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Doppler Radar Profiler for Launch Winds at the Kennedy Space Center (Phase 1a)

Daniel G. Murri/NESC
Langley Research Center, Hampton, Virginia

December 2011

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National Aeronautics and
Space Administration

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Hampton, Virginia 23681-2199

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October 27, 2011

Report Approval and Revision History

NOTE: This document was approved at the October 27, 2011, NRB. This document was submitted to the NESC Director on November 16, 2011, for configuration control.

Approved:	*Original Signature on File*	11/17/11
	NESC Director	Date

Version	Description of Revision	Office of Primary Responsibility	Effective Date
1.0	Initial Release	Mr. Daniel G. Murri, NASA Technical Fellow for Flight Mechanics, Langley Research Center	10/27/11

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Technical Assessment Report

1.0 Notification and Authorization

The NASA Engineering and Safety Center (NESC) received a request from Mr. Daniel Murri, NASA Technical Fellow for Flight Mechanics at Langley Research Center (LaRC), to develop a database from multiple Doppler radar wind profiler (DRWP) sources and develop data processing algorithms to construct high temporal resolution DRWP wind profiles for day-of-launch (DOL) vehicle assessment. The request was received on February 9, 2011. The development of capability was planned to be conducted in four phases (1a, 1b, 2, and 3). An initial evaluation for these phases was presented at the March 10, 2011, NESC Review Board (NRB). The assessment was deferred, pending further development of phases and identification of potential future partners. An assessment plan was approved by the NRB on May 26, 2011.

The key stakeholders for this assessment are the NESC (including the disciplines of Flight Mechanics; Guidance, Navigation, and Control (GN&C); and Loads and Dynamics); the NASA Space Launch System (SLS) Program; and other current and future NASA and commercial space launch vehicle programs that use atmospheric winds to evaluate structural loading and to perform trajectory evaluations.

2.0 Signature Page

Submitted by:

Team Signature Page on File – 12/9/11

Mr. Daniel G. Murri Date

Significant Contributors:

Mr. Robert E. Barbre Date

Mr. Douglas C. Brown Date

Mr. Ryan K. Decker Date

Mr. Frank B. Leahy Date

Signatories declare the findings and observations compiled in the report are factually based from data extracted from Program/Project documents, contractor reports, and open literature, and/or generated from independently conducted tests, analysis, and inspections.

3.0 Team List

Name	Discipline	Organization
Core Team		
Dan Murri	NESC Lead, NASA Technical Fellow for Flight Mechanics	LaRC
Ryan Decker	NESC Deputy Lead	MSFC
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Donna Gilchrist	Planning and Control Analyst	LaRC/ATK
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Pam Sparks	Project Coordinator	LaRC/ATK

4.0 Executive Summary

Atmospheric winds are a major factor that must be addressed during launch vehicle design and day-of-launch (DOL) operations to maximize flight performance and minimize structural loads. Current launch site wind databases at the Kennedy Space Center (KSC), including Cape Canaveral Air Force Station (CCAFS), utilize historical balloon measurements, which are limited in number of samples and temporal sampling intervals. These database limitations lead to uncertainty in predicting wind-induced vehicle loading during the design and certification process. These uncertainties result in the use of knockdown factors with unknown conservatism, which could result in unneeded structural weight. For DOL operations, wind profile balloon measurements have the additional limitations of taking significant time (e.g., approximately 60 minutes) and potentially drifting a large distance (>80 km) from the launch trajectory. These DOL limitations cause more uncertainty in wind-induced loading and can result in more stringent wind limitations and reduced launch opportunities.

This assessment is pursuing the development of a historical Doppler radar wind profiler (DRWP) database from 10 years of wind measurements (i.e., 2000–2009) made by KSC/CCAFS vertically pointing DRWP systems. This alternate database will provide higher fidelity in sample size and temporal wind change, resulting in more accurate quantification of wind effects on vehicle loads and the potential for increased performance and DOL flight opportunities for launch vehicles. In addition to developing the historical database, the assessment would pursue the generation of algorithms to process DRWP measurements to be used for DOL analyses and launch decisions. These algorithms would provide a better characterization of winds as compared to balloon measurements, which could result in more accurate prediction of ascent loading, improved launch opportunities, and reduced system risk.

KSC/CCAFS employs one 50-megahertz (MHz) DRWP system and a network of 915-MHz DRWP systems. KSC operates the 50-MHz system and CCAFS operates the 915-MHz system. For the remainder of this report, the system at KSC/CCAFS will be referred to as the KSC system. Depending on the amount of backscattering media in the atmosphere, the 915-MHz systems measure wind profiles from about 150 to 3,000 meters (m), and the 50-MHz system measures profiles from about 2,400 to 18,300 m. If a 915-MHz wind profile extends to at least the minimum measurement altitude of the 50-MHz DRWP and exists simultaneously with the 50-MHz wind profile, then the two profiles can be combined to produce a vertically complete wind profile to 18,300 m. Having wind data over this altitude range is usually sufficient for most launch vehicles, as they typically are not sensitive to wind-induced loading above 18,300 m. Any wind requirements above this altitude would still need to incorporate the use of wind profiles from a balloon system, which usually reach an altitude of 30,500 m.

The proposed assessment to develop the database and the DOL algorithms involves four phases. This report describes results from the initial phase — Phase 1a. This initial phase began a quality control (QC) process that determined which KSC 915-MHz wind profiles had altitude content reaching or overlapping with the 50-MHz wind profiles and then determined which of those sets were concurrent. This process determined the number of potential vertically complete profiles from the total number of available profiles.

The Phase 1a results indicate that between 1,000 and 7,000 vertically complete wind profiles per month can be extracted from the historic KSC DRWP data, which is a significant improvement in sample size from the historical balloon databases that contain roughly 200 wind profiles per month. Two primary attributes of the KSC DRWP database drive the variation in the number of vertically complete KSC DRWP wind profiles. First, the KSC DRWP system provides wind profiles by measuring the backscatter from index of refraction fluctuations in the atmosphere. Since these fluctuations are less abundant in clear, dry air, fewer wind profiles are available in the winter months than in the summer months. Second, the sample size of the KSC DRWP database depends on whether multiple KSC 915-MHz DRWPs are accepted for a given application. When accounting for these attributes, the KSC DRWP database is projected to provide an order of magnitude increase of wind profiles for use in flight vehicle loads and trajectory assessments. This increase in sample size from the balloon datasets provides a reduction in the uncertainty that a wind or wind change represents the universal population at a given percentile. This reduction depends on many factors and can be quantified for specific cases. For example, a winds database with the projected sample size range of the vertically complete DRWP database provides a 55 to 83-percent reduction in uncertainty of the 99^{th} percentile vector wind change from the February monthly mean, assuming the wind changes fit a generalized extreme value (GEV) distribution. The DRWP database of vertically complete profiles can be used in other applications (e.g., simulating temporal wind change on DOL, projecting the landing footprint of a capsule after a pad abort, and assessing vehicle maneuvers at low altitudes), which may improve the reduction in uncertainty to a different degree.

After the completion of Phase 1a, the Space Launch System (SLS) Program decided to pursue the follow-on phases of this assessment to most quickly integrate the results into their launch vehicle development program. As a result, the NASA Engineering and Safety Center (NESC) has completed its participation in this assessment with the publication of this report. Follow-on phases could remove erroneous wind output from the wind profiler network (Phase 1b), develop a database of vertically complete profiles (Phase 2), and develop algorithms for use in KSC DOL software (Phase 3). Vandenberg Air Force Base (VAFB) has a DRWP system comparable to the one at KSC, and a similar effort to develop a historical DRWP database and DOL algorithms could be conducted for that launch site.

5.0 Assessment Plan

The proposed assessment to develop the KSC database and the DOL algorithms involves four phases (1a, 1b, 2, and 3). For Phase 1a, the objective was to begin QC processing on the KSC 915-MHz DRWP historic data by determining which 915-MHz wind profiles had altitude content reaching or overlapping with the 50-MHz DRWP altitude coverage. Those wind profiles were then compared to the KSC 50-MHz DRWP wind profiles to determine which 915-MHz profiles were concurrent with the 50-MHz profiles. Assessing the number of concurrent profiles that contain overlapping altitude content determined the number of potential vertically complete profiles.

After the completion of Phase 1a, the SLS Program decided to pursue the follow-on phases of this assessment to most quickly integrate the results into their launch vehicle development program. As a result, the NESC has completed its participation in this assessment with the publication of this report. Phase 1b would apply additional QC techniques to the KSC 915-MHz DRWP historic data. Phase 2 would develop and apply algorithms to filter KSC data so the wind profile would have common energy spectra. The processed data would be used to build databases of discrete profiles and temporally variable wind profile sets for use in space flight vehicle loads and trajectory simulations. Phase 3 would involve transferring the QC algorithms to the KSC DRWP systems to construct the vertically complete wind profiles for DOL loads and trajectory assessments. VAFB has a DRWP system comparable to the one at KSC, and a similar effort to develop a historical DRWP database and DOL algorithms could be conducted for that launch site.

6.0 Problem Description and Proposed Solutions

Space launch vehicles have to account for atmospheric wind loading effects throughout multiple phases in the lifecycle process to ensure robust structural integrity and optimized trajectory during launch operations. The current technique for measuring atmospheric winds for space launch vehicle evaluations at KSC is through the use of balloons to loft measurement instruments (e.g., to measure wind, temperature, and pressure). Databases of balloon-based discrete wind profiles and temporal wind profile pairs to characterize wind variability and define load "knockdowns" have been constructed for application in the vehicle design and certification process. Because of cost, time, and programmatic requirements, the databases are limited in number of samples. Furthermore, balloon-based wind profiling systems require significant time to generate a wind profile (e.g., approximately 60 minutes to reach 18 kilometers (km)) and balloons potentially drift a large distance (e.g., greater than 80 km) from the launch trajectory. These time and distance factors can result in DOL measurements that are not representative of the winds that could be experienced by the vehicle during ascent.

This assessment utilizes another means of measuring atmospheric winds using KSC ground-based DRWP systems. These systems can be used to build higher-fidelity wind databases for vehicle analyses and provide more timely wind measurements used in DOL flight vehicle analyses. The winds that DRWP systems measure do not directly align with vehicle launch trajectories, but typically are much closer than the balloon measurements. The intent of the DRWP systems is not to replace the balloon systems but to provide an increase in the number and frequency of available wind profiles. The balloon system is required to provide launch site temperature and pressure profiles since the radar systems only measure wind.

Ground-based DRWP systems derive wind velocity and direction at discrete range intervals through transmission of radio signal to measure backscattered signal generated by index of refraction irregularities and the presence of objects (e.g., moisture and dust) within the atmosphere. There are two DRWP systems at KSC operating at different frequencies (50 MHz and 915 MHz) to sample the atmospheric winds from 150 to 18,300 m. Depending on the amount of backscattering media in the atmosphere, the 915-MHz systems typically measure wind profiles from about 150 to 3,000 m, and the 50-MHz systems typically measure profiles from about 2,400 to 18,300 m. Wind profiles are generated every 5–15 minutes based on the DRWP system configuration. An advantage of the DRWP systems over the balloon-based system is the ability to operate continuously. Continuously operating systems produce thousands of wind profiles that can improve the statistical characterization of temporal wind variability over the balloon-based database. The DRWP system can provide increased flexibility in defining time intervals to assess wind variability, which could result in improved confidence in vehicle loads analyses. However, data from both DRWP systems (and balloons) are susceptible to error and the effective vertical resolution of the two DRWP systems is not the same. Therefore, to construct a complete wind profile resolving the same energy spectra, an extensive QC process is required to remove erroneous data and a common wavelength filter must be applied.

This report describes results from Phase 1a. This initial phase began a QC process that determined which KSC 915-MHz wind profiles had altitude content reaching or overlapping the 50-MHz wind profiles and then determined which of those sets were concurrent. Assessing the number of concurrent KSC profiles that contain overlapping altitude content determined the number of potential vertically complete profiles.

7.0 Data Analysis

An analysis was performed to examine the number of potentially available, vertically complete wind profiles from the KSC DRWP network. An extensive database of quality-controlled 50-MHz DRWP profiles is available for use in launch vehicle loads and trajectory assessments [ref. 1]. Data from the KSC 915-MHz DRWP for the 2000–2009 period of record (POR) were obtained through the Tropical Rainfall Measurement Mission archive (*http://trmm.ksc.nasa.gov*), but the data had not been subjected to the QC process. Integrating the DRWP profiles requires an extensive screening of the 915-MHz DRWP data. This section documents Phase 1a, which determined the number of profiles that can be expected when generating vertically complete DRWP wind profiles and examined the potential benefit of performing the 915-MHz data QC.

Four analyses were performed to determine the number of available vertically complete profiles:

1. Determine the number of KSC 915-MHz DRWP profiles.
2. Determine the number of KSC 915-MHz DRWP profiles that reach or overlap the minimum altitude of the 50-MHz DRWP.
3. Determine the number of concurrent KSC 50-MHz and 915-MHz DRWP profiles.
4. Determine the number of concurrent KSC 50-MHz and 915-MHz DRWP profiles that contain overlapping altitude content.

All analyses were performed using the 2000–2009 POR. Analysis 1 is the least restrictive. Analyses 2 and 3 are independent of each other, but are more restrictive than Analysis 1. Analysis 4 is the most restrictive. Note that Analysis 4 counted the number of profiles that met the criteria for Analyses 2 and 3 simultaneously.

Each analysis was performed two ways. One way assumed that an individual 915-MHz DRWP was combined with the 50-MHz DRWP to generate vertically complete profiles. The other way assumed that any 915-MHz DRWP was combined with the 50-MHz DRWP to generate vertically complete profiles. Figure 7.0-1 displays the KSC DRWP network locations. Four 915-MHz DRWPs are located in a diamond-shaped pattern surrounding the 50-MHz DRWP and the Merritt Island 915-MHz DRWP. The 50-MHz DRWP is located near the north end of the Shuttle Landing Facility, about half way between the Mosquito Lagoon and the Merritt Island 915-MHz DRWPs. This DRWP network has the capability of providing up to five 915-MHz DRWP measurements and one 50-MHz DRWP measurement at a given time. Data can be accumulated from a single 915-MHz DRWP, a combination of 915-MHz DRWPs, or any 915-MHz DRWP. Therefore, each analysis was performed examining each 915-MHz DRWP individually and all 915-MHz DRWPs at a given time to envelope the potential sample size of a database generated by a given 915-MHz DRWP combination.

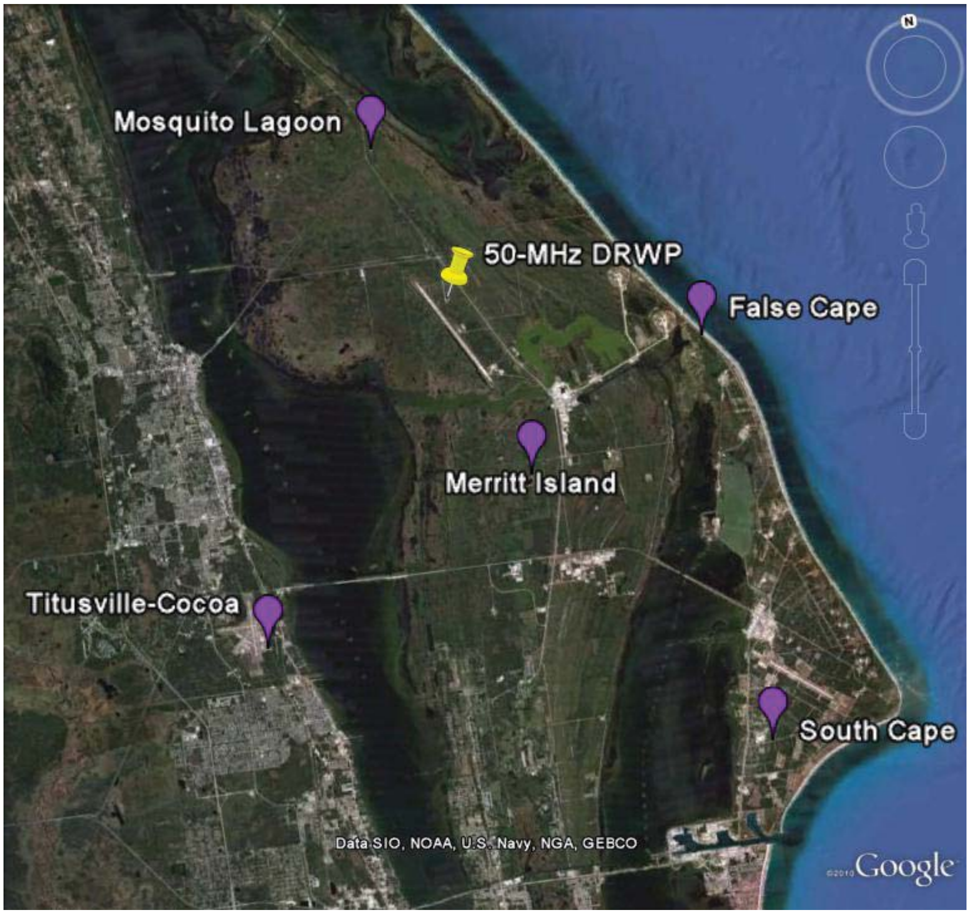

Figure 7.0-1. Google Earth Image of the KSC DRWP Network. Each 915-MHz DRWP is Shown by a Purple Marker and is Labeled Accordingly. The 50-MHz DRWP is Shown by a Yellow Thumbtack.

Analysis 1 counted the number of observations from the 915-MHz DRWP network, ignoring data from the 50-MHz DRWP. The number of observations from each 915-MHz DRWP and the number of 15-minute periods containing at least one 915-MHz DRWP measurement were tallied. Figure 7.0-2 shows the results of Analysis 1. Ideally, approximately 29,000 profiles per month would be generated from each 915-MHz DRWP if it took a measurement every 15 minutes over the POR. From the data, if any of the five 915-MHz DRWPs was chosen at a given time, it was found that approximately 14,000–18,000 profiles were actually generated for a given month. Roughly 9,000–16,000 measurements were generated per month from an individual 915-MHz DRWP.

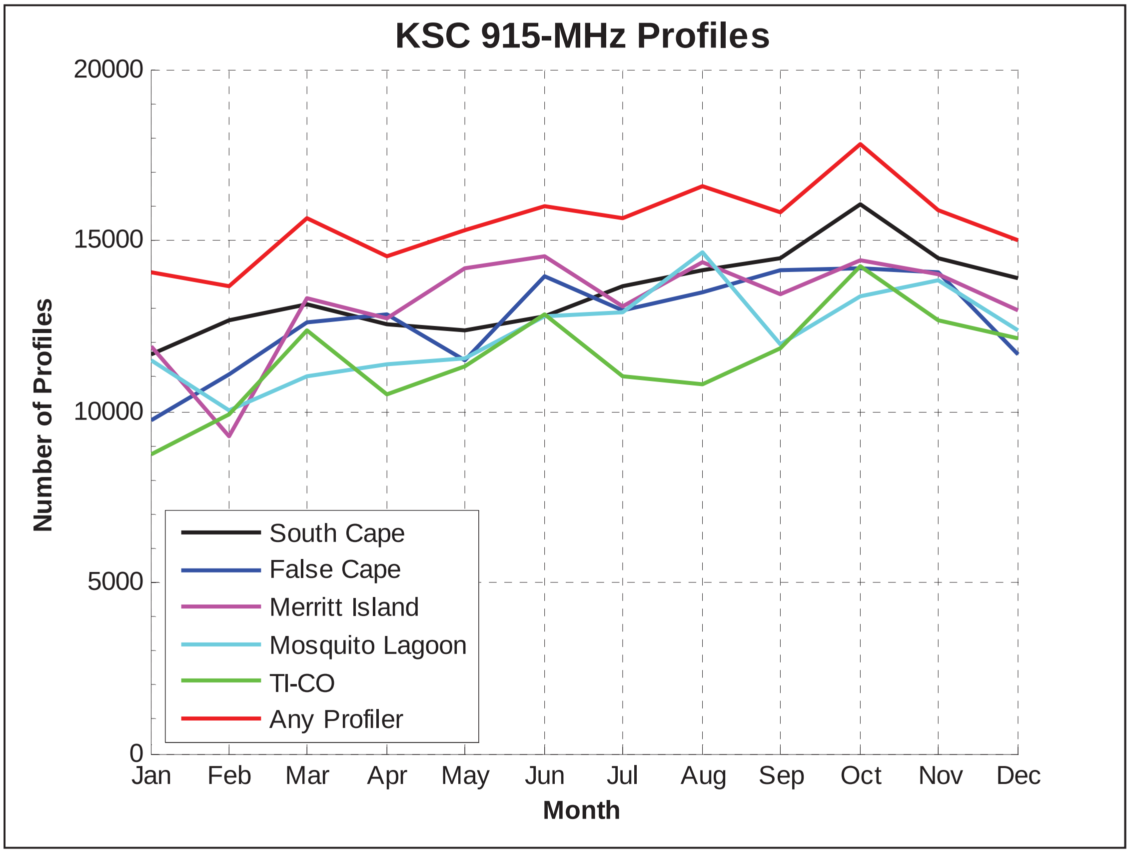

Figure 7.0-2. Number of Measurements from the KSC 915-MHz DRWP Network for Each Month over the 2000–2009 POR

Analysis 2 counted the number of 915-MHz DRWP profiles, which reached the ideal minimum altitude of the 50-MHz DRWP and showed the number of 915-MHz DRWP profiles that would be available to generate vertically complete profiles (with no interpolation) if a 50-MHz DRWP measurement existed at the same time and contained data to its minimum altitude. First, the maximum altitude of each 915-MHz DRWP was found for profiles starting at approximately 150 m. Next, a threshold (T) was derived as

$$T = \min(z_{50}) - 0.5(gs_{50} + gs_{915}) \quad \text{Eq. (7.0-1)}$$

where $\min(z_{50})$ is the ideal minimum 50-MHz DRWP measurement altitude and gs_{50} and gs_{915} are the gate spacing (i.e., vertical sampling interval) of the 50-MHz DRWP and 915-MHz DRWP, respectively. During the 2000–2009 POR, gs_{915} remained constant at 101.0 m. However, a system upgrade [ref. 2] caused $\min(z_{50})$ and gs_{50} to change in July 2004 from 2011.0 to 2666.0 m, and from 150.0 to 145.0 m, respectively. Inserting these values into Equation (7.0-1) produced thresholds of 1885.5 m and 2543.5 m for 915-MHz DRWP profiles taken before August 2004 and from August 2004 to the end of the POR, respectively. The number of 915-MHz profiles that extended to at least the threshold was tallied for each 915-MHz DRWP and for any 915-MHz DRWP at a given time. Figure 7.0-3 shows results from Analysis 2. Approximately 2,000–12,000 profiles from an individual 915-MHz DRWP reached the minimum altitude, and roughly 7,000–15,000 profiles from any 915-MHz DRWP at a given time reached the minimum altitude, depending on the month. A seasonal variation is shown from Analysis 2, with fewer 915-MHz DRWP profiles reaching the altitude threshold during the winter months. This attribute exists because the air exhibited lower absolute humidity (less scattering off index of refraction fluctuations) in the winter months for the 915-MHz DRWP to record a wind measurement successfully.

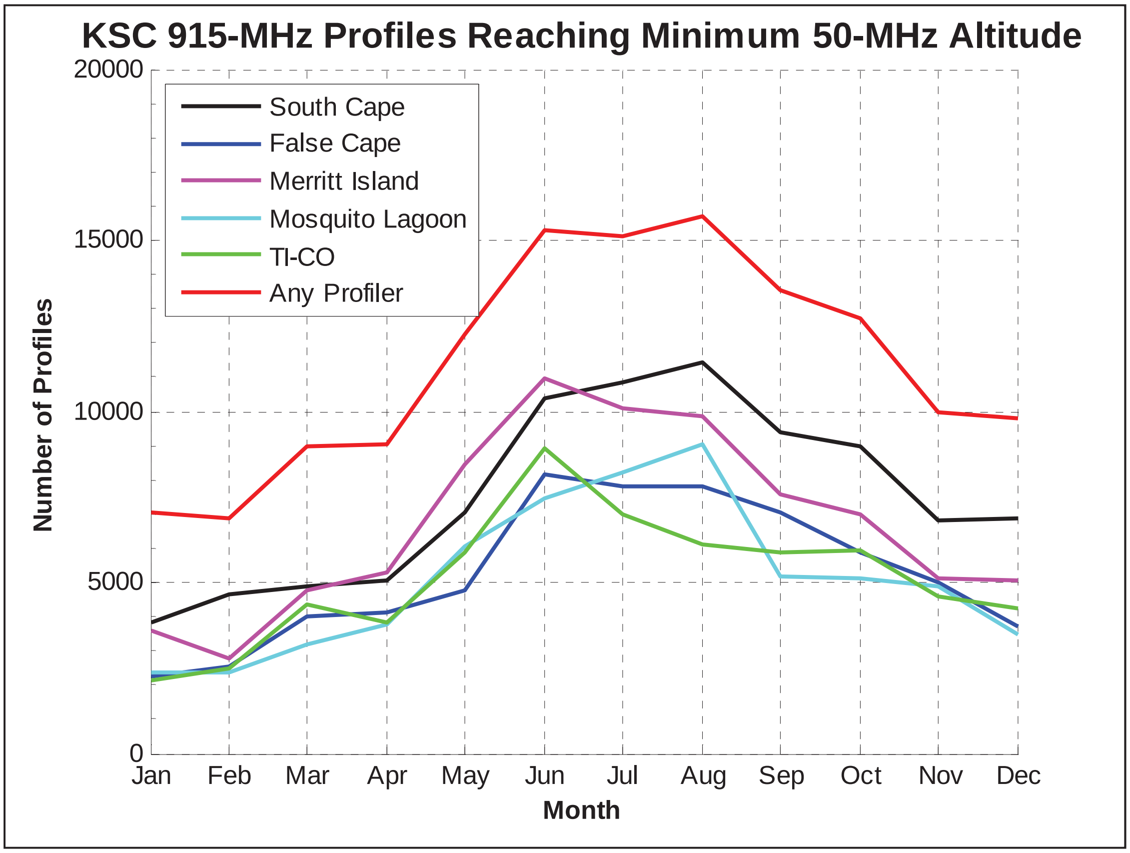

Figure 7.0-3. Number of KSC 915-MHz DRWP Profiles that Reach the Ideal Minimum 50-MHz DRWP Altitude for Each Month over the 2000–2009 POR

Analysis 3 counted the number of concurrent 50-MHz and 915-MHz DRWP measurements and showed the number of vertically complete profiles that would exist if all concurrent 915-MHz DRWP profiles reach the minimum altitude of the 50-MHz profile. An averaging method was implemented for this analysis to account for the two DRWP systems not having the same sampling periods [refs. 3 and 4]. The 50-MHz DRWP recorded measurements every 3–5 minutes and the 915-MHz DRWP winds were averaged over a given period of time (usually

11–14 minutes) at each altitude during the sampling period. Wind components from the 50-MHz DRWP were averaged over the 915-MHz DRWP averaging window at each altitude to best simulate the 915-MHz DRWP measurement process. The window is defined as T_{915}-1 minute $\geq T_{50} \geq T_{915} + T_{ap}$ + 1 minute, where T_{915} and T_{50} are the timestamps in the 915-MHz and 50-MHz DRWP databases, respectively, and T_{ap} is the averaging time period used to derive the given 915-MHz profile. If T_{50} fell within the bounds provided, then the profile at T_{50} was included in the process to generate an averaged profile from the 50-MHz DRWP. Note that the averaging window included a 1-minute buffer on either side to account for the non-identical timestamps between the 50-MHz and 915-MHz DRWP databases. The minimum altitude of each averaged 50-MHz DRWP profile was then found. For Analysis 3, the number of minimum altitudes was tallied since the existence of a minimum altitude indicated that data exist in the 50-MHz DRWP averaged profile. Figure 7.0-4 shows the results of Analysis 3. Approximately 7,000–10,000 averaged 50-MHz DRWP profiles were concurrent with individual 915-MHz DRWP profiles, and roughly 9,000–12,000 50-MHz DRWP profiles were concurrent with any 915-MHz DRWP profile. Although similar results existed when compared to Analysis 2, the seasonal variation disappeared since the 915-MHz DRWP profiles were not required to meet an altitude threshold.

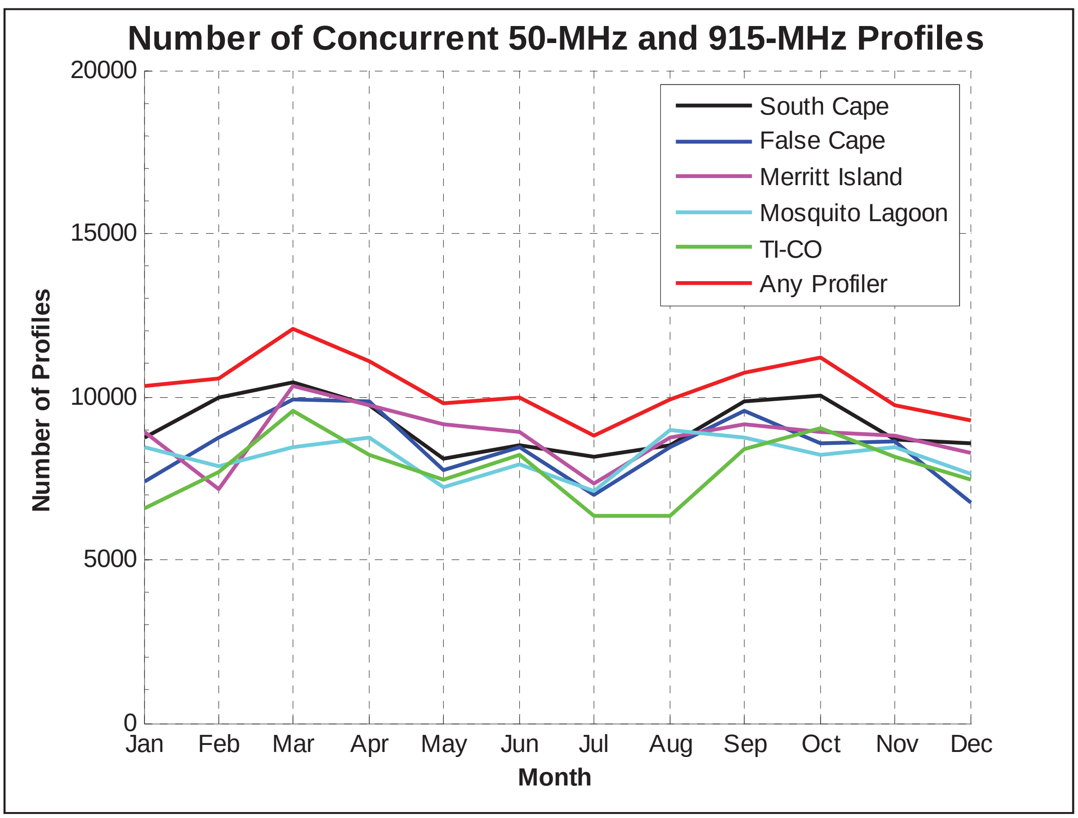

Figure 7.0-4. Number of Concurrent KSC 50-MHz and 915-MHz DRWP Profiles for Each Month over the 2000–2009 POR

Analysis 4 provided the end result of Phase 1a. In addition to interrogating the DRWP databases, it provided the number of DRWP profiles that are available for generating a database of vertically complete profiles prior to the 915-MHz DRWP QC process. All cases where the 50-MHz DRWP minimum altitude from Analysis 3 is at or below the 915-MHz DRWP maximum altitude from Analysis 2 were tallied for each 915-MHz DRWP individually and the entire 915-MHz DRWP network at a given time. Figure 7.0-5 shows the results of Analysis 4. Approximately 1,000–5,000 and 3,000–7,000 concurrent, overlapping profiles exist when using an individual 915-MHz DRWP and any 915-MHz DRWP at a given time, respectively. These results present the number of profiles that can be combined into a database of vertically complete profiles prior to the 915-MHz QC process. The QC process to be applied to the 915-MHz data in Phase 1b would consist of automated and manual checks to remove unrealistic data and would reduce the number of available, vertically complete DRWP profiles. The extent to which the sample size would be reduced is unknown. However, for application to a specific flight vehicle program, allowances could be made to consider profiles over a narrower vertical range and/or allow a small number of data gaps in the profiles. Winds would be linearly interpolated over these data gaps. If either the altitude range is narrowed or a tolerance for a small number of data gaps is accepted, then the resulting sample size would increase. In comparison, the historical balloon databases contain approximately 200 wind profiles per month.

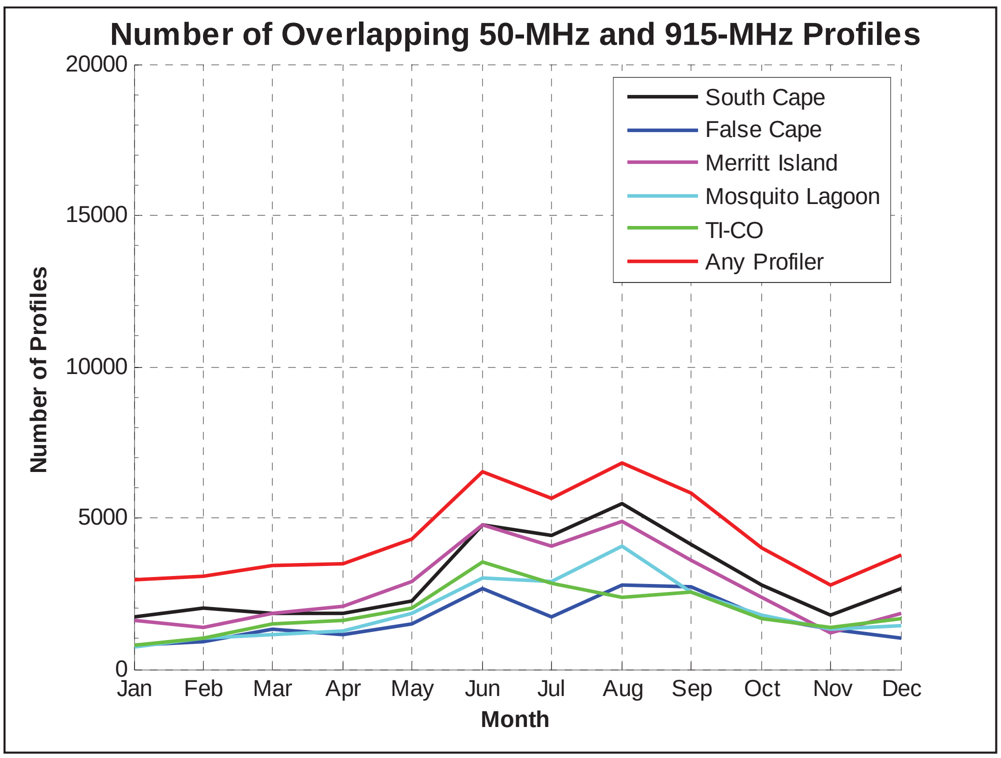

Figure 7.0-5. Number of Concurrent and Overlapping 50-MHz and 915-MHz DRWP Profiles for Each Month over the 2000–2009 POR

The increase in sample size provided by the database of vertically complete DRWP profiles reduced the uncertainty that a sample's distribution of winds and wind changes represents its universal population. However, a single quantification of uncertainty reduction was not feasible as many different subsets can be formed from the vertically complete DRWP profiles and multiple balloon databases exist. These two factors lead to different amounts of uncertainty reduction when comparing DRWP and balloon databases. The extent to which the width of the 95-percent confidence bounds (CB) decreases, using a large sample of vector wind changes from the February mean wind versus using a smaller sample of wind changes in the region of maximum dynamic pressure, is presented as an example of quantifying one possible uncertainty reduction. The vector wind difference from the February mean in the 8,000–10,000 m altitude region is assumed to fit a GEV distribution with the computed shape parameter (K), location parameter (μ), and scale parameter (σ). The 99th percentile estimates were found using the inverse of the GEV distribution with these parameters. Low and high CBs were obtained using the Asymptotic Distribution of Percentiles theorem [ref. 5], which states that the distribution of a variable at a specified percentile is Gaussian. The upper and lower CBs were calculated using:

$$(Low\ cb, High\ cb) = \varepsilon_p \pm z_{\alpha/2}\sqrt{\frac{p(1-p)}{n \cdot GEV(\varepsilon_p, K, \mu, \sigma)^2}} \qquad \text{Eq. (7.0-2)}$$

where ε_p is the estimate from the distribution at percentile p, and p ranges from 0 to 1. The GEV probability density function is expressed by $GEV(\varepsilon_p, K, \mu, \sigma)$, n is the sample size, and $z_{a/2}$ is the standardized Gaussian variable. Because the estimates of the 99th percentile at the 95-percent confidence level are of interest, p and $z_{a/2}$ are set to 0.99 and 1.96, respectively. The upper and lower CBs were subtracted to obtain the confidence width.

Table 7.0-1 displays results of this exercise. The fit parameters were assumed to be constant and only n was varied. An initial sample size of 200 was selected to represent the balloon databases, and sample sizes of 1,000 and 7,000 were selected to represent the projected sample size range of the vertically complete DRWP database. The confidence width at the 99th percentile for n = 200 is 13.3 meters/second (m/s). Increasing n to 1,000 yields a confidence width of 6.0 m/s, which is a 55.3-percent reduction in uncertainty. Increasing n to 7,000 yields a confidence width of 2.3 m/s, or an 83.1-percent reduction in uncertainty. It is important to note that this exercise is presented only as an example. Comparing actual distributions of wind and wind change from separate databases is more complex for two main reasons. First, much of the wind data applied to vehicle assessments does not fit a particular distribution. Second, if data were to fit a distribution, different wind variables can be examined and the same variable can be examined for different months, which will change the distribution and/or fit parameters leading to different reductions in uncertainty when compared to a given database with a smaller sample size.

Table 7.0-1. Characteristics of the Wind Distributions Used to Calculate Percent Reduction in Vector Wind Change from the February Mean

GEV Distribution Parameters					Confidence at 99th percentile (m/s)		
n	K	μ	σ	99% (m/s)	Low CB	High CB	Width
200	-0.85133	7.1057	17.222	44.271	37.614	50.927	13.313
1000	-0.85133	7.1057	17.222	44.271	41.294	47.248	5.954
7000	-0.85133	7.1057	17.222	44.271	43.145	45.396	2.251

8.0 Findings, Observations, and NESC Recommendations

8.1 Findings

The following findings were identified:

F.1. Historical KSC balloon databases contain approximately 200 wind profiles per month.

F.2. There are 3,000–7,000 vertically complete profiles that potentially exist if any 915-MHz DRWP were of interest, and 1,000–5,000 profiles that potentially exist for an individual 915-MHz DRWP.

- These profiles would increase the database sample size used in current and previous flight vehicle programs by an order of magnitude.
- Uncertainty reduction depends on many factors, but a hypothetical case of comparing wind deviations from the February mean reduces the range by 55 to 83 percent.

F.3. Fewer profiles exist during the winter months due to lower absolute humidity (less scattering off the index of refraction fluctuations) at the higher 915-MHz measurement altitudes.

F.4. The DRWP systems produce vertically complete profiles up to an altitude of about 18,300 m. If wind data is required above this altitude, the use of a balloon system will then be needed, which typically provides wind profiles up to about 30,500 m.

F-5. Stating confidence for wind profiles requires the calculation of confidence intervals for an extreme percentile (i.e., 99th) of the wind profile population.

F-6. Distributions of wind data from any measurement system change as a function of the data being examined and time of year, and much of the wind data applying to loads and trajectory assessments does not fit a theoretical distribution. Although confidence of a sample representing the universal population will improve using the DRWP database, quantifying confidence on a mixed distribution has not yet been investigated.

8.2 Observations

The following observations were identified:

O.1. The 915-MHz DRWP data used in this analysis were not subjected to the QC process. Applying the QC process to this data will reduce the number of available vertically complete DRWP profiles, but the extent to which the sample size will be reduced is currently unknown.

O.2. VAFB has a DRWP system comparable to the one at KSC, and a similar effort to develop a historical DRWP database and DOL algorithms could be conducted for that launch site.

8.3 NESC Recommendations

The following NESC recommendations were identified and directed toward the SLS Program, which will be pursuing the future phases of this assessment.

R.1. Future phases of this assessment should address implementing the QC process on 915-MHz data from KSC. ***(F-2, O-1)***

R.2. Future phases of this assessment should determine the most accurate methods for calculating confidence intervals on wind percentiles. ***(F-6)***

9.0 Alternate Viewpoints

There were no alternate viewpoints identified during the course of this assessment by the NESC team or the NRB quorum.

10.0 Other Deliverables

No unique hardware, software, or data packages, outside those contained in this report, were disseminated to other parties outside this assessment.

11.0 Lessons Learned

No applicable lessons learned were identified for entry into the NASA Lessons Learned Information System.

12.0 Definition of Terms

Corrective Actions	Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a problem.
Finding	A conclusion based on facts established by the investigating authority.

Lessons Learned	Knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. A lesson must be significant in that it has real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or limits the potential for failures and mishaps, or reinforces a positive result.
Observation	A factor, event, or circumstance identified during the assessment that did not contribute to the problem, but if left uncorrected has the potential to cause a mishap, injury, or increase the severity should a mishap occur. Alternatively, an observation could be a positive acknowledgement of a Center/Program/Project/Organization’s operational structure, tools, and/or support provided.
Problem	The subject of the independent technical assessment.
Proximate Cause	The event(s) that occurred, including any condition(s) that existed immediately before the undesired outcome, directly resulted in its occurrence and, if eliminated or modified, would have prevented the undesired outcome.
Recommendation	An action identified by the NESC to correct a root cause or deficiency identified during the investigation. The recommendations may be used by the responsible Center/Program/Project/Organization in the preparation of a corrective action plan.
Root Cause	One of multiple factors (events, conditions, or organizational factors) that contributed to or created the proximate cause and subsequent undesired outcome and, if eliminated or modified, would have prevented the undesired outcome. Typically, multiple root causes contribute to an undesired outcome.

13.0 Acronyms List

ATK	Alliant Techsystems, Inc.
BAH	Booz Allen Hamilton
CB	Confidence Bounds
CCAFS	Cape Canaveral Air Force Station
DOL	Day-of-Launch
DRWP	Doppler Radar Wind Profiler
GEV	Generalized Extreme Value
GN&C	Guidance, Navigation, and Control

GSFC	Goddard Space Flight Center
JSC	Johnson Space Center
km	kilometers
KSC	Kennedy Space Center
LaRC	Langley Research Center
m	meters
m/s	meters/second
MHz	megahertz
MSFC	Marshall Space Flight Center
MTSO	Management and Technical Support Office
NESC	NASA Engineering and Safety Center
NRB	NESC Review Board
POR	Period of Record
QC	Quality Control
SLS	Space Launch System
TDT	Technical Discipline Team
VAFB	Vandenberg Air Force Base

14.0 References

1. Decker, R. and R. Barbré, "Quality Control Algorithms and Proposed Integration Process for Wind Profilers Used by Launch Vehicle Systems," Paper 9.5, *Proceedings of the 15th Annual Conference on Aviation, Range, and Aerospace Meteorology*, 3 August 2011.

2. Pinter, D.J., F.J. Merceret, and C.V. Hatley, "Performance Validation of Upgraded Eastern Range 50-Megahertz Doppler Radar Wind Profiler," *J. Spacecr. Rockets*, **43(3)**, pp. 693-695, May 2006.

3. Schumann, R.S., Taylor, G.E., Merceret, F.J., and T.L. Wilfong, "Performance Characteristics of the Kennedy Space Center 50-MHz Doppler Radar Wind Profiler using the Median Filter/First – Guess Data Reduction Algorithm," *J. Atm. Ocean. Tech*, **16**, pp. 532-549, 30 June 1998.

4. Lambert, W.C., Merceret, F.J., Taylor, G.E., and Ward, J.G., "Performance of five 915-MHz Wind Profilers and an Associated Automated Quality Control Algorithm in an Operational Environment," *J. Atm. Ocean. Tech.*, **20**, pp. 1488-1495, 7 May 2003.

5. DasGupta, A., *Asymptotic Theory of Statistics and Probability,* Springer Science and Business Media, New York, New York, p.693, 2008.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The NASA Engineering and Safety Center (NESC) received a request from the, NASA Technical Fellow for Flight Mechanics at Langley Research Center (LaRC), to develop a database from multiple Doppler radar wind profiler (DRWP) sources and develop data processing algorithms to construct high temporal resolution DRWP wind profiles for day-of-launch (DOL) vehicle assessment. This document contains the outcome of Phase 1a of the assessment including Findings, Observations, NESC Recommendations, and Lessons Learned.

15. SUBJECT TERMS
Doppler Radar Wind Profiler; Guidance, Navigation, and Control; Generalized Extreme Value; NASA Engineering and Safety Center; Quality Control

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