-4K), strongest wind in the lowest 3000 ft of the sounding (SW-3K), wind speed at the top of the temperature inversion

(WS-INV), inversion depth (INV-D), and inversion strength (INV-S). If no surface-based temperature inversion was observed in the sounding, then WS-INV was set to the surface wind speed. The inversion depth and strength were set to zero if no inversion was observed. Not every combination of predictors was used, given limited time resources.

The skill of PR was evaluated first. A persistence forecast assumes the peak wind speed from the previous day will be the PWSD on the current day. Figure 4 shows scatter plots for the 11-hour (1300 UTC – 0000 UTC) and 24-hour (1300 UTC – 1300 UTC) PR forecasts. The plots show a large amount of scatter across the linear regression line. While both 11-hour and 24-hour PR forecasts performed poorly, the 24-hour forecast had a significantly larger coefficient of determination (R^2) and slightly lower mean absolute error (MAE).

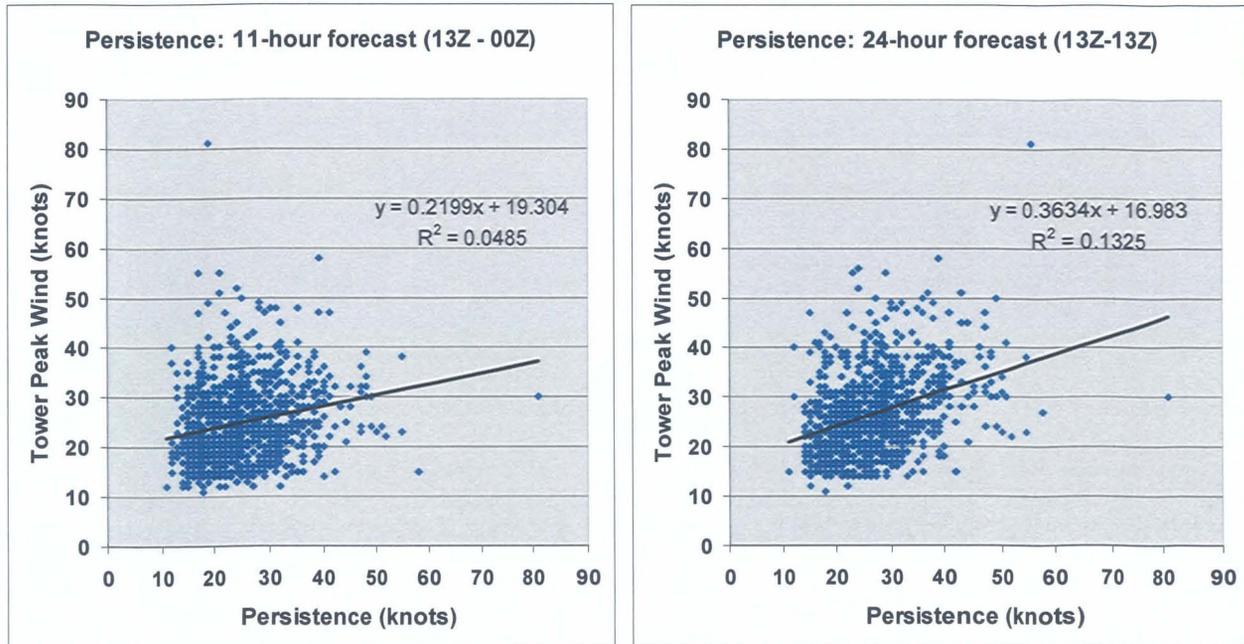


Figure 4. Scatter plots of observed PWSD versus a PR forecast for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid on the data points.

Next, the strongest winds in the lowest 3000, 4000, and 5000 ft were evaluated. Figures 5-7 show scatter plots for the SW-3K to SW-5K predictors. For all three predictors, the 11-hour forecasts performed better than the 24-hour forecasts. This indicates peak wind speed becomes less predictable as the number of hours since the morning sounding increases. There is a slight decrease in scatter across the linear regression line from the SW-5K to SW-3K predictors, showing that winds above 3000 ft are less important in predicting peak wind speeds.

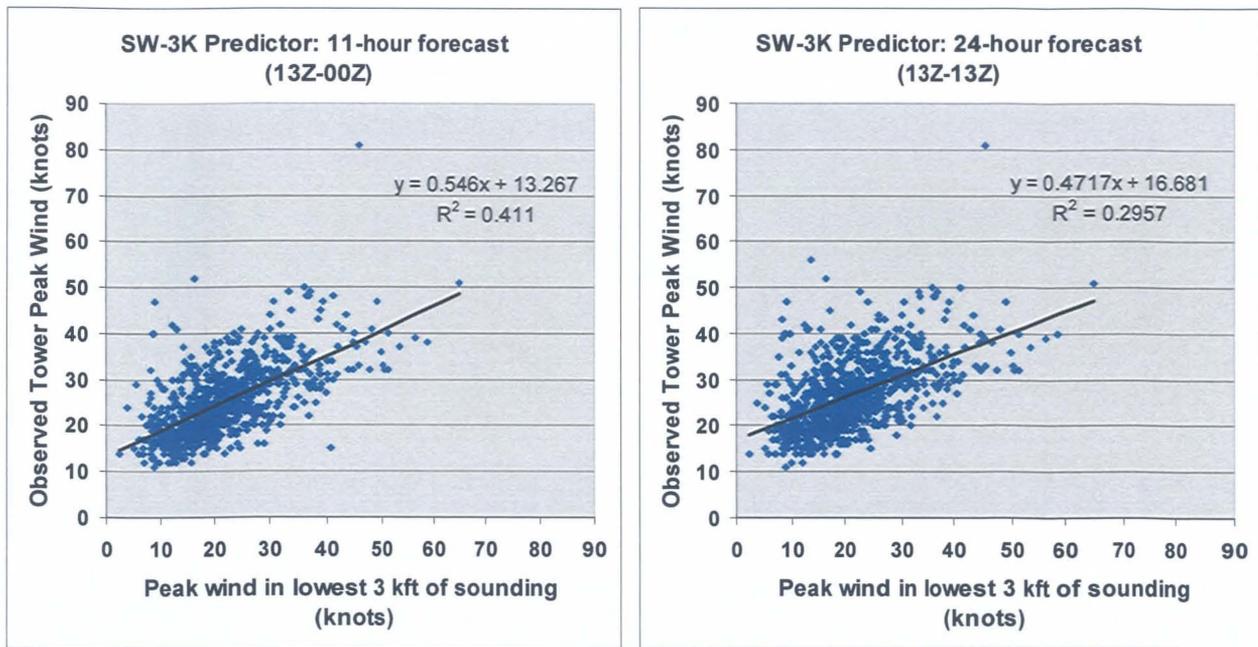


Figure 5. Scatter plots of observed PWSD versus the strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid on the data points.

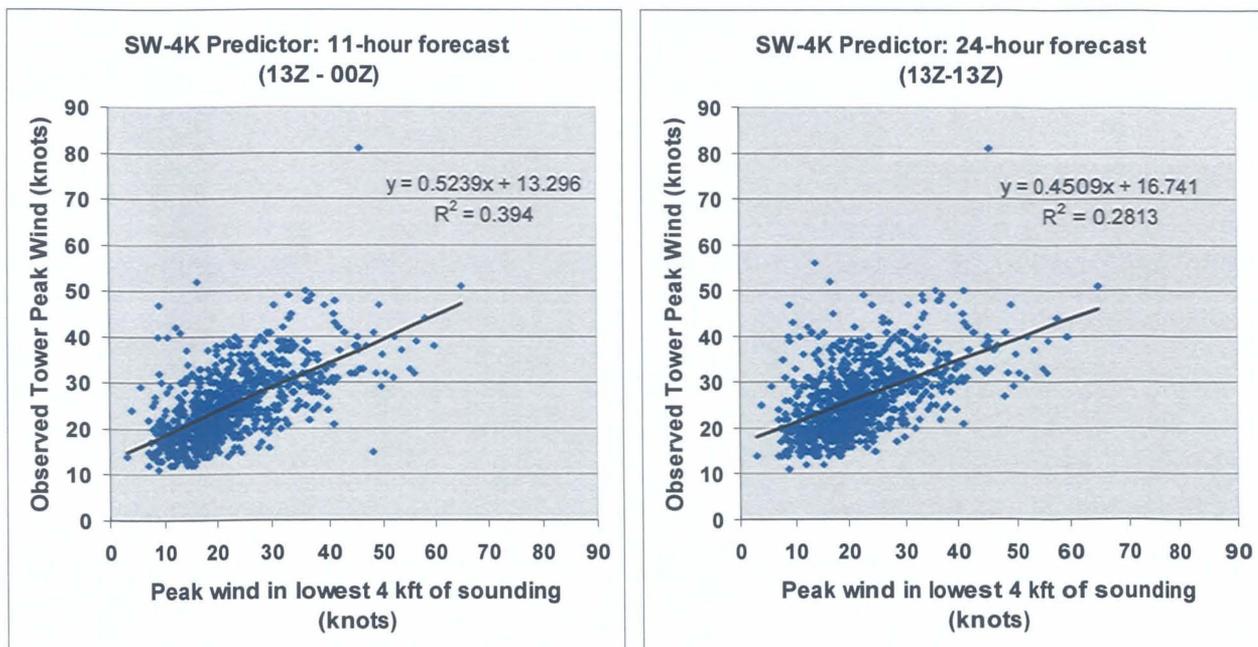


Figure 6. Scatter plots of observed PWSD versus the strongest wind in the lowest 4000 ft of the sounding for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid on the data points.

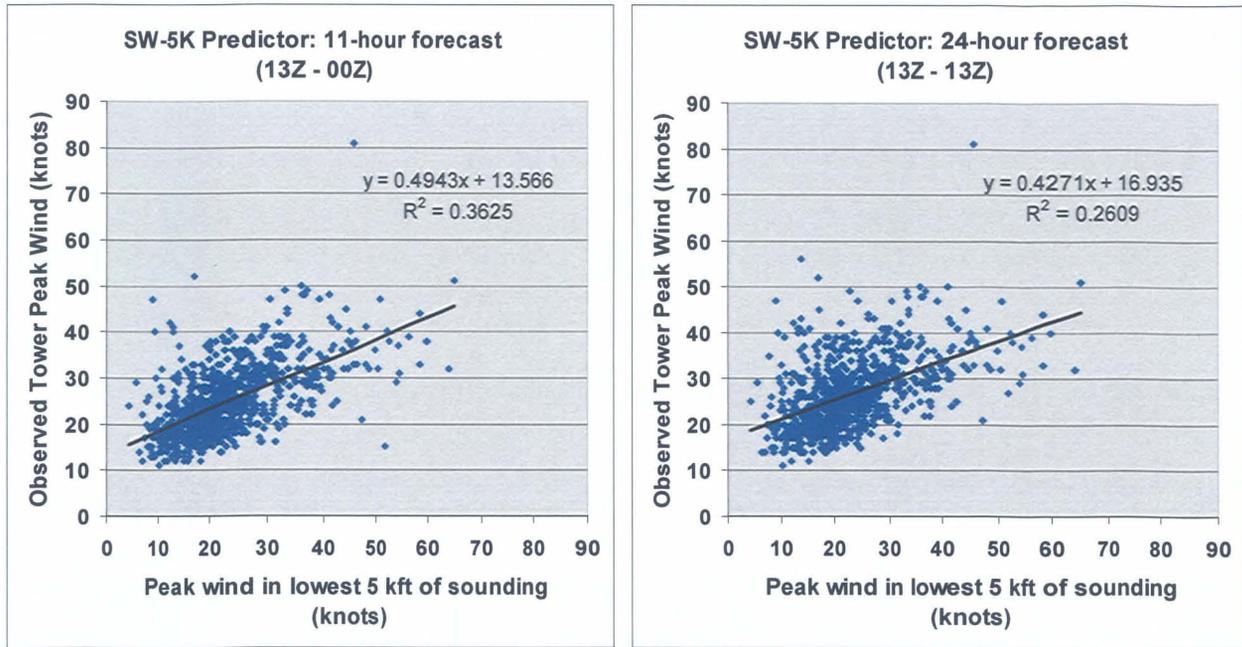


Figure 7. Scatter plots of observed PWSD versus the strongest wind in the lowest 5000 ft of the sounding for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid on the data points.

Figure 8 shows scatter plots for the WS-INV predictor. The plots show little predictive skill compared to the SW-3K, SW-4K, and SW-5K predictors.

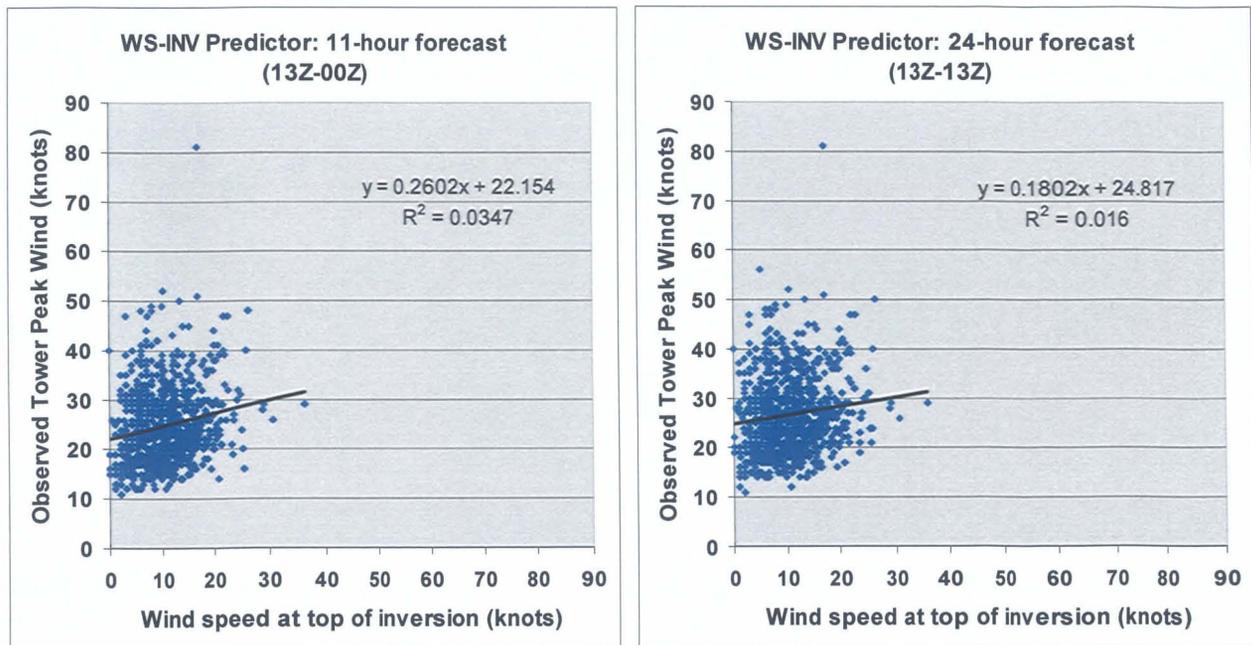


Figure 8. Scatter plots of observed PWSD versus the wind speed at the top of the inversion in the sounding for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid on the data points.

Finally, multiple linear regressions were created using different combinations of predictors. Figure 9 compares the skill of the regression equations for the 11-hour period, using R^2 . The regression equations that included the SW-

3K predictor performed the best, although the SW-4K and SW-5K predictors performed nearly as well. The worst-performing predictors were PR and WS-INV. Figure 10 compares the skill of the regression equations for the 24-hour period, using R^2 . Once again, the SW-3K predictor performed the best, closely followed by the SW-4K and SW-5K predictors. The PR and WS-INV predictors performed the worst. Figure 11 compares the MAE of the regression equations for the 11-hour period. The regression equations with the SW-3K, SW-4K, or SW-5K predictors performed the best, with MAE between 4 and 4.5 kts. The PR and WS-INV predictors did the worst. Figure 12 compares the MAE of the regression equations for the 24-hour period. Once again, the regression equations with the SW-3K, SW-4K, or SW-5K predictors performed the best, with MAE around 5 kts. The PR and WS-INV predictors performed the worst. Compared to the 11-hour period, there is less difference in performance between the SW-3K to SW-5K predictors and the PR and WS-INV predictors for the 24-hour period. This is due to the decrease in skill as the time since the observed sounding increases.

Overall, the SW-3K predictor performed the best, closely followed by the SW-4K and SW-5K predictors. The regression equation with the best predictive skill, as indicated by R^2 and MAE, was a multiple linear regression composed of three predictors: SW-3K, INV-D, and INV-S.

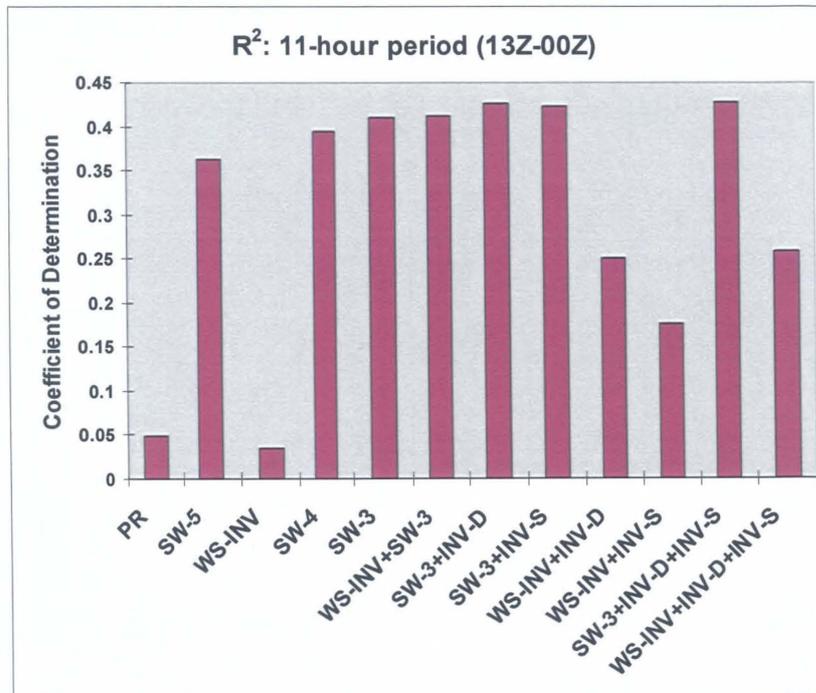


Figure 9. R^2 values of the candidate predictors for peak wind speed in the 11-hour period. PR = persistence, WS-INV = wind speed at top of inversion, SW-3 to SW-5 = strongest wind in lowest 3000 to 5000 ft, INV-D = inversion depth, and INV-S = inversion strength.

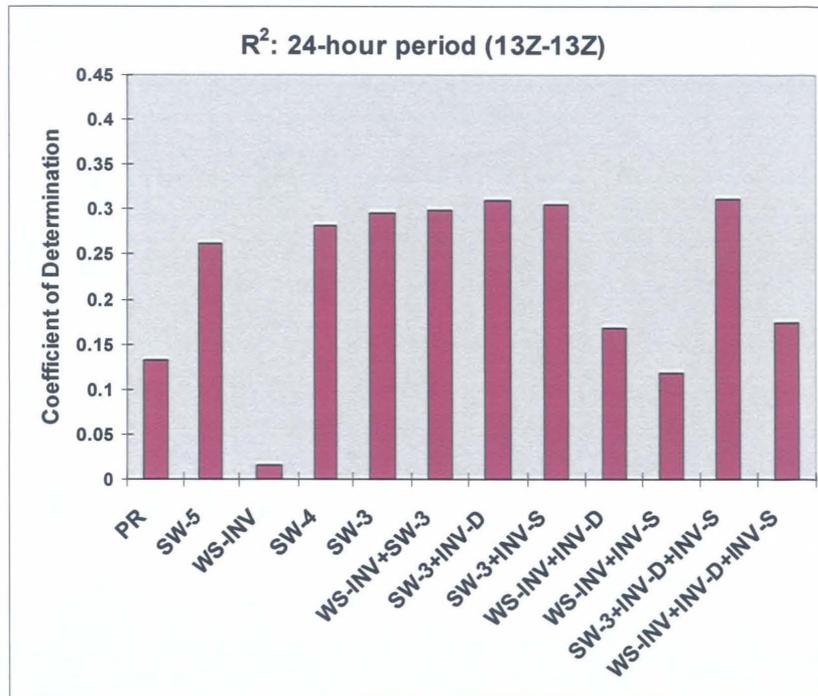


Figure 10. R² values of the candidate predictors for peak wind speed in the 24-hour period. PR = persistence, WS-INV = wind speed at top of inversion, SW-3 to SW-5 = strongest wind in lowest 3000 to 5000 ft, INV-D = inversion depth, and INV-S = inversion strength.

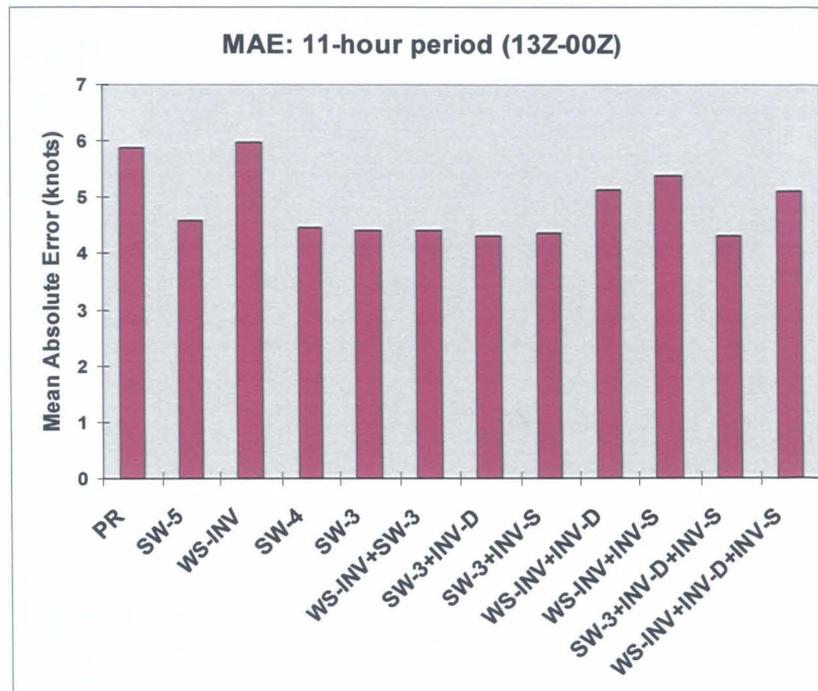


Figure 11. MAE values of the candidate predictors for peak wind speed in the 11-hour period. PR = persistence, WS-INV = wind speed at top of inversion, SW-3 to SW-5 = strongest wind in lowest 3000 to 5000 ft, INV-D = inversion depth, and INV-S = inversion strength.

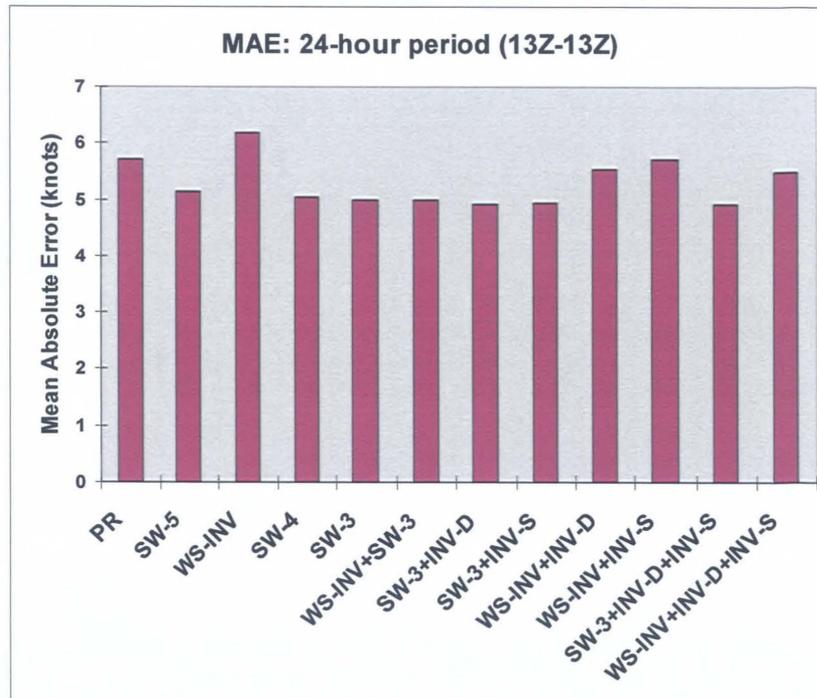


Figure 12. MAE values of the candidate predictors for peak wind speed in the 24-hour period. PR = persistence, WS-INV = wind speed at top of inversion, SW-3 to SW-5 = strongest wind in lowest 3000 to 5000 ft, INV-D = inversion depth, and INV-S = inversion strength.

3.1.2 Peak Wind Speed Forecast Based on Inversion/Precipitation Stratification

Each day in the period of record was classified into one of four categories: inversion observed/SLF precipitation occurred (YY), inversion observed/no SLF precipitation (YN), no inversion observed/SLF precipitation occurred (NY), and no inversion observed/no SLF precipitation (NN). The number of days in each category varied. For the 11-hour period, they ranged from only 97 days in category NY, to 421 days in category YN. For the 24-hour period, they ranged from 117 days in category NY to 366 days in category YN.

Figure 13 shows the composite wind profiles from the surface to 5000 ft for the four inversion/precipitation stratifications. The lightest winds occurred on days with an inversion and no precipitation, while the strongest winds occurred on days with precipitation and no inversion. 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. This implies that the inversion/precipitation stratification may dictate which wind levels in the XMR sounding are most useful in predicting peak wind speeds.

Figure 14 shows the composite temperature profiles from the surface to 5000 ft for the same stratifications. Days with no inversion and no precipitation had the coolest temperatures 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. This implies that winds at and below 500 ft may not be useful for predicting peak wind speeds.

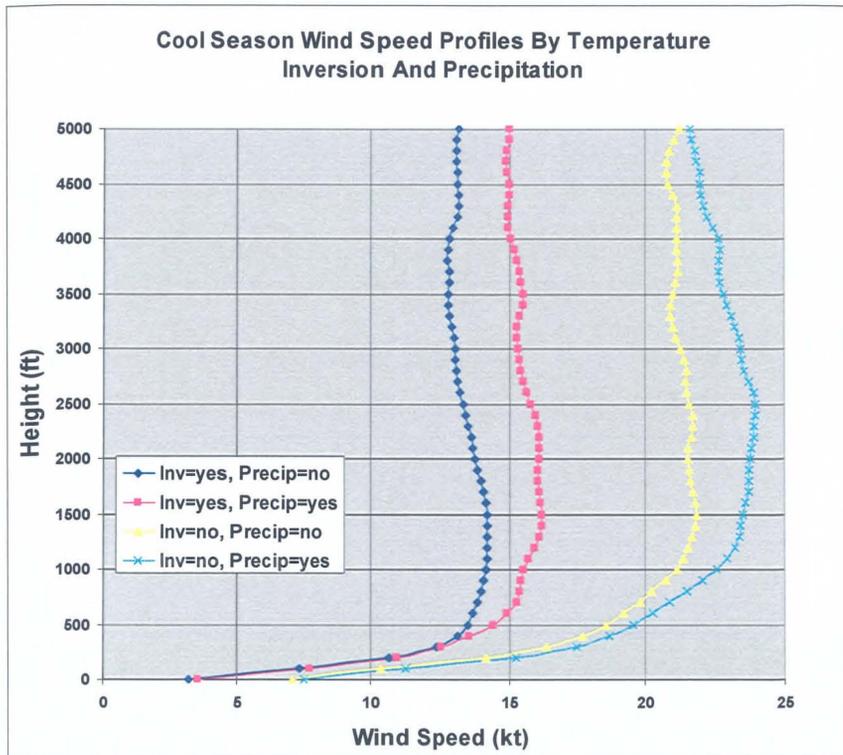


Figure 13. Average vertical profiles of wind speed (kts) for the four inversion (Inv)/precipitation (Precip) stratification categories. The legend shows the colors and symbols used for each profile.

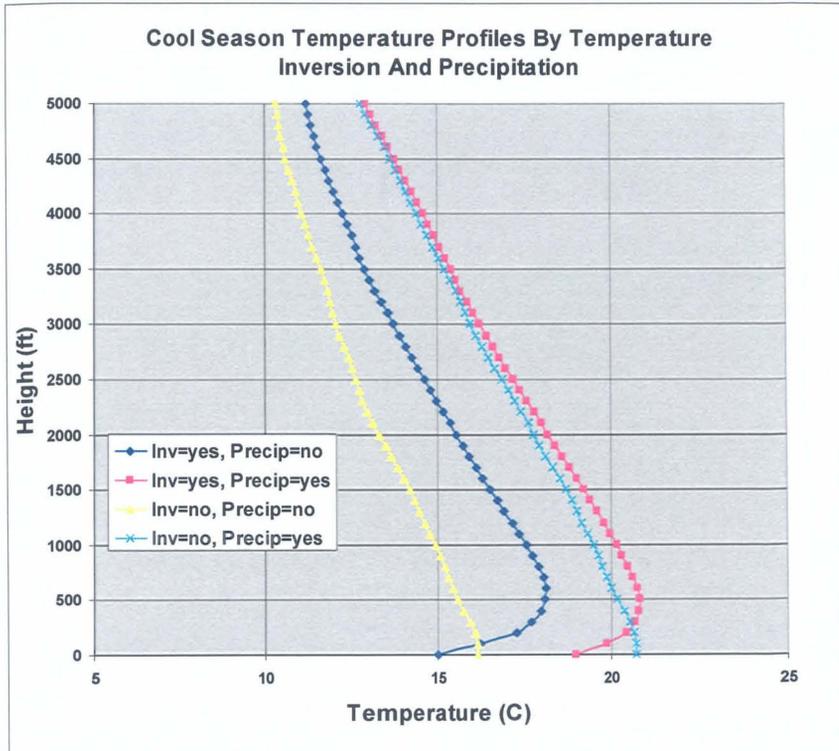


Figure 14. Average vertical profiles of temperature (C) for the four inversion (Inv)/precipitation (Precip) stratification categories. The legend shows the colors and symbols used for each profile.

For each of the four inversion/precipitation stratifications, given the time constraints for this task, only four predictors were evaluated: SW-5K, SW-4K, SW-3K, and WS-INV. The linear regression equations and scatter plots for the 11-hour and 24-hour periods were similar. However, the linear relationships between the predictors and the observed PWSD were slightly stronger for the 11-hour period. As the time since the morning sounding increased, the skill of the predictors decreased. Since the tool only produces a 24-hour forecast, the figures for the 11-hour period are not shown. Also, only figures for the SW-3K and WS-INV predictors are shown. The linear regression relationships for the SW-3K to SW-5K predictors are similar. However, the skill of the SW-3K predictor is slightly better than the SW-4K and SW-5K predictors. Figures 15-18 show scatter plots for the YY category, YN category, NY category, and NN category. For each category, the SW-3K predictor tended to show the most skill, while the WS-INV predictor had the least skill. An interesting result from the regression equations is that the predictability of the PWSD varied with the inversion/precipitation category. Using the best predictor, SW-3K, the MAE of the regression equations was the lowest on days with an inversion and no precipitation and highest on days with precipitation and no inversion. However, R^2 was the largest on days with no inversion and no precipitation at the SLF. Thus, peak winds appear to be most predictable on dry days.

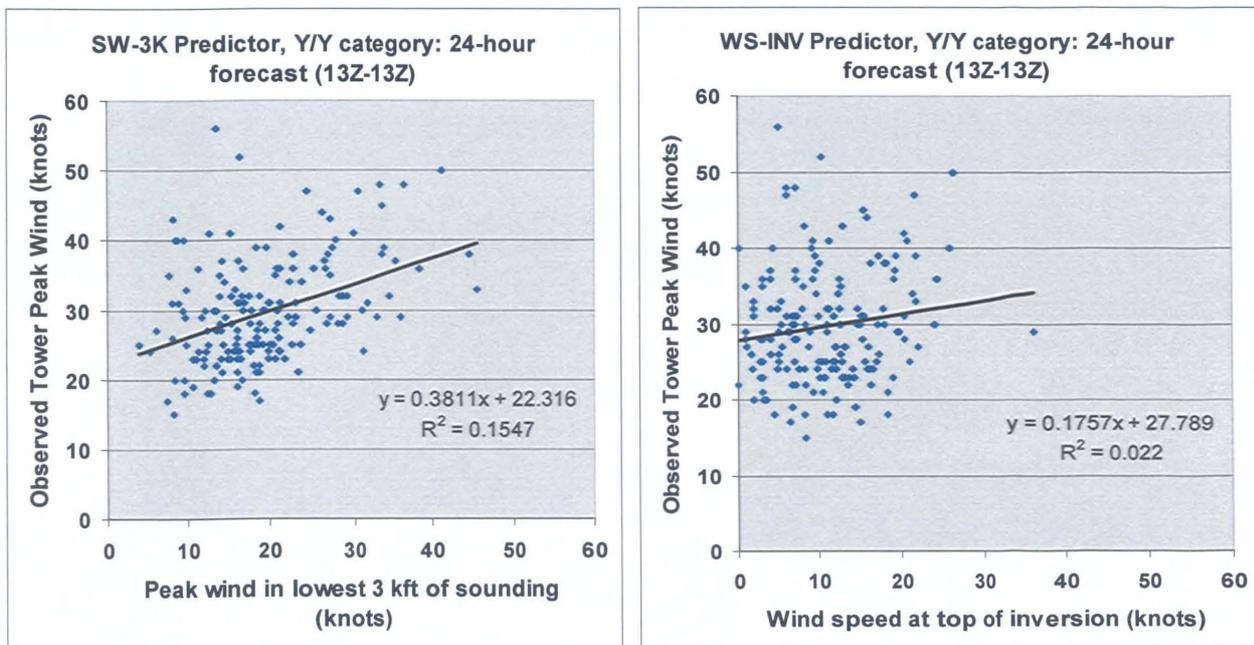


Figure 15. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when both an inversion and precipitation are observed. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

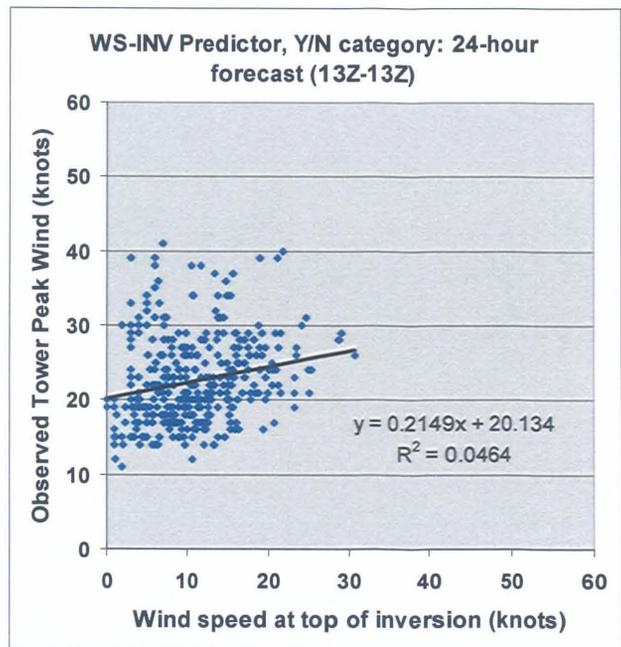
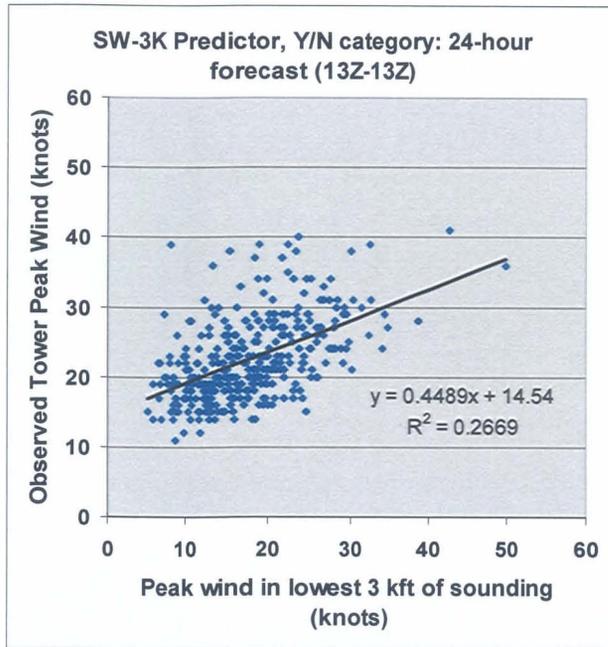


Figure 16. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when an inversion and no precipitation are observed. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

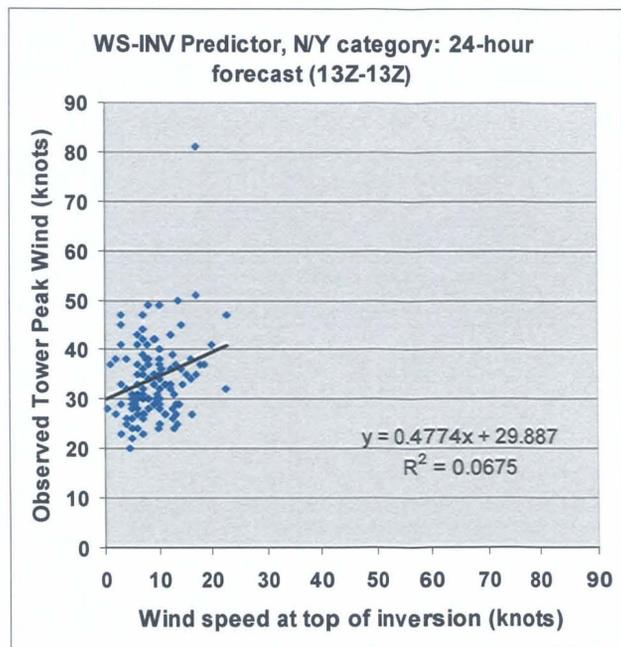
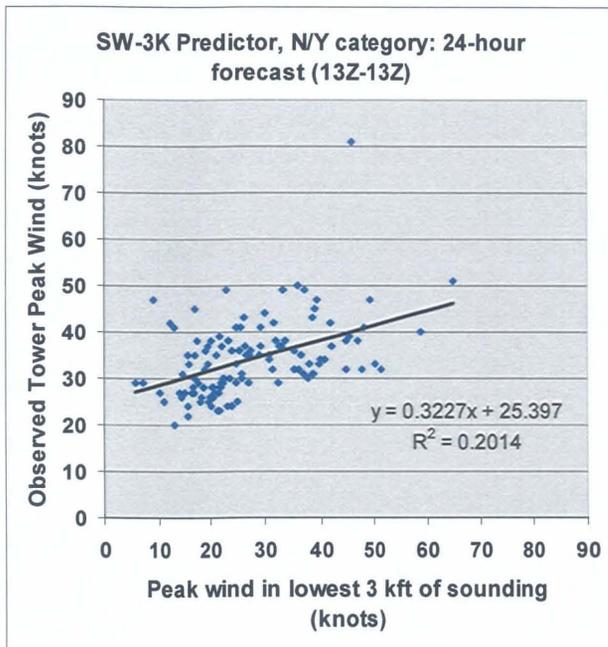


Figure 17. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when precipitation and no inversion are observed. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

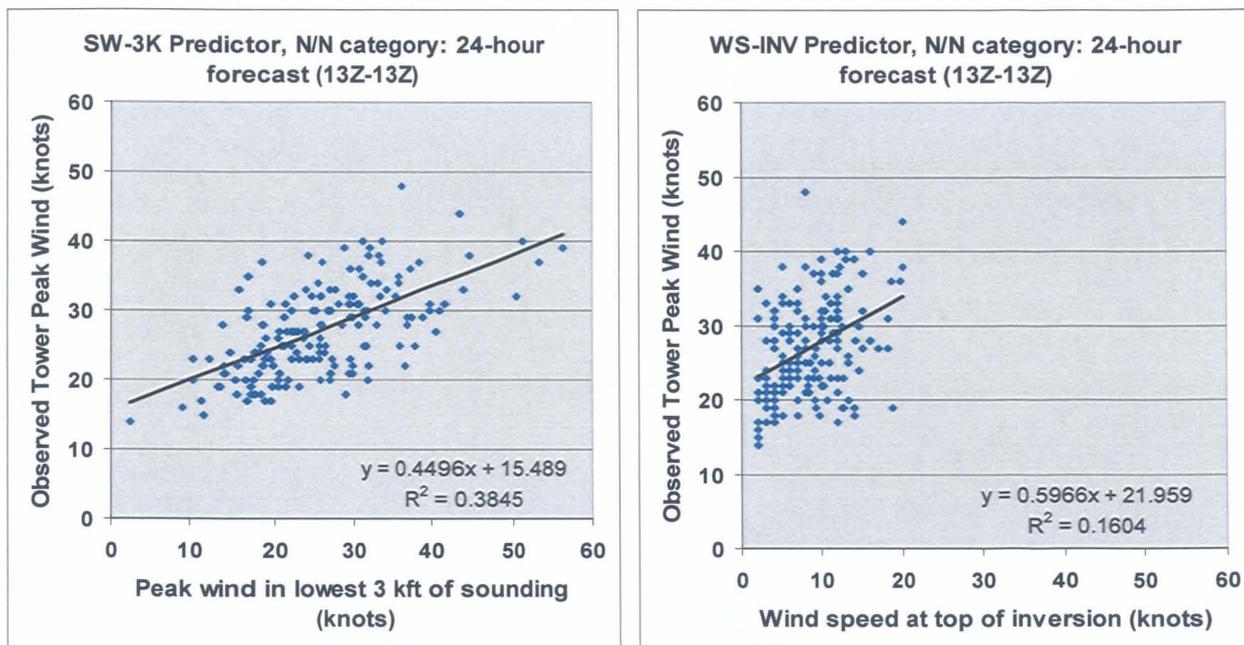


Figure 18. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when no inversion and no precipitation are observed. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

Figure 19 summarizes the skill of the predictors based on the inversion/precipitation stratification. For each of the four categories, there is a noticeable drop-off in R^2 from the 11-hour forecast to the 24-hour forecast. The SW-3K predictor has the highest R^2 values, followed by the SW-4K and SW-5K predictors. There is very little difference in MAE between the SW-5K, SW-4K, and SW-3K predictors. Overall, the SW-3K predictor is the best performer out of the four.

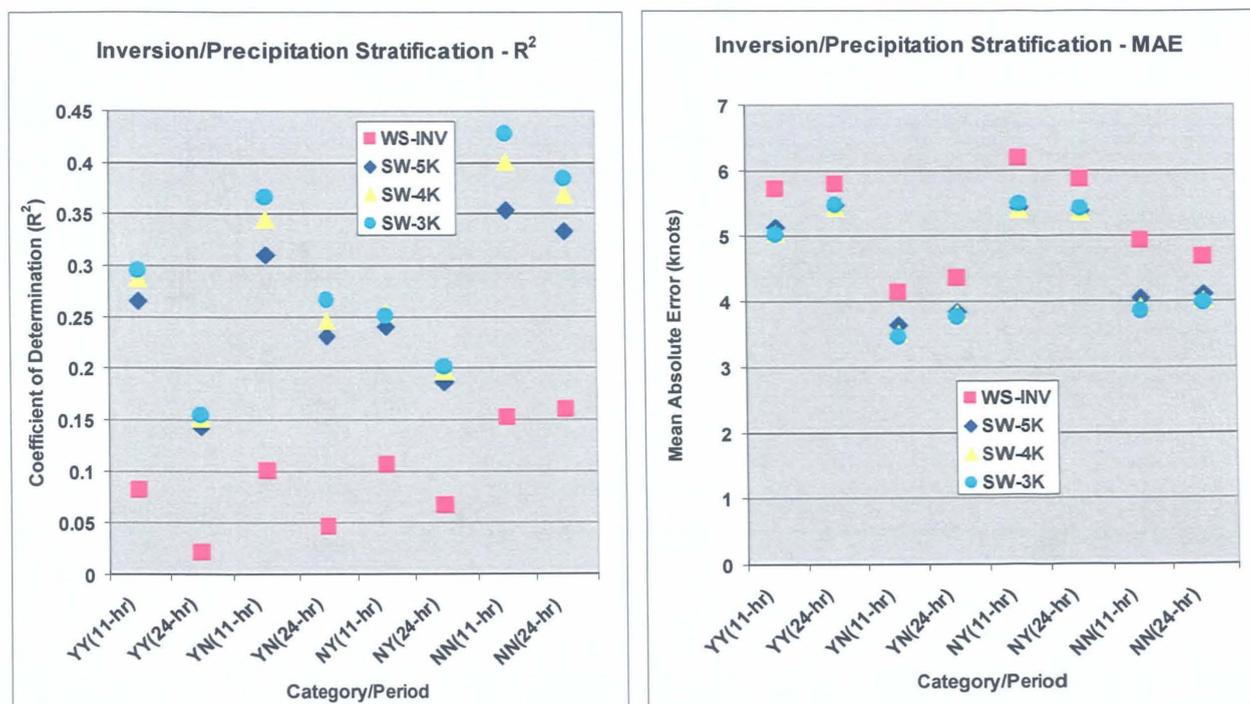


Figure 19. R^2 and MAE values for several predictors for the 11-hour and 24-hour periods, using the inversion/precipitation stratification.

3.1.3 Peak Wind Speed Equations Based on Synoptic Weather Pattern

As mentioned in Section 3.1, each day in the period of record was also classified into one of six categories according to the synoptic pattern at 1200 UTC that morning:

- 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 south of central Florida (P6).

Section 3.1 showed the number of days in each synoptic pattern during the period of record. Because of missing and erroneous observation data, the number of days in two of the categories differed between the 11-hour and 24-hour periods. For the 11-hour period, there were 294 days in P2 and 160 days in P6. For the 24-hour period, there were 289 days in category P2 and 158 days in category P6.

Figure 20 shows the composite wind profiles up to 5000 ft for the six synoptic weather patterns. Wind speeds from the surface to 4000 ft were similar for days with surface fronts approaching or across Florida (categories P4-P6). Winds were weakest when surface high pressure was over or near Florida (category P1). Figure 21 shows the composite temperature profiles for the synoptic patterns. Each weather pattern contained a surface-based temperature inversion, although the inversion was strongest when surface high pressure is across Florida (category P1). Therefore, it may take longer for the inversion to break on days with surface high pressure across Florida.

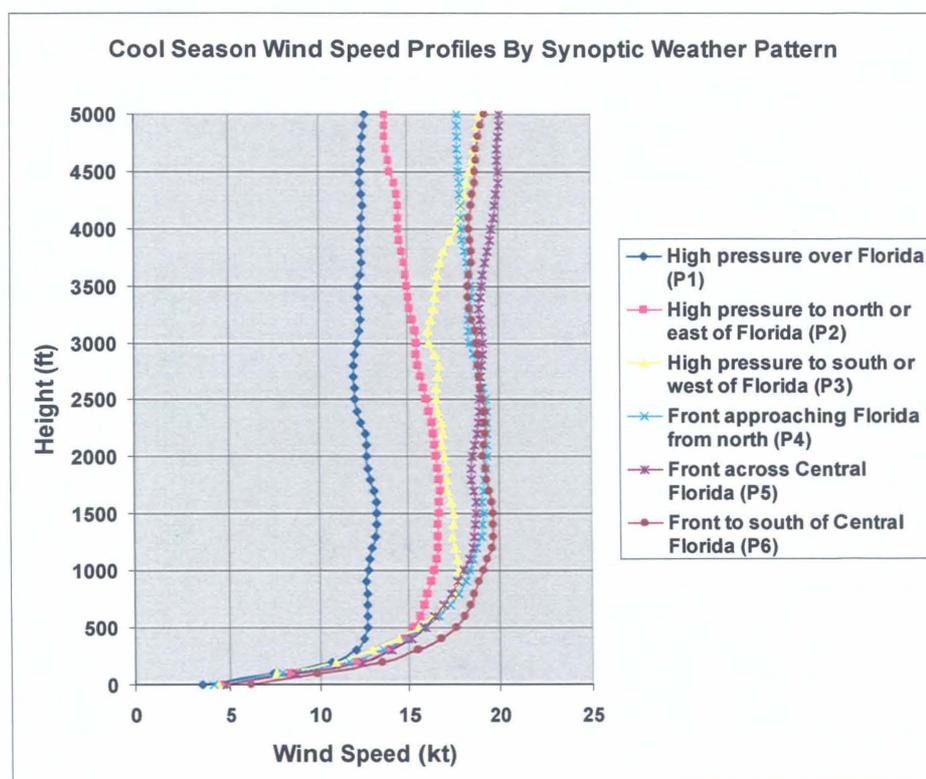


Figure 20. Average vertical profiles of wind speed (kts) for the six synoptic weather patterns. The legend shows the colors and symbols used for each profile.

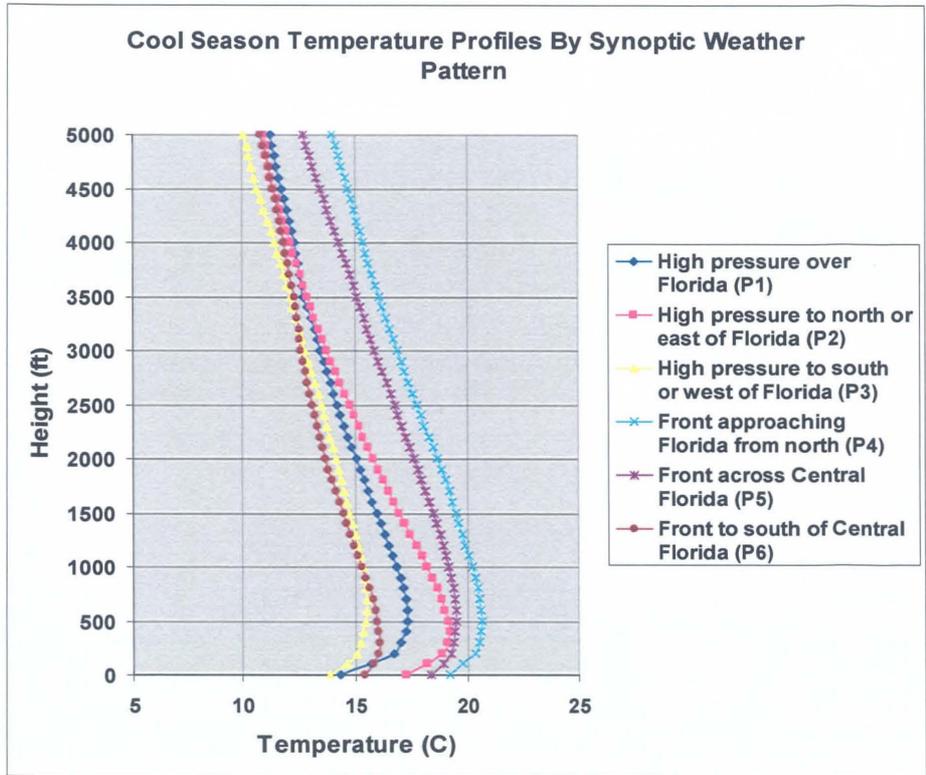


Figure 21. Average vertical profiles of temperature (C) for the six synoptic weather patterns. The legend shows the colors and symbols used for each profile.

For each of the six synoptic patterns, the same four predictors as in Section 3.1.2 were evaluated: SW-5K, SW-4K, SW-3K, and WS-INV. Figures 22-27 show scatter plots for the six categories. Just like the inversion/precipitation stratification, the SW-3K predictor tended to show the most skill, while the WS-INV predictor had the least skill. The predictability of the peak wind speeds varied with the synoptic pattern. The best skill occurred with easterly winds and high pressure to the north of Florida (category P2), while the least skill occurred with an approaching front (category P4). One possible explanation is that easterly winds indicate a slowly changing wind pattern, while a front indicates a more dynamic wind pattern.

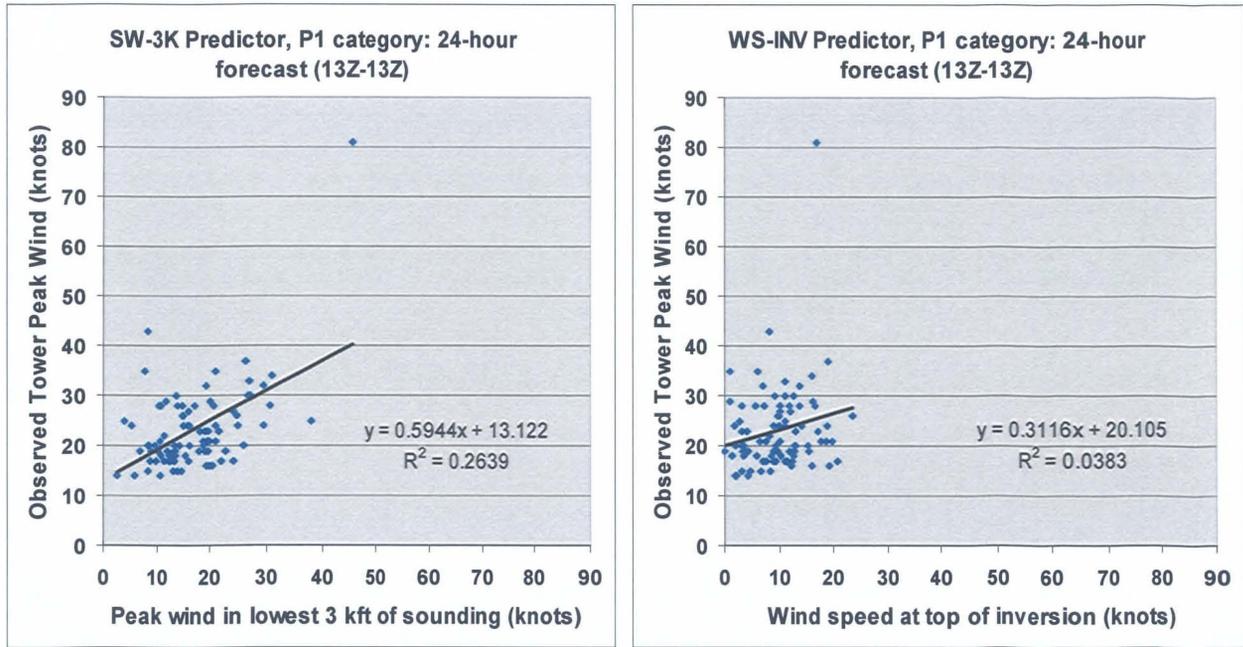


Figure 22. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when surface high pressure is across Florida. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

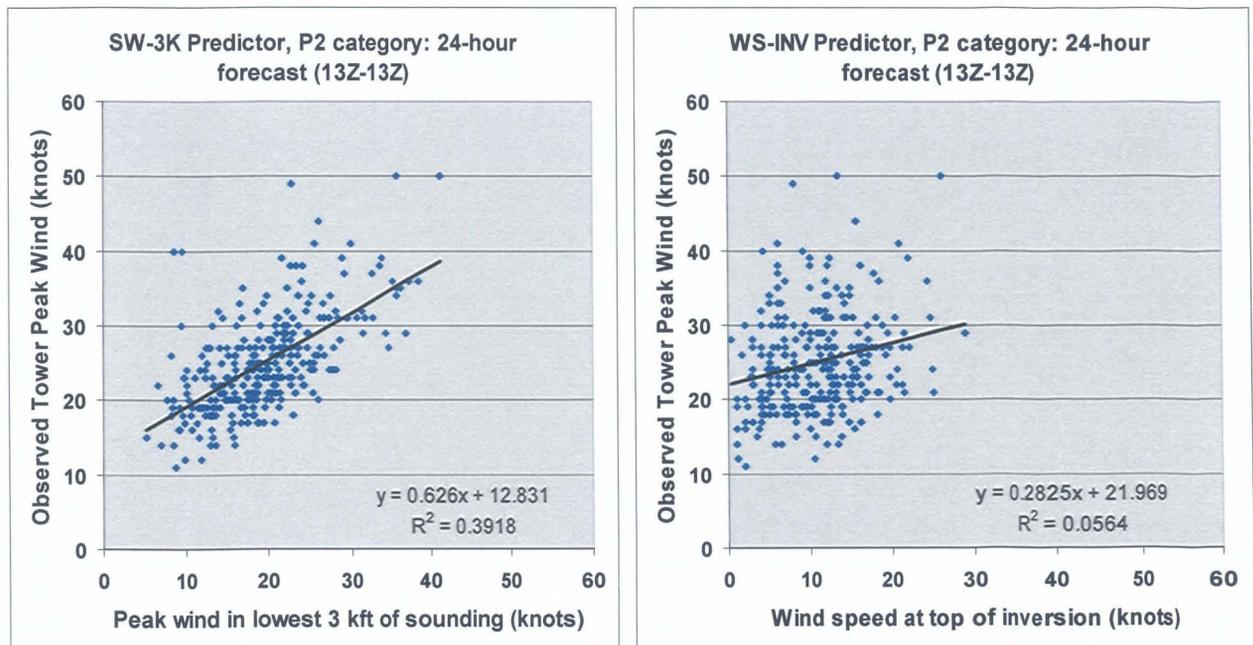


Figure 23. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when surface high pressure is north or east of Florida. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

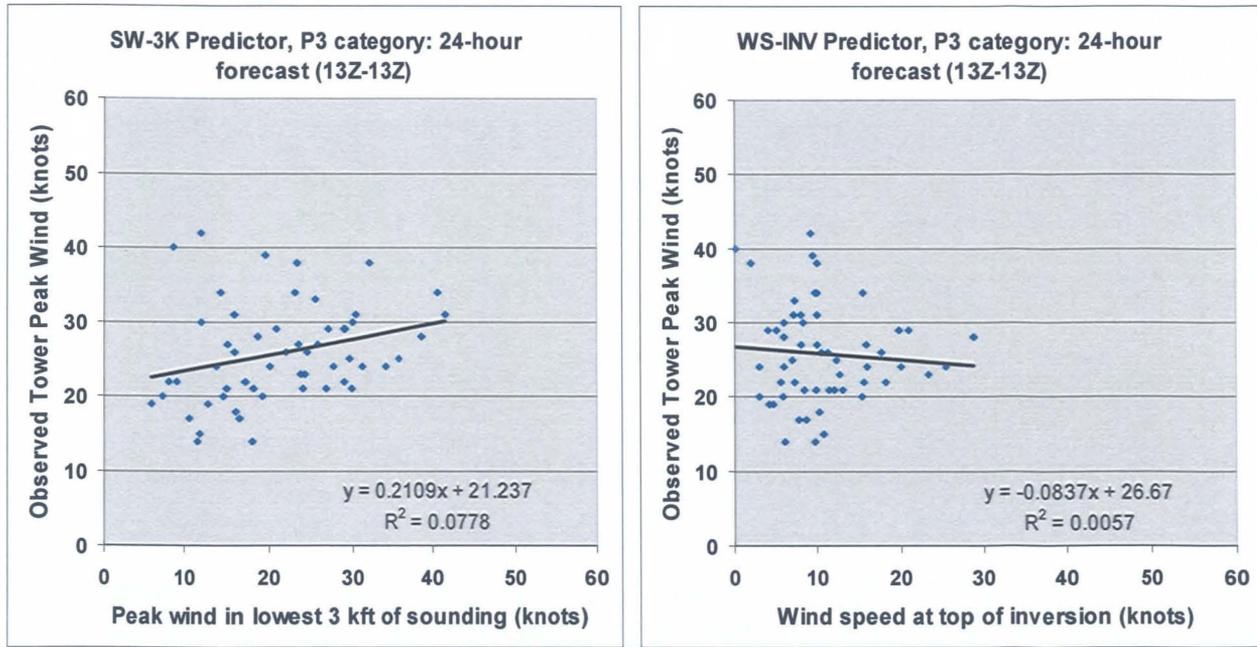


Figure 24. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when surface high pressure is south or west of Florida. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

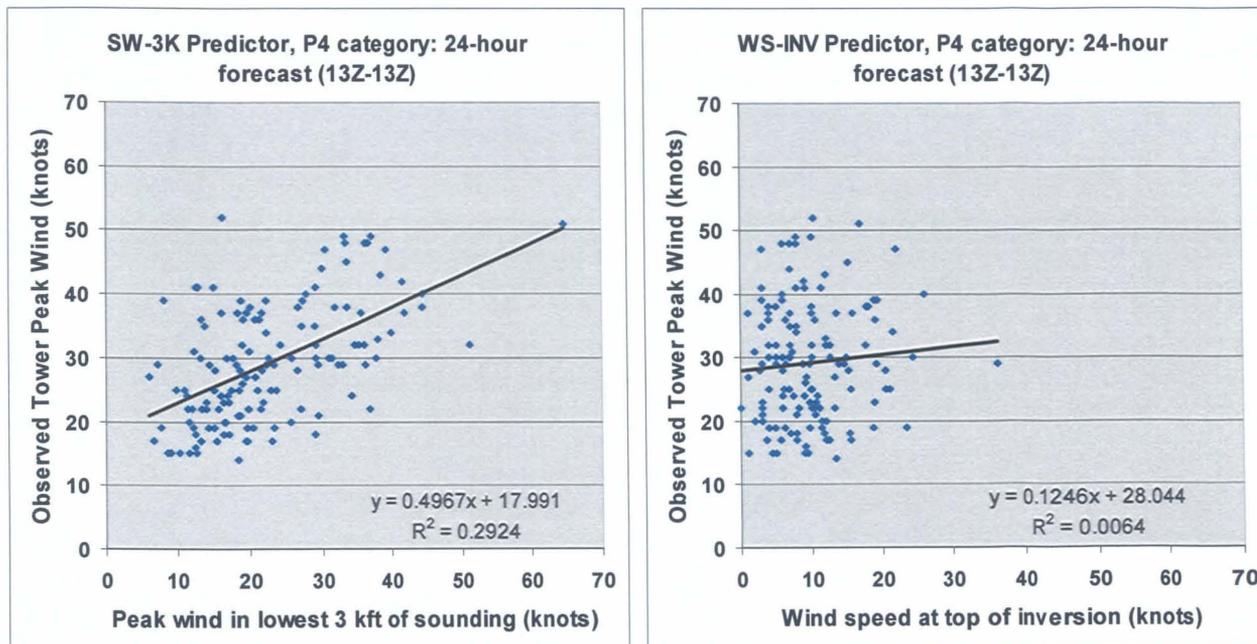


Figure 25. Scatter plots of observed PWSD versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when a front is approaching Florida from the north. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

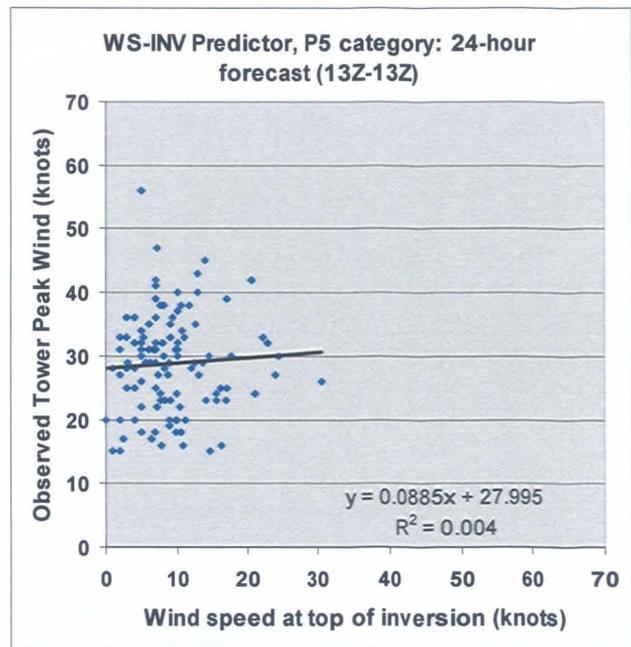
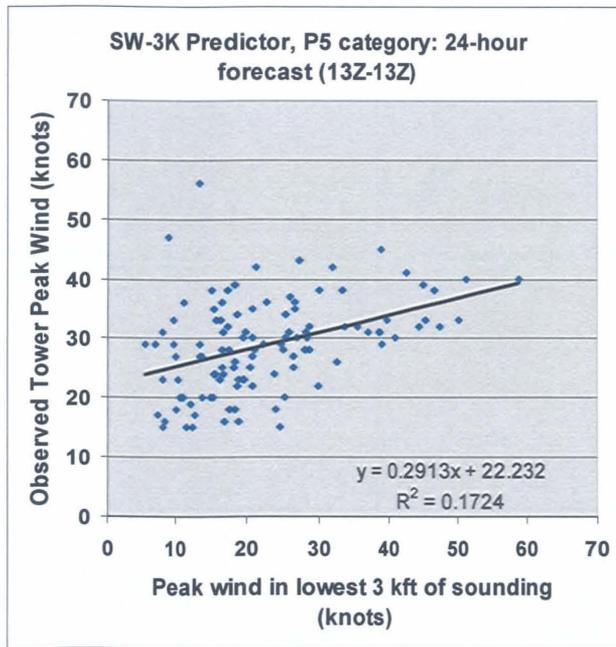


Figure 26. Scatter plots of observed PWSW versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when a front is across central Florida. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

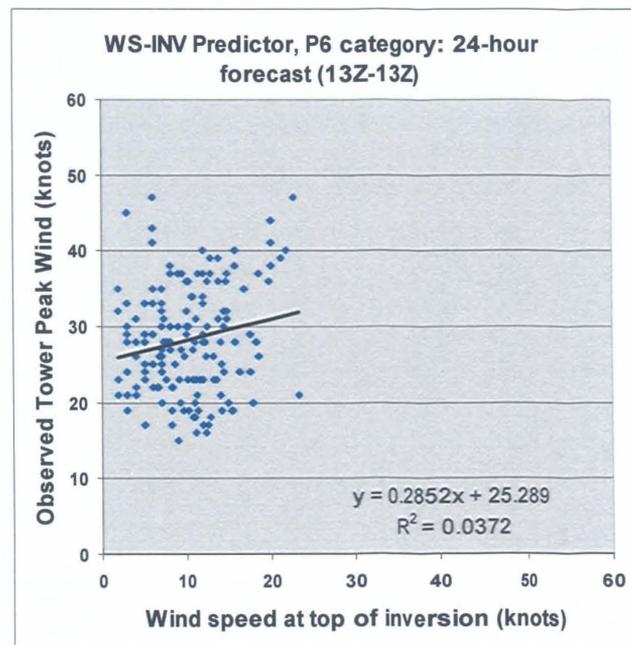
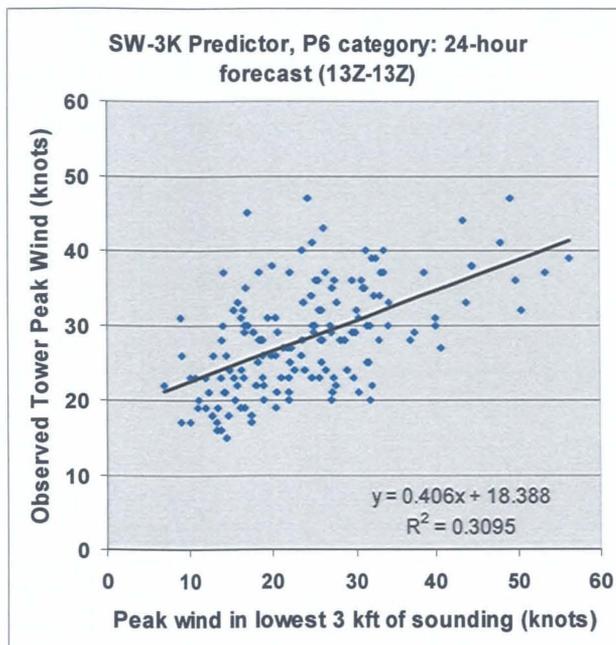


Figure 27. Scatter plots of observed PWSW versus strongest wind in the lowest 3000 ft of the sounding for the 11-hour and 24-hour periods, when a front is to the south of central Florida. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

Figure 28 summarizes the skill of the predictors based on the synoptic weather pattern stratification. For most of the six categories, there is a large drop-off in skill from the 11-hour forecast to the 24-hour forecast. There is very little difference in MAE between the SW-5K, SW-4K, and SW-3K predictors, just like the inversion/precipitation stratification. The skill of the predictors varies significantly between the different synoptic weather patterns. When a front is approaching or over central Florida (P4 and P5), the MAE of the best predictor (SW-3K) for the 24-hour period was greater than 5 kts. The lowest MAE occurred when surface high pressure is north or east of Florida (P2), with a 24-hour MAE near 4 kts.

Since all three prediction methods discussed in Sections 3.1.1-3.1.3 showed skill above persistence (compare Figure 4 with Figures 19 and 28), the forecast tool used an ensemble of all three methods. The forecast peak wind speed from each method was weighted by the inverse of the MAE. The weighted forecast peak wind speeds from the three methods were then averaged to give a final forecast peak wind speed.

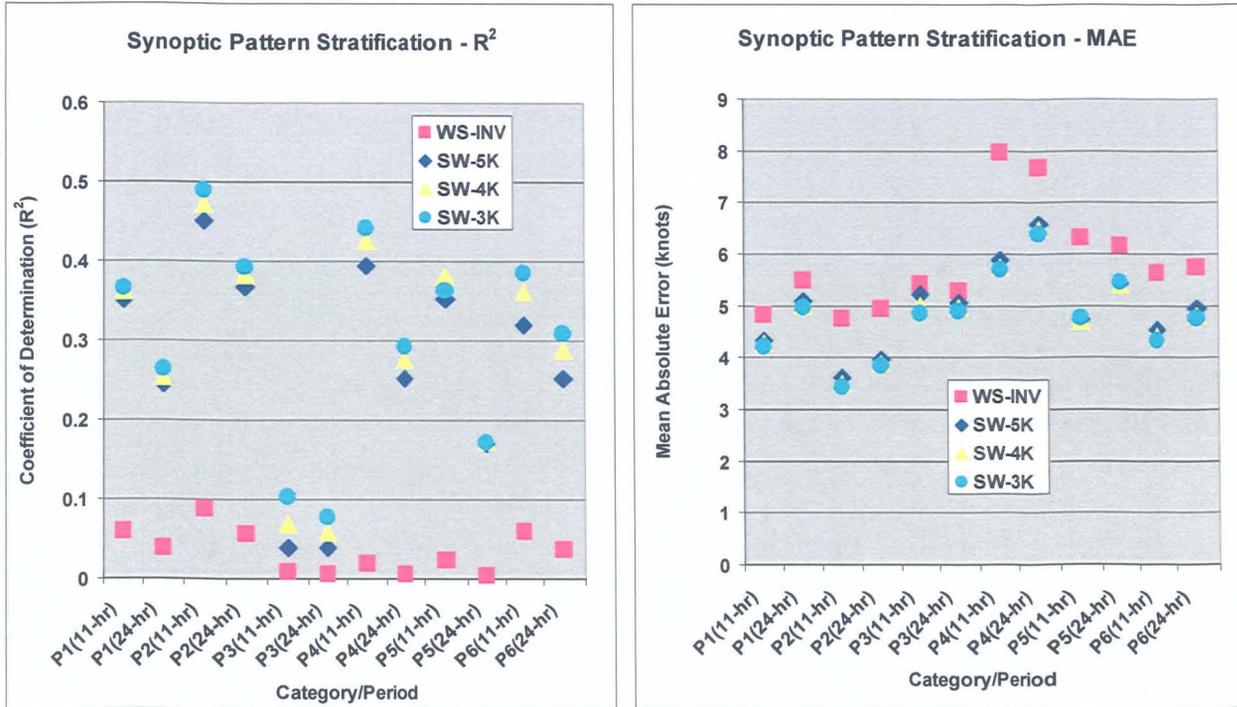


Figure 28. R² and MAE values for several predictors for the 11-hour and 24-hour periods, using the synoptic weather pattern stratification. P1 is days with surface high pressure across Florida, P2 is days with surface high pressure north or east of Florida, P3 is days with surface high pressure south or west of Florida, P4 is days with a front approaching Florida from the north, P5 is days with a front across central Florida, and P6 is days with a front to the south of central Florida. SW-3K to SW-5K = strongest wind in lowest 3000 to 5000 ft of the sounding, WS-INV = wind speed at top of inversion.

3.2 Average Wind Speed during Peak Wind Speed Occurrence

Only one regression equation was created to predict the 5-minute average wind speed at the time of the PWSD. The regression equation used the PWSD as the predictor and the average wind speed at the same time as the predictand. Figure 29 shows scatter plots of average wind speed as a function of peak wind speed for both the 11- and 24-hour periods. The forecast tool used the predicted peak wind speed as the predictor, which came from the three prediction methods discussed in Section 3.1.

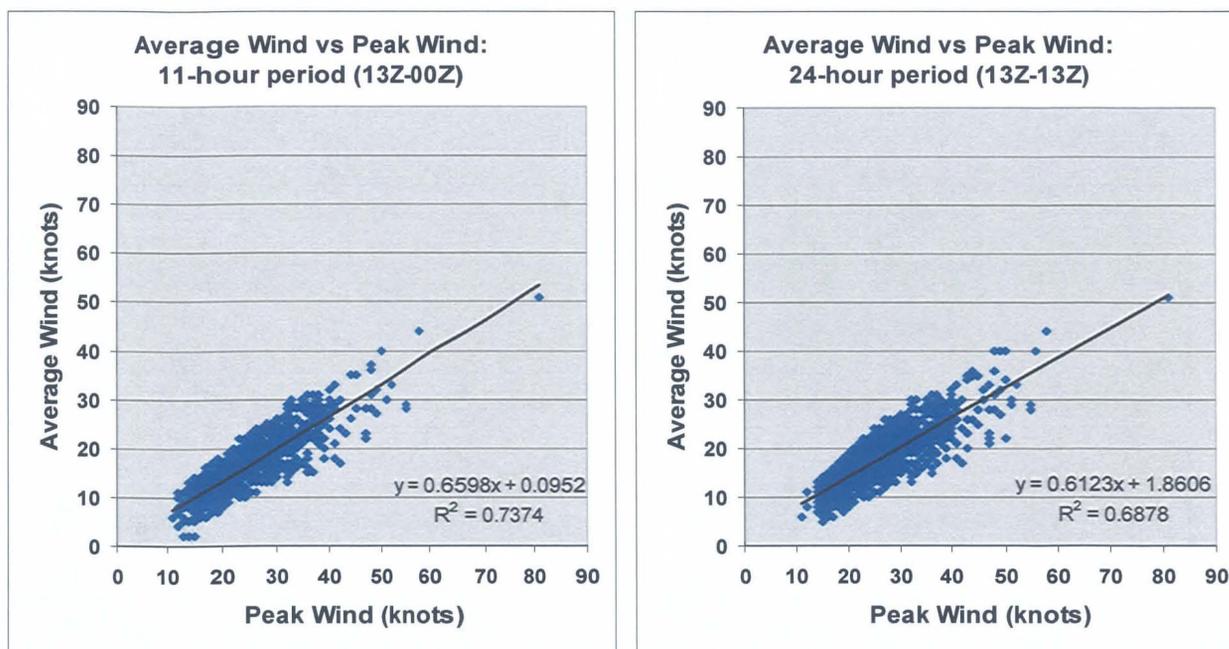


Figure 29. Observed 5-minute average wind speed versus peak wind speed for the 11-hour and 24-hour periods. The linear regression line, regression equation, and R^2 value are overlaid over the data points.

The AMU also performed a preliminary investigation of gust factors and their relationships with peak wind speed and sensor height. The relationships were very weak and showed little skill in forecasting the average wind speed.

3.3 Timing of Peak Wind Speed of the Day

Figure 30 and Figure 31 show the frequency of occurrence of the PWSD for each hour of the day. The afternoon hours had the highest frequency of occurrence. Three prediction methods were created to predict the timing of the PWSD. The forecast tool used the average time from the three methods. The first method was a multiple linear regression with inversion depth and inversion strength as predictors. The PWSD tended to occur later when the inversion was strong and deep. A strong and deep inversion may delay the PWSD until surface heating or temperature advection is sufficient to allow the inversion to break. The second prediction method stratified the data using the six synoptic patterns discussed in Section 3.1.3. The PWSD tended to occur the earliest with a front to the south of Florida, or with surface high pressure to the south or west of Florida. The PWSD tended to occur the latest with a front approaching Florida from the north, or surface high pressure across Florida. Further research is necessary to provide an explanation. The third prediction method stratified the data using the inversion/precipitation stratification discussed in Section 3.1.2. The PWSD occurred earliest on days with no inversion or precipitation.

The AMU evaluated the relationship between the PWSD and the timing of the PWSD, and this predictor exhibited less skill than the others (see Figure 32 and Figure 33). Table 2 summarizes the prediction methods that were evaluated for the timing of the PWSD.

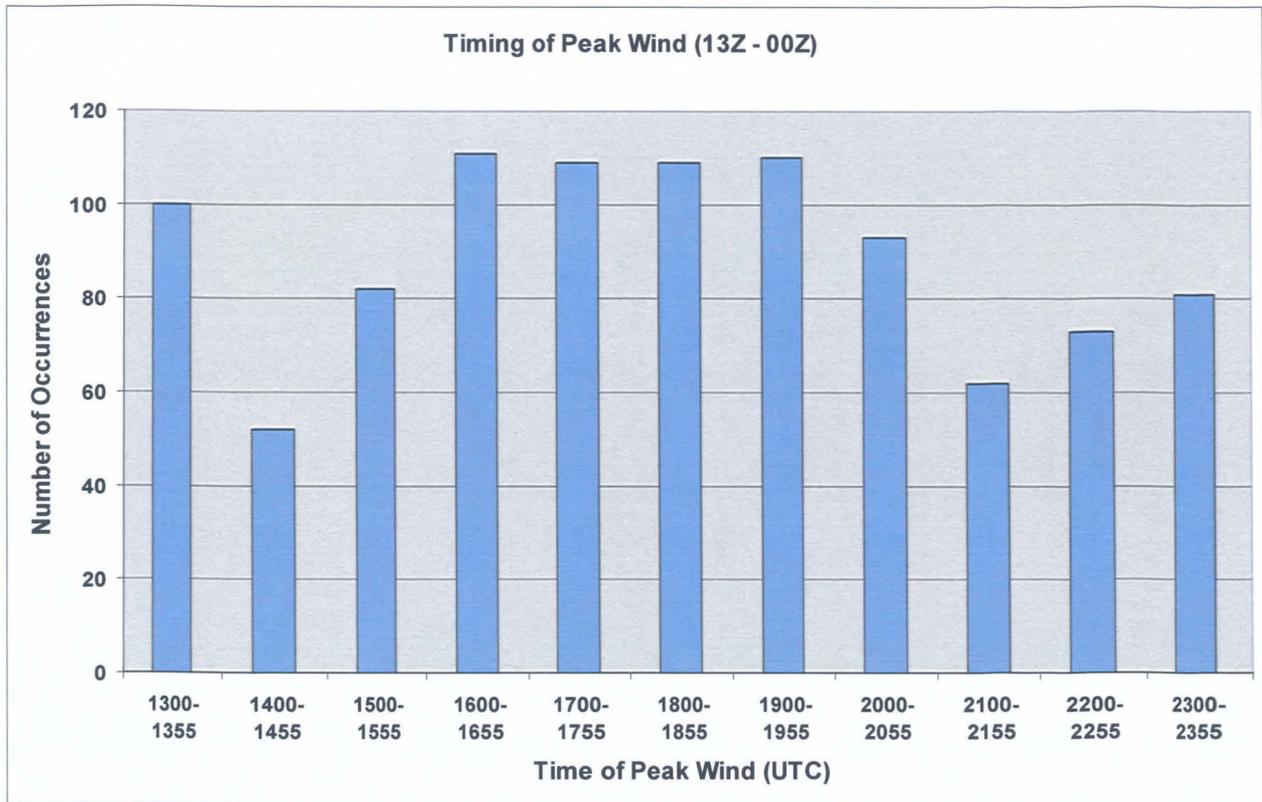


Figure 30. Frequency of the peak wind speed of the day per hour for the 11-hour period.

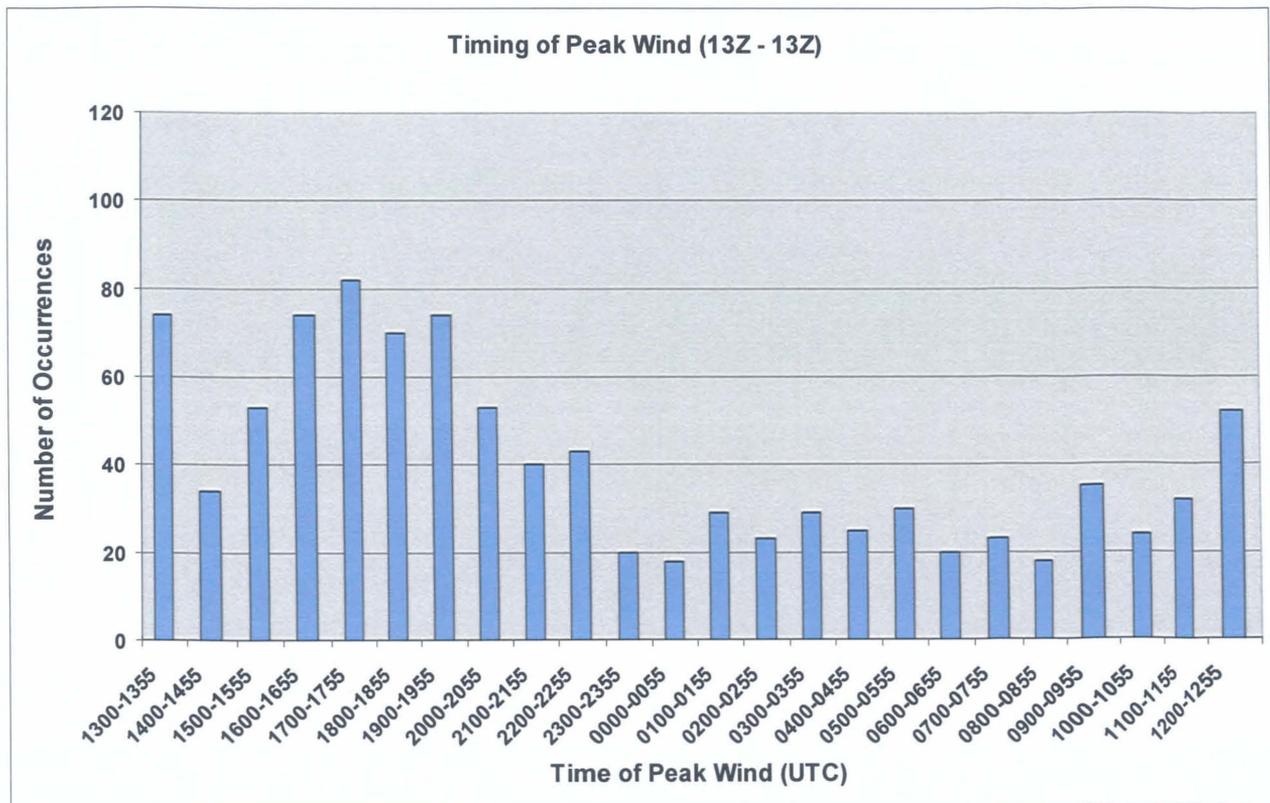


Figure 31. Frequency of the peak wind speed of the day per hour for the 24-hour period.

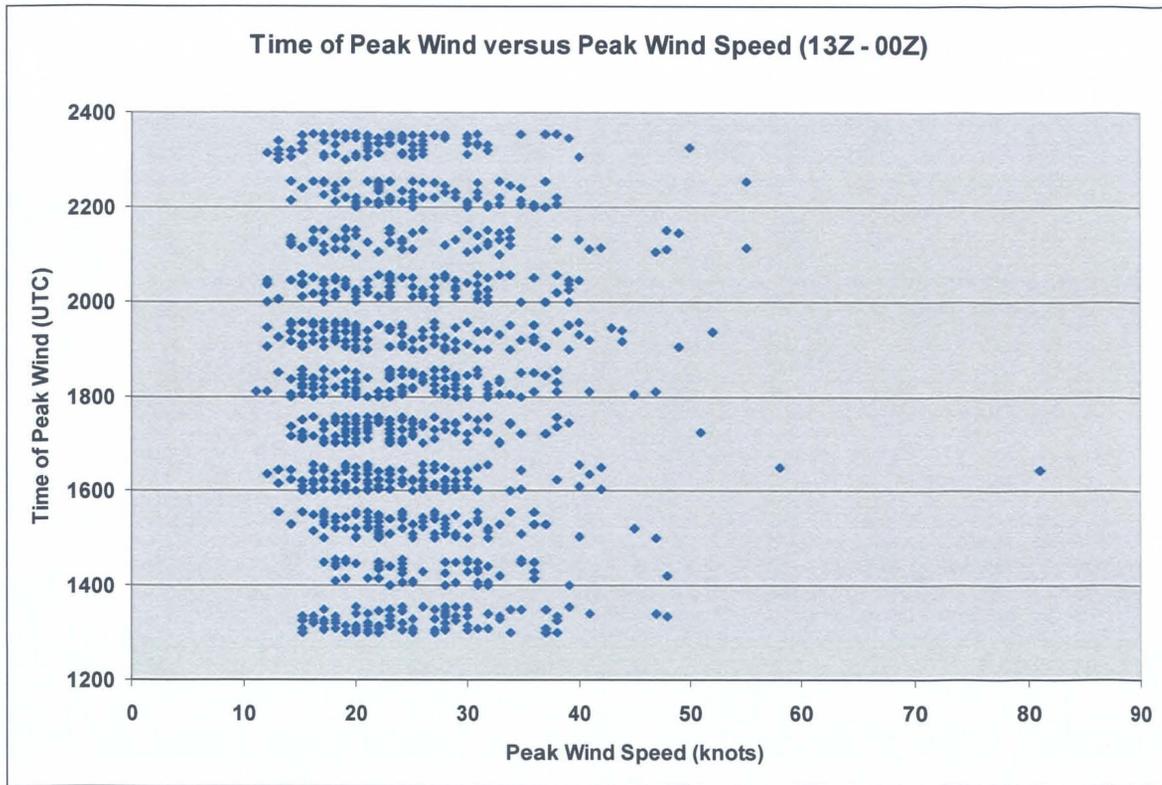


Figure 32. Scatter diagram showing the speed (knots) and time (UTC) of each observed PWSD in the task, for the 11-hour period.

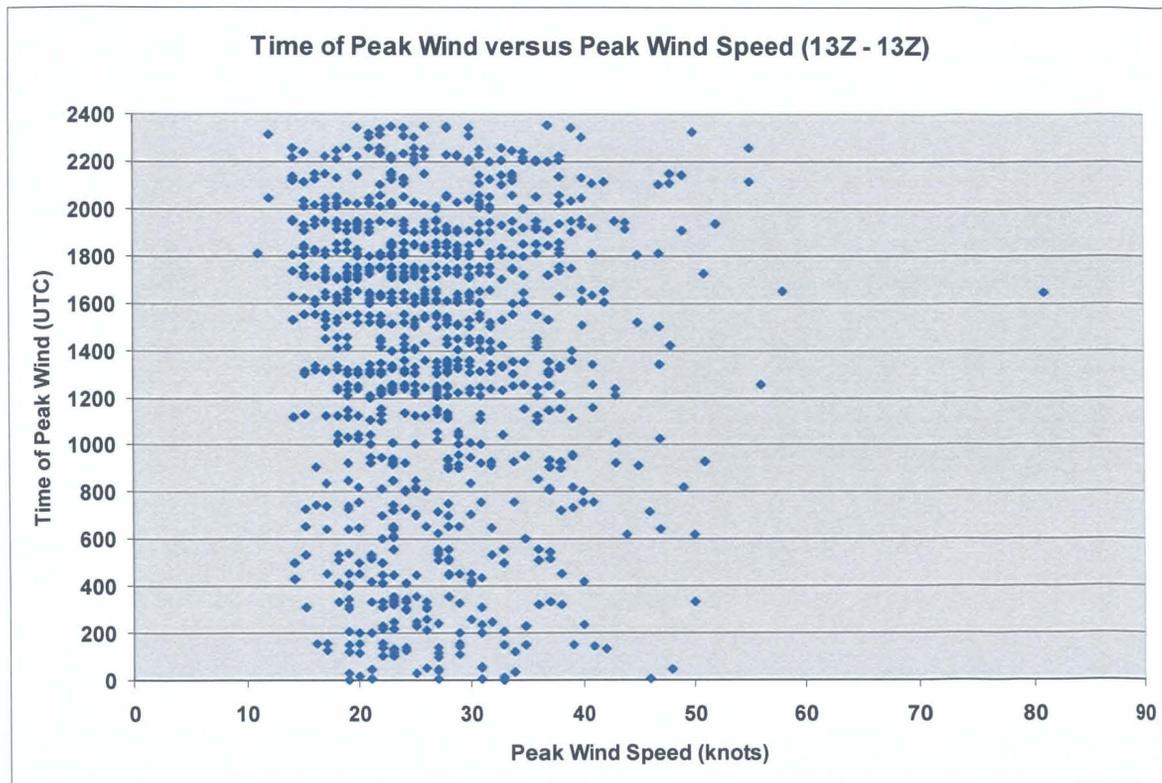


Figure 33. Scatter diagram showing the speed (knots) and time (UTC) of each observed PWSD in the task, for the 24-hour period.

Table 2. Predictors for Timing of PWSD.

<i>Predictor</i>	<i>Average Time (13Z-00Z)</i>	<i>Average Time (13Z-13Z)</i>
P1	1857 UTC	0033 UTC
P2	1809 UTC	2229 UTC
P3	1824 UTC	2128 UTC
P4	1900 UTC	0017 UTC
P5	1820 UTC	2234 UTC
P6	1749 UTC	2129 UTC
YY	1915 UTC	0109 UTC
YN	1832 UTC	2239 UTC
NY	1808 UTC	2257 UTC
NN	1732 UTC	2024 UTC
Peak Wind 10-20 kts	1828 UTC	2147 UTC
Peak Wind 21-30 kts	1811 UTC	2300 UTC
Peak Wind 31-40 kts	1833 UTC	2300 UTC
Peak Wind > 40 kts	1831 UTC	0003 UTC
INV-D = 0 ft	1755 UTC	2142 UTC
INV-D < 185 ft	1833 UTC	2235 UTC
185 ≤ INV-D < 385 ft	1830 UTC	2347 UTC
INV-D ≥ 385 ft	1852 UTC	0004 UTC
INV-S = 0 C	1755 UTC	2142 UTC
INV-S < 1.0 C	1810 UTC	2158 UTC
1.0 ≤ INV-S < 3.0 C	1834 UTC	2344 UTC
INV-S ≥ 3.0 C	1904 UTC	0009 UTC
P1-P6 = synoptic pattern category YY-NN = inversion/precipitation stratification category INV-D = inversion depth, INV-S = inversion strength		

3.4 Probability the Peak Wind Speed will Meet or Exceed the Warning Thresholds

The 45 WS developed a statistical method for estimating the probability that the peak wind speed will meet or exceed a given wind threshold. The method is based on the error bars of the linear regressions. The equation to predict the probability was derived from equations 4.29 and 6.22 from Wilks (2006):

$$\Phi(z) \approx \frac{1}{2} \left[1 \pm \sqrt{1 - e^{\left(\frac{-2z^2}{\pi}\right)}} \right]$$

Equation 4.29 of Wilks (2006). $\Phi(z)$ is the approximation to the standard Gaussian cumulative distribution function and z is the predicted value. The positive root is taken for $z \geq 0$ and the negative root is taken for $z < 0$. The maximum error in the equation is approximately 0.3%, which occurs at $z = \pm 1.65$.

$$s_{\hat{y}}^2 = s_e^2 \left[1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{\sum_{i=1}^n (x_i - \bar{x})^2} \right]$$

Equation 6.22 of Wilks (2006). $s_{\hat{y}}^2$ is the prediction variance for a forecast value of y using the predictor value x_0 . s_e^2 is the mean squared error, n is the sample size, \bar{x} is the observed mean, and x_i is an individual observation.

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

Equation that is used to calculate the probability that the peak wind speed will meet or exceed a given threshold, derived from Equations 4.29 and 6.22 of Wilks (2006). The equation gives the area under the right-side of the Gaussian curve. x is the threshold value (35, 50, or 60 kts), y is the predicted PWSD, and z is the predicted sigma (estimated error of the linear regression equation). The predicted sigma (z) is equal to $s_{\hat{y}}$ in Equation 6.22 of Wilks (2006). The + sign before the radical is used for $y \leq x$, and the - sign used for $y > x$. For each 45 WS wind warning threshold, three probability values are calculated from the three regression equations. The three probability values are then averaged, weighted by each equation's MAE.

As an example, Figure 34 shows a scatter plot of the observed peak wind speed versus wind speed from the XMR morning sounding. The solid red line depicts the linear regression line. The dotted light blue and red curves depict the values estimated to be one and two standard deviations (1σ and 2σ) away from the linear regression line. Based on Equation 6.22 of Wilks (2006), Table 3 displays the peak wind speeds that will be exceeded at 16% (at 1σ) and 2.3% (at 2σ) of the time, when the predicted peak wind speed is 20, 25, 30, and 35 kts. Using the third equation in this section, Table 4 displays the probability that the peak wind speed will meet or exceed 35, 50, and 60 kts, given various predicted peak wind speed and sigma values.

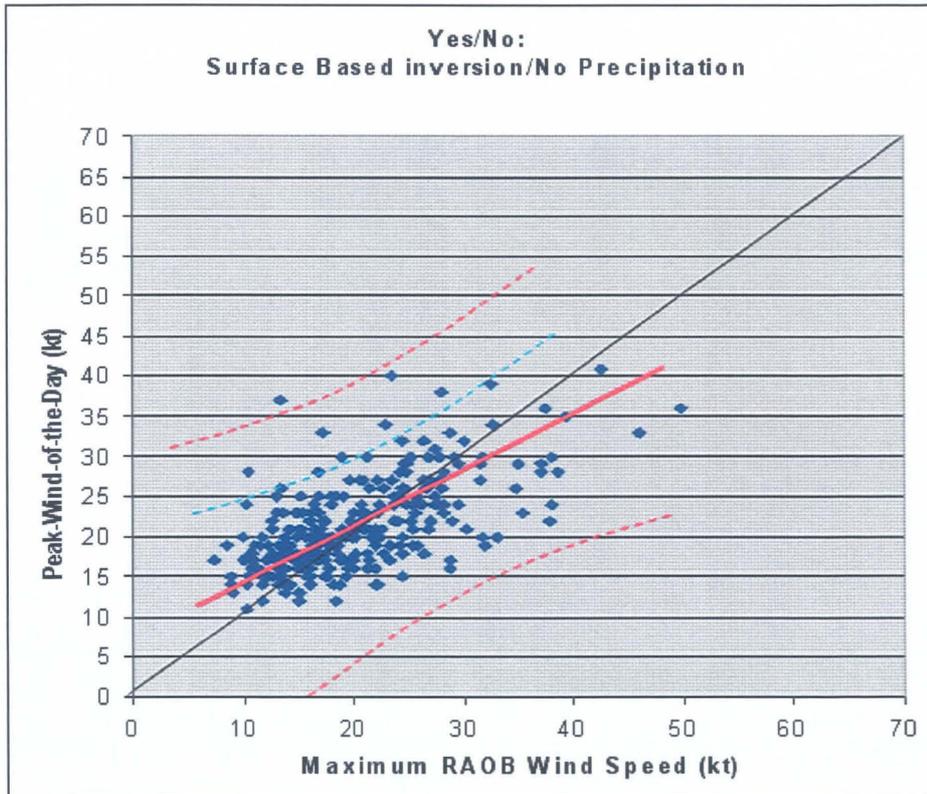


Figure 34. Scatter plot of the observed peak wind speed versus wind speed from the XMR morning sounding, for days in which the sounding contained a surface-based temperature inversion and no precipitation occurred. The dotted light blue and red curves depict the values estimated to be 1 σ and 2 σ away from the linear regression line.

Table 3. Predicted Peak Wind Speeds at 1 σ and 2 σ Prediction Intervals, based on the linear regression in Figure 34. The prediction intervals were manually estimated.

<i>Predicted Peak Wind Speed</i>	<i>Peak Wind Speed Exceeded 16% of Time (1σ)</i>	<i>Peak Wind Speed Exceeded 23% of Time (2σ)</i>
20 kts	29 kts	37 kts
25 kts	33 kts	43 kts
30 kts	40 kts	49 kts
35 kts	47 kts	57 kts

Table 4. Probability that the peak wind speed will meet or exceed 35, 50, and 60 kts, given various predicted peak wind speeds and predicted sigma values.

<i>Predicted Peak Wind Speed</i>	<i>Predicted Sigma</i>	<i>Probability ≥ 35 kt</i>	<i>Probability ≥ 50 kt</i>	<i>Probability ≥ 60 kt</i>
20 kts	5 kts	0.001	0.000	0.000
20 kts	10 kts	0.064	0.001	0.000
20 kts	15 kts	0.157	0.020	0.003
30 kts	5 kts	0.157	0.000	0.000
30 kts	10 kts	0.308	0.020	0.001
30 kts	15 kts	0.369	0.088	0.020
35 kts	5 kts	0.500	0.001	0.000
35 kts	10 kts	0.500	0.064	0.005
35 kts	15 kts	0.500	0.157	0.045
50 kts	10 kts	0.936	0.500	0.157
50 kts	25 kts	0.726	0.500	0.344
60 kts	10 kts	0.995	0.843	0.500
60 kts	25 kts	0.843	0.656	0.500
70 kts	32 kts	0.865	0.735	0.623

4. Graphical User Interface

The AMU created the Peak Wind Tool graphical user interface (GUI) in Microsoft Excel, using the Visual Basic for Applications programming language (VBA). The tool displays the speed and timing of the PWSD and average wind speed. In addition, the tool predicts the probability of meeting or exceeding the 45 WS’s warning thresholds for peak wind speeds of 35 kts, 50 kts, and 60 kts. Even though the 11-hour forecast (1300 – 0000 UTC) showed more skill than the 24-hour forecast (1300 – 1300 UTC), the 45 WS was only interested in displaying the 24-hour forecast. This is because the tool will be used for the planning forecast, valid from 0800 to 0800 local time.

To run the tool, the user first opens the Excel file (AMU_PeakWindTool_v8_oper_protected.xls). The user then navigates to the “Intro” worksheet and clicks the “Start Peak Wind Calculation” button (Figure 35). The input GUI is then displayed (Figure 36). After the forecaster finishes entering data, the output GUI displays the predicted values (Figure 36).

The GUI provides the following features:

- The PWSD, timing of the peak wind speed, 5-minute average wind speed at the time of the PWSD, and the MAE for the peak and average wind speeds. The PWSD is calculated from the weighted average of three prediction methods (Section 3.1). The timing of the peak wind speed is also the average of three prediction methods (Section 3.3). The average wind speed is calculated using the predicted peak wind speed (Section 3.2),
- The probabilities of exceeding the three warning thresholds were calculated using the 1- σ error estimates from the linear regressions (third equation in Section 3.4),
- 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.
- Print buttons so that forecasters can print out the results from the tool.
- User instructions and a Frequently Asked Questions (FAQ) page. The FAQ are shown in Appendix A.

Extensive testing was carried out on the tool to verify the accuracy of its calculations, as described in Appendix B. The Excel worksheets in the tool were protected with passwords, to prevent the forecasters from accidentally modifying the tool. The AMU delivered the tool to the 45 WS for testing and evaluation.

The screenshot shows an Excel spreadsheet with the following content:

- Row 11:** **Peak Wind Tool for General Forecasting**
- Row 12:** Developed by Applied Meteorology Unit
- Row 13:**
- Row 14:** **Start Peak Wind Calculation** (button)
- Row 19:** **Description of Peak Wind Tool for General Forecasting:**
- Row 21-24:** This is a graphical user interface (GUI) tool that allows the user to enter current data from the morning upper-air sounding and other observations, in order to calculate the speed and timing of the peak and average wind speed from 8:00 am today to 8:00 am tomorrow (local time).
- Row 25:** **Instructions on how to use the tool:**
- Row 26:** 1. Start the tool by clicking on the "Start Peak Wind Calculation" button.
- Row 28-29:** 2. The Peak Wind Calculation GUI is displayed with default input values. You must change the values based on current observations.
- Row 31-34:** 3. In the "Temperature Inversion up to 500 ft" section of the GUI, select the "Yes" radio button if the surface temperature in the morning sounding is cooler than the temperature at 500 ft. Select the "No" radio button if the surface temperature is equal to or warmer than the temperature at 500 ft.
- Row 35-38:** 4. In the "Precipitation Expected" section, select the "Yes" radio button if precipitation (rain, showers, thunderstorms, drizzle, etc.) is expected between 8:00 am today and 8:00 tomorrow (local time) across the KSC/CCAFS area. Otherwise, select the "No" radio button.
- Row 39-41:** 5. In the "Synoptic Pattern at 1200 UTC today" section, select the synoptic weather pattern that best represents the observed or expected weather at 1200 UTC today.
- Row 42-46:** 6. In the "Morning Sounding" section, select the "Yes" radio button if there is a surface-based temperature inversion in the morning sounding. Otherwise, select the "No" radio button. Notice that the text to the right of the first three listboxes in this section are greyed out when the "No" radio button is selected.
- Row 47-49:** 7. If the "Yes" radio button in the "Morning Sounding" section has been selected, then select the temperature (Celsius) at the top of the inversion. Next, select the surface temperature in the sounding. Select the height (ft) above ground level of the top of the inversion.
- Row 51-52:** 8. In the bottom listbox in the "Morning Sounding" section, select the strongest wind speed (kt) that was observed in the lowest 3,000 ft of the sounding.
- Row 54-57:** 9. After you have finished your input, click on the "Calculate Peak Wind" button. The Peak Wind Prediction GUI is displayed, showing the predicted peak wind speed, average wind speed, timing of the peak wind speed, and the probability that the peak wind speed will meet or exceed 35 kt, 50 kt, and 60 kt.
- Row 59-60:** 10. Click on the "Return to Start" button to return to the Peak Wind Calculation GUI. You can re-enter values to make another prediction, or exit out of the tool by clicking on the "Cancel" button.

Figure 35. Excel worksheet that the peak wind tool is run from. To start the tool, the “Start Peak Wind Calculation” button is selected.

Peak Wind Calculation

Temperature Inversion up to 500 ft

Yes In the morning sounding, is the surface temperature cooler than the temperature at 500 feet, AGL?

No

Precipitation Expected

Yes Is precipitation expected over the KSC/CCAFS area today?

No

Synoptic Pattern at 1200 UTC today

Surface high near or over Florida, variable wind direction

Surface high north or east of Florida, with east wind

Surface high south or west of Florida, with west wind

Surface front approaching Florida from north

Surface front over central Florida

Surface front across south Florida

Morning Sounding

0.7
0.8
0.9
1

Temperature at top of surface-based inversion in degrees Celsius.

-0.3
-0.2
-0.1
0

Surface temperature in degrees Celsius.

100
200
300
400

Height of top of surface-based inversion in feet, AGL.

Yes Is there a surface-based temperature inversion?

No

17
18
19
20

Strongest wind speed in lowest 3 kft of sounding, in knots.

Print Input Cancel Calculate Peak Wind

Peak Wind Prediction

Peak Wind Speed (13Z-13Z)

Peak Wind Speed knots Mean Absolute Error knots

5-Minute Average Wind Speed (13Z-13Z)

Based on the expected peak wind speed, the 5-minute average wind speed at the time of the peak wind speed is:

Average Wind Speed knots Mean absolute error knots

Time of Peak Wind (13Z-13Z)

Peak Wind Speed Time UTC

Probability of Peak Wind Meeting or Exceeding Thresholds

35 knots percent

50 knots percent

60 knots percent

Print Output Return To Start

Figure 36. The input GUI (on the left) displays the default input values. The output GUI (on the right) displays 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.

5. Summary and Future Work

The 45 WS's daily 24-Hour and Weekly Planning Forecasts are used for ground and space launch operations at KSC and CCAFS. The 45 WS forecasters have indicated peak wind speeds are challenging to forecast. The AMU developed a new tool to help the 45 WS make forecasts of non-convective daily peak winds from the surface to 300

ft during the cool season months, October-April. The tool also forecasts the timing of the daily peak wind and its associated average wind, as well as the probability that the peak wind will meet or exceed 35 kts, 50 kts, and 60 kts.

5.1 Summary

The AMU evaluated several candidate predictors for each of the tool's forecast parameters. Three separate prediction methods were developed for the PWSD forecast. The first method used a multiple linear regression with three predictors: strongest wind in the lowest 3000 ft of the sounding, inversion depth, and inversion strength. The second method used the strongest wind in the lowest 3000 ft as the predictor, and used one of four linear regression equations corresponding to these four categories:

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

The third method also used the strongest wind in the lowest 3000 ft as the predictor, and used one of six linear regression equations corresponding to the synoptic weather pattern:

- 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 final predicted PWSD used the average of the three methods, weighted by each method's MAE.

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

The timing of the PWSD 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 PWSD used the average of the three methods.

The AMU also developed a GUI to manage the inputs, calculations, and display of the final results. The GUI displays the expected PWSD, its timing, and the average wind speed associated with the peak wind. The GUI also displays the probability of meeting or exceeding the three wind warnings issued by the 45 WS: 35 kts, 50 kts, and 60 kts. The probability calculations used the estimated error of the linear regression equations for peak wind speed.

5.2 Future Work

The AMU will perform a follow-on task to include the following improvement to the forecast tool:

- Add observations from October 1996 - April 2002 and March 2007 - April 2008 in order to increase the sample data set,
- Evaluate additional predictors from the XMR morning sounding, including wind speeds between 500 and 3000 ft, stability classification, Bulk Richardson Number, mixing depth, vertical wind shear, and wind direction,
- Compare the performance of the current tool with the new version,
- Compare the performance of the tool with at least two seasons' worth of wind warnings/advisories issued by the 45 WS, and

- Transition the tool to the Meteorological Interactive Data Display System (MIDDS) to use weather model data to provide 5-day forecasts.

The 2-year follow-on task is expected to begin this summer and end in summer or early fall of 2010.

Appendix A

Frequently Asked Questions on the Forecast Tool

1. General Questions

Q1. I can open the Excel spreadsheet, but when I click on the "Start Peak Wind Calculation" button, nothing happens.

A1. Macros (such as the Peak Wind tool) are probably disabled. When you open up the spreadsheet, you should get a dialog box asking whether to allow macros. Select the Enable Macros button. You can also change the security level in Excel to allow macros to run. Go to Tools -> Macro -> Security. Decrease the security level if macros will not run.

Q2. When I close or exit the Excel spreadsheet, I get prompted to save the file. What should I do?

A2. Since the file is protected from modification, it does not matter whether you save the file or not.

Q3. During what time of year can I use the tool?

A3. The tool was developed using past data during the cool season months (October to April) from October 2002 to February 2007. Therefore, the tool should only be used between October and April.

Q4. Can I use the tool for forecasting beyond the day one forecast?

A4. Yes, but you will have to estimate the future observed data based on model forecasts.

Q5. I used the default input values, but I received an error message that I was missing input data.

A5. When you first begin a session using the tool, you must select data from the listboxes even though there are default selections. This is a "feature" of GUIs that are created in Excel.

Q6. Can I use the tool to predict the daytime peak wind (i.e. from 8:00 am today to 8:00 pm today)?

A6. No. The tool was developed to predict the peak wind between 8:00 am today and 8:00 am tomorrow.

2. Sounding data

Q1. Can I only use the Cape Canaveral Air Force Station (CCAFS) sounding (KXMR)?

A1. The tool was developed using sounding data from KXMR, so it is preferred that other soundings not be used. However, if the KXMR sounding is missing or late, you can use a nearby sounding (such as KJAX or KTBW) if you believe it is representative of the conditions at CCAFS. Also, you can use model data to represent the sounding.

Q2. Can I use a sounding from last night or yesterday afternoon?

A2. No. The tool was developed using sounding data between 0930 and 1230 UTC. The tool should only use observed data in that time period.

3. "Temperature Inversion up to 500 ft" section of the Peak Wind Calculation GUI

Q1. Why does the inversion have to extend up to 500 ft?

A1. This is to ignore shallow and weak temperature inversions that often occur in the morning soundings during the cool season.

Q2. How does the presence of an inversion affect the peak wind?

A2. An inversion will act to decrease the peak wind speed and delay the occurrence of the peak wind.

Q3. What if there is a morning sounding, but no data at 500 ft?

A3. You can estimate the data at 500 ft using interpolation.

4. "Precipitation Expected" section of the Peak Wind Calculation GUI

Q1. During what time period is the precipitation forecast for?

A1. The precipitation forecast is for the period from 8:00 am today to 8:00 am tomorrow (local time).

Q2. For what chance of rain should I select "Yes" for precipitation expected?

A2. Since the peak wind forecast is for the entire KSC/CCAFS area, you probably should select "Yes" if the chance of rain is 30% or greater or if showers will cover at least 30% of the KSC/CCAFS area.

Q3. How does precipitation affect the peak wind?

A3. Precipitation will increase the peak wind speed, since it can allow stronger winds aloft to mix down towards the surface. Precipitation tends to delay the occurrence of the peak wind. The tool was not designed for convective wind gusts, so the tool will underestimate the peak wind speed from strong showers or thunderstorms.

5. "Synoptic Pattern at 1200 UTC today" section of the Peak Wind Calculation GUI

Q1. What do I do if the synoptic pattern is changing?

A1. Only use the synoptic pattern at 1200 UTC today.

Q2. Does the tool take into effect the strength or timing of surface fronts?

A2. No. Since the tool only provides a "first-guess", you may have to adjust the timing of the peak wind because of the movement of fronts or other weather features. You may want to increase the peak wind for fronts that are associated with strong pressure gradients.

Q3. If there is a surface front across the Florida Keys or northern Cuba, should I select the "Surface front across south Florida" radio button?

A3. Yes, if no other synoptic pattern fits better.

Q4. There is a cold front over north Florida that is approaching central Florida. Should I select the "Surface front approaching Florida from north" radio button?

A4. Yes, if no other synoptic pattern fits better.

Q5. How does the synoptic pattern affect the peak wind speed?

A5. The skill in predicting peak wind speed varies with the synoptic pattern. During the development of the tool, it was observed that the best skill occurred with high pressure over or north of Florida, while the least skill occurred when a surface front was across Florida.

Q6. How does the synoptic pattern affect the timing of the peak wind?

A6. The peak wind tends to occur the earliest when there is a surface high south or west of Florida or when a surface front is across south Florida. It tends to occur the latest when surface high pressure is near or over Florida or when a surface front is approaching Florida from the north.

6. "Morning Sounding" section of the Peak Wind Calculation GUI

Q1. What is the point of asking if there is a surface-based temperature inversion, when there was already a question on whether there is a temperature inversion up to 500 ft?

A1. The Morning Sounding section is used to determine the strength and depth of a surface-based temperature inversion. It is possible that the inversion only extends to 400 ft or less.

Q2. Will the tool allow me to select "No" in the "Temperature Inversion up to 500 ft" section, and then have the top of the inversion above 500 ft?

A2. Yes. For the most part, the tool assumes that you are entering the data correctly. However, the tool will not allow you to enter the surface temperature, temperature at the top of the inversion and the inversion depth, if there is no surface-based inversion. If there is a surface-based inversion, the tool will not allow you to have a surface temperature that is equal to or warmer than the top of the inversion.

Q3. Why am I entering the strongest wind in the lowest 3,000 ft of the sounding?

A3. During the development of the tool, it was determined that this was a useful predictor of the peak wind speed. As expected, increasing the strongest wind in the lowest 3,000 ft of the sounding will increase the predicted peak wind speed.

Q4. How do the surface/top of inversion temperatures and inversion top affect the peak wind?

A4. The temperatures are used to calculate the strength of the inversion, in degrees Celsius. The height of the inversion top is used for the inversion depth. A strong and deep inversion is associated with weaker peak wind speeds and a delay in the peak wind.

7. Peak Wind Prediction GUI

Q1. How is the mean absolute error calculated for the peak wind speed and average wind speed.

A1. The mean absolute error values are calculated from the regression equations that calculate the peak and average wind speeds.

Q2. How can I use the mean absolute error?

A2. The mean absolute error will give you a rough idea of the range of the predicted values. For example, assume that the predicted peak wind speed is 30 kt, with a mean absolute error of 4 kt. Most of the time, the observed peak wind speed will lie between 26 kt and 34 kt. However, there will be times in which the peak wind speed is much lower or higher than 30 kt.

Q3. How does the tool calculate the probability that the peak wind speed will meet or exceed the different warning thresholds?

A3. The probabilities are calculated from the predicted peak wind speed and the estimated error in the regression equations.

Q4. Over what time period is the peak wind speed calculated?

A4. The peak wind speed is the fastest speed over a 1-second period.

Appendix B

Test Procedures for the Peak Wind Tool for General Forecasting ENSCO, Applied Meteorology Unit (AMU)

date – 12/31/2007 – 1/4/2008

*version – AMU_PeakWindTool_v7.xls

language – Microsoft Excel Visual Basic for Applications (VBA)

platform – Windows XP running Microsoft Excel 2003

tester - Joe Barrett, AMU

location - Applied Meteorology Unit, ROCC, Rm. 151

*Note – an upgrade to v8 was later created so that the user can print out the input and output GUIs.

1. Verify the accuracy of the tool with manual calculations (used both operational and test versions of the tool)

Description: Verify the accuracy of the calculations done by the tool, by manually calculating the peak wind, average wind, and probability that the peak wind speed will meet or exceed 35, 50, and 60 kts. Use all six synoptic pattern and four inversion/precipitation categories. It is not necessary to use every combination of the two stratifications.

- a) Temperature inversion up to 500 ft = Yes
Precipitation Expected = Yes
Synoptic Pattern = surface high north or east of FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 27.0 kts, MAE = 4.7 kts

AWS = 18.4 kts, MAE = 2.6 kts

PWST = 2320 UTC

≥ 35 kts = 10.7% (p35All = 9.6%, p35InvP = 23.1%, p35Syn = 2.7%)

≥ 50 kts = 0.0%

Manual output:

PWS = 27.05 kts, MAE = 4.746 kts

AWS = 18.39 kts, MAE = 2.642 kts

PWST = 2320 UTC

≥ 35 kts = 10.7% (p35All = 9.6%, p35InvP = 23.2%, p35Syn = 2.75%)

≥ 50 kts = 0.0%

- b) Temperature inversion up to 500 ft = Yes
Precipitation Expected = No
Synoptic Pattern = surface high near or over FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 24.9 kts, MAE = 4.6 kts

AWS = 17.1 kts, MAE = 2.6 kts

PWST = 2311 UTC

≥ 35 kts = 5.8% (p35All = 9.6%, p35InvP = 0.76%, p35Syn = 8.5%)

≥ 50 kts = 0.0%

Manual output:

PWS = 24.91 kts, MAE = 4.552 kts

AWS = 17.111 kts, MAE = 2.642 kts

PWST = 2311 UTC

≥ 35 kts = 5.76% (p35All = 9.61%, p35InvP = 0.75%, p35Syn = 8.45%)

≥ 50 kts = 0.0%

- c) Temperature inversion up to 500 ft = No
Precipitation Expected = Yes
Synoptic Pattern = surface high south or west of FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 27.8 kts, MAE = 5.1 kts

AWS = 18.9 kts, MAE = 2.6 kts

PWST = 2215 UTC

Manual output:

PWS = 27.85 kts, MAE = 5.078 kts

AWS = 18.88 kts, MAE = 2.642 kts

PWST = 2216 UTC

- d) Temperature inversion up to 500 ft = No
Precipitation Expected = No
Synoptic Pattern = surface front approaching FL from north
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 26.1 kts, MAE = 5.1 kts

AWS = 17.8 kts, MAE = 2.6 kts

PWST = 2221 UTC

Manual output:

PWS = 26.07 kts, MAE = 5.099 kts

AWS = 17.84 kts, MAE = 2.642 kts

PWST = 2221 UTC

- e) Temperature inversion up to 500 ft = Yes
Precipitation Expected = Yes
Synoptic Pattern = surface front over central FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 28.1 kts, MAE = 5.3 kts
AWS = 19.1 kts, MAE = 2.6 kts
PWST = 2321 UTC

Manual output:

PWS = 28.15 kts, MAE = 5.282 kts
AWS = 19.07 kts, MAE = 2.642 kts
PWST = 2322 UTC

- f) Temperature inversion up to 500 ft = Yes
Precipitation Expected = No
Synoptic Pattern = surface front across south FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 20 kts

Tool output:

PWS = 25.4 kts, MAE = 4.5 kts
AWS = 17.4 kts, MAE = 2.6 kts
PWST = 2210 UTC

Manual output:

PWS = 25.37 kts, MAE = 4.483 kts
AWS = 17.41 kts, MAE = 2.642 kts
PWST = 2210 UTC

- g) Temperature inversion up to 500 ft = No
Precipitation Expected = Yes
Synoptic Pattern = surface high north or east of FL
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Top of inversion = 100 ft
Strongest wind in lowest 3000 ft = 70 kts

Tool output:

≥ 35 kts = 98.4% (p35All = 98.1%, p35InvP = 96.4%, p35Syn = 100.0%)
≥ 50 kts = 59.5% (p50All = 39.5%, p50InvP = 39.2%, p50Syn = 89.6%)
≥ 60 kts = 13.0% (p60All = 3.3%, p60InvP = 4.8%, p60Syn = 26.5%)

Manual output:

≥ 35 kts = 98.4% (p35All = 98.2%, p35InvP = 96.5%, p35Syn = 100.0%)
≥ 50 kts = 59.5% (p50All = 39.8%, p50InvP = 39.3%, p50Syn = 89.4%)
≥ 60 kts = 12.9% (p60All = 3.4%, p60InvP = 4.9%, p60Syn = 26.2%)

Results: Passed.

2. Increasing the strength and depth of the inversion delays the PWS of the day and decreases the peak wind speed (used both operational and test versions of the tool)

Description: Increasing the strength and depth of the surface-based temperature inversion should delay the occurrence of the peak wind speed of the day, while decreasing the peak wind speed.

Temperature inversion up to 500 ft = Yes
Precipitation Expected = No

Synoptic Pattern = surface high north or east of FL
Surface-based temperature inversion = Yes
Strongest wind in lowest 3000 ft = 25 kts

- a) Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C
Top of inversion = 200 ft
Tool Output:
PWS = 27.4 kts, MAE = 4.2 kts
PWST = 2239 UTC
- b) Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C
Top of inversion = 500 ft
Tool Output:
PWS = 27.1 kts, MAE = 4.2 kts
PWST = 2243 UTC
- c) Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C
Top of inversion = 1000 ft
Tool Output:
PWS = 26.6 kts, MAE = 4.2 kts
PWST = 2249 UTC
- d) Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C
Top of inversion = 1500 ft
Tool Output:
PWS = 26.0 kts, MAE = 4.2 kts
PWST = 2256 UTC
- e) Temperature at top of inversion = 5.0 C
Surface temperature = 0.0 C
Top of inversion = 200 ft
Tool Output:
PWS = 27.3 kts, MAE = 4.2 kts
PWST = 2304 UTC
- f) Temperature at top of inversion = 5.0 C
Surface temperature = 0.0 C
Top of inversion = 500 ft
Tool Output:
PWS = 27.0 kts, MAE = 4.2 kts
PWST = 2308 UTC
- g) Temperature at top of inversion = 5.0 C
Surface temperature = 0.0 C
Top of inversion = 1000 ft
Tool Output:
PWS = 26.4 kts, MAE = 4.2 kts
PWST = 2314 UTC
- h) Temperature at top of inversion = 5.0 C
Surface temperature = 0.0 C
Top of inversion = 1500 ft

Tool Output:

PWS = 25.9 kts, MAE = 4.2 kts
PWST = 2321 UTC

Results: Passed.

3. Having an inversion or precipitation delays the occurrence of the PWS. An inversion decreases the peak wind speed, while precipitation increases it. The operational and test versions of the tool were used.

Description: Having an inversion or precipitation should delay the occurrence of the PWS. An inversion will decrease the peak wind speed, while precipitation will increase it.

Synoptic Pattern = surface high near or over FL
Surface-based temperature inversion = yes
Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C
Top of inversion = 500 ft
Strongest wind in lowest 3000 ft = 20 kts

- a) Inversion up to 500 ft = Yes
Precipitation expected = Yes

Tool Output:

PWS = 26.5 kts, MAE = 5.1 kts
PWST = 0014 UTC

- b) Inversion up to 500 ft = Yes
Precipitation expected = No

Tool Output:

PWS = 24.4 kts, MAE = 4.6 kts
PWST = 2324 UTC

- c) Inversion up to 500 ft = No
Precipitation expected = Yes

Tool Output:

PWS = 27.1 kts, MAE = 5.1 kts
PWST = 2330 UTC

- d) Inversion up to 500 ft = No
Precipitation expected = No

Tool Output:

PWS = 24.8 kts, MAE = 4.6 kts
PWST = 2239 UTC

Results: Passed.

4. If there is a surface-based temperature inversion, the top of the inversion must be warmer than the bottom (Used both operational and test versions of the tool)

Description: If there is a surface-based temperature inversion, then the temperature at the top of the inversion should be warmer than the temperature at the bottom. Test this by trying to set the top temperature at or below the surface temperature when there is a surface-based temperature inversion.

Synoptic Pattern = surface front approaching FL from the north
Top of inversion = 500 ft
Temperature inversion up to 500 ft = Yes
Precipitation expected = No
Strongest wind in lowest 3000 ft = 30 kts
Surface-based temperature inversion = Yes

a) Temperature at top of inversion = 2.0 C
Surface temperature = 0.0 C

Tool Output:

Input accepted by tool

b) Temperature at top of inversion = 0.1 C
Surface temperature = 0.0 C

Tool Output:

Input accepted by tool

c) Temperature at top of inversion = 0.0 C
Surface temperature = 0.0 C

Tool Output:

Input rejected by tool

d) Temperature at top of inversion = 0.0 C
Surface temperature = 0.1 C

Tool Output:

Input rejected by tool

e) Temperature at top of inversion = 0.0 C
Surface temperature = 2.0 C

Tool Output:

Input rejected by tool

Results: Passed.

5. Warning threshold speed greater than the predicted peak speed (used both operational and test versions in part a, used test version in parts b and c)

Description: If a warning threshold (35 kts, 50 kts, or 60 kts) is greater than the predicted peak wind speed, then the probability of meeting or exceeding the threshold should be less than 50% (tested in part a). For the same predicted peak wind speed, increasing the sigma (estimated error in the linear regression equation) should give an increasing probability of exceeding the warning threshold (tested in parts b and c).

a) Synoptic Pattern = surface high north or east of Florida

Top of inversion = 100 ft

Temperature inversion up to 500 ft = Yes

Precipitation expected = Yes

Surface-based temperature inversion = Yes

Temperature at top of inversion = 1.0 C

Surface temperature = 0.0 C

I. Strongest wind in lowest 3000 ft = 20 kts

PWS = 27.0 kts MAE = 4.7 kts

≥ 35 kts = 10.7%

≥ 50 kts = 0.0%

≥ 60 kts = 0.0%

II. Strongest wind in lowest 3000 ft = 25 kts

PWS = 29.5 kts MAE = 4.7 kts

≥ 35 kts = 18.5%

≥ 50 kts = 0.1%

≥ 60 kts = 0.0%

III. Strongest wind in lowest 3000 ft = 30 kts

PWS = 32.0 kts MAE = 4.7 kts

≥ 35 kts = 30.7%

- ≥ 50 kts = 0.3%
 - ≥ 60 kts = 0.0%
 - IV. Strongest wind in lowest 3000 ft = 35 kts
PWS = 34.5 kts MAE = 4.7 kts
 - ≥ 35 kts = 46.6%
 - ≥ 50 kts = 0.6%
 - ≥ 60 kts = 0.0%
 - V. Strongest wind in lowest 3000 ft = 65 kts
PWS = 49.4 kts MAE = 4.7 kts
 - ≥ 35 kts = 97.6%
 - ≥ 50 kts = 48.3%
 - ≥ 60 kts = 5.7%
 - VI. Strongest wind in lowest 3000 ft = 67 kts
PWS = 50.3 kts MAE = 4.7 kts
 - ≥ 35 kts = 98.2%
 - ≥ 50 kts = 53.7%
 - ≥ 60 kts = 8.2%
- b) PWS = 28.0 kts
 - I. Strongest wind in lowest 3000 ft = 25 kts
Synoptic pattern = surface high near or over FL
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = third (synoptic pattern stratification)
Sigma = 7.37 kts
MAE = 4.96 kts
Exact PWS = 27.98 kts
≥ 35 kts = 16.9%
 - II. Strongest wind in lowest 3000 ft = 15 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = Yes
Precipitation expected = Yes
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 6.92 kts
MAE = 5.47 kts
Exact PWS = 28.03 kts
≥ 35 kt = 15.5%
 - III. Strongest wind in lowest 3000 ft = 30 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = Yes
Precipitation expected = No
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)

Sigma = 4.90 kts
MAE = 3.78 kts
Exact PWS = 28.01 kts
≥ 35 kts = 7.4%

- IV. Strongest wind in lowest 3000 ft = 23 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Surface-based temperature inversion = Yes
Top of inversion = 100 ft
Temperature at top of inversion = 0.5 C
Surface temperature = 0.0 C
Equation = first (multiple linear regression)
Sigma = 6.5 kts
MAE = 4.91 kts
Exact PWS = 27.98 kts
≥ 35 kts = 13.8%

c) PWS = 33.0 kts

- I. Strongest wind in lowest 3000 ft = 35 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Surface-based temperature inversion = Yes
Top of inversion = 100 ft
Temperature at top of inversion = 1.7 C
Surface temperature = 0.0 C
Equation = first (multiple linear regression)
Sigma = 6.51 kts
MAE = 4.91 kts
Exact PWS = 33.01 kts
≥ 35 kts = 38.0%
≥ 50 kts = 0.3%
- II. Strongest wind in lowest 3000 ft = 28 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = Yes
Precipitation expected = Yes
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 6.92 kts
MAE = 5.47 kts
Exact PWS = 32.99 kts
≥ 35 kts = 38.5%
≥ 50 kts = 0.5%
- III. Strongest wind in lowest 3000 ft = 41 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = Yes
Precipitation expected = No
Surface-based temperature inversion = N/A
Top of inversion = N/A

Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 4.92 kts
MAE = 3.78 kts
Exact PWS = 32.95 kts
≥ 35 kts = 33.8%
≥ 50 kts = 0.01%

- IV. Strongest wind in lowest 3000 ft = 39 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = No
Precipitation expected = No
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 5.02 kts
MAE = 3.99 kts
Exact PWS = 33.02 kts
≥ 35 kts = 34.7%
≥ 50 kts = 0.02%

Results: Passed.

6. Warning threshold speed equal to the predicted peak speed (used both operational and test versions in part a, used test version in parts b-e)

Description: If a warning threshold (35 kts, 50 kts, or 60 kts) is equal to the predicted peak wind speed, then the probability of meeting or exceeding the threshold should be 50% (tested in part a). Because of rounding errors, the probability may not be exactly 50%. For the same predicted peak wind speed, increasing the sigma should give a constant probability (i.e. 50%) of exceeding the warning threshold (tested in parts b-e).

- a) Synoptic Pattern = surface high north or east of Florida
Top of inversion = 100 ft
Surface-based temperature inversion = Yes
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C

- I. Temperature inversion up to 500 ft = Yes
Precipitation expected = Yes
Strongest wind in lowest 3000 ft = 36 kts

Tool output:

PWS = 35.0 kts MAE = 4.7 kts
≥ 35 kts = 50.0%
≥ 50 kts = 0.7%
≥ 60 kts = 0.0%

- II. Temperature inversion up to 500 ft = Yes
Precipitation expected = Yes
Strongest wind in lowest 3000 ft = 37 kts

Tool output:

PWS = 35.5 kts MAE = 4.7 kts

- ≥ 35 kts = 53.4%
- ≥ 50 kts = 0.9%
- ≥ 60 kts = 0.0%

III. Temperature inversion up to 500 ft = Yes
 Precipitation expected = Yes
 Strongest wind in lowest 3000 ft = 66 kts

Tool output:

- PWS = 49.9 kts MAE = 4.7 kts
- ≥ 35 kts = 97.9%
- ≥ 50 kts = 51.0%
- ≥ 60 kts = 6.9%

IV. Temperature inversion up to 500 ft = No
 Precipitation expected = No
 Strongest wind in lowest 3000 ft = 38 kts

Tool output:

- PWS = 34.6 kts MAE = 4.3 kts
- ≥ 35 kts = 46.9%
- ≥ 50 kts = 0.3%
- ≥ 60 kts = 0.0%

V. Temperature inversion up to 500 ft = No
 Precipitation expected = No
 Strongest wind in lowest 3000 ft = 39 kts

Tool output:

- PWS = 35.1 kts MAE = 4.3 kts
- ≥ 35 kts = 50.4%
- ≥ 50 kts = 0.4%
- ≥ 60 kts = 0.0%

VI. Temperature inversion up to 500 ft = No
 Precipitation expected = No
 Strongest wind in lowest 3000 ft = 68 kts

Tool output:

- PWS = 49.8 kts MAE = 4.3 kts
- ≥ 35 kts = 98.8%
- ≥ 50 kts = 48.3%
- ≥ 60 kts = 7.8%

VII. Temperature inversion up to 500 ft = No
 Precipitation expected = No
 Strongest wind in lowest 3000 ft = 69 kts

Tool output:

- PWS = 50.3 kts MAE = 4.3 kts
- ≥ 35 kts = 99.0%
- ≥ 50 kts = 51.0%
- ≥ 60 kts = 9.2%

b) Strongest wind in lowest 3000 ft = 39 kts
 Temperature inversion up to 500 ft = N/A

Precipitation expected = N/A
Synoptic Pattern = N/A
Top of inversion = 100 ft
Surface-based temperature inversion = Yes
Temperature at top of inversion = 0.1 C
Surface temperature = 0.0 C
Equation = first (multiple linear regression)
Sigma = 6.51 kts
MAE = 4.91 kts
Exact PWS = 34.96 kts
≥ 35 kts = 49.8%
≥ 50 kts = 0.8%

- c) Strongest wind in lowest 3000 ft = 30 kts
Temperature inversion up to 500 ft = No
Precipitation expected = Yes
Synoptic Pattern = N/A
Top of inversion = N/A
Surface-based temperature inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 7.27 kts
MAE = 5.42 kts
Exact PWS = 35.08 kts
≥ 35 kts = 50.4%
≥ 50 kts = 1.7%

- d) Strongest wind in lowest 3000 ft = 65 kts
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Synoptic Pattern = surface high south or west of FL
Top of inversion = N/A
Surface-based temperature inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = third (synoptic pattern stratification)
Sigma = 6.47 kts
MAE = 4.90 kts
Exact PWS = 34.94 kts
≥ 35 kts = 49.6%
≥ 50 kts = 0.8%

- e) Strongest wind in lowest 3000 ft = 44 kts
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Synoptic Pattern = surface front over central FL
Top of inversion = N/A
Surface-based temperature inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = third (synoptic pattern stratification)
Sigma = 7.12 kts
MAE = 5.46 kts
Exact PWS = 35.05 kts
≥ 35 kts = 50.3%

≥ 50 kts = 1.5%

Results: Passed.

7. Warning threshold speed less than the predicted peak speed (used both operational and test versions in part a, used test version in part b)

Description: If a warning threshold (35 kts, 50 kts, or 60 kts) is less than the predicted peak wind speed, then the probability of meeting or exceeding the threshold should be greater than 50% (tested in part a). For the same predicted peak wind speed, increasing the sigma should give a decreasing probability of exceeding the warning threshold.

- a) Synoptic Pattern = surface high near or over Florida
 - Top of inversion = N/A
 - Temperature inversion up to 500 ft = No
 - Precipitation expected = Yes
 - Surface-based temperature inversion = No
 - Temperature at top of inversion = N/A
 - Surface temperature = N/A
 - I. Strongest wind in lowest 3000 ft = 36 kts
 - PWS = 35.1 kts MAE = 5.1 kts
 - ≥ 35 kts = 50.6%
 - ≥ 50 kts = 1.8%
 - ≥ 60 kts = 0.0%
 - II. Strongest wind in lowest 3000 ft = 37 kts
 - PWS = 35.6 kts MAE = 5.1 kts
 - ≥ 35 kts = 53.1%
 - ≥ 50 kts = 2.1%
 - ≥ 60 kts = 0.0%
 - III. Strongest wind in lowest 3000 ft = 38 kts
 - PWS = 36.1 kts MAE = 5.1 kts
 - ≥ 35 kts = 55.6%
 - ≥ 50 kts = 2.4%
 - ≥ 60 kts = 0.0%
 - IV. Strongest wind in lowest 3000 ft = 70 kts
 - PWS = 50.6 kts MAE = 5.1 kts
 - ≥ 35 kts = 98.2%
 - ≥ 50 kts = 51.8%
 - ≥ 60 kts = 11.5%
 - V. Strongest wind in lowest 3000 ft = 71 kts
 - PWS = 51.0 kts MAE = 5.1 kts
 - ≥ 35 kts = 98.4%
 - ≥ 50 kts = 54.1%
 - ≥ 60 kts = 12.7%
 - VI. Strongest wind in lowest 3000 ft = 72 kts
 - PWS = 51.5 kts MAE = 5.1 kts
 - ≥ 35 kts = 98.6%
 - ≥ 50 kts = 56.3%
 - ≥ 60 kts = 14.0%
- b) PWS = 37.0 kts
 - I. Strongest wind in lowest 3000 ft = 50 kts
 - Synoptic pattern = N/A
 - Temperature inversion up to 500 ft = Yes
 - Precipitation expected = No
 - Surface-based temperature inversion = N/A

Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 4.94 kts
MAE = 3.78 kts
Exact PWS = 36.99 kts
≥ 35 kts = 65.6%
≥ 50 kts = 0.3%

II. Strongest wind in lowest 3000 ft = 48 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = No
Precipitation expected = No
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 5.04 kts
MAE = 3.99 kts
Exact PWS = 37.07 kts
≥ 35 kts = 66.0%
≥ 50 kts = 0.4%

III. Strongest wind in lowest 3000 ft = 36 kts
Synoptic pattern = N/A
Temperature inversion up to 500 ft = No
Precipitation expected = Yes
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = second (inversion/precipitation stratification)
Sigma = 7.27 kts
MAE = 5.42 kts
Exact PWS = 37.01 kts
≥ 35 kts = 60.9%
≥ 50 kts = 3.4%

IV. Strongest wind in lowest 3000 ft = 51 kts
Synoptic pattern = surface front over central FL
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Surface-based temperature inversion = N/A
Top of inversion = N/A
Temperature at top of inversion = N/A
Surface temperature = N/A
Equation = third (synoptic pattern stratification)
Sigma = 7.14 kts
MAE = 5.46 kts
Exact PWS = 37.09 kts
≥ 35 kts = 61.5%
≥ 50 kts = 3.2%

V. Strongest wind in lowest 3000 ft = 44 kts

Synoptic pattern = N/A
Temperature inversion up to 500 ft = N/A
Precipitation expected = N/A
Surface-based temperature inversion = Yes
Top of inversion = 100 ft
Temperature at top of inversion = 1.0 C
Surface temperature = 0.0 C
Equation = first (multiple linear regression)
Sigma = 6.5 kts
MAE = 4.91 kts
Exact PWS = 37.00 kts
 ≥ 35 kts = 62.1%
 ≥ 50 kts = 2.0%

Results: Passed.

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List of Acronyms

Term	Description
45 WS	45th Weather Squadron
ABL	Atmospheric Boundary Layer
AFCCC	Air Force Combat Climatology Center
AFWA	Air Force Weather Agency
AGL	Above Ground Level
AMU	Applied Meteorology Unit
CCAFS	Cape Canaveral Air Force Station
FAQ	Frequently Asked Questions
GRIB2	General Regularly-distributed Information in Binary form, Edition 2
GUI	Graphical User Interface
KSC	Kennedy Space Center
MAE	Mean Absolute Error
MIDDS	Meteorological Interactive Data Display System
NDFD	National Digital Forecast Database
NWS	National Weather Service
PWSD	Peak Wind Speed of the Day
QC	Quality Control
RUC	Rapid Update Cycle model
SL	Surface-layer deflection
SLF	Shuttle Landing Facility
SR	Surface-roughness-based
VBA	Visual Basic for Applications language
WGE	Wind Gust Estimate
XML	Extensible Markup Language
XMR	CCAFS rawinsonde 3-letter identifier

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14. ABSTRACT This report describes work done by the Applied Meteorology Unit (AMU) in predicting peak winds at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). The 45th Weather Squadron requested the AMU develop a tool to help them forecast the speed and timing of the daily peak and average wind, from the surface to 300 ft on KSC/CCAFS during the cool season. Based on observations from the KSC/CCAFS wind tower network, Shuttle Landing Facility (SLF) surface observations, and CCAFS soundings from the cool season months of October 2002 to February 2007, the AMU created multiple linear regression equations to predict the timing and speed of the daily peak wind speed, as well as the background average wind speed. Several possible predictors were evaluated, including persistence, the temperature inversion depth and strength, wind speed at the top of the inversion, wind gust factor (ratio of peak wind speed to average wind speed), synoptic weather pattern, occurrence of precipitation at the SLF, and strongest wind in the lowest 3000 ft, 4000 ft, or 5000 ft.					
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