

A Comparison of Boundary Layer Wind Profiling Systems for Use with Space Launch Vehicles

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Background

- The United States Air Force (USAF) operates two space launch vehicle launch ranges.
 - Eastern Range (ER) at Cape Canaveral Air Force Station.
 - Western Range (WR) at Vandenberg Air Force Base.
- Both ranges use 915-MHz Doppler Radar Wind Profilers (DRWP) to measure winds within the lowest few kilometers of the atmosphere.
 - Important input in toxic dispersion models and in case of low-level aborts.
- However, the 915-MHz DRWPs are experiencing equipment obsolescence.
- The USAF funded evaluations of two boundary layer wind profiling systems for approximately three months at each range and also funded NASA Marshall Space Flight Center (MSFC) Natural Environments Branch (NE) to evaluate wind output from the two systems.

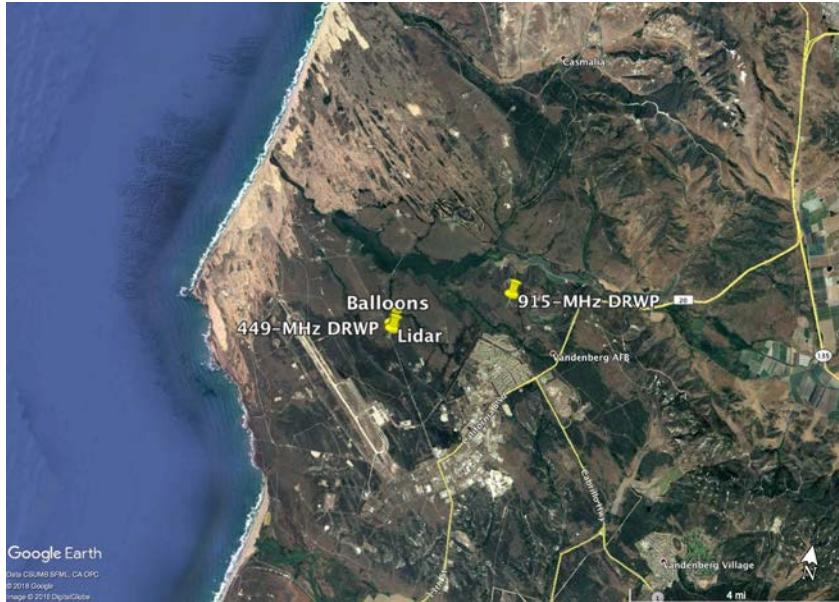
Background – Wind Observing Systems

- 449-MHz DRWP.
 - Operates in two modes - Low and High.
 - Low mode observes winds from ~100 m - ~3000 m in 67 m intervals.
 - High mode observes winds from ~1600 m - ~7000 m in 81 m intervals.
 - Observations are made every five minutes.
- WINDCUBE® Lidar.
 - Observes winds from 400 m – 3000 m in 100 m intervals.
 - Profiles are provided approximately every three seconds.
- 915-MHz DRWP.
 - Observes winds from 130 m – 6100 m in 100 m intervals.
 - Profiles are provided every 15 minutes.
- Automated Meteorological Profiling System (AMPS) Low Resolution (LR) Weather Balloons.
 - Observe winds from the surface to over 30000 m in one second intervals.

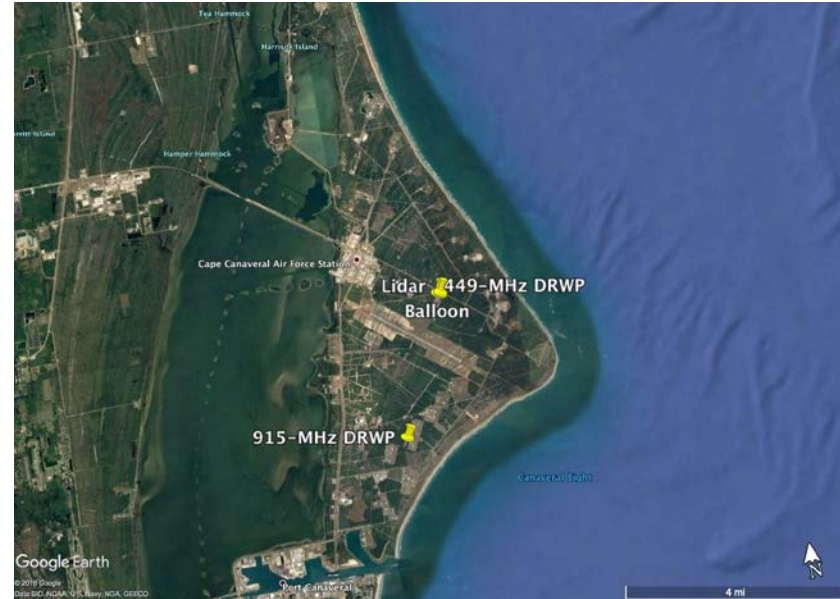


Background – Wind Observing Systems

WR



ER



System	Period of Record
AMPS Balloon	11/20/2017 - 3/14/2018, 5/10/2018 – 5/30/2018
449-MHz DRWP	11/16/2017 - 3/4/2018
Lidar	11/20/2017 - 1/19/2018, 5/10/2018 – 5/30/2018
915-MHz DRWP	11/20/2017 - 3/14/2018

System	Period of Record
AMPS Balloon	2/5/2018 - 4/27/2018
449-MHz DRWP	1/22/2018 – 4/27/2018
Lidar	2/5/2018 – 4/30/2018
915-MHz DRWP	2/1/2018 - 4/29/2018

Analyses

- Compared the U and V wind components to concurrent AMPS measurements to quantify the delta of the three systems relative to balloon measurements.
- Assessed data availability versus altitude to quantify how often it is expected to obtain data to an altitude of interest.
- Examined the Effective Vertical Resolution (EVR) of each system which quantified the granularity of the wind features that each system resolves.
 - This defines the boundary between instrument noise and real wind features.

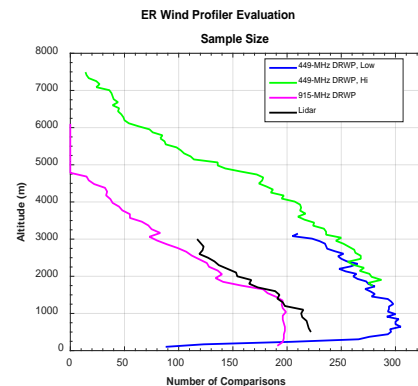
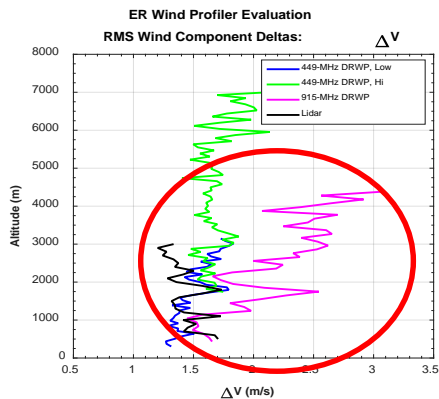
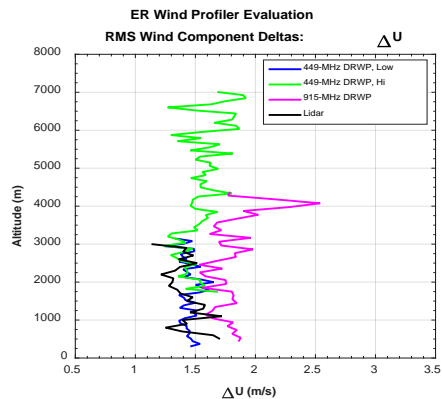
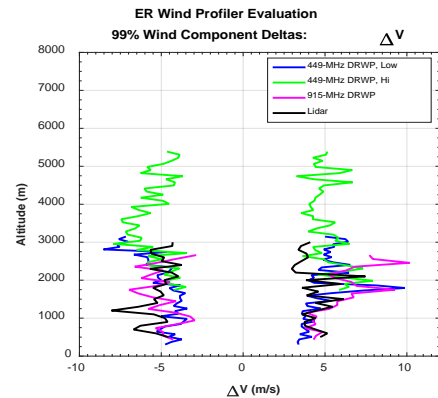
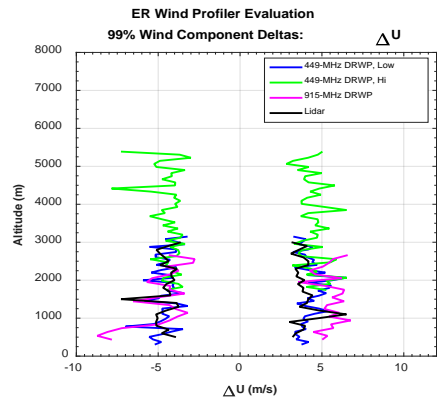
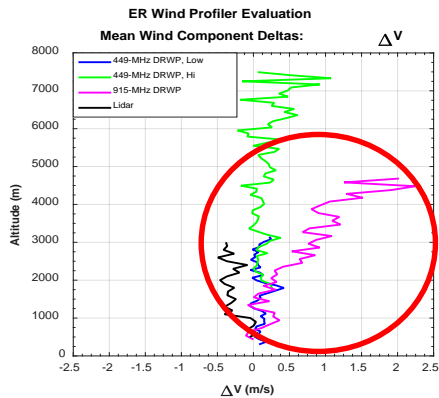
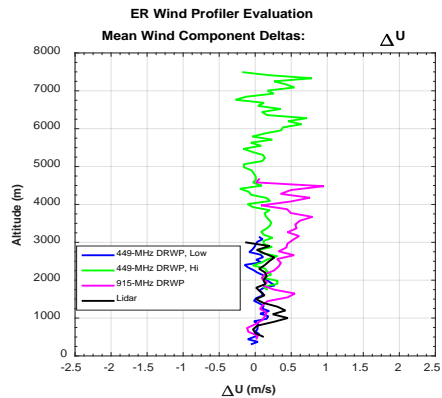


Balloon Comparisons - Methodology

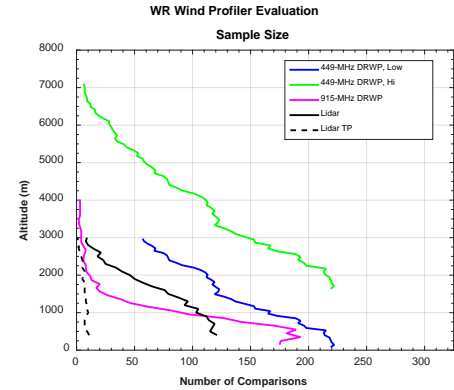
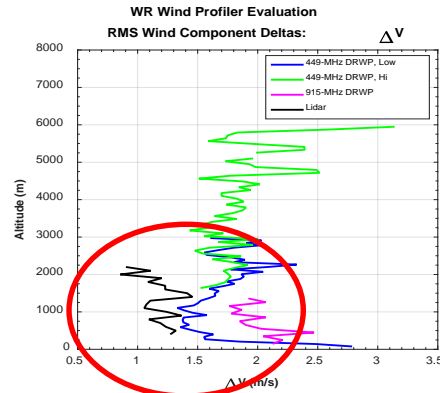
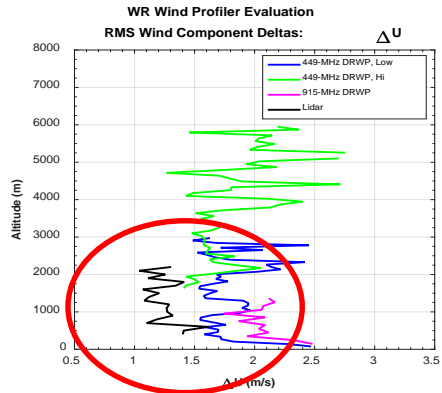
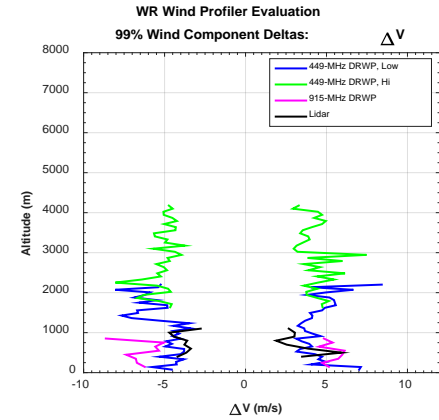
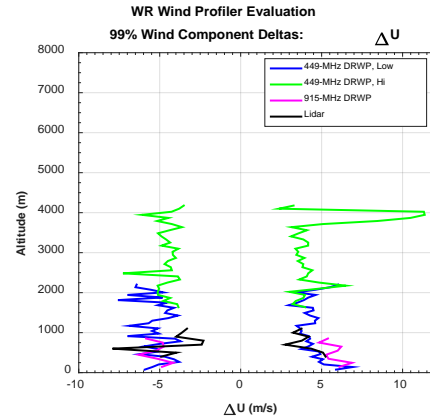
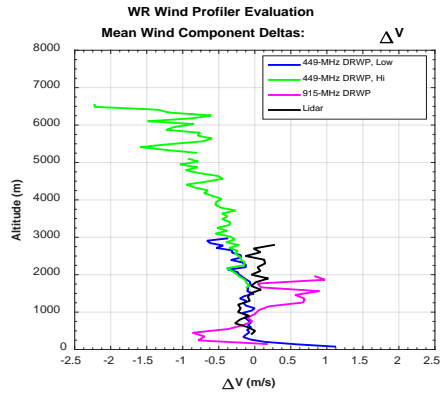
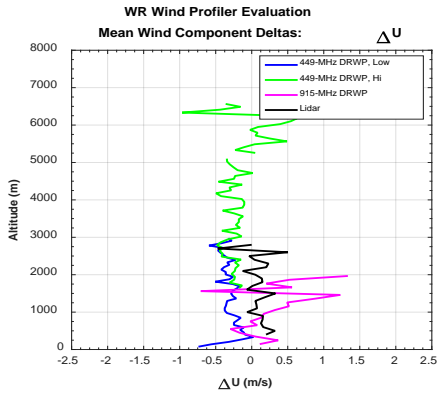
- Wind component profiles from the 449-MHz DRWP, 915-MHz DRWP, and Lidar were compared to concurrent wind component profiles from AMPS.
- Data from each remote sensing system were temporally and vertically matched to AMPS data.
- Mean wind component deltas, root-mean-square (RMS) wind component deltas, and 99% envelopes of the wind component deltas versus altitude were calculated for all systems.
 - The deltas were used to determine system accuracy of each system.
 - RMS deltas were used to provide and estimate of the error of each system.
 - Envelopes characterize extreme wind component deltas from each system.

System	Vertical Averaging Interval	Temporal Criteria
449-MHz DRWP, Low	67 m (ER), 64 m (WR)	+/- 2.5 minutes
449-MHz DRWP, High	81 m (ER), 77 m (WR)	+/- 2.5 minutes
915-MHz DRWP	101 m	+/- 7.5 minutes
Lidar	9 m (no averaging)	+/-2.5 seconds

ER Balloon Comparisons - Results

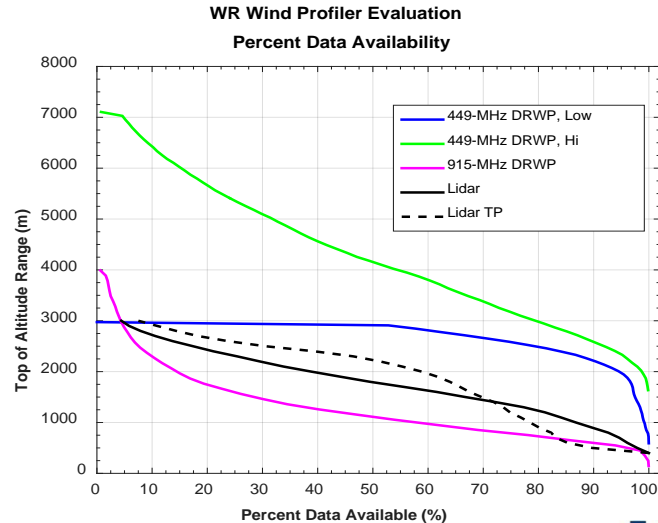
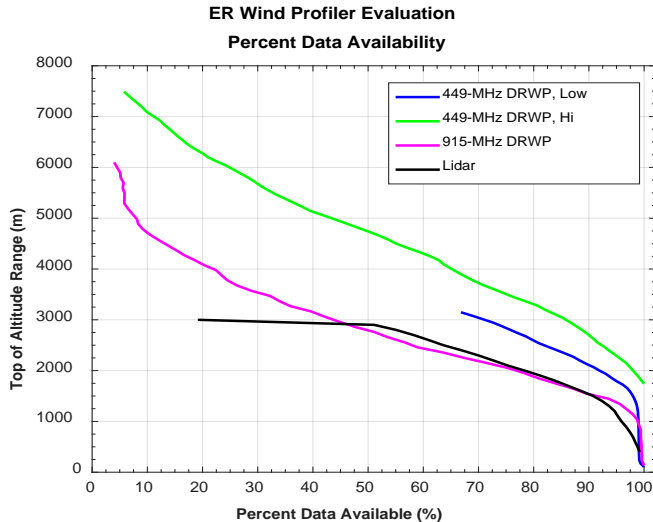


WR Balloon Comparisons - Results



Data Availability

- To show the probability of receiving vertically complete profiles from a given system within a specified altitude range, an analysis of data availability versus altitude was conducted.
- For each system, the number of profiles that contained data at all altitudes between the bottom of the profile and each subsequent altitude was tallied.



Effective Vertical Resolution - Methodology

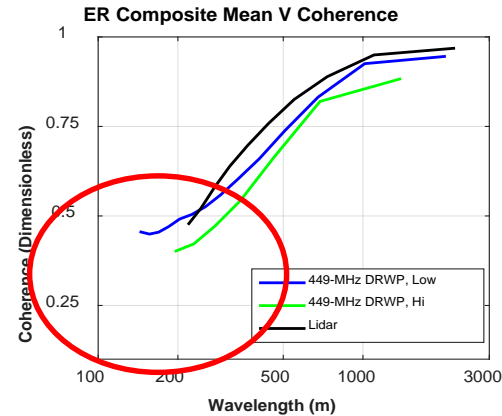
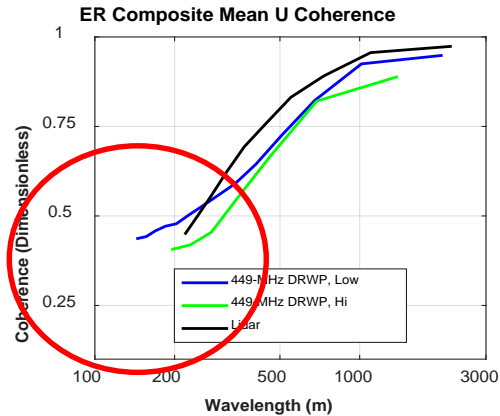
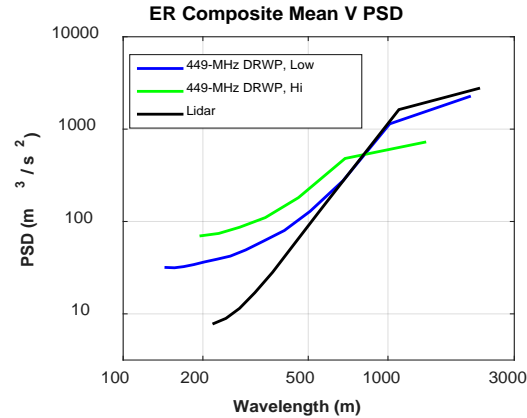
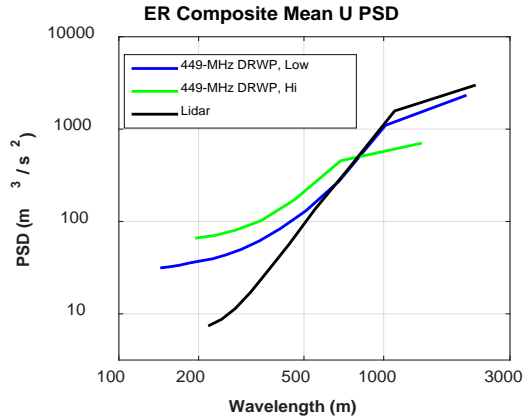
- EVR is determined by examining the magnitude-squared coherence (Coh^2), from Merceret (1999):
 - For an individual day, wind component profile pairs spaced by a specified time were first extracted.
 - Both profiles had to contain continuous data within specified altitude ranges.
 - Once the profiles and pairs were determined, the linear trend was removed from each wind component profile and a Hanning window with zero overlap was applied to the profile.
 - Then the Fast Fourier Transform of each profile was computed as a function of wavelength and used to generate each profile's Power Spectral Density (PSD) and each pair's Cross-Spectral Density (CSD).

$$Coh^2 = \frac{|\langle CSD \rangle|^2}{\langle PSD_1 \rangle \langle PSD_2 \rangle}$$

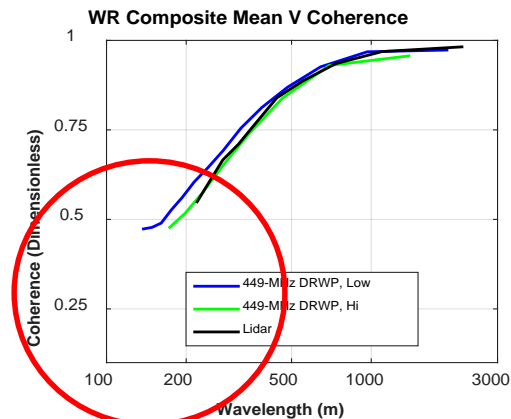
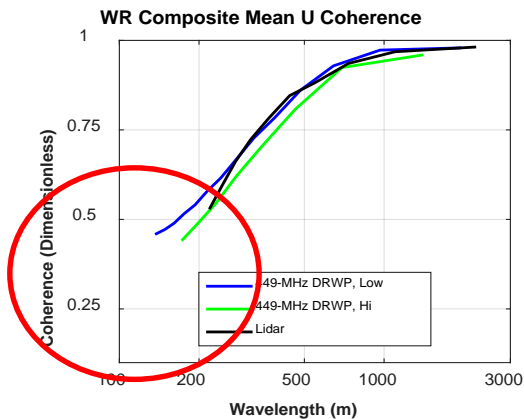
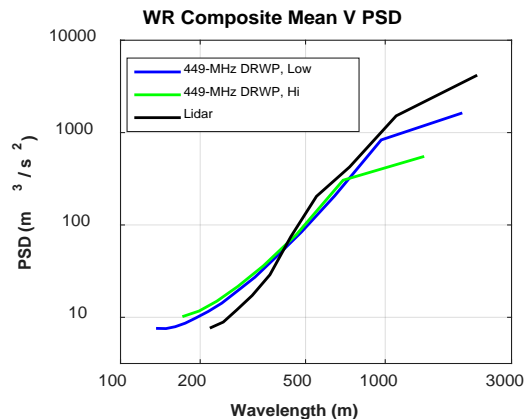
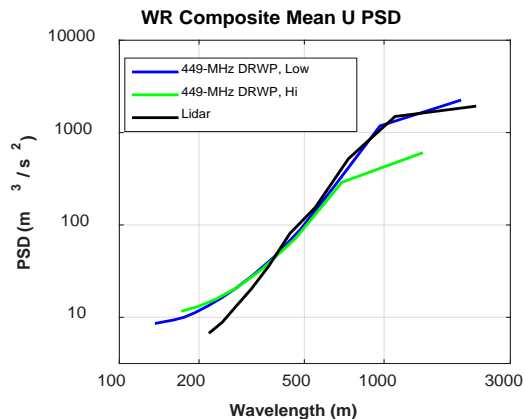
- Coherence describes the relationship between two signals at each wavelength.
 - Incoherent noise dominates this relationship at values below 0.25 as this value corresponds to a signal-to-noise ratio of unity.

System	Time Between Pairs	Required Altitudes (m AGL)	Sampling Interval (m)
449-MHz DRWP Low Mode	5 minutes	102 – 2,065 m (ER) 76 – 2,007 m (WR)	67.7 m (ER) 64.0 m (WR)
449-MHz DRWP High Mode	5 minutes	1,742 – 3,038 m (ER) 1,636 – 3,022 m (WR)	81.0 m (ER) 77.0 m (WR)
Lidar	1-15 seconds	400 – 2,500 m (ER and WR)	100.0 m (ER and WR)

Effective Vertical Resolution – Results ER



Effective Vertical Resolution – Results WR



Summary

- Wind component profiles from a 449-MHz DRWP, 915-MHz DRWP, and Lidar were compared to concurrent AMPS wind profiles at both the ER and WR.
 - The mean, RMS, and 99% delta of each system was approximately 1.0 m/s, 1.5 – 2.0 m/s, and 5.0 m/s, respectively, at a given altitude. Higher mean and RMS deltas were noted from the 449-MHz DRWP at lower levels at both ranges and at higher altitudes at the WR. The Lidar produced a slightly greater negative bias in ΔV at the ER.
- The percent of complete profiles that reached specified altitudes from the bottom of the profile was examined.
 - The percent of available profiles decreased or remained constant with increasing height for all systems.
 - The 449-MHz DRWP tended to have higher data availability than the Lidar.
- The EVR of each system was determined.
 - All systems found to be Nyquist limited, but the 449-MHz DRWP can resolve smaller features due to its finer altitude spacing.
 - 449-MHz DRWP High Mode: 128 m.
 - 449-MHz DRWP Low Mode: 154 m.
 - Lidar: 200 m.

Questions?



References

F. Merceret, "The Vertical Resolution of the Kennedy Space Center 50 MHz Wind Profiler," *Journal of Atmospheric and Oceanic Technology*, vol. 16, pp. 1273-1278, 1999.