Quality-Controlled Wind Data from the Kennedy Space Center 915 Megahertz Doppler Radar Wind Profiler Network

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The National Aeronautics and Space Administration's (NASA) Kennedy Space Center (KSC) has installed a five-instrument 915-Megahertz (MHz) Doppler Radar Wind Profiler (DRWP) system that records atmospheric wind profile properties. The purpose of these profilers is to fill data gaps between the top of the KSC wind tower network and the lowest measurement altitude of the KSC 50-MHz DRWP. The 915-MHz DRWP system has the capability to generate three-dimensional wind data outputs from approximately 150 meters (m) to 6,000 m at roughly 15-minute (min) intervals. NASA's long-term objective is to combine the 915-MHz and 50-MHz DRWP systems to create complete vertical wind profiles up to 18,300 m to be used in trajectory and loads analyses of space vehicles and by forecasters on day-of-launch (DOL). This analysis utilizes automated and manual quality control (QC) processes to remove erroneous and unrealistic wind data returned by the 915-MHz DRWP system. The percentage of data affected by each individual QC check in the period of record (POR) (i.e., January to April 2006) was computed, demonstrating the variability in the amount of data affected by the QC processes. The number of complete wind profiles available at given altitude thresholds for each profiler in the POR was calculated and outputted graphically, followed by an assessment of the number of complete wind profiles available for any profiler in the POR. A case study is also provided to demonstrate the QC process on a day of a known weather event.

Nomenclature

dB	=	decibels
DOL	=	day-of-launch
DRWP	=	Doppler Radar Wind Profiler
GUI	=	graphical user interface
km	=	kilometers
KSC	=	Kennedy Space Center
m	=	meters
MHz	=	megahertz
min	=	minutes
MSFC	=	Marshall Space Flight Center
NASA	=	National Aeronautics and Space Administration
NE	=	Natural Environments [Branch]
POR	=	period of record
QC	=	quality control
SNR	=	signal-to-noise ratio
SSP	=	Space Shuttle Program
u	=	westerly wind component
UTC	=	Coordinated Universal Time
v	=	southerly wind component
VV	=	vertical velocity

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I. Introduction

The atmospheric environment is of crucial import to the aerospace community to ensure safe travels in the advancement of space exploration. Recording accurate wind features is of primordial interest in trajectory loads and design of spacecrafts and subsequently in the ascent of space vehicles on DOL. Historically, balloon instruments are launched to collect wind profile properties up to 30,000 m. This provides a snap shot of wind components during the ascent of the instrument at given altitude thresholds. However, balloon measurements do not provide a continuous picture of the atmosphere due to large gaps between adjacent measurements. These devices are also costly; require approximately one hour to reach altitude; and yield a limited sample size available for DOL simulations. In fact, only about 200 balloon measurements per month are considered in current design processes and on DOL operations. Although precise, balloon launches fail to generate an uninterrupted representation of atmosphere dynamics.

A 50-MHz DRWP was installed near KSC to supplement historic balloon data. This DRWP returns thousands of wind data outputs per month, decreasing the data gapes between measurements in comparison to balloon systems. The 50-MHz DRWP provides wind data at roughly five-minute intervals from approximately 2,400 m to 18,300 m. Despite the benefits of the 50-MHz DRWP, it was not approved by the Space Shuttle Program (SSP) due to costs incurred with implementing a new measurement tool late in the Shuttle's life cycle (Barbré 2011). Moreover, a 50-MHz DRWP climatological database has been created for the August 1997 to December 2009 POR; the system continues to record wind profile properties and measurements are added to the database periodically. In addition, the 50-MHz DRWP does not return low-altitude data below 2,400 m. Therefore, balloon measurements continue to be the primary determinant of wind characteristics used in space vehicle analyses and in DOL procedures.

Due to the 50-MHz DRWP limitations, KSC has installed a five-instrument 915-MHz DRWP system that is capable of generating wind data outputs from 150 m up to 6,000 m at approximately 15 min intervals. The 915-MHz DRWP system is configured in a diamond-shaped pattern each comprised of 2 oblique beams that point 15° off zenith and 1 vertical beam. Fig. 1.1 below shows the geographic locations of the five 915-MHz profilers: South Cape, False Cape, Merritt Island, Mosquito Lagoon, and Titusville-Cocoa. A climatological database for the 915-MHz DRWP network is currently being developed for the 2000 to 2009 POR. NASA's objective is to create a vertically complete wind profile up to 18,300 m to be used in trajectory and loads analyses of space vehicles and on DOL operations. This will be fulfilled by combining the 50- and 915-MHz climatological databases after the 915-MHz data has been completely QC'ed.

Despite the convenience of the 915-MHz network, data are subject to contamination. Weather events, ground clutter, convection cells, signal-to-noise interferences, among others can return erroneous wind data by the 915-MHz DRWP system. In addition, profilers are suspect to periodic data gaps due to severe weather events, testing procedures, and general maintenance operations. Therefore, automated and manual QC processes are utilized to remove erroneous and unrealistic wind data outputs. The QC process begins with automated checks that either flag data or remove data that defy the determined parameters. After the automated QC process is run, data are removed manually at the discretion of the analyst. The analyst assesses both unflagged data and flagged data that did not pass a particular QC check and omits erroneous data as needed within a graphical user interface (GUI), a product of MATLAB created by Robert E. Barbré, Jacobs ESTS / MSFC NE (Fig. 1.8). This GUI displays a time-height cross section of data with altitude in km on the y-axis and timestamps in Coordinated Universal Time (UTC) on the

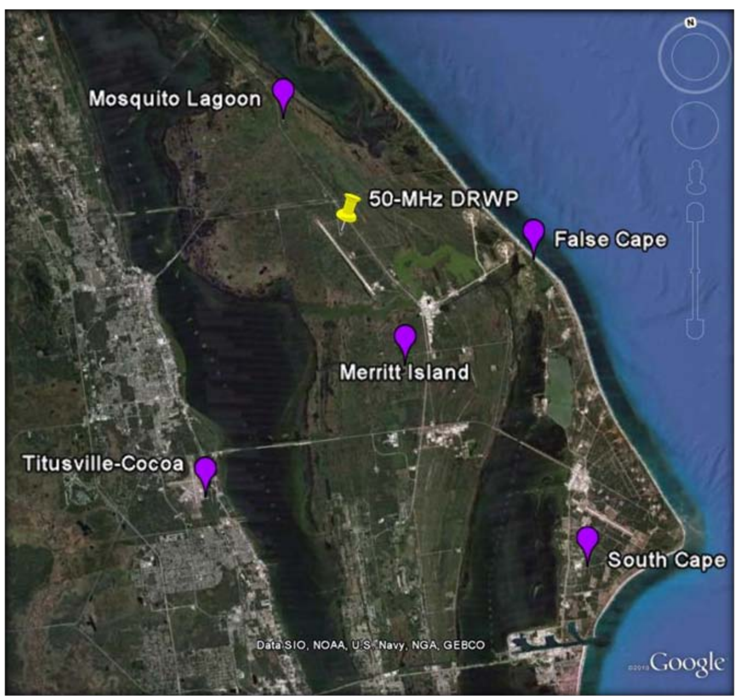

Figure 1.1. Google Earth image of the 915-MHz DRWP network at Kennedy Space Center. Each 915-MHz DRWP is illustrated by a purple marker and is labeled accordingly. The 50-MHz DRWP is denoted by a yellow thumbtack. Image credit: Robert Barbré.

x-axis. The user is able to view data such as windspeed, wind direction, westerly (*u*-) and southerly (*v*-) wind components, radial velocity, and SNR. A similar GUI for the 50-MHz DRWP is described in Barbré 2011. The procedure and results section will further explain the automated and manual QC methods.

II. Procedure

The methodology employed within this analysis is a dichotomy of both automated and manual QC processes. Specific QC flags are applied to data when the thresholds of a certain QC check are not met. A summary of the QC processes and their corresponding descriptions are shown in Table 1.1. Some QC checks remove erroneous data, while others only flag the suspect data. The flagged data is then assessed by the analyst during the manual QC process to determine its reliability. Subsequently, the remaining data are evaluated and removed according to the analyst's discretion.

Table1.1. Summary of Quality Control Processes

QC Check	Description
Data not affected by any quality control checks	Data were not affected by any QC process
Altitudes Filled*	Missing altitude data are filled up to 6.1 kilometers
Vertical Beam not used*	< 60% of available vertical beam consensus records are used
Convection Flag Test M	Data that failed the discriminant function test (see Barbré 2011)
Missing Data*	Wind data are missing
Consensus Averaging Period P	Profiler data collection system will be reset if its computer time is > 5 seconds off from the central Range Operations Control Center computer
# Oblique Beam Consensus Records P	Radial velocity and signal-to-noise ratio data are removed if < 60% of available records exist for the oblique beam
Signal-to-Noise Ratio	< -20 dB from any beam
Unrealistic Wind	Windspeeds that are < 0 m/s, wind directions that are < 0, or wind directions that are > 360
$\lvert w \rvert$	The absolute value of the vertical wind component is > 10.0 m/s
Automated Radio Frequency Interference M	The absolute value of the vertical wind component is > 5.0 m/s and the radial velocity from all of the beams are within 0.5 m/s of one another
Vector Shear	If vector shear is > $0.1 s^{-1}$
Small-Median Test	Compares the median of the *u*- and *v*-components of a horizontal wind estimate to the median of the surrounding *u*- and *v*-component wind estimates (see Barbré 2011)
Isolated Datum	Signifies that the small median test was not conducted, due to lack of unflagged surrounding points
Manual	Based on analyst's discretion

Table1.1. Legend

* No wind data were removed
M Data were removed manually
P Entire data profiles omitted

III. Results

Once this assessment's POR was QC'ed, software was created to display the desired outputs. Table 1.2 illustrates the percentage of affected data for each individual QC process. Percentages were computed for each individual month in the POR and represent the amount of data affected by each QC check. This product considers all data that were flagged or removed by the automated and manual QC process. The results show that the percent of affected data for any given QC process is fairly consistent in the four months of the POR.

The values presented in Table 1.2 must be carefully weighed in that some of the percentages do not equate the true amount of data that were affected by each QC check. For example, attention should be drawn to the significant amount of data removed manually. In this analysis, the automated QC process flagged data based on the convection flag test algorithm. These data were then analyzed and removed during the manual QC process, and therefore added to the manual QC check total.

Table 1.2.* Percentage of Affected Data for Individual Quality Control Processes

Quality Control Checks	January	February	March	April
Data not affected by any quality control checks	66.17	60.87	65.17	65.85
Vertical Beam not used	7.37	7.85	4.81	3.49
Convection Flag Test	0.13	2.31	0.02	0.15
Consensus Averaging Period	0.03	0.00	0.14	0.05
Oblique Beam Consensus Records	0.00	0.00	0.00	0.00
Signal-to-Noise Ratio	0.17	0.21	0.05	0.01
Unrealistic Wind	0.00	0.00	0.00	0.00
|w|	0.00	0.00	0.04	0.00
Automated Radio Frequency Interference	0.00	0.00	0.15	2.00
Vector Shear	1.99	0.93	0.42	0.68
Small-Median Test	0.42	0.57	0.49	0.40
Isolated Datum	1.36	0.94	0.68	1.35
Manual	22.36	26.32	28.04	26.01
	(%) Affected Data			

***Table1.2. Percentages for all flagged quality control (QC) data for each respective month (i.e., January, February, March, and April 2006). Percentages were computed for each individual month and represent the amount of data that were flagged for each corresponding QC process. Values labeled '0.00' denote that less than five-thousandths of the data were affected.**

A. Analysis of Complete Wind Profiles Available in the POR

Fig. 1.2 represents the number of complete wind profiles available at given altitudes for each profiler in January 2006. A complete wind profile is defined as all measurements passing the QC process between the minimum and maximum 915-MHz altitude thresholds that do not contain missing data.

The general trend shows that with increasing altitude, the number of complete wind profiles decreases. The South Cape and Ti-Co profilers return the largest sample of complete wind profiles in the month of January. Below 2 km, South Cape and Ti-Co combined offer approximately 1,000 complete wind profiles in January, 2006. For comparison, the historic balloon databases contain a few hundred profiles per month over many years. The limited amount of complete wind profiles available for the 915-MHz DRWP Merritt Island and Mosquito Lagoon are due to trends observed by the analyst. In the month of January, wind data for these profilers were largely unavailable for extended periods of time, possibly due to frequent maintenance on each of the instruments. Therefore, only a fraction of data collected by these profilers was available in this analysis.

Since the ultimate goal is to merge the 50- and 915-MHz climatological databases, the minimum altitude reached by the 50-MHz DRWP is plotted to show the amount of complete wind profiles that are available for each 915-MHz DRWP. In January 2006, nearly 600 complete wind profiles are available up to the minimum altitude reached by the 50-MHz DRWP.

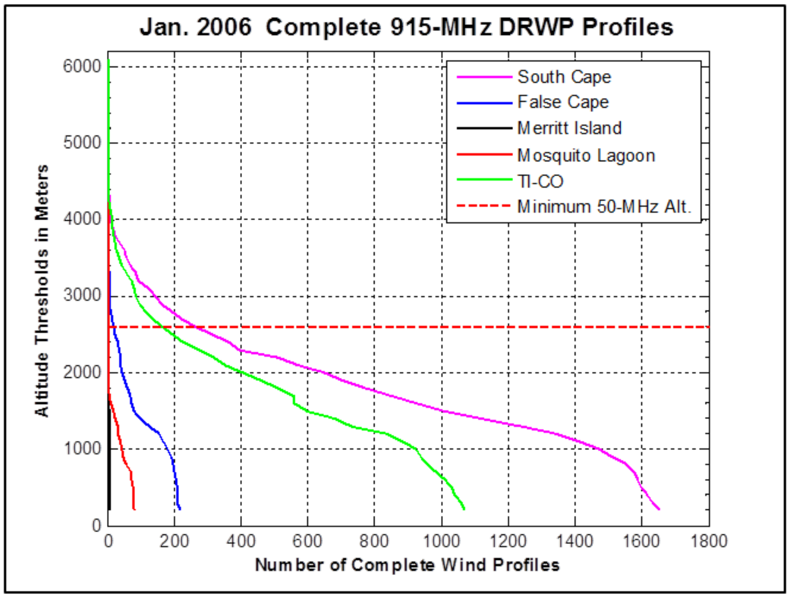

Figure 1.2. Number of complete wind profiles available at given altitude thresholds for each profiler in January 2006.

Fig. 1.3 represents the same analysis as depicted in Fig. 1.2, except the data were plotted for the month of February. In general, more complete wind profiles were available for February compared to January. In fact, approximately 3,500 wind profiles are available in February compared to 3,000 available profiles in January. False Cape becomes the profiler with the second most available wind profiles in February instead of third. However, both January and February offer about 500 complete wind profiles that reach the minimum altitude of the 50-MHz DRWP. Yet again, the limited amount of data available for Mosquito Lagoon was due to extended periods of unavailable data for the profiler, possibly due to maintenance operations.

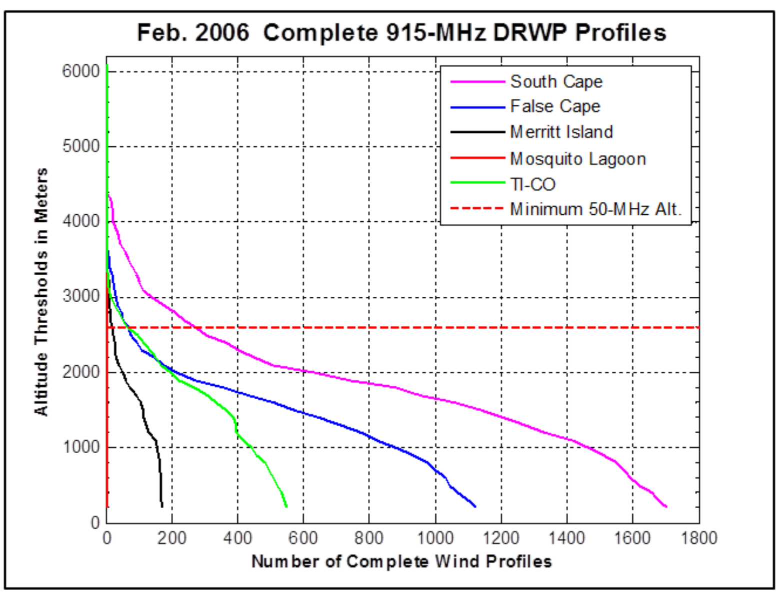

Figure 1.3. Number of complete wind profiles available at given altitude thresholds for each profiler in February 2006.

Fig. 1.4 correlates the previous analyses, except the data were plotted for the month of March. The same general trends are found as explicated in the previous graphs. The Mosquito Lagoon profiler continues to be down most of the month of March, and South Cape remains the profiler measuring the most wind profiles. The relatively large gap between available profiles between South Cape and the rest of the network is possibly, due to more data contamination removed during the manual QC process among the other profilers.

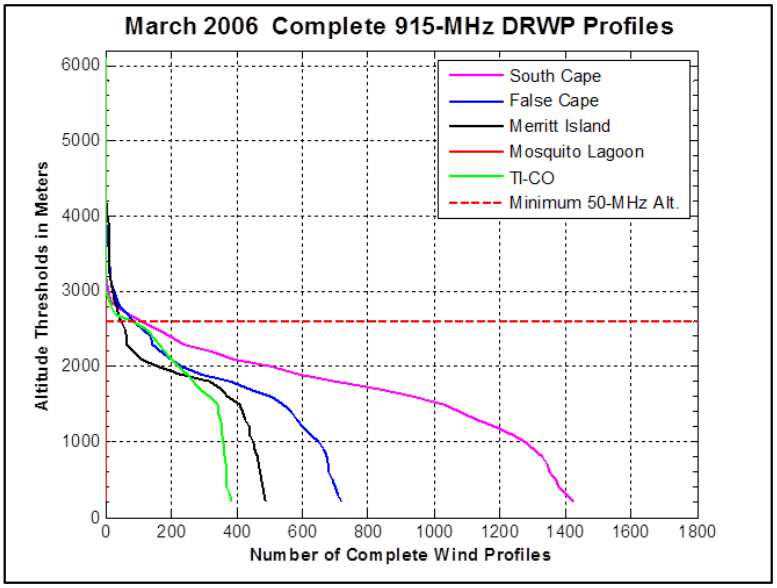

Figure 1.4. Number of complete wind profiles available at given altitude thresholds for each profiler in March 2006.

Fig. 1.5 correlates the previous analyses, except the data were plotted for the month of April. Mosquito Lagoon remains largely unavailable and the South Cape profiler continues to measure the highest number of wind profiles in the month of April. Approximately 3,000 complete wind profiles are available in April, with about 400 profiles reaching the minimum recording altitude of the 50-MHz DRWP.

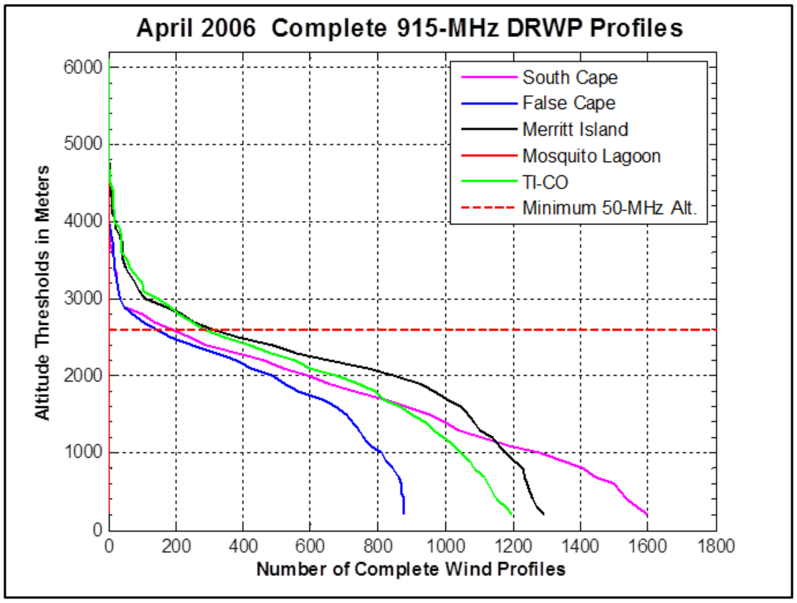

Figure 1.5. Number of complete wind profiles available at given altitude thresholds for each profiler in April 2006.

Fig. 1.6 plots available wind profiles versus altitude thresholds for individual months in the POR. This analysis shows the number of complete wind profiles available for any profiler in the period of record rather than computing profile totals for each individual profiler. This analysis allows the user to view the number of complete wind profiles available in a given month disregarding which profiler recorded the measurements. The month of April offers the most available wind profiles, while the other months in the POR offer relatively the same amount of wind data. April may yield more wind measurements due to less maintenance needed at the passing of winter.

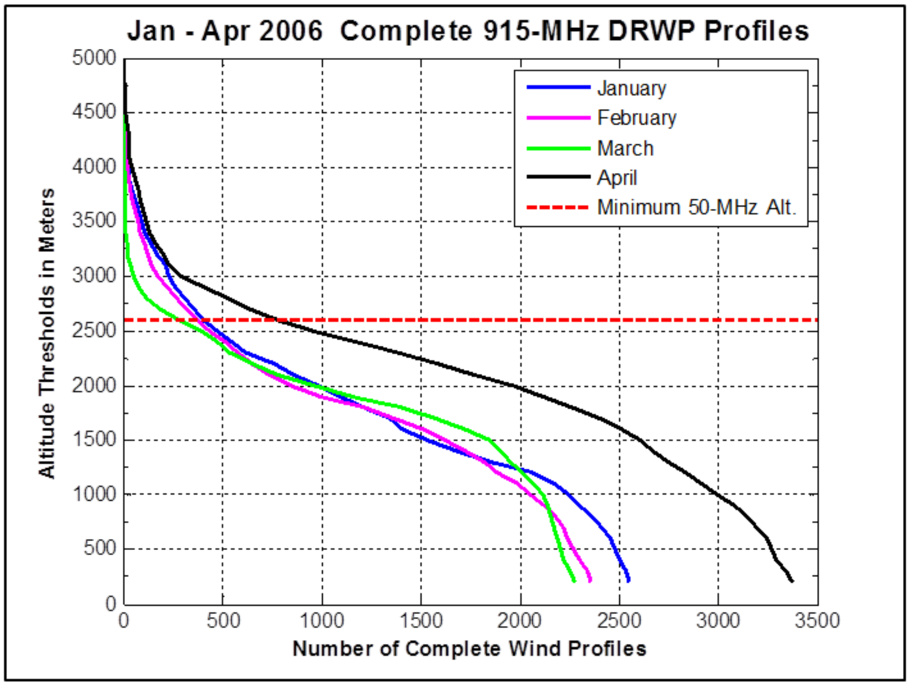

Figure 1.6. Number of complete wind profiles available at given altitude thresholds for any profiler in the period of record (January to April 2006).

B. Case Study Figures

The April 9, 2006-case study represents a known weather event in the POR, as viewed by the analyst in the 915-MHz climatological database. The weather map below shows atmospheric conditions at 850 millibars, which depict strong winds converging ahead of a cold front approaching central Florida. This wind filed coupled with the high dewpoints in the region implies clouds and precipitation near KSC. The case study investigates the coincidence of the conditions the weather map shows versus the variables returned by the 915-MHz DRWP network.

2006 April 9: 850 millibars

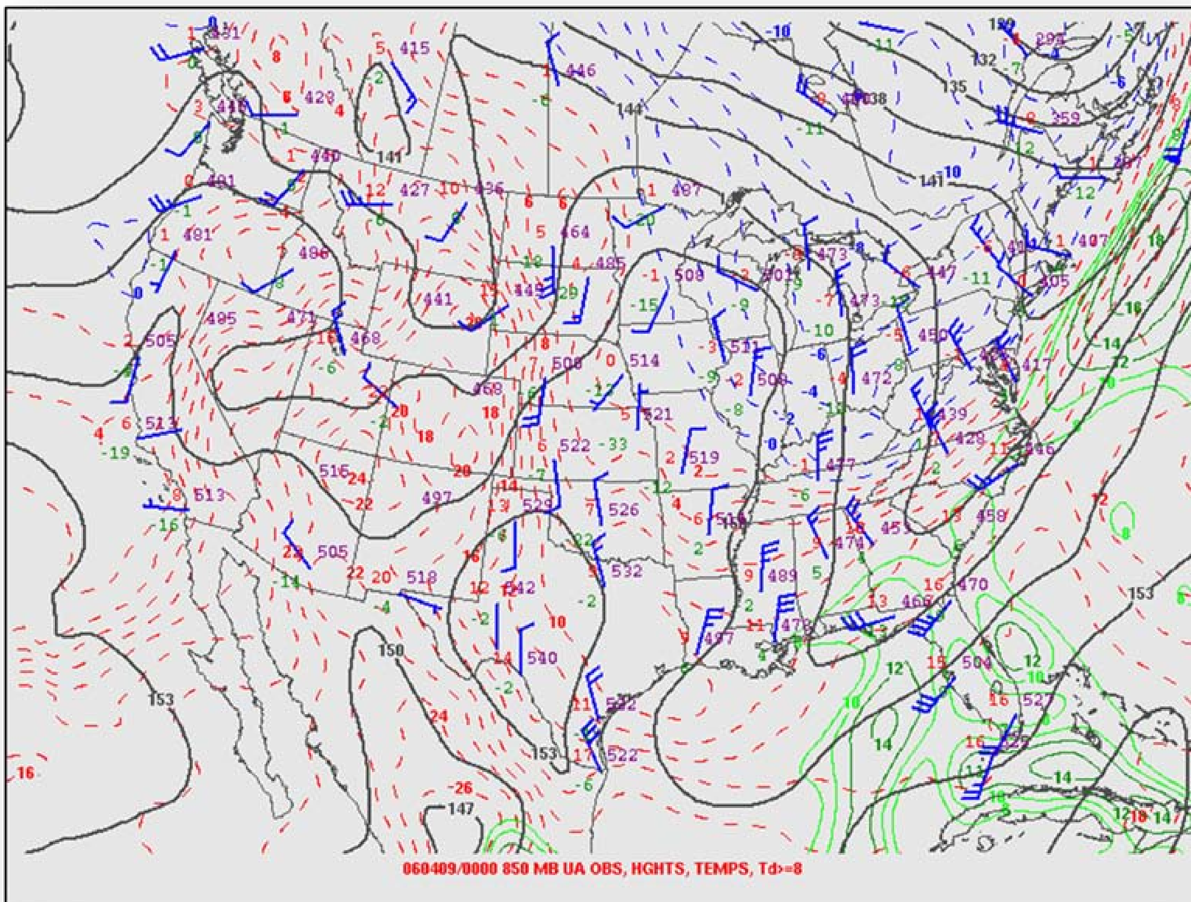

Figure 1.7. **Image credit: NOAA'S National Weather Service, Surface and Upper Air maps.**

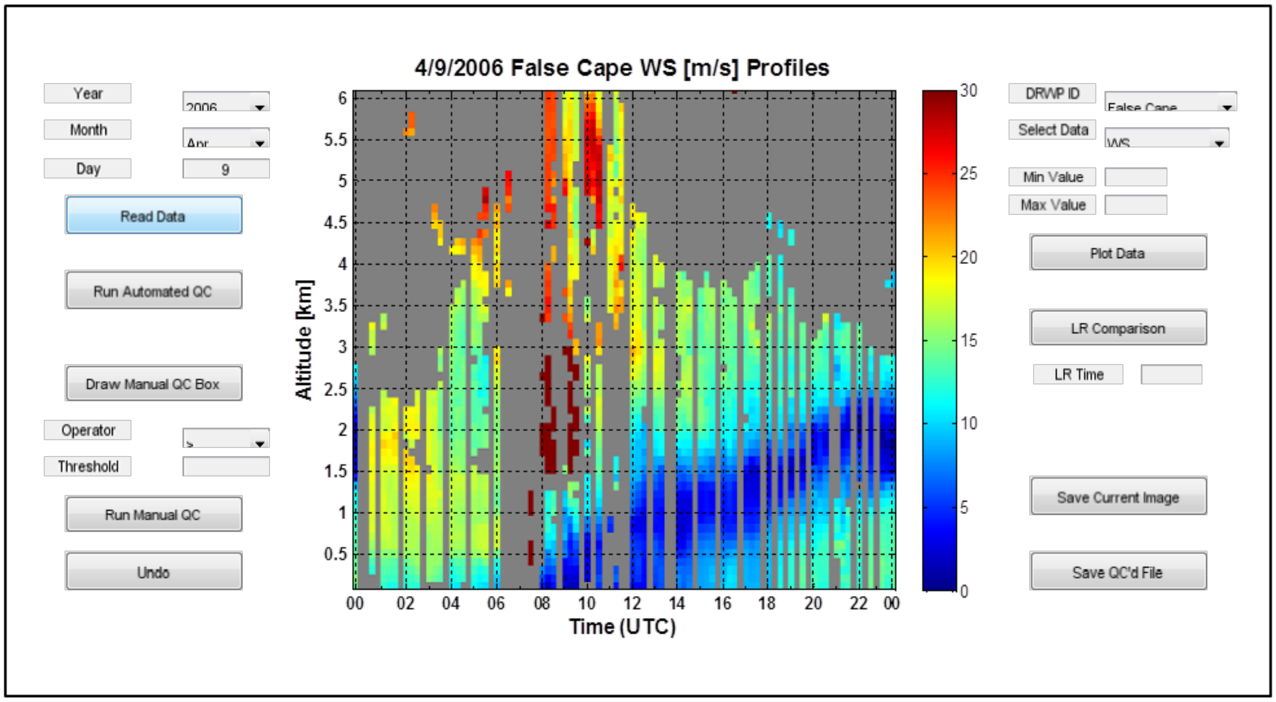

Figure 1.8. Illustrates the QC process used in this analysis within the 915-MHz GUI system.

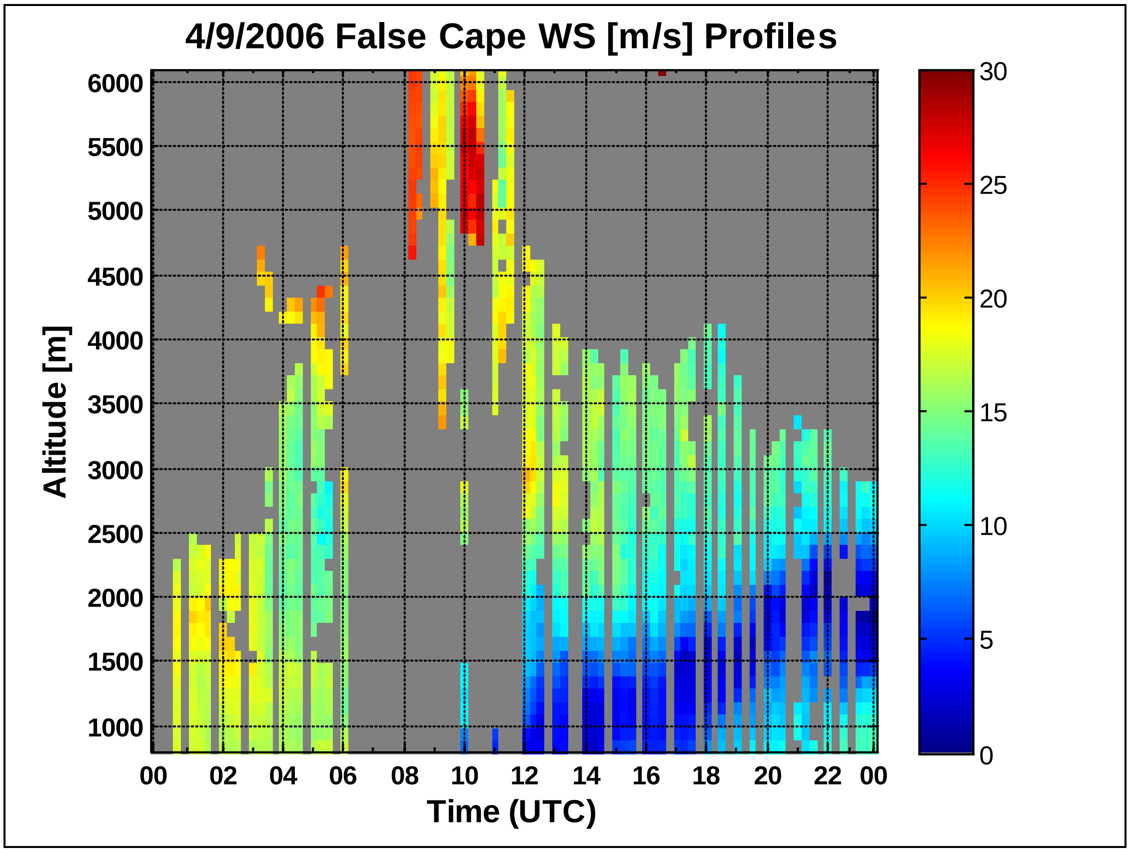

Figure 1.9. Illustrates the windspeed values recorded by the False Cape profiler on April 9, 2006.

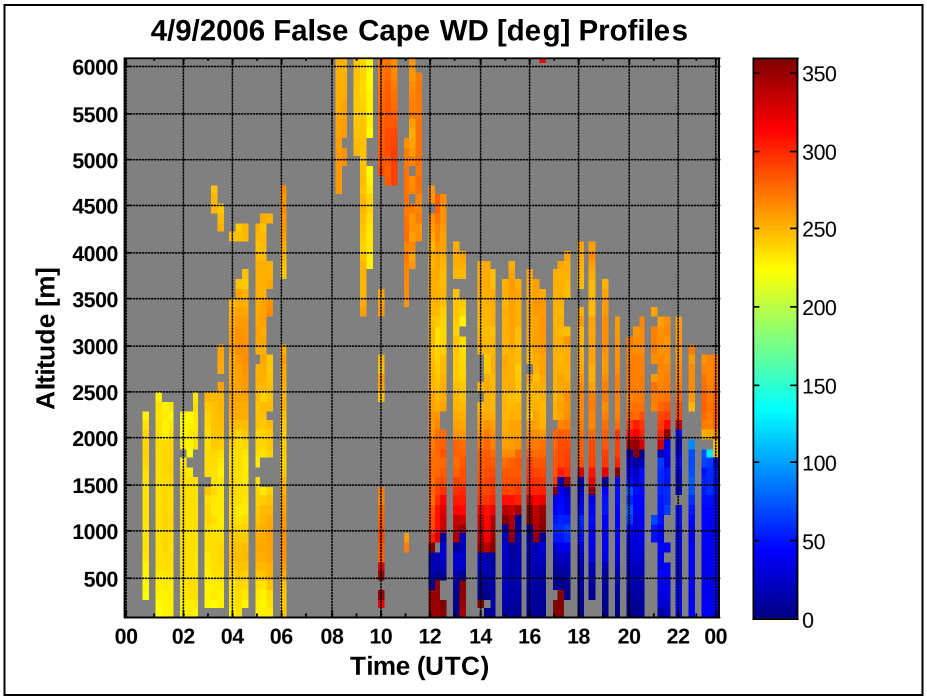

Figure 1.10. Illustrates the wind direction recorded by the False Cape profiler on April 9, 2006.

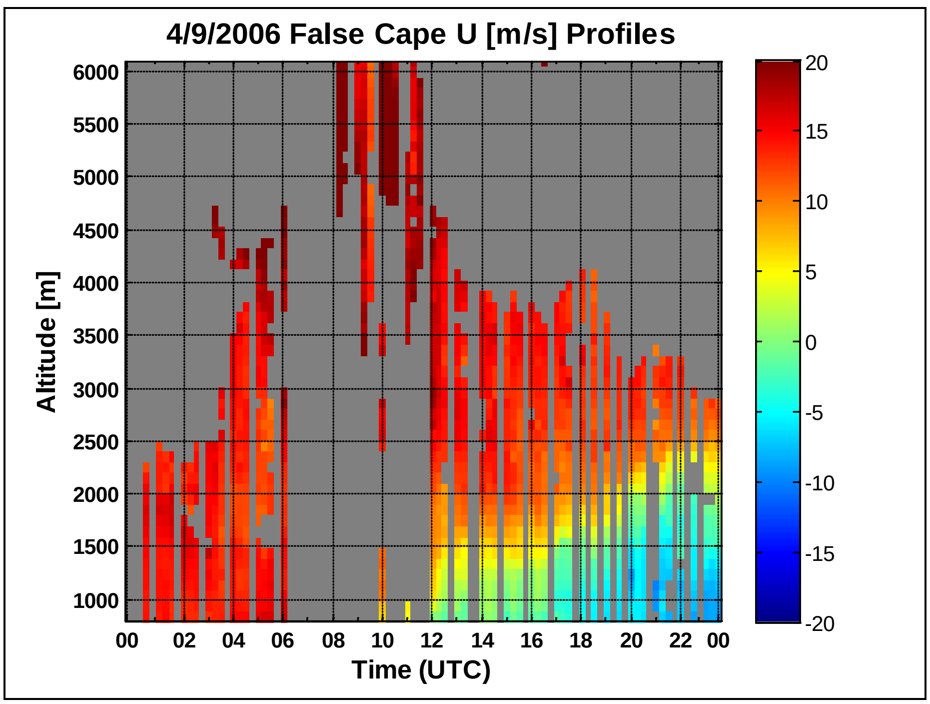

Figure 1.11. Illustrates the westerly wind component values recorded by the False Cape profiler on April 9, 2006.

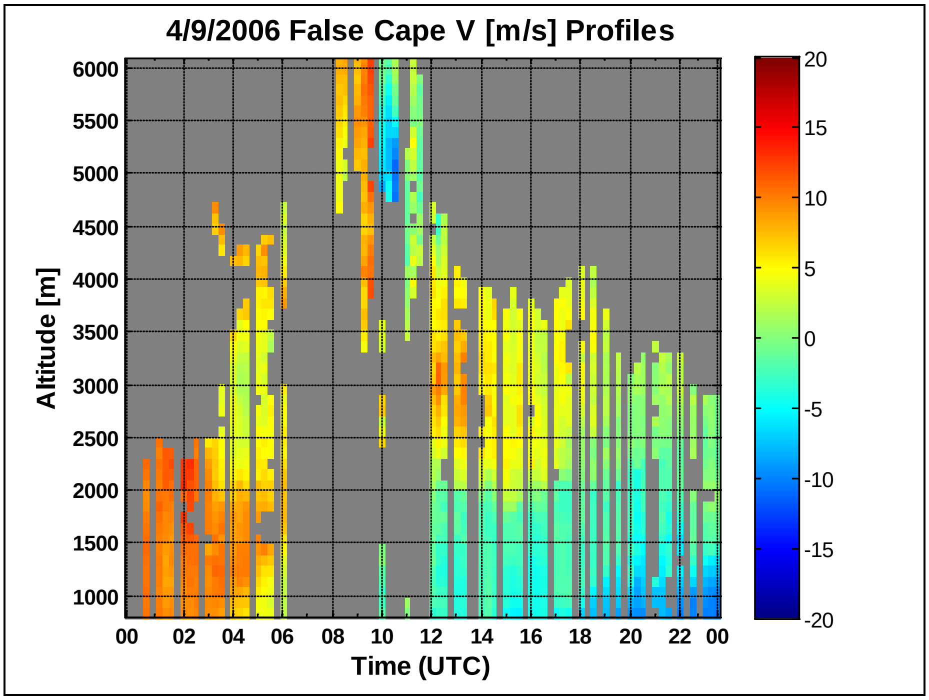

Figure 1.12. Illustrates the southerly wind component values recorded by the False Cape profiler on April 9, 2006.

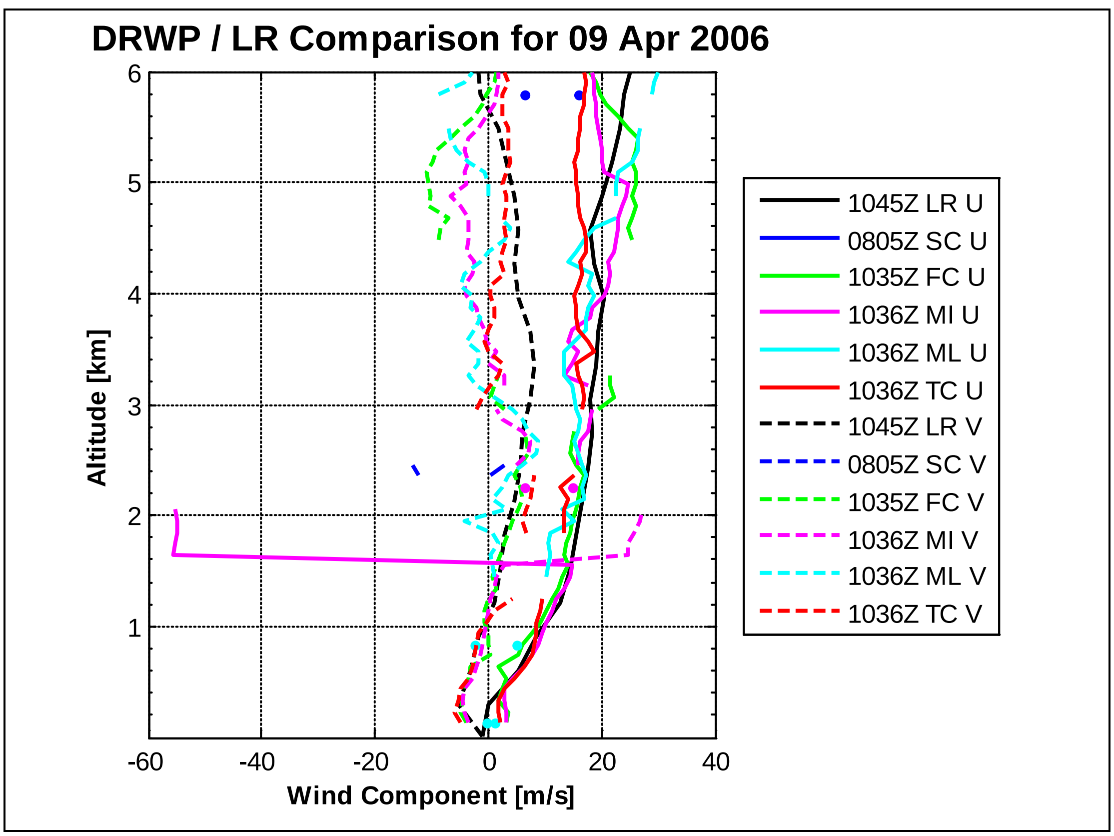

Figure 1.13. LR balloon comparison at 12 00 UTC. The balloon measurements are shown in solid and dotted black lines. The corresponding 915-profilers are represented in different colors.

1. Discussion

By interpreting the preceding 915-MHz climatological database plots for the April 9, 2006, case study, observations have been confirmed; a weather event occurred on this day, including a cold front and precipitation. This conclusion is supported by the preceding graphs. The weather map provided shows a low-pressure system near KSC, and rain contamination is suggested in the windspeed plot. Windspeeds greater than 25 m/s between 7 00 and 11 00 UTC demonstrate the results of rain contamination returned by the 915-MHz False Cape profiler in Fig. 1.9. In addition, the wind direction plot as well as the sudden shifts in the *u*- and *v*- wind components supports the entrance of a cold front on the day of the case study. The wind direction plot begins with winds coming from the west southwest direction; then, winds from the northeast take over beginning at 12 00 UTC, as shown in Fig. 1.10. The *u*- and *v*-wind component plots shown in Fig. 1.11 and Fig. 1.12 show shifts in the westerly and southerly wind components at approximately 12 00 UTC; this corresponds to the wind direction plot suggesting a cold front entering central Florida. Fig. 1.13 is a balloon measurement comparison that verifies that the 915-MHz False Cape profiler was in-line with the accurate readings of the balloon launches. This aids in concluding that the profiler was returning very accurate results on April 9, 2006. The strange measurement returned by the Merritt Island profiler is possibly due to the profiler mistaking precipitation for wind data. In summation, the 915-MHz DRWP network provides data that coincides with upper-atmospheric weather maps.

IV. Conclusion

The key conclusions developed from this analysis are provided to verify concepts discussed in previous scholarship in this field:

C1: Historic balloon measurements offer limited sample sizes due to the time needed to reach altitude (i.e., approximately one hour), their costly features, and their inability to create an uninterrupted picture of atmospheric conditions.

C2: Unlike historic balloon data that yield approximately 200 measurements per month, the 915-MHz DRWP network has the capability of producing thousands of profiles per month from any given profiler.

C3: Once the 915-MHz DRWP climatological database has been QC'ed for the 2000 to 2009 POR, the 50-MHz DRWP will be combined to create a continuous, complete wind profile up to 18,300 m. This will not replace historic balloon measurements; rather, the DRWP data will support the historic balloon measurements database. Future data collection will be appended to this database and used in trajectory and loads design of space vehicles and on DOL.

C4: As found in the case study, the 915-MHz DRWP network returns accurate measurements that correspond with historic balloon data and upper-atmospheric weather maps.

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