Quality Control of Wind Data from 50-MHz Doppler Radar Wind Profiler

Austin D. Vacek

Marshall Space Flight Center

August 7, 2015

Reviewed by NASA Mentor
Ryan Decker
EV44 – Natural Environments Branch

____
Mentor Signature Here

Quality Control of Wind Data from 50-MHz Doppler Radar Wind Profiler

Austin D. Vacek
EV44 Summer Intern 2015, Marshall Space Flight Center, AL, 35812

Upper-level wind profiles obtained from a 50-MHz Doppler Radar Wind Profiler (DRWP) instrument at Kennedy Space Center are incorporated in space launch vehicle design and day-of-launch operations to assess wind effects on the vehicle during ascent. Automated and manual quality control (QC) techniques are implemented to remove spurious data in the upper-level wind profiles caused from atmospheric and non-atmospheric artifacts over the 2010-2012 period of record (POR). By adding the new quality controlled profiles with older profiles from 1997-2009, a robust database will be constructed of upper-level wind characteristics. Statistical analysis will determine the maximum, minimum, and 95th percentile of the wind components from the DRWP profiles over recent POR and compare against the older database. Additionally, this study identifies specific QC flags triggered during the QC process to understand how much data is retained and removed from the profiles.

Nomenclature

DRWP	=	50-MHz Doppler radar wind profiler	*SW*	=	Spectrum Width
FGP	=	First-guess propagation	*U*	=	East-west wind component
GUI	=	Graphical user interface	*UTC*	=	Universal Time Coordinate
POR	=	Period of record	*V*	=	North-south wind component
QC	=	Quality control	*w*	=	Vertical Velocity

I. Introduction

This report documents the QC process and analysis by the MSFC Natural Environments Branch (EV44) of wind profiles collected from the DRWP located at the Kennedy Space Center (KSC). DRWP data provides an important asset for the National Aeronautics and Space Administration (NASA) to understand the effects of the wind environment on the structural integrity of launch vehicles during ascent.

The ascent wind environment of launch vehicles were traditionally determined from weather balloons launched at KSC site co-located on the United States Air Force's Eastern Range (ER) at the Cape Canaveral Air Force Station. However, weather balloon launches levy problematic issues and limitations. First, it is unattainable to release a large number of weather balloons due to high cost and hardware resource limitations. Thus, wind databases from balloon systems are limited from the small sample size collected. Another issue that arises is the temporal resolution of the atmosphere resolved from weather balloon launch. Typical weather balloons take around 1 hour to create a vertical profile of the atmosphere. The long time period between balloon launches could prevent wind data from atmospheric events to be collected, such as frontal passages or convection. Lastly, balloons drift with the wind as they rise through the atmosphere, which could create a false representation of the ascent wind environment that the launch vehicle would experience.

This study continues the QC process and analysis from January 2010 to January 2013 POR to further increase the current DRWP database. Currently, a QCed database of DRWP wind profiles from August 1997 to December 2009 exists and is used for design assessments.[1] NASA's Space Launch System and future vehicle launch programs are currently using DRWP wind data in vehicle trajectory design analyses.

II. Background

Located east of the Shuttle Landing Facility at KSC in Florida, the DRWP transmits radio pulses at 49.25 MHz from three beams to measure wind components. One beam is pointed vertically to determine vertical motion, and two beams are 15° off zenith at azimuths of 45° and 135° east from north to determine horizontal winds.[1] Pulses are backscattered to the receiver by fluctuations of humidity and temperature in the atmosphere with scale lengths of 3 m approximately.[2] Using a Fast Fourier Transform, the return signal at each range gate is converted into a power spectra and placed in frequency bins. After obtaining the power spectra, radial velocities are calculated from the resultant Doppler shift. Wind components are then determined from triangulation of the radial velocities assuming a homogeneous atmosphere.[3] After an upgrade in 2004, a total of 111 gates are used between 2,666 to 18,616 m every 145 m for a single profile that is generated every 3 minutes.[4]

The 50-MHz DRWP data outputs have been archived by MSFC through receiving data from KSC across the Meteorological Interactive Data Display System. The DRWP data outputs provide horizontal wind speed (m s^{-1}), wind direction (°), internal shear values (s^{-1}), vertical velocity (*w*; m s^{-1}), spectral width (SW; m s^{-1}), signal power (dB), noise power (dB), and number of FGPs (dimensionless). Also westerly (U) and southerly (V) wind components are computed in the data output from wind speed and wind direction.[4]

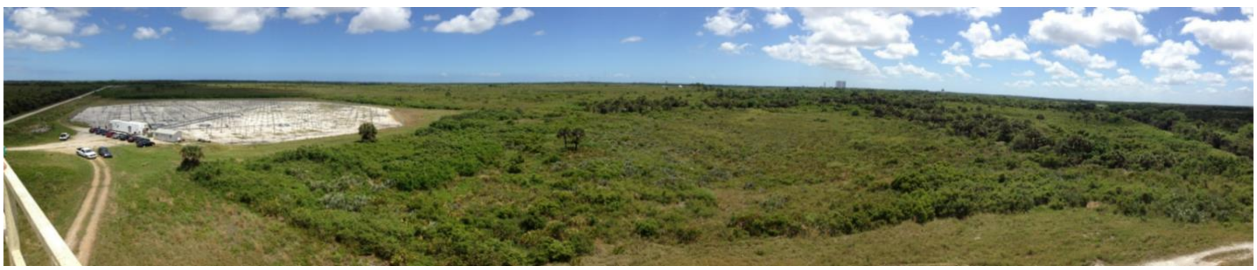

Figure 1. Photograph of the 50-MHz DRWP (courtesy of R. Decker).

III. Methodology

Daily profiles are read in to a GUI that was developed in the previous DRWP QC data study. If an individual profile is missing, likely due to either maintenance down-time or system malfunctions, an error message would be displayed and marked as a missing day. The GUI allows multiple variables to be viewed and examined during the QC process. Algorithms developed at MSFC are used to QC wind profiles obtained from the DRWP.[3] The automated QC process is implemented first on the daily profile, followed by the manually QC process. After the QC process is complete, the manual QC logs and QCed files are saved into a database by year. Statistical analysis of the QCed data followed on complete profiles.

A. Automated QC Process

The automated QC process consisted of a series of checks developed from previous studies that remove flagged[1]. The first procedure of the automate QC process is filling data gaps greater than six minutes existing between timestamps. A missing data flag is assigned for the appropriate profiles at five-minute intervals. This ensures the database contains profiles occurring at least every six minutes.[1] Next, the vertical beam is evaluated to remove data from a noise power discrepancy or missing signal. This process involves retaining the oblique beams and horizontal winds since the vertical beam is not used to calculate horizontal winds.[5,6] Ensuring that a valid wind calculation is not flagged due to an inaccurate vertical beam measurement.

After the completion of the vertical beam QC, a series of previously derived threshold checks are implemented in sequential order by flagging data that do not satisfy the threshold.[4,7] This process accounts for checking unrealistic wind, isolated data, small median test, oblique beam SW, meteorological shear, *w*, and oblique beam signal power. Table 1 displays the threshold used for each check. Additional automated QC algorithms for convection and FGP were applied for the DRWP database and are described in further detail in previous documentation.[5]

Table 1. Data were removed in the automated QC check if it did not satisfy the threshold.

QC check	Threshold
Vertical SW	>3.0 m s^{-1}
Vertical 0 Doppler shift	$\|w\|$ > 1.5 m s^{-1} and vertical SNR < 40 dB
Vertical signal or noise	Missing
Unrealistic wind	Wind speed < 0 m s^{-1} or wind direction < 0° or wind direction > 360°
East or north SW	>3.0 m s^{-1}
DRWP shear	>0.1 s^{-1}
w	>2.0 m s^{-1}
Meteorological Shear	>0.1 s^{-1}
East or north signal	Missing

B. Manual QC Process

After the completion of the automated QC check, individual profiles were examined manually for erroneous data. Time-height sections of multiple variables within the GUI were evaluated to determine if spurious data were consistently noticeable throughout a particular region. If evidence suggests spatial discontinuities or unrealistic temporal changes occurred, then the data would be removed manually. Radar sidelobes, ground clutter, and convection are often the cause of data being manually removed from individual profiles. Data appearing to be affected by convection or ground clutter received their own manual QC flag. Periodically, entire profiles were removed in the event invalid extensive time-height regions of invalid data exist.

Figure 2 shows an example of the before (left) and after (right) QC process on wind speed that occurred on 21 February 2010. A barlike feature can be observed around 5.0 km during 0900-1430 UTC (Local time = UTC – 4 hrs). This feature is likely a false representation of the wind due to a radar sidelobe. Third-party comparisons are also implemented when analyzing wind components. Weather balloon data launched from the ER can be overlaid with concurrent DRWP profiles to determine if invalid wind data exist. The middle panel in Figure 2 is a comparison of DRWP and weather balloon in the U and V components. Both wind components from the DRWP stray vastly from the weather balloon wind components around 5.0 km at 1145 UTC. This sidelobe feature exists in the time-height variables and the weather balloon comparison, so it is removed as shown in the right panel. Other third-party comparisons include rainfall measurements collected from KSC and 3 hour wind composites from the National Oceanic and Atmospheric Administration's North American Regional Reanalysis database.

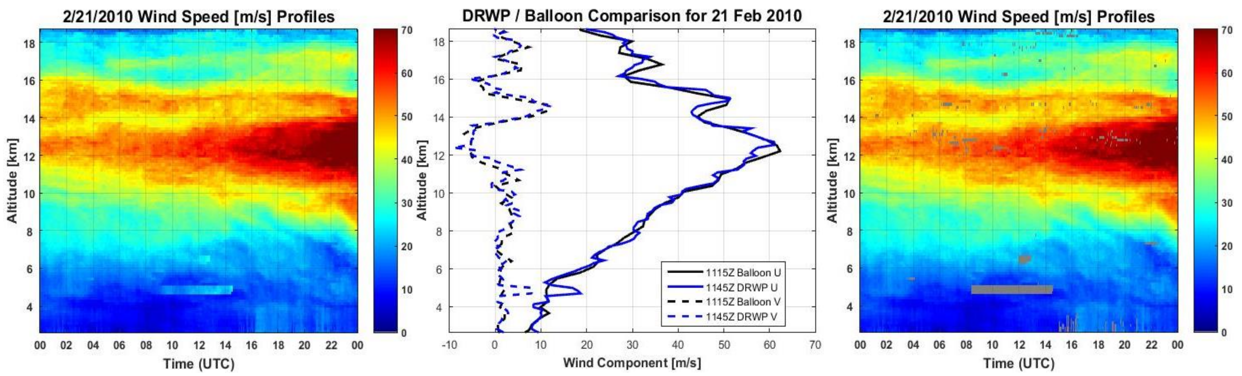

Figure 2. Example of the time-height sections of wind speed before (left) and after (right) implementing the automated and manual QC process for an individual day. The range of wind speeds are displayed in the color bar. Comparison to a concurrent weather balloon launch (middle) shows the corresponding wind components at a particular time during

IV. Results

A. QC Data

Implementing the process described in the previous sections produced QCed 5-min wind profiles from January 2010 to the end of January 2013. Missing data existed within and throughout whole profiles as well as entire daily files. The SW, meteorological shear, small median test, missing oblique beam signal, and isolated datum QC checks removed data sporadically. The convection flag was often triggered when data extended vertically throughout a region of the daily profile. Manual QC removed ground clutter often located at lower altitudes, sidelobe features, regions surrounded by flagged data, and inaccurate features.

The number and percentage of gates affected by the QC process are shown in Table 2 were then examined. A total of 48.3 million gates were collected from the DRWP, ranging from 3.6 to 4.9 million gates for a given month. Percentages of affected data herein are noted as % of the database (compared to the 1997-2009 database). The missing data flag was tallied most accounting for 22.3% (35.4%) because 178 days had no data. The QC process removed 4.4% (6.5%) of the possible data. The importance of the manual QC process is evident after removing 3.9% (5.5%) of the possible data. Only 7 QC flags for SW existed, while unrealistic wind and vertical wind speed did not account for any of the QC flags. The new QCed database retained 73.3% (58.1%) of the possible wind observations from the DRWP.

Table 2. Number (top) and percentage (bottom) of data affected by each QC check during each month from January 2010 to January 2013.

No. Gates	No Flag	Vertical QC	Convection Flag	Missing	Unreal	SW	DRWP Shear	Vertical Speed	FGP	Met Shear	Median	Ground Clutter	No Signal	Isolated	Manual	Convection	Removed	Retained	Total
Jan	3706773	56417	133614	828726	0	0	1142	0	39878	12	106	22168	9996	789	106001	44	1008862	3896804	4905666
Feb	2902805	42991	247108	449550	0	0	2163	0	10555	12	37	21388	6597	24	54618	965	545909	3192904	3738813
Mar	3304418	38996	22980	522477	0	0	3883	0	6466	9	63	23079	4619	15	140633	1593	702837	3366394	4069231
Apr	2314040	31746	153457	1254189	0	0	1229	0	10753	6	275	16165	5638	27	116423	1156	1405861	2499243	3905104
May	3000004	79876	388052	479742	0	0	1113	0	5980	10	73	14740	4953	10	140567	7642	654830	3467932	4122762
Jun	2047398	81730	104279	1520922	0	7	2367	0	1227	4	191	13094	1947	4	169531	4459	1713753	2233407	3947160
Jul	2268917	92383	23711	1510155	0	0	1097	0	9768	1	125	11075	7007	46	173502	3219	1715995	2385011	4101006
Aug	2840789	156709	148364	433233	0	0	2033	0	14319	0	2022	17012	7466	206	312178	9055	797524	3145862	3943386
Sep	2115004	96645	167676	1131645	0	0	3587	0	2807	3	179	15268	3417	26	159534	1635	1318101	2379325	3697426
Oct	2828799	68607	150500	588300	0	0	2917	0	9533	2	194	21398	5360	108	116474	801	745087	3047906	3792993
Nov	3028222	37815	262600	468420	0	0	3716	0	8957	11	151	23285	5131	62	114261	0	623994	3328637	3952631
Dec	2266764	27232	126005	1572093	0	0	1101	0	7461	4	64	15602	5166	18	54567	459	1656535	2420001	4076536
Tot	32623933	811147	1928346	10759452	0	7	26348	0	127704	74	3480	214274	67297	1335	1658289	31028	12889288	35363426	48252714

Percentage of Total Gates	No Flag	Vertical QC	Convection Flag	Missing	Unreal	SW	DRWP Shear	Vertical Speed	FGP	Met Shear	Median	Ground Clutter	No Signal	Isolated	Manual	Convection	Removed	Retained
Jan	75.6	1.2	2.7	16.9	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.5	0.2	0.0	2.2	0.0	20.6	79.4
Feb	77.6	1.1	6.6	12.0	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.6	0.2	0.0	1.5	0.0	14.6	85.4
Mar	81.2	1.0	0.6	12.8	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.6	0.1	0.0	3.5	0.0	17.3	82.7
Apr	59.3	0.8	3.9	32.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.1	0.0	3.0	0.0	36.0	64.0
May	72.8	1.9	9.4	11.6	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.1	0.0	3.4	0.2	15.9	84.1
Jun	51.9	2.1	2.6	38.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	4.3	0.1	43.4	56.6
Jul	55.3	2.3	0.6	36.8	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3	0.2	0.0	4.2	0.1	41.8	58.2
Aug	72.0	4.0	3.8	11.0	0.0	0.0	0.1	0.0	0.4	0.0	0.1	0.4	0.2	0.0	7.9	0.2	20.2	79.8
Sep	57.2	2.6	4.5	30.6	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.4	0.1	0.0	4.3	0.0	35.6	64.4
Oct	74.6	1.8	4.0	15.5	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.6	0.1	0.0	3.1	0.0	19.6	80.4
Nov	76.6	1.0	6.6	11.9	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.6	0.1	0.0	2.9	0.0	15.8	84.2
Dec	55.6	0.7	3.1	38.6	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.1	0.0	1.3	0.0	40.6	59.4
Tot	67.6	1.7	4.0	22.3	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.4	0.1	0.0	3.4	0.1	26.7	73.3

B. Complete Profiles

Complete profiles retained were also examined to support potential launch vehicle trajectory assessments over a meteorological season. The seasons consist of winter (December – March), summer (June – September), and transition (April, May, October, and November). A total of 115,457 complete profiles exist in the database, with the transition season containing the most complete profiles (42,153) and the summer season containing the least complete profiles (31,574). An average of 3,120 complete profiles exist per month, ranging from 80 complete profiles (June 2010) to 5,001 complete profiles (May 2012). Summer months tended to contain fewer complete profiles due to numerous occurrences of convection resulting in contaminated DRWP wind data. Periods of February 2013 to December 2013 have yet to be QCed, therefore having 0 complete profiles in Table 3.

Table 3. Number of complete profiles for each month and year.

Complete Profiles					
	2010	2011	2012	2013	Month Tot
Jan	3804	3387	4976	2277	14444
Feb	3328	2294	4297	0	9919
Mar	4074	3157	2852	0	10083
Apr	3951	677	3349	0	7977
May	4605	3848	5001	0	13454
Jun	80	3142	4710	0	7932
Jul	2156	2762	1433	0	6351
Aug	2857	2996	4215	0	10068
Sep	2759	3195	1269	0	7223
Oct	2799	3173	3827	0	9799
Nov	2963	4360	3600	0	10923
Dec	2692	2092	2500	0	7284
Year Tot	36068	35083	42029	2277	115457

Comparisons of the current database (1997-2009) and the newly QCed database (2010-2013) were made by overlapping the maximum, minimum, and 95th percentiles of complete profiles as shown in Figure 3. This creates a visual representation of where new maximum and minimum wind components exceed previous maximum and minimum values from the current database. For instance, Figure 4 displays an event that exceeded the previous minimum V wind component of the QCed database during the winter season. Around 9,000 to 11,500 m, the V wind component drastically increases to values ~ -60 m s^{-1}. A balloon comparison was evaluated during this time period to determine if this data was valid. As the V wind components align in the comparison, this ensures that this is a new atmospheric event that exceeds the previous minimum in the QCed database.

The 95th percentile is used to depict the range of wind components that will most likely be experienced during ascent. The new 95th percentiles tend to follow the current 95th percentiles. However, variations do occur in the new database due to different sample populations. Maximum and minimum wind components must still be accounted for on structural integrity of space launch vehicles when concepts are being developed. By adding the new QCed data to the current database, 532,841 complete profiles exist increasing the database by 27.7%.

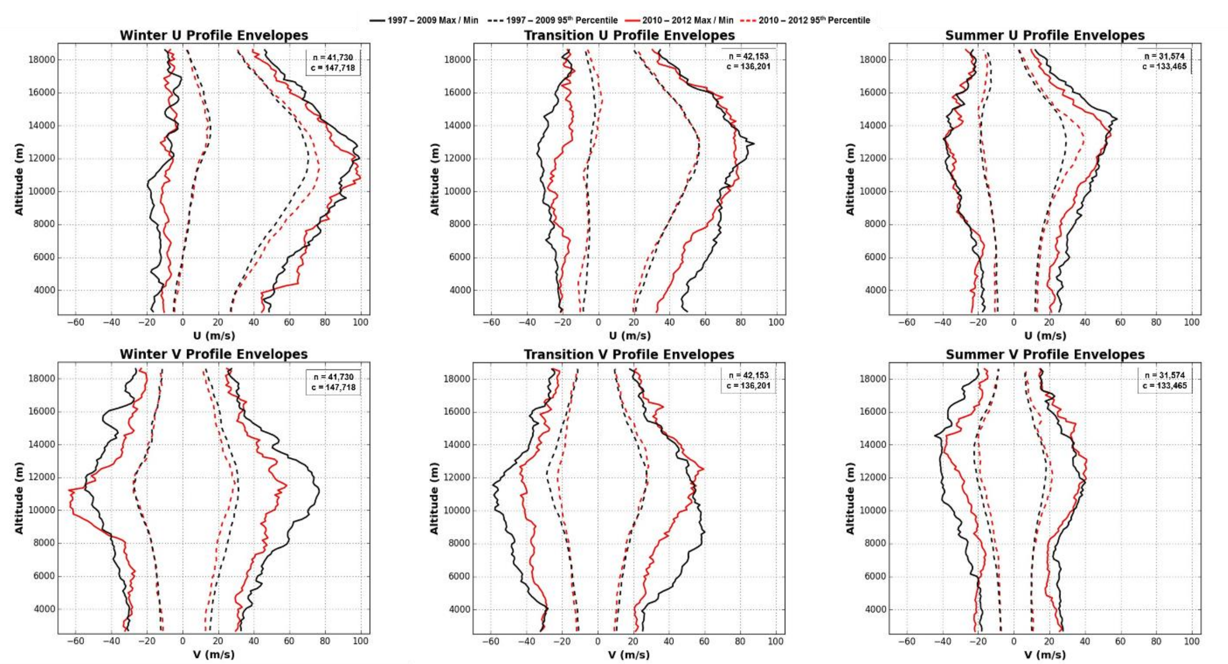

Figure 3. Comparisons of U and V profiles from the DRWP. Wind components (m s^{-1}) are along the x-axis and altitude (m) is along the y-axis. 1997 – 2009 Max/Min (solid black lines) and 95th percentile (dashed black lines), 2010 – 2012 Max/Min (solid red lines) and 95th percentile (dashed red lines), number of new complete profiles per season (n), and number of current complete profiles per season (c) are shown.

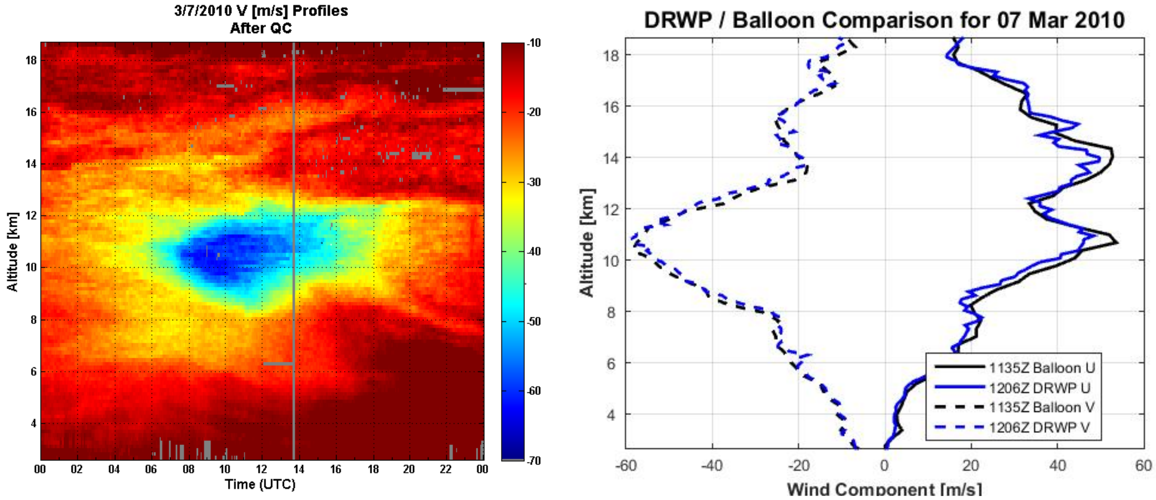

Figure 4. Daily profile from 7 March, 2010 corresponding to a new minimum V wind component experienced during the winter V season. The V wind component (left) and the balloon comparison (right) for that time period are shown.

C. Weather Patterns

Further examination upon the complete profiles showed distinct weather patterns occur by season. During the winter season, westerly winds are more predominant than any other season due to the upper atmospheric polar jet stream developing trough patterns in the lower part of the United States. As the jet stream fluctuates, easterly winds still remain present during the winter season. However, easterly winds prevail during the transition and summer seasons due to tropical cyclones and the fluctuation of the subtropical jet. During the summer season, slightly larger northerly winds can be observed as the Azores High intensifies over the Atlantic Ocean.

V. Conclusion

Wind data measure by the DRWP from January 2010 to January 2013 underwent an automated and manual QC process to remove erroneous data within daily profiles. The automated QC process removed a portion of spurious wind data, however a manual QC process is essential to ensure that only valid wind data is used for the new database. Also by using third-party comparisons, other anomalies such as convection and radar sidelobes were removed manually from the profiles. A larger amount of data is retained in the new database due to the less frequent malfunctions and maintenance that occurred compared to the current database. This can be observed by the larger percentage of data missing from the current database to the new database.

Increasing the current sample size of the DRWP wind database will allow better representation of the atmosphere that a launch vehicle could experience during ascent. Also new maximum and minimum wind observations will be added to the current database, which will be used to account for the structural integrity of launch vehicles. This new database will help with design assessments of the Space Launch System as well as any other application that requires high-fidelity wind data.

Acknowledgments

The author would like to thank Ryan Decker of EV44 for his guidance and support as a mentor, as well as Robert Barbré Jr. (EV44/Jacobs) for his guidance and programming assistance. Much appreciation also goes to the Natural Environments Branch at MSFC for their assistance during this internship. This project was funded by the Space Launch System Project Office.

References

[1]Robert, Barbré, E. Jr., "Quality Control Algorithms for the Kennedy Space Center 50-MHz Doppler Radar Wind Profiler Winds Database," *Journal of Atmospheric and Oceanic Technology*, Vol. 29, 2013, pp. 1731-1743.

[2]Rinehart, R. E., *Radar for Meteorologists*, 4th ed., Rinehart Publications, 2004, pp. 482.

[3]Schumann, R. S., Taylor, G. E., Merceret, F. J., and Wilfong, T. L., "Performance Characteristics of the Kennedy Space Center 50-MHz Doppler Radar Wind Profiler Using the Median Filter/First-Guess Data Reduction Algorithm," *Journal of Atmospheric and Oceanic Technology*, Vol. 16, 1999, pp. 532-549.

[4]Pinter, R. E., Merceret, F. J., and Hatley, C. V., "Performance Validation of Upgraded Eastern Range 50-Megahertz Doppler Radar Wind Profiler," *Journal of Spacecraft and Rockets*, Vol. 43, 2006, pp. 693-695.

[5]Merceret, F. J., "Rapid Temporal Changes of Midtropospheric Winds," *Journal of Applied Meteorology and Climatology*, Vol. 36, 1997, pp. 1567-1575.

[6]Wilfong, T. L., Smith, S. A., and Creasey, R. L., "High Temporal Resolution Velocity Estimates from a Wind Profiler," *Journal of Spacecraft and Rockets*, Vol. 30, 1993, pp. 348-354.

[7]Carr, F. H., Spencer, P. L., and Doswell, C. A., "A Comparison of Two Objective Analysis Techniques for Profiler Time-height Data," *Monthly Weather Review*, Vol. 123, 1995, pp. 2165-2180.