Engineering Notes

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Performance Validation of Upgraded Eastern Range 50-Megahertz Doppler Radar Wind Profiler

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I. Introduction

SINCE the early 1990s, NASA has operated a 50-MHz Doppler radar wind profiler (DRWP) at the NASA Kennedy Space Center (KSC) in Florida to support space shuttle launches and landings (Fig. 1).

The DRWP provides complete wind profiles from 2 to 18 km in 150-m increments every 5 min from the measuring site near the launch pads. This high temporal resolution is important because balloons take about an hour to make an equivalent sounding, and the small-scale upper air winds can change significantly within that hour. In addition, the balloons follow the wind and may be many tens of kilometers away from the space shuttle and other launch sites by the time they reach the altitude of maximum aerodynamic loads on the ascending vehicle.

These advantages led to the adoption of the DRWP as a day-of-launch source of wind profiles by other launch vehicle programs including Titan and Atlas that operate from the adjacent Eastern Range (ER) launch sites at Cape Canaveral Air Force Station. Its identical twin, formerly located at White Sands Space Harbor, New Mexico, was transferred to the Western Range (WR) as part of the range standardization and automation (RSA) program.

Both the ER and WR profilers were upgraded according to the RSA plan. The measurements reported in this Note were part of the ER acceptance test procedures, which required balloon-profiler comparisons before and after the modifications to assure that the performance of the modified DRWP was at least as good as that of the original unit. Because the two instruments will again be identical after acceptance at the ER and WR, the results reported in this Note should also apply to the modified WR instrument.

Received 24 August 2005; revision received 8 November 2005; accepted for publication 8 November 2005.

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Acceptance criteria for the mean and root mean square differences between balloon and profiler measurements of the u (east–west) and v (north–south) components of the horizontal wind vector were included in the acceptance test plan. These criteria, presented in Sec. IV, were based on the historical performance of the balloons and the profiler described in Sec. II.

II. Measurement Systems

The DRWP is a three-beam phased-array Doppler radar wind profiler operating at 49.25 MHz, but it is commonly referred to as the 50-MHz DRWP on the ranges and throughout this Note. The profiler and its performance have been well documented in the literature,[1–3] and only a brief summary is presented here. Wind profiles are obtained every 5 min using a median-filter first guess wind-finding algorithm with a premodification estimated rms error on the order of 1 ms^{-1} (Refs. 1 and 4). The vertical gate spacing and effective vertical averaging interval is 150 m, and the effective vertical resolution ranges from Nyquist limited at 300 m to a value noise limited at approximately 500 m depending on the state of the atmosphere.[3]

Global positioning system (GPS)-tracked automated meteorological profiling system (AMPS) high-resolution (HR) rawinsondes and radar-tracked jimspheres were used for the comparisons reported in this Note. The AMPS HR rawinsondes were derived from the original jimspheres[5] estimated to have an rms error of about 1 ms^{-1} for winds integrated over approximately 30 m (Refs. 4, 6, and 7). Jimspheres and AMPS/HR are essentially identical balloons except for the method used to track them. Both are constant volume balloons 2 m in diameter with conical protrusions on the surface to control the boundary-layer flow over the balloon, thus reducing errors due to asymmetric wake separation effects. The major difference between the jimsphere and AMPS HR balloons is that the balloon skin is aluminized Mylar (reflective) tracked by radar vs transparent Mylar tracked using differential GPS from the radiosonde, respectively.

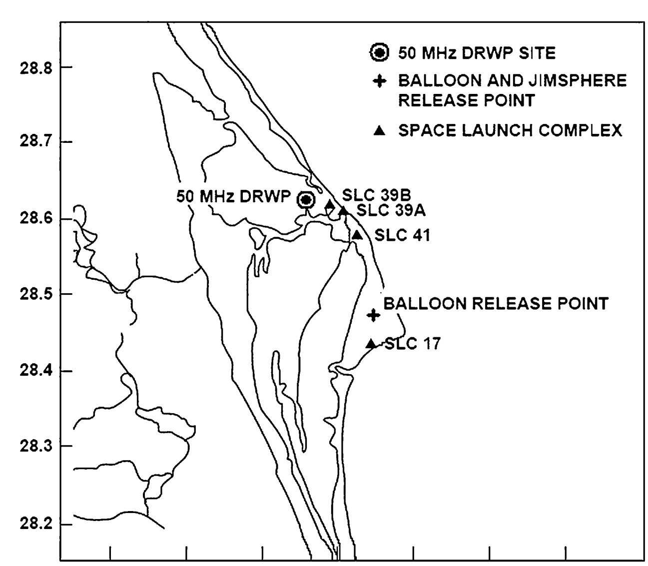

Fig. 1 KSC 50-MHz DRWP/AMPS HR balloon release locations.

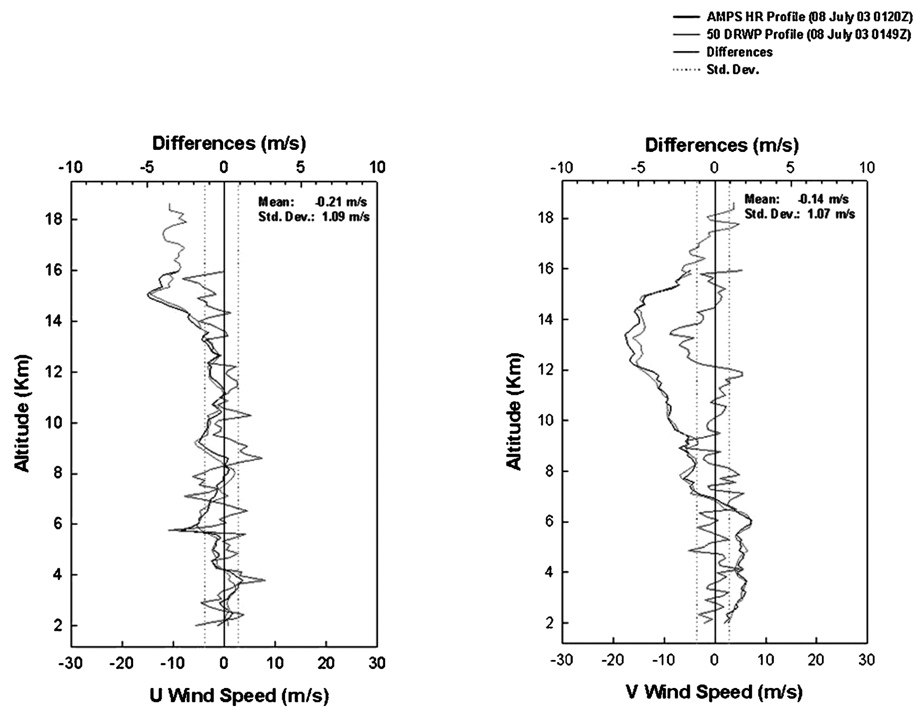

Fig. 2 Premodification baseline comparison, 8 July 2003.

III. Data

The DRWP samples wind measurements every 150 m from approximately 2- to 18-km altitude approximately every 5 min. Each DRWP 150-m interval reported wind measurement represents a wind vector averaged over approximately 5 min within a 150-m layer. AMPS HR rawinsondes report the wind at 30.5-m intervals from the surface to approximately 18 km. Each AMPS HR 30.5-m interval reported wind measurement represents a wind vector averaged over 6 s (30.5-m layer). The HR rawinsonde takes an hour to rise from the surface to 18 km. To make the data from the two instruments as equivalent as possible, the HR data were averaged over a five adjacent samples (152.4 m) centered on the center of each DRWP 150-m gate. The 50-DRWP profile closest in time to the middle of the balloon's ascent was used. This enabled comparison of measurements from wind-profile altitude layers of the same thickness with a time separation of no more than 30 min.

There were 34 profile pairs collected before modification of the DRWP. Figure 2 is 1 of the 34 profile comparison plots shown for reference.

The data were collected from June through September 2003 under ideal conditions in which the winds were strong enough to provide interpretable comparisons but not so strong that the balloons were blown more than 40 km from the DRWP location. The DRWP Modification Integrated Product Team (IPT) agreed that limits on violation criterion should be set for 50-DRWP pre and postmodification comparison testing. Component wind speeds, u and v, should only range from about 5 ms^{-1} (9.7 k) to no more than about 25 ms^{-1} (49 K). Comparisons were not made during convective weather when they could be significantly distorted by turbulent, small-scale features.

There were 44 postmodification profile pairs collected under less ideal conditions. Figure 3 is 1 of the 44 profile comparison plots shown for reference.

The modifications were scheduled to be complete by July 2004, with data collection in August and September. Because of the time necessary to correct some software errors, the data were actually taken between late October 2004 and early January 2005. As a result, it was impossible to get an acceptable sample size without accepting wind components as large as 40 ms^{-1} because the winter jet streams had arrived. The stronger winds violated a preagreed validation criterion of wind speeds not to exceed 26 ms^{-1}, but the DRWP modification IPT decided to proceed with data collection rather than delay acceptance of the DRWP another year. If the winter season comparisons met the same standards designed for summer conditions, acceptable DRWP performance would certainly be demonstrated.

Table 1 Means and rms differences of u and v components

Variable	Premodification value, ms^{-1}[a]	Acceptance criterion, ms^{-1}	Postmodification value, ms^{-1}[b]
u Mean	−0.14	<=1	−0.12
u Standard deviation	1.44	<=3	1.70
u rms	1.45	<=3	1.70
v Mean	−0.04	<=1	0.01
v Standard deviation	1.38	<=3	1.65
v rms	1.38	<=3	1.65

[a]With 34 profile comparisons. [b] With 44 profile comparisons.

IV. Results

Each profile provided up to 112 comparisons of u and v, 1 at each 150-m DRWP gate. The mean and rms difference between the 152.4-m layer averages of wind values measured by the AMPS-HR and the DRWP were computed over the entire collection of data before and after modification. The results are shown in Table 1. Note that none of the profile comparison data were excluded in the Table 1 calculations.

Each statistic was based on 34 or more profiles, each containing 89–101 gates for a sample size exceeding 3000 points. As was expected, the premodification values were consistent with earlier work. The postmodification values were a pleasant surprise given that the data were taken under stronger wind flow winter conditions.

Indeed, 9 of the 44 postmodification profile pairs in Table 1 were taken on days when there were large horizontal wind gradients and the balloon trajectories crossed them for distances approaching 50 km. The IPT recommended excluding those postmodification data from the analysis, reducing the mean error in u and v, respectively, to −0.08 and −0.02 ms^{-1}. The corresponding postmodification rms u and v wind component errors were adjusted to 1.57 and 1.56 ms^{-1} on a sample size still exceeding 3000. T-tests on the means and F-tests on the variances indicated no statistically significant difference between the premodification data and either of the two postmodification data sets.

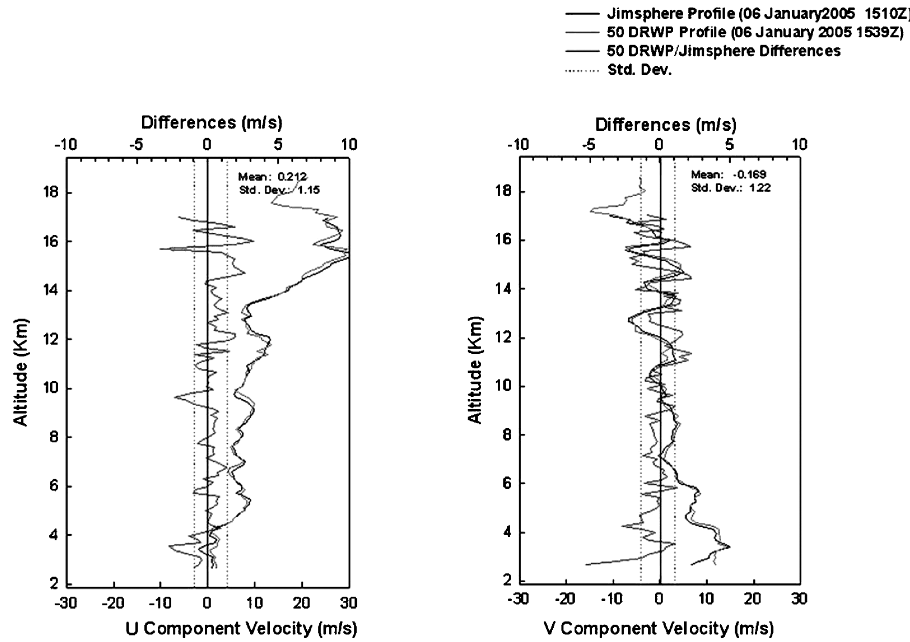

Fig. 3 Postmodification baseline comparison, 6 Jan. 2005.

Table 2 Pre/postmodification rms wind differences by altitude range

	Premodification[a]		Postmodification[b]	
Altitude range	Δu Component	Δv Component	Δu Component	Δv Component
Low (2–6 km)	1.38	1.14	1.85	1.78
Medium (6–14 km)	1.68	1.62	1.40	1.40
High (14–18 km)	1.83	1.78	2.16	2.09

[a]With 34 profile comparisons. [b] With 44 profile comparisons.

Table 3 Simultaneous balloon release coherence by altitude range

	Low (1–9 km)		High (9–17 km)	
Variable	Δu Wind component	Δv Wind component	Δu Wind component	Δv Wind component
Mean absolute difference	0.86	0.84	1.27	1.45
Standard deviation	1.2	1.3	1.7	2.2

The separation between the balloon and the DRWP generally increases with height as the balloon blows downwind. To evaluate the extent to which spatial separation rather than instrument error and noise contribute to the differences between the two instruments, we stratified the statistics by altitude in three ranges as shown in Table 2, which presents the results.

The premodification rms differences in Table 2 for both velocity components systematically increase with altitude as expected. The postmodification differences are largest at the highest range as expected, but the lowest values occur in the middle range rather than the lowest range. No explanation for this unexpected condition is known to the authors.

Finally, to place the magnitudes of the differences in context, Table 3 presents the results of comparisons of profiles from two identical balloons released less than 1 min apart from the same location within 10 m of each other. The standard deviations of the component differences and the mean of the absolute value of the component differences shown in Table 3 establish the essential limit on the accuracy of the balloon measurements as a reference for evaluating the DRWP. As may be seen by comparing Table 3 with Tables 1 and 2, the rms deviations of the differences between the DRWP and the balloons are close to the standard deviation of the differences between two identical balloons released at the same time in place, and therefore, the error in the DRWP cannot be significantly larger than the error in the balloons.

V. Conclusions

The premodification baseline tests reported here verified earlier studies showing the rms error for 150-m interval (layer) wind measurements of the original DRWP to be on the order of 1 ms^{-1} with negligible bias. These baseline tests had a much larger sample size and the comparisons were performed in a better meteorological environment and, thus, are substantially more definitive. The postmodification tests reported in this paper are the first involving the new RSA configuration that will be used on the ER and the WR for the foreseeable future. Again, the sample size was large, and despite less favorable meteorological conditions due to the large horizontal gradients, the data show that the performance of the modified DRWP is at least as good as it was before the modifications. Launch (and landing) customers at both ranges may continue to use the 50-MHz DRWP with confidence.

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