12.6 DETERMINING THE PROBABILITY OF VIOLATING UPPER-LEVEL WIND CONSTRAINTS FOR THE LAUNCH OF MINUTEMAN III BALLISTIC MISSILES AT VANDENBERG AIR FORCE BASE

Jaclyn A. Shafer *
NASA Applied Meteorology Unit / ENSCO, Inc. / Cape Canaveral Air Force Station, Florida

Tyler M. Brock
USAF 30th Operational Support Squadron Weather Flight/Vandenberg Air Force Base, California

1. INTRODUCTION

The 30th Operational Support Squadron Weather Flight (30 OSSWF) provides comprehensive weather services to the space program at Vandenberg Air Force Base (VAFB) in California. One of their responsibilities is to monitor upper-level winds to ensure safe launch operations of the Minuteman III ballistic missile. The 30 OSSWF requested the Applied Meteorology Unit (AMU) analyze VAFB sounding data to determine the probability of violating (PoV) upper-level thresholds for wind speed and shear constraints specific to this launch vehicle, and to develop a graphical user interface (GUI) that will calculate the PoV of each constraint on the day of launch. The AMU suggested also including forecast sounding data from the Rapid Refresh (RAP) model. This would provide further insight for the launch weather officers (LWOs) when determining if a wind constraint violation will occur over the next few hours, and help to improve the overall upper winds forecast on launch day.

2. HISTORICAL DATA

The primary goal of this work was to build a GUI that will aid the LWOs in determining if a wind constraint violation will occur when launching Minuteman III ballistic missiles. The AMU collected, processed, and analyzed VAFB sounding data to determine the PoV of their specific wind speed and shear constraints. This included interpolating data to heights required for operations and determining how the data were distributed.

2.1 Collection

In order to analyze the upper-level thresholds for wind speed and shear and calculate their PoV, the AMU collected historical sounding data from VAFB. The ideal data for this task would have been the soundings collected through the Automated Meteorological Profiling System (AMPS) at VAFB. Unfortunately, due to limitations of the VAFB AMPS system, these data were not provided to the AMU.

To circumvent this issue, the 45th Weather Squadron (45 WS) suggested using the Range Reference Atmosphere (RRA) data for VAFB. The RRA contains the monthly means and standard deviations of the sounding variables every 0.25 km (~820 ft) using soundings collected in the years 1990-2001 (https://bsx.edwards.af.mil/weather/rcc.htm). Assuming the variable values were normally distributed, the means and standard deviations were used in an Excel formula to calculate the probabilities of exceeding the desired thresholds. The probabilities never exceeded 1%, and were more often much closer to 0%. The AMU determined this would not be useful information for the 30 OSSWF.

The AMU team met and decided that useful results would more likely be found by using individual soundings. VAFB soundings were available in the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) archive in a format that was easy to process. These VAFB soundings were downloaded from the NOAA ESRL website (http://www.esrl.noaa.gov/raobs/) and were collected for the years 1994-2011.

2.2 Processing

To calculate the PoV for each wind constraint, the data for each sounding needed to be interpolated to consistent 1000-ft height levels. The AMU used Perl scripts to add the required levels to each sounding and then interpolated the wind direction and speed to those 1000-ft heights. So that the PoV could be depicted accurately for the different times of the year, the soundings were stratified into four sub-seasons: January-March, April-June, July-August, and October-December. The maximum wind speed and maximum 1000-ft shear values for each sounding per sub-season were then determined. The 30 OSSWF also requested the 1000-ft shear be calculated at multiple intervals. For example, in addition to the 1000-2000 ft shear, the 1100-2100 ft, 1200-2200 ft, etc. values were also calculated. These values were used in statistical equations to calculate the PoV for each constraint. All 1000-ft layer shear values were calculated using the equations depicted in Table 1.

* *Corresponding author address:* Jaclyn A. Shafer, ENSCO, Inc., 1980 N Atlantic Ave, Suite 830, Cocoa Beach, FL 32931; email shafer.jaclyn@ensco.com.

Table 1. Summary of calculations used to determine 1000-ft shear

Variable	Formula
u-component wind	u = Wspd*cos(270 – Wdir)*pi/180
v-component wind	v = Wspd*sin(270 – Wdir)*pi/180
u-component shear	u-shear(Layer) = u(Upper) – u(Lower)
v-component shear	v-shear(Layer) = v(Upper) – v(Lower)
Shear of layer	Shear(Layer) = Sqrt(u-shear^2 + v-shear^2)
Where:	Wspd = Wind speed (kt) at given height. Wdir = Wind direction (degrees) at given height. Upper = top height (ft) of layer of interest. Lower = bottom height (ft) of layer of interest. pi = 3.14159265358979

2.3 Data Distributions

In order to accurately calculate the PoV for each wind constraint, the distribution of the maximum wind speed and shear datasets had to be determined. The AMU estimated the theoretical distributions of the observations with the help of Dr. Frank Merceret of the Kennedy Space Center (KSC) Weather office.

The most common distribution in classical statistics, and with many applications in the atmospheric sciences, is the Gaussian distribution (Wilks 2006). If the mean and standard deviation of each dataset can be calculated, the probability for exceeding a value X can be obtained directly from Gaussian distribution tables, including those in standard software packages like Excel (Merceret 2009). Similarly, the lognormal distribution is often observed in nature, particularly with wind features (Smith and Merceret 2000). Based on this previous work, the AMU first created the probability density functions (PDFs) of the maximum speed observations and the natural log (ln) of the observations, shown in Figure 1, to help determine if the data distribution was Gaussian or lognormal. The observation curve was noisy and positively skewed, but the ln curve was smooth and negatively skewed. **Error! Reference source not found.** shows the skewness and kurtosis of the datasets. For Gaussian and lognormal distributions, skewness and kurtosis are 0. The values for the observed distributions in **Error! Reference source not found.** are not 0, but have absolute values of less than 1. The observations have smaller magnitudes of skewness and kurtosis than the ln values, indicating they may be more Gaussian distributed than lognormal.

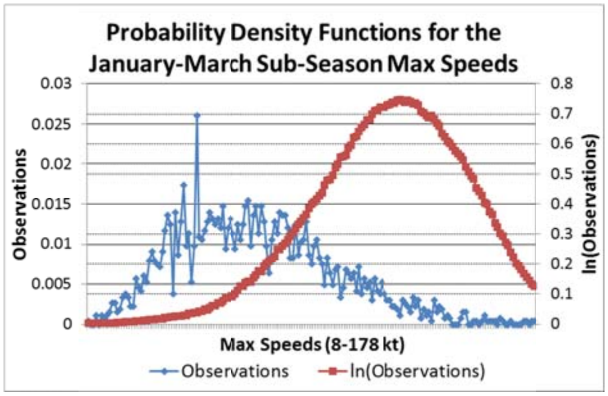


Figure 1. The PDFs of the maximum speed observations (blue, left axis and solid grid lines) and ln of the observations (red, right axis and dotted grid lines).

Table 2. The skewness and kurtosis of the observations and ln(observations) wind speed data for January-March

Values	***Skewness***	***Kurtosis***
Observations	0.51	-0.06
ln(Observations)	-0.62	0.44

Dr. Merceret transformed these datasets to normalized values used in standard Gaussian probability tables.

$$z = \frac{x - \bar{x}}{s},$$

where x is the observed or ln value, $\bar{x}$ is the mean, and s is the standard deviation of the sample. The value z is dimensionless. Figure 2 compares the z values for the observations and ln of the observations to the theoretical value of z for the Gaussian cumulative distribution. For both curves, z increases as speed increases on the x-axis. A straight line would indicate a Gaussian or lognormal distribution for the corresponding set of values. Neither curve is straight from end to end, but the observations curve becomes straight close to x = -1 and y = -1 in the graph. That corresponds to a wind speed of 42 kt; above this speed, the data appear to be Gaussian distributed. The ln curve is straight below 42 kt. Since the speeds of interest are above 42 kt, the AMU assumed a Gaussian distribution when calculating PoV for the maximum wind speeds.

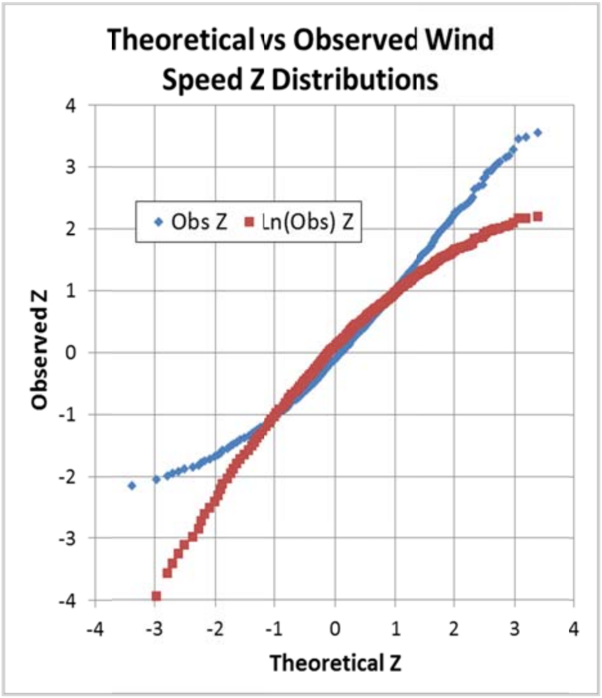


Figure 2. Curves showing the relationship of the z values for the observations (blue) and the ln of the observations (red) to the theoretical Gaussian z values.

The AMU performed similar analysis for the wind shear values. Table 3 shows the skewness and kurtosis for the observations and ln of the observations datasets. The values for the observations dataset indicate it is not likely Gaussian distributed; the skewness and kurtosis are far from 0. The values for ln of the observations are more indicative of a Gaussian distribution. The curve for the observations in Figure 3 is not straight at any point, but the ln curve becomes straight at x = -2.5 and y = -3 where the shear is 1.9 kt/1000 ft and remains quasi-straight through the point x = 2.5 and y = 2 where the shear value is 45 kt/1000 ft. The shear value of interest is well within the linear portion of the ln curve, leading the AMU to assume a lognormal distribution for the shear values.

2.4 Probability of Violation

For the maximum wind speed PoV calculation, the mean and standard deviation of the maximum wind speed values were determined in each sounding within a given sub-season. Since the distribution of the 1000-ft shear values was found to be lognormal, the AMU calculated the ln of the maximum shear values. The mean and standard deviation of these values were then used in the PoV calculation. The respective PoV values were calculated for each wind constraint per sub-season using the equations containing the Excel functions shown in Table 4. The “TRUE” option was selected to use the cumulative distribution function since it returns the probability of exceeding the variable constraint. The “FALSE” option would have returned a probability that the variable would be exactly equal to the constraint.

Table 3. The skewness and kurtosis of the observations and ln(observations) wind shear data for January-March

Values	***Skewness***	***Kurtosis***
Observations	1.79	8.49
ln(Observations)	-0.49	0.32

Figure 3. Same as Figure 2 but for wind shear.

Table **4**. List of Excel’s PoV calculations for the maximum wind speed and shear datasets. The output values were multiplied by 100 to convert to percentages.

Dataset	**Excel PoV Formula**
Maximum Wind Speed Gaussian	PoV = (1 – NORM.S.DIST((X-x)/σ, TRUE))*100
Maximum Wind Shear Lognormal	PoV = (1 – LOGNORM.DIST(Y,LN(y),LN(σ_y),TRUE))*100

Where: X = maximum wind speed constraint
x = mean maximum wind speed values
σ = standard deviation values
Y = maximum shear constraint
y = mean ln(max shear) value
σ_y = standard deviation values

3. EXCEL GUI

The primary goal of this project was to develop a tool to determine the PoV for the upper-level wind constraints specific to the Minuteman III ballistic missile launch vehicle at VAFB. This tool was developed in Excel using Visual Basic for Applications (VBA) to create a GUI that displays critical sounding data easily and quickly for the LWOs on the day of launch. Figure 4 shows the main page of the GUI, which consists of 13 worksheet tabs, each with their own displays.

3.1 Sounding Data

Information for the soundings is in the first 12 worksheet tabs of the GUI. The "REVIEW" tab summarizes the essential launch constraints for the latest sounding and associated sub-season. Once the LWOs click the "LOAD NEW BALLOON DATA" button they should check the "CURRENT DISPLAYED BALLOON DATA" box to ensure the correct sounding has loaded into the GUI. To easily compare the current sounding data to the climatology for the present sub-season, the "CURRENT SUB-SEASON INFO" box displays the average maximum wind speed and 1000-ft shear values for the time period and the sub-season PoV of each wind constraint. The PoV results for each sub-season are shown in Table 5.

The "LAUNCH CONSTRAINTS AT A GLANCE" box focuses on the latest sounding data. It shows the maximum wind speed and its height, the maximum 1000-ft shear and its layer, plus calculates the PoV for each constraint. The PoV for the current sounding is calculated using the same equation as the historical data, however the mean maximum wind speed value is replaced with the current maximum wind speed in the layer of interest. The climatological standard deviation is still used. This is true for both the maximum wind speed and maximum shear wind constraint PoV. The PoV calculation assumes the standard deviation for the sounding is similar to that of the sub-season, and as such, is climatological in nature. The 30 OSSWF could not provide launch day soundings that occur within a few hours of each other, therefore the AMU could not create a method to determine the PoV for some future time. Instead, the calculation best indicates the PoV of exceeding the given threshold in the current sounding assuming the level of peak value was not sampled.

Below the summary boxes are the "Maximum Wind Speed" and "Maximum 1000-ft Shear" graphs that display the current sounding data every 100-ft. The 10 worksheet tabs labeled "X000", "X100", … "X900" contain data for the additional 100-ft interval shear levels the 30 OSSWF requested as mentioned in section 2.2. Figure 5 shows an example screen capture of the "X100" worksheet tab. This includes the wind speed and shear values at the 25,100-26,100 ft, 26,100-27,100 ft, etc heights. Each worksheet tab displays the sounding data at the respective heights, calculates the shear and then graphs the wind speed and shear values within the range of interest. The "RAW DATA" worksheet tab displays the latest raw data for the current sounding loaded in the GUI as shown in Figure 4.

3.2 Model Data

Although not originally requested, the AMU and the 30 OSSWF discussed adding model point forecast sounding data to the GUI. This will provide additional insight to the LWOs on launch day when determining if a wind constraint violation will occur over the next few hours. The 30 OSSWF agreed this would be valuable information and so the AMU added this to the tool. The RAP model was selected for this application. The model was developed for users needing frequently updated short-term weather forecasts. It replaced the Rapid Update Cycle (RUC) as the operational NOAA hourly-updated assimilation/modeling system at the National Centers for Environmental Prediction (NCEP) on 1 May 2012. The latest RAP sounding data are available from Iowa State University Archive Data Server (http://mtarchive.geol.iastate.edu) every hour and normally updated by 1 hour and 45 minutes after the hour. The "RAP" tab in the GUI displays two sounding graphs: one for wind speed and one for wind direction (Figure 6). Each graph displays the respective variable for the current sounding profile plus 12 1-hour RAP forecast soundings. The RAP initialization time is based on the current UTC time.

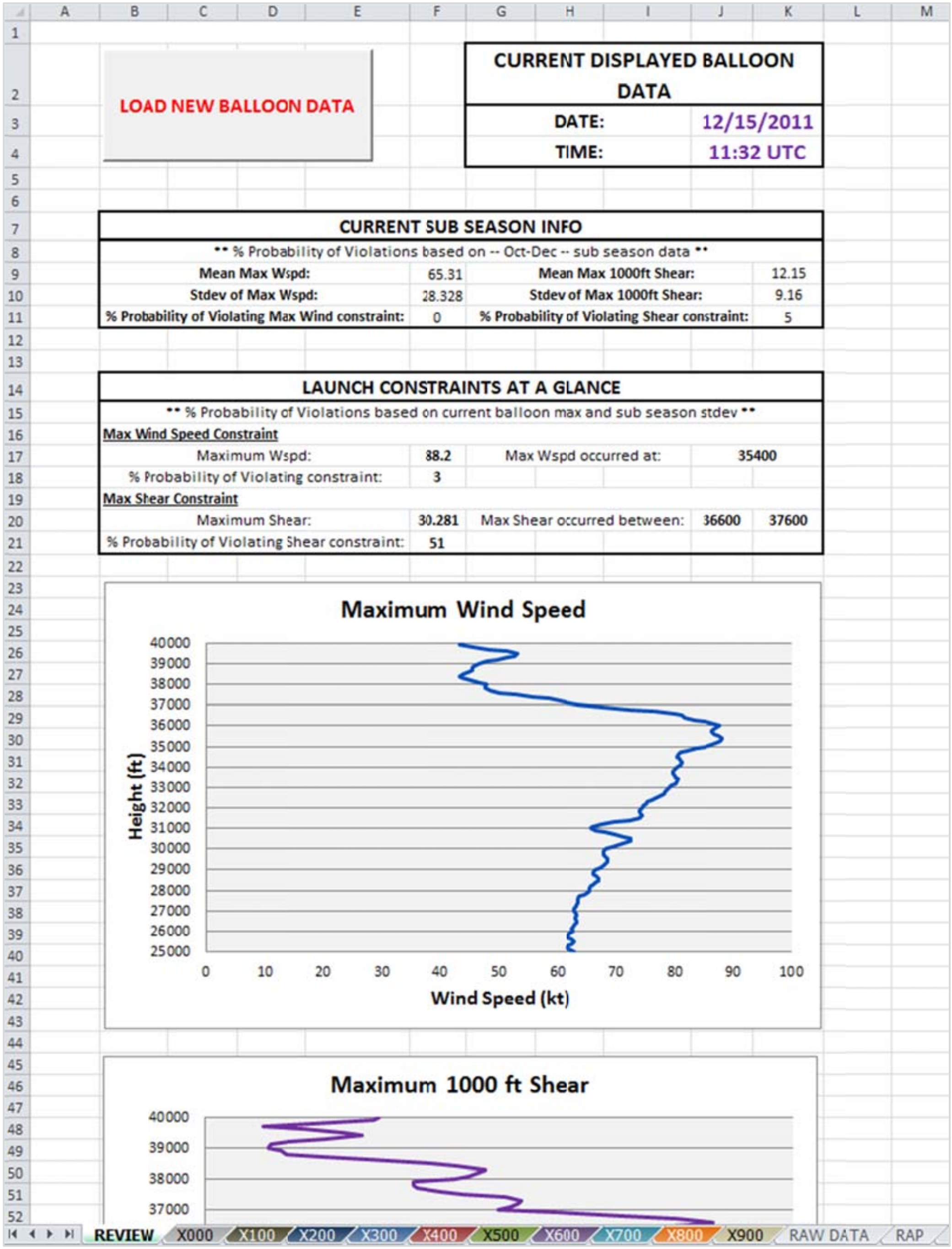
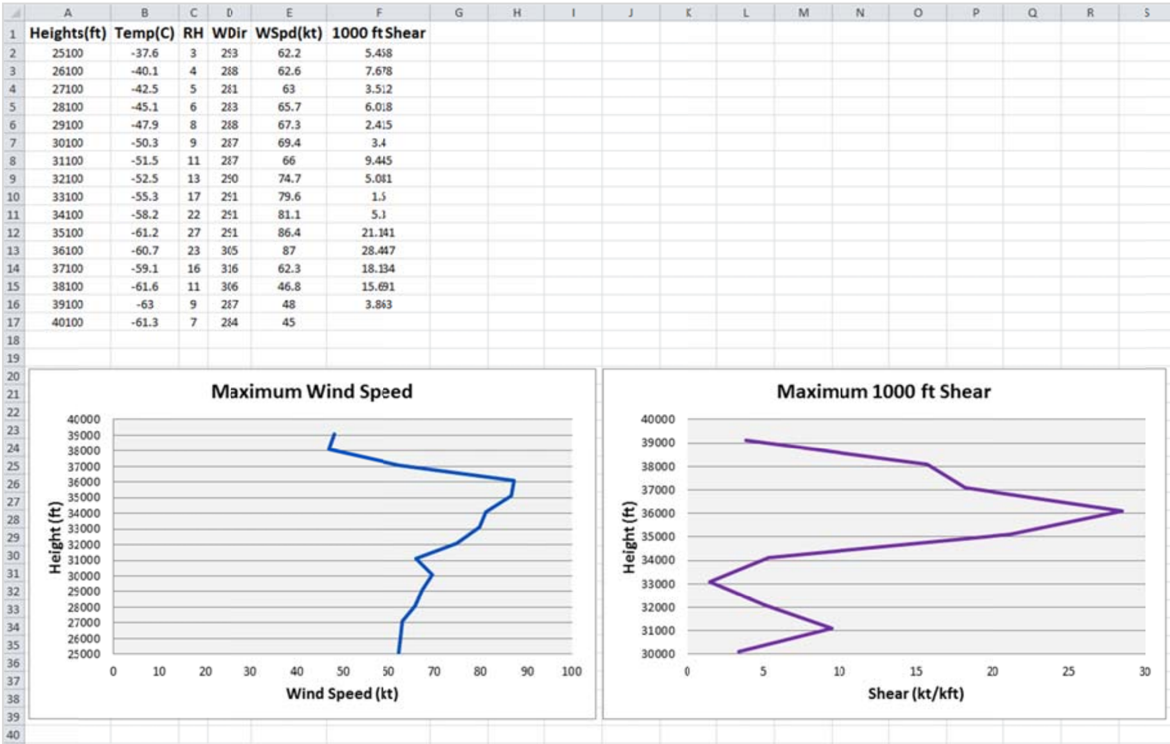


Figure 4. Screen capture overview of 30 OSSWF GUI display.

Table 5. Summary of PoV (%) values per sub-season.

Sub-Season	Max Wind Speed	1000-ft Shear
January-March	1	7
April-June	0	3
July-September	0	2
October-December	0	5



Heights(ft)	Temp(C)	RH	WDir	WSpd(kt)	1000 ft Shear
25100	-37.6	3	293	62.2	5.458
26100	-40.1	4	288	62.6	7.678
27100	-42.5	5	281	63	3.512
28100	-45.1	6	283	65.7	6.018
29100	-47.9	8	288	67.3	2.415
30100	-50.3	9	287	69.4	3.4
31100	-51.5	11	287	66	9.445
32100	-52.5	13	290	74.7	5.081
33100	-55.3	17	291	79.6	1.5
34100	-58.2	22	291	81.1	5.3
35100	-61.2	27	291	86.4	21.141
36100	-60.7	23	305	87	28.447
37100	-59.1	16	316	62.3	18.134
38100	-61.6	11	306	46.8	15.691
39100	-63	9	287	48	3.863
40100	-61.3	7	284	45	

Figure 5. Example screen capture of the X100 worksheet tab in GUI.

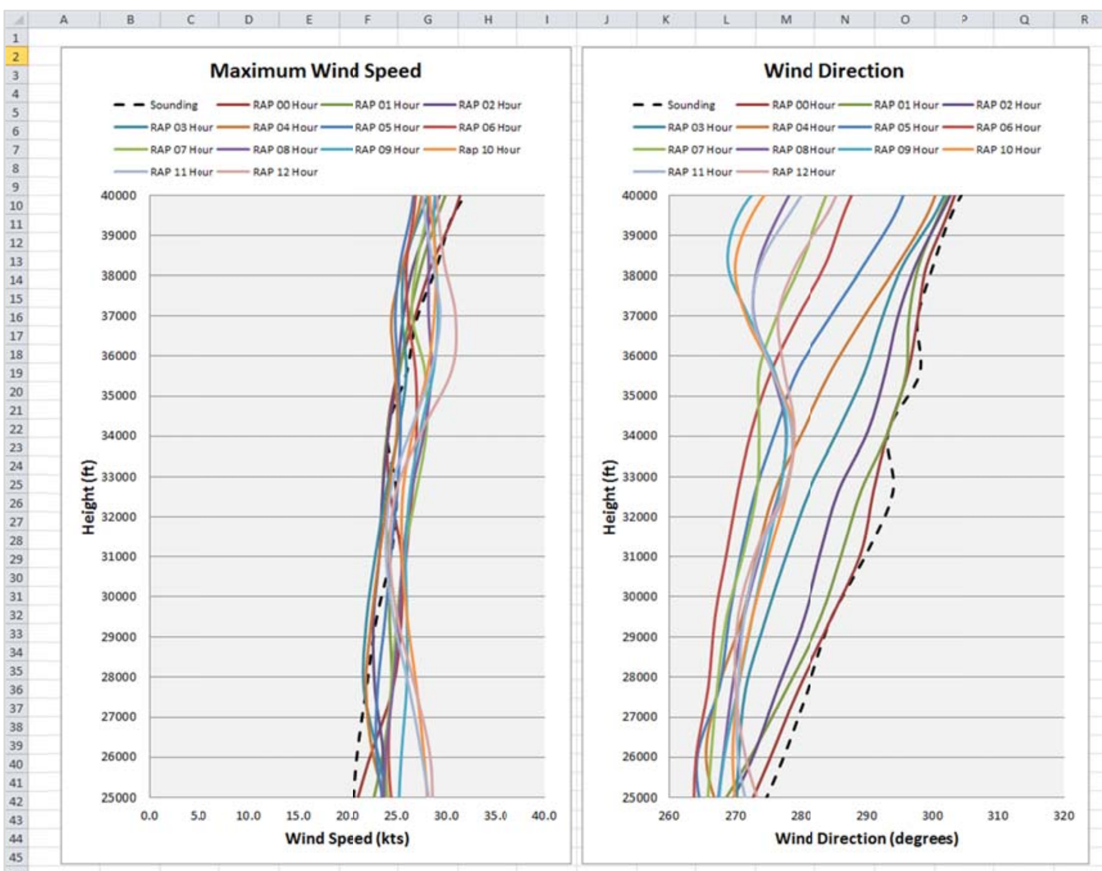


Figure 6. Screen capture of the RAP tab in GUI.

4. SUMMARY AND FUTURE WORK

The 30 OSSWF requested the AMU develop a tool that will calculate the PoV of the upper-level wind speed and shear constraints specific to the Minuteman III ballistic missile on the day of launch. In order to calculate each PoV the AMU first collected historical sounding data from VAFB. The AMU retrieved the data from the NOAA ESRL archive for the years 1994-2011 and stratified into four sub-seasons for analysis: January-March, April-June, July-September and October-December. The AMU then determined the maximum wind speed and 1000-ft shear values in increments of 100-ft for each sounding per sub-season. To accurately calculate the respective PoVs the AMU determined the distribution of the maximum wind speed and maximum shear datasets by fitting these datasets to theoretical distributions. The AMU discovered that the maximum wind speeds followed a Gaussian distribution while the maximum shear values followed a lognormal distribution.

The AMU then developed a GUI in Excel using VBA that calculates the PoV for each wind constraint and displays current sounding data easily and quickly for the LOWs on launch day. In addition to the requirements originally requested, the AMU also included forecast sounding data from the RAP model. This information provides further insight for the LWOs when determining if a wind constraint violation will occur over the next few hours and will help to improve the overall upper-level winds forecast.

Another way to determine if a wind constraint violation will occur over the next few hours would be to conduct a statistical wind change study using 50 MHz Doppler radar wind profiler data similar to the calculations done in Merceret (1997). The results provided probabilities of exceeding a magnitude of wind vector change over 0.25, 1, 2 and 4 hours. The LWOs would determine what wind change between the last sounding and the launch time would pose an operational threat, and then use pre-calculated values to determine the PoV of the constraint. The VAFB 50 MHz wind profiler is not yet functioning. Once it becomes operational, the AMU suggests the data be archived in order to create these values for the 30 OSSWF.

5. REFERENCES

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