5.2   THE WEATHER ANALYSIS DISPLAY (WAND) TOOL: DEVELOPING A METEOROLOGICAL DATA DISPLAY TOOL FOR SITUATIONAL AWARENESS DURING DAY-OF-LAUNCH OF SPACE LAUNCH VEHICLES USING PYTHON

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1.   INTRODUCTION

Atmospheric conditions are an important driver in the design and operation of space launch vehicles. The Profile Envision and Splicing Tool (PRESTO) was developed by NASA's Marshall Space Flight Center (MSFC) Natural Environments Branch (NE) to generate vertically complete atmospheric profiles from various data sources at NASA's Kennedy Space Center (KSC), co-located on the United States Air Force (USAF) Eastern Range (ER), for NASA's Space Launch System (SLS) day-of-launch (DOL) loads and trajectory analysis. PRESTO was designed solely to generate a vertically complete atmospheric profile (Orcutt et al., 2017). However, NE has also been tasked to provide a quality assessment of meteorological data examined on DOL, which goes beyond PRESTO's utility. Thus, NE developed the Weather Analysis Display (WAND) to visualize data from all available observation systems in conjunction with climatological databases. WAND can display data from various sources in multiple ways, including Skew-T Log-P plots, time-height cross sections, and time series. WAND was developed in Python 3 taking advantage of common packages, such as NumPy for data handling, SciPy for mathematical functions, Matplotlib for data visualization, and Tkinter for the execution of the Graphical User Interface (GUI).

2.   DATA SOURCES AT THE EASTERN RANGE

A highly dense network of meteorological instrumentation exists at the USAF ER. The network consists of weather towers, weather balloons, and Doppler Radar Wind Profilers (DRWP). Additionally, there are climatological databases and upper level wind forecasts available for the ER.

There are over 30 weather towers located at the ER. However, only the two most important towers to the SLS Program are displayed in WAND. Tower 313 is a 152.4 m (500 ft) tower located approximately five kilometers from Launch Complex 39-B. Tower 313 measures wind speed, wind direction, temperature, and relative humidity at seven altitudes and has two sensors on opposing sides of the tower at each level. Tower 397 is comprised of three separate 152.4 m (500 ft) towers that surround Launch Complex 39-B.

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Each tower measures wind speed, wind direction, temperature, and relative humidity at four levels, and only has one sensor per level. Both Tower 313 and Tower 397 report data every minute.

Three types of weather balloons can also be released at the ER. The most common type is the Automated Meteorological Profiling System (AMPS) Low Resolution (LR) balloon. LR balloons report wind speed, wind direction, temperature, relative humidity, density, and pressure. LRs report observations every 33 – 333 m and reach altitudes of 30 km. In addition to LR balloons, the ER can launch AMPS High Resolution (HR) balloons and Jimsphere balloons. HR balloons only measure wind speed and wind direction and are Global Positioning System (GPS) tracked. Jimsphere balloons also only measure wind speed and direction, but are radar tracked. Both HR and Jimsphere balloons report every 33 m up to approximately 20 km (Divers et al., 2000).

Additionally, there exists a single Tropospheric Doppler Radar Wind Profiling (TDRWP) system at KSC and five boundary layer DRWPs at the ER. The TDRWP operates at 48 MHz, observes winds from approximately 2 – 20 km, and reports a profile every five minutes (McLaughlin et al., 2017). The boundary layer DRWPs operate at 915 MHz, nominally observe winds from approximately 150 – 3,000 m, and report every 15 minutes (Lambert et al., 2003).

3.   SOFTWARE DEVELOPMENT

WAND was developed to run in the Huntsville Operations Support Center (HOSC), which is a highly secured facility. The NE machines were approved to have Anaconda 5.1 (https://www.anaconda.com/download/) installed, which runs Python 3.6. Anaconda comes bundled with a large number of packages. As such, the packages Numpy, Scipy, matplotlib, and Tkinter were able to be used to help build WAND. The development team used Numpy for its array handling capabilities, Scipy to perform mathematical functions, matplotlib to visualize data, and Tkinter to create and execute the GUI. WAND was designed to maximize code reuse and was also built to be modular to allow easier additions of new instrumentation or visualizations in the future.

Code was reused and pre-developed solutions were used when possible to simplify the code. A function was created to generate check buttons for available profiles, as this is a major part of the GUI. A single function was created to read in data from any balloon source. Pre-developed solutions, such as mathematical functions within Scipy, were leveraged as well. The WAND code

was simplified and development time was reduced by reusing code and leveraging existing solutions.

4. SOFTWARE DESIGN

When WAND is initialized, the first window to appear is the WAND Search window. This window allows the operator to choose input and output directories, and to set the angle for in-plane and out-of-plane wind component calculation. The in-plane and out-of-plane wind components are the wind components in relation to the vehicles trajectory. The operator can either manually input the directories or they can click on buttons to the right of the text boxes and use the operating systems file browser GUI (Figure 1).
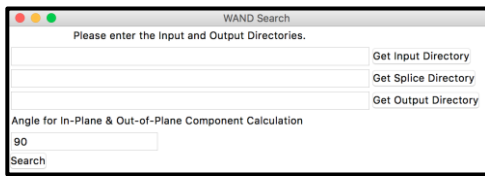
Figure 1: Example of the WAND Search window when WAND first initializes.

Clicking on the "Search" button starts the visualization part of WAND after a few safety checks are performed. These safety checks include checking that the directories exist, data exist in the input directories, and the supplied angle is a valid angle. Once the safety checks are complete, WAND collects data that were valid within the past 24 hours, and then the WAND Visualization window opens. The WAND Visualization window is navigated by tabs (Figure 2). A tab exists for each system: TDRWP, 915-MHz DRWP, Balloons, Tower 397, and Tower 313. Two additional tabs exist for comparing vertical profiles from all systems and viewing the raw text files, respectively.
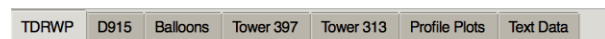

Figure 2: A close up view of the tab navigation in the WAND Visualization window.

The WAND visualization window opens to the TDRWP tab (Figure 3). The TDRWP tab is divided into three columns. The first column (on the left) is a list of all profiles available from the past 24 hours. Each profile is selectable, and if selected it will plot a vertical profile of the U (East-West) wind component and the V (North-South) wind component in the plot in the lower right corner of the page. The second column shows a time-height cross section of the U and V components over the past 24 hours. Vertical black lines are shown at the times balloons are launched to increase situational awareness of when concurrent profiles exist. The final column contains a time-height cross section of the quality control flags from the past 24 hours.
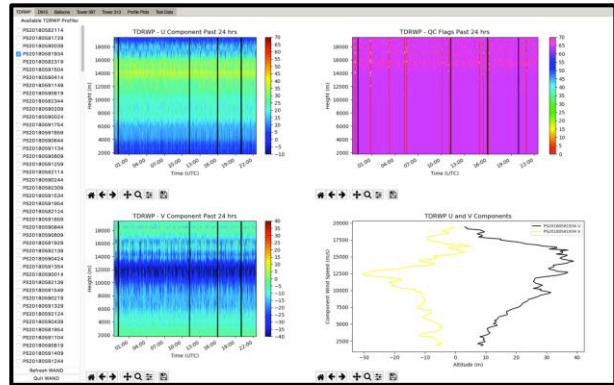

Figure 3: Example of data shown on the TDRWP tab.

The second tab, "D915," contains access to data from the 915-MHz DRWP system (Figure 4). This tab is nearly identical to the TDRWP tab, except the 915-MHz data files have no quality control information. Thus, there is no quality control time-height cross section. The first column, on the left, contains a list of all available 915-MHz DRWP profiles from the past 24 hours. Directly to the right are radio buttons to select which 915-MHz DRWP site to display in the time-height cross sections. The U and V wind component time-height cross sections are to the right of the radio buttons. The U and V wind components vertical profile is displayed on the far right.
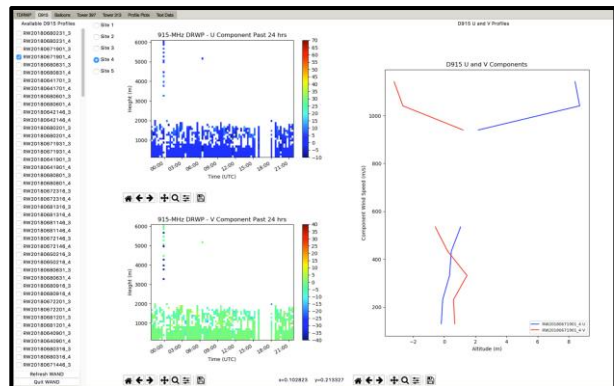

Figure 4: Example of data shown on the 915-MHz DRWP tab.

The Balloon tab contains access to all balloon data (Figure 5). It displays data from any of the balloons that could be launched at the ER. The left column contains a list of all available balloons from the past 24 hours. Each of the available balloons in this list are selectable. The next column contains radio buttons of variables from which vertical profiles can be plotted. The third column contains a vertical profile of the selected variable for the selected balloon. Below that is a ground track of all selected balloons. The last column contains a skew-T log-P from the most recent LR balloon that has been selected.
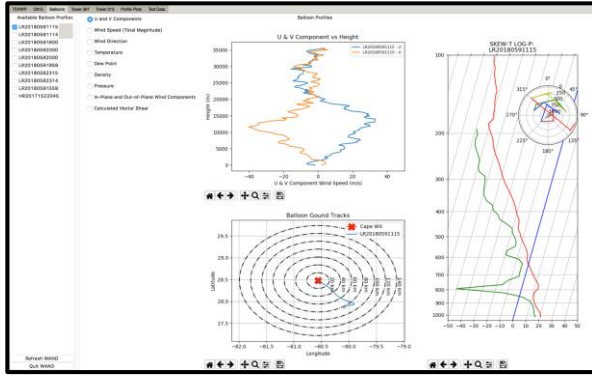
Figure 5: Example of data shown on the Balloon tab.

The Tower 397 tab contains access to all Tower 397 data (Figure 6). The left column contains radio buttons to select the variable to display in the time series plot, and there exist check boxes to select the tower from which data are displayed. Tower selections comprise of either one of the three individual towers at the site, or the up-wind tower (Orcutt et al., 2016). A time series of the selected variable is plotted over the past 24 hours in the upper left of the second column. Next to the time series plot exists a table with the most recent wind speed and wind direction observations. Another table that contains wind speed and wind direction observations from the up-wind tower during the most recent ten minutes exists at the bottom of the GUI.
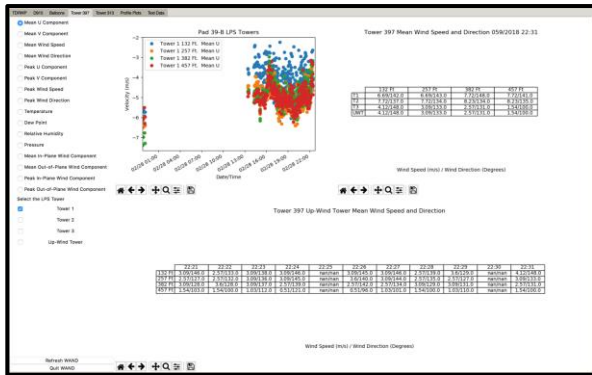

Figure 6: Example of data shown on the Tower 397 tab.

The Tower 313 data are contained in the Tower 313 tab (Figure 7). This tab's layout is nearly identical the Tower 397 tab. The first column contains selectable radio buttons of variables to plot and which sensors on the tower to plot. A time series from the most recent 24 hours of the selected variable and sensor is displayed to the upper left of the second column. The most recent wind speed and wind direction observations are displayed in a table to the right of the time series plot. Finally, a table displaying the past ten minutes wind speed and wind direction observations from the up-wind sensor are displayed at the bottom of the window.
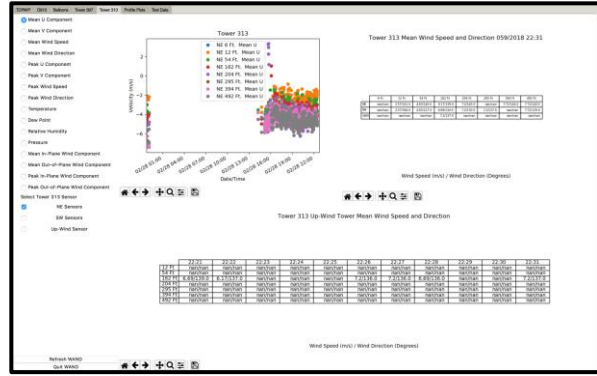

Figure 7: Example of data shown on the Tower 313 tab.

The Profile Plots tab allows the operator to plot vertical profiles from all profiling systems (Figure 8). The left column shows a list of all available profiling systems. The next column to the right allows the operator to select the desired variable to display, and has a list of statistical envelopes for each month to select to plot if desired. The next column to the right is the plot of selected profiles for the selected variable. The final column on the right displays the composition of any selected PRESTO spliced profiles.
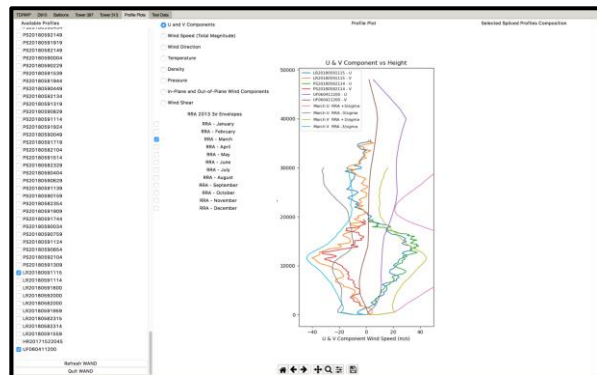

Figure 8: Example of data shown on the Profile Plots tab.

The Text Data tab (Figure 9) displays selected profile(s) data files as plain text. The left column is a list of all available profiles to view (except wind tower files). The right part of the window is where the text is displayed.
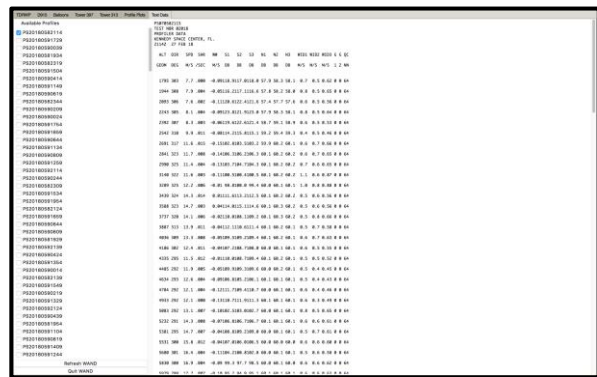

Figure 9: Example of data shown on the Text Data tab.

5. SUMMARY

MSFC NE developed a software tool, WAND, using Python 3 to provide DOL personnel with displays of the meteorological conditions at and around the launch site for situational awareness. WAND has the capabilities to display data from a variety of systems at the ER, as well as upper level wind forecasts, PRESTO spliced profiles, and monthly statistical envelopes. This tool utilizes several large, well known packages (i.e., Numpy, Scipy, Matplotlib, etc.) to provide array handling, mathematical functions, data visualization, and GUI creation. Code reuse was prioritized to keep the development of the tool simple.

6. ACKNOWLEDGEMENTS

7. REFERENCES

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