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AN EVALUATION OF 915-MHz RADAR WIND PROFILER/RASS BY TOWER AND SODAR MEASUREMENTS

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1. INTRODUCTION

The accuracy and precision of the 915-MHz low-atmosphere wind profiler/RASS have been investigated through comparisons with other better-understood instruments such as rawinsonde (Strauch et al., 1987 and May et al., 1989), sodar (Neff and Wilczak, 1993), and tower instruments (Ye et al., 1993). These studies have provided useful information as well as confidence in the performance of this new technology in boundary-layer research and monitoring. However, because the accuracy of the profiler/RASS measurements depends to a large degree on the strength and homogeneity of small-scale turbulence and the amount of moisture in the atmosphere, the performance of the profiler may change significantly from one environment to another. As the radar wind profiler/RASS technology becomes more widely applied to a variety of research applications and moves toward operational wind, temperature, and eventually flux profiling, it is crucial to quantify its performance under different environmental and meteorological conditions.

South-central Washington is a semi-arid shrub-steppe environment with an average annual precipitation of only about 15 cm, which is significantly different from the other locations where comparative studies have been conducted. The performance of the RADIAN 915-MHz wind profiler/RASS in such an environment was evaluated using data from standard instruments mounted on a 120-m meteorological tower and a nearby sodar at the Hanford Meteorological Station. The results of this evaluation are presented in this paper.

2. DATA COLLECTION

The radar data used in this comparative study are hourly averaged wind speed, direction, and virtual temperature from April 1993. During this month the radar was operated continuously, and a total of 720 hourly samples were collected at each range gate. The radar was set to cycle through five different beam directions in sequence, including four oblique beams, tilted 21° from the vertical and separated by 90° in azimuth, and one vertical beam. The radar was operated at 60-m vertical resolution, and the height range covered was from 160 to 2020 m. The sampling time for each beam was about 40 s, including time for calculations and for beam steering and stabilizing. The RASS unit employed a new RASS technique based on 2048-point fast Fourier transform to simultaneously measure acoustically generated signals propagating at the local speed of sound and vertical air motion to allow the observed sound speed to be corrected by vertical air motion.

Between April 6 and 13, a sodar was operated near the radar profiler for the purpose of intercomparison. The sodar used in this comparison is a REMTECH PA1 phased-array Doppler sodar. Successive sound pulses are steered into the vertical and into oblique directions 30° from the vertical and separated by 90° in azimuth. A typical cycling time for pulses is about 18 s. The basic system parameters of the profiler/RASS and the sodar used for this period are given in Table 1.

The 120-m meteorological tower, located about 500 m southeast of the profiler, is instrumented with bivanes and cup anemometers, and thermocouples at 2, 30, 60, 90, and 120 m to measure wind, temperature, and dew point.

Table 1. System characteristics of the 915-MHz radar wind profiler/RASS and sodar.

Parameter	Radar	Sodar
Frequency	915 MHz	1600 KHz
Peak power	500 W	300 W
Beam width	9°	11°
Pulse length	400 nsec	200 msec
Spectral points	64	
Lowest gate	160 m	50 m
Height resolution	60 m	30 m
Averaging time	60 min	15 min
	RASS	
Acoustic frequency	2000 (Hz)	
Acoustic power	50 (W)	
Acoustic beam width	10°	

3. RESULTS OF COMPARISON

a. Radar-Tower Intercomparison

The hourly averaged wind speed, direction, and virtual temperature at the lowest range gate of the radar were compared with corresponding averages from measurements at the highest level of the tower. The radar data used in the comparisons were those that had passed the hourly consensus test. No other editing and screening for bad measurements were done except that data with wind direction between 45° to 135° were excluded in statistics calculation to eliminate the effect of tower shadowing. Fig. 1 and 2 show scatter plots of radar versus tower wind speed and direction. Although some scatter is noticeable, most of the hundreds of points are clustered close to the line of perfect agreement. The statistics from the radar-tower comparisons are summarized in Table 2. The table shows that the difference between the radar and tower measurements is very small: overall bias is close to zero in wind speed and about 5° in wind direction, with a standard deviation of the mean difference less than 1.5 m s^{-1} and 30° for wind speed and direction, respectively. These results are comparable to those obtained in the profiler-BAO Tower comparison of Ye et al. (1993). The scatter here is slightly smaller.

Table 2 also summarizes the statistics when the data are broken down into wind speed greater or less than 3 m s^{-1} and into daytime or nighttime. The scatter of wind direction for low wind speed is, as expected, much larger

Table 2. Radar profiler-tower wind comparison statistics

Statistics	All time Spd	All time Dir	≤ 3 m/s Spd	≤ 3 m/s Dir	>= 3 m/s Spd	>= 3 m/s Dir	Daytime Spd	Daytime Dir	Nighttime Spd	Nighttime Dir
Sample points	635	635	230	230	405	405	335	335	300	300
Bias (m s^{-1} or deg)	-0.006	-4.89	-0.40	-4.60	0.22	-5.04	0.10	-6.16	-0.12	-3.46
Std. Deviation (m s^{-1} or deg)	1.54	29.77	0.95	42.3	1.76	18.9	1.17	34.3	1.87	23.7

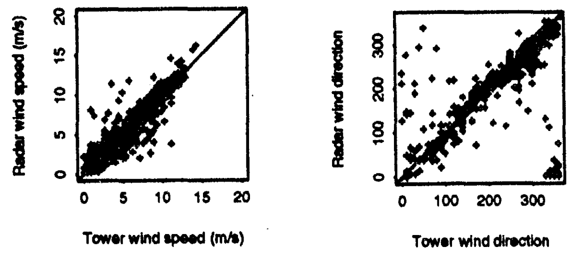

Fig. 1. Radar profiler - tower wind comparison

than that for higher wind speed. Notice that the wind speed bias is positive for higher winds and negative for lower winds, which, together, gives a near zero overall bias. Negative bias at low wind speed is well understood. At low wind speeds, the spectral peaks due to wind velocity are Doppler-shifted small increments from the transmit frequency. When the signal to noise ratio is low, and a significant background noise of fixed echoes (zero Doppler shifts) exists, the radar signal processing algorithm can confuse the spectral peak due to air motion with the fixed echoes and output low speed. The positive bias at higher wind speed is expected in this comparison considering the real differences in wind speed at separated sampling heights between the lowest range gate of the profiler and the highest level of the tower. Dividing the data into daytime and nighttime reveals a slightly better performance of the profiler under nighttime stable conditions, which is consistent with that found in the radar profiler - BAO Tower comparison. A significant portion of the differences are likely to be accounted for by the separation of the instrument locations (500 m) and the sampling differences because the radar profiler samples volumes of the air while the tower instruments sample points in space.

Figure 2 shows the scatter plot of RASS virtual temperature versus the tower temperature; the comparison statistics are summarized in Table 3. The excellent agreement is consistent with those reported in other comparative studies (May et al., 1989 and Martner et al., 1993) with a very small bias of about 0.1°C in the mean temperature, and standard deviation of the difference of approximately 1°C. Separating the data into daytime and nighttime reveals much less scatter in nighttime stable conditions than in daytime unstable conditions. The relatively larger scatter during the daytime is probably explained by the measurement error of vertical velocity when the correction for vertical velocity is made, which is particularly important in the unstable lower boundary layer.

b. Radar-Sodar Intercomparison

Doppler sodars played an essential role in boundary-layer-wind profiling before the development of the low-level 915 MHz radar profiler. A major limitation in sodar profiling is their range, normally below 800 m, while the boundary layer can grow as deep as 2 - 3 km. However, since the maximum range of sodar usually overlaps the lowest ranges of a 915-MHz profiler, it provides an opportunity for system integration and a tool for real-time evaluation of boundary-layer radar profiler.

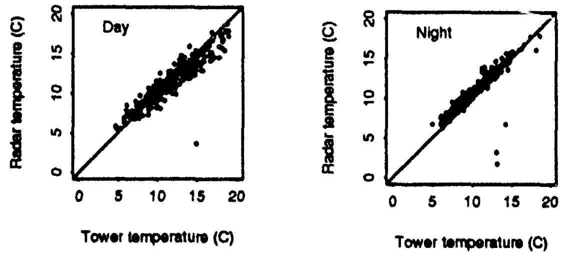

Fig. 2. RASS - tower temperature comparison

Table 3. RASS-tower temperature comparison statistics

Statistics	All Time	Day	Night
Sample points	701	355	346
Bias (°C)	-0.12	-0.35	0.61
Std. Deviation (°C)	0.93	0.99	0.26

During the one-week period from April 6 to 13, hourly averaged wind speed and direction measured at the lowest 6 range gates from the radar profiler were compared with sodar data from the nearest heights. Together, 790 sample points that had passed the consensus tests of the radar and the sodar were used for comparison. Fig. 3 shows the scatter plots of speed and direction with data from all five heights; the statistics are summarized in Table 4.

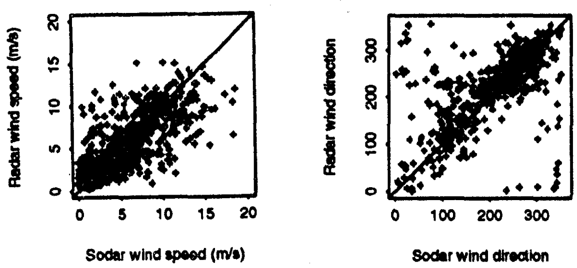

Fig. 3. Radar profiler - sodar wind comparison.

Table 4. Radar-sodar wind comparison statistics

Statistics	Speed	Direction
Sample points	790	790
Bias (m s^{-1})	-0.23	7.38
Std. deviation (m s^{-1})	1.79	32.77

The overall biases and the standard deviation seem larger than those in radar-tower comparison. But separating the data by their height levels reveals that points with the greatest discrepancy were from the uppermost heights of the sodar, where the signal-to-noise ratio is weakest. Fig. 4 shows the biases and standard deviations at each of the 5 levels. Both the biases and the scatter increase significantly above 400 m, where the number of samples from the sodar that passed the consensus tests are considerably smaller than those in the lower levels. Below 250 m, the standard deviation of the mean differences is less than 1.3 m s^{-1} for wind speed and less than 30° for wind direction. Above 400 m, it increased to about 2.5 m s^{-1} and about 39° in speed and direction, respectively. Again, a significant portion of the observed variation in radar-sodar intercomparison is likely due to the differences in scattering volume and sampling efficiency.

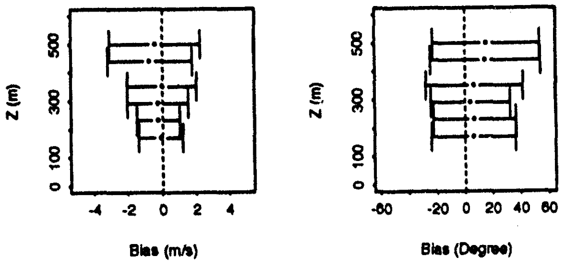

Fig. 4. The distributions of the biases and the standard deviations with height. The center point of the error bar corresponds to the mean difference at that height and the length of the error bar equals twice the standard deviation.

c. Height Coverage And Sensitivity to Humidity.

Knowing the height coverage of the wind and temperature measurements by the profiler/RASS is important for many applications, especially for long-term operations. The semi-arid shrub-steppe environment around the Hanford Meteorological Station in south-central Washington provides a considerable opportunity to explore the profiler's sensitivity to humidity variations. Hourly averaged values of mixing ratio obtained from the top level of the tower were used to group the data into relatively dry and moist periods. Fig. 5 shows the histograms of the height coverage of wind and temperature measurements for mixing ratio values greater or less than 5 g kg^{-1}. The plot indicates a strong dependence of height coverage on the humidity level in the lower atmosphere. At lower humidity, the highest range was also lower. However, the profiler generally provided usable data from the lowest couple of range gates for mixing ratios greater than 1 g kg^{-1}. Separating the data into daytime and nighttime indicates a significant decrease in height overage at night because the atmosphere is more stable.

4. CONCLUSIONS

The performance of a 915-MHz low-level radar wind profiler/RASS in a semi-arid shrub-steppe environment has been evaluated by detailed comparison with tower and sodar measurements. The results show excellent agreement between the remote and in situ measurements and between the remote sensing instruments. The performance statistics are comparable to those obtained by previous studies in different environment. Although the height coverage decreases as the humidity level drops, the profiler/RASS generally provides useful data in the lowest couple of range gates as long as the mixing ratio is above 1 g kg^{-1}. This study provides confidence in applying the profiler/RASS technology in a semi-arid environment where the humidity level in the atmosphere is usually low.

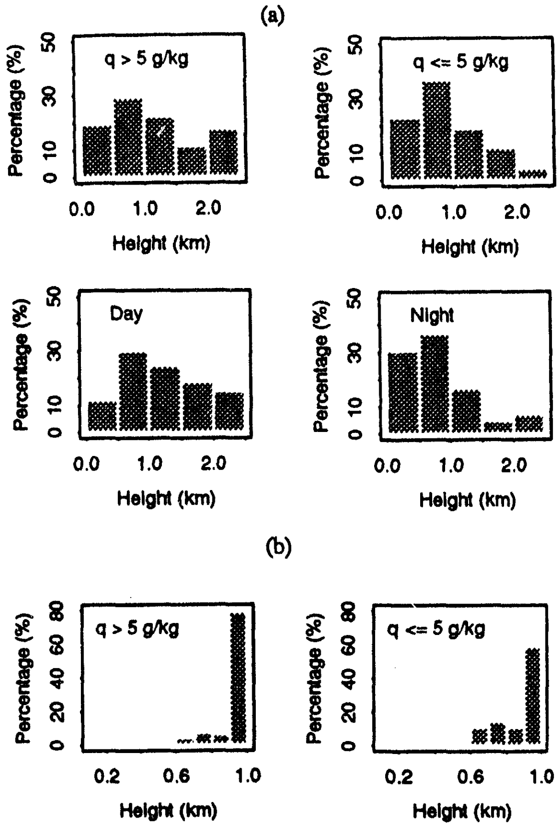

Fig. 5. Histograms of the height coverage of wind (a) and virtual temperature (b).

5. ACKNOWLEDGMENTS

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