1.4.2 PERFORMANCE CHARACTERISTICS OF WIND PROFILING RADARS

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INTRODUCTION

Doppler radars used to measure winds in the troposphere and lower stratosphere for weather analysis and forecasting are lower-sensitivity versions of MST (mesosphere-stratosphere-troposphere) radars widely used for research. We have used the term "wind profiler" to denote these radars because measurements of vertical profiles of horizontal and vertical wind are their primary function. It is clear that wind profilers will be in widespread use within five years: procurement of a network of 30 wind profilers is underway (CHADWICK, 1986). The Wave Propagation Laboratory (WPL) has operated a small research network of radar wind profilers in Colorado for about two and one-half years (STRAUCH et al., 1985). Table 1 lists the transmitted power and antenna aperture for these radars. Data archiving procedures have been in place for about one year, and we are able to use this data base to evaluate the performance of the radars.

Table 1. WPL wind profilers (1985)

Site	Wavelength (m)	Average Power (W)	Antenna area (M^2)
Stapleton Airport	0.3	450	100
Platteville, CO	0.74	400	54
Platteville, CO	6.02	400	10,000
Fleming, CO	6.02	400	2,500
Flagler, CO	6.02	400	2,500

One of the prime concerns of potential wind profiler users is how often and how long wind measurements are lacking at a given height. Since these "outages" constitute an important part of the "performance" of the wind profilers, they are calculated at three radar frequencies, 50-, 405-, and 915-MHz, (wavelengths of 6-, 0.74-, and 0.33-m) at monthly intervals to determine both the number of outages at each frequency and annual variations in outages. This study on the monthly performance of the wind profilers (i.e., measurement or no measurements at various heights) is based on the more recent archived data from the Colorado Wind Profiler network. It does not consider the accuracy of the wind measurements.

RADAR SENSITIVITY COMPARISONS

The three radars operated with pulse widths of 3- and 9-μs. (The 405- and 915-MHz radars also have a 1-μs pulse mode.) We can compare the sensitivities of the various radars and their modes using the meteorological equation.

First, when we compare pulse widths for the same radar, we find relative sensitivity is proportional to $[\Delta R \bar{P}_t \sqrt{T_o}]$ where ΔR is the range resolution P_t is the average transmitted power and T_o is the observation time. For our radars the 9-μm mode is more sensitive than the 3-μs mode as shown below:

50 MHz, + 6.4 dB
405 MHz, + 7.3 dB
915 MHz, + 7.1 dB

These relative sensitivity values are important for evaluating the performance of a given radar with different pulse widths.

Second, when we compare the three radars and assume scattering from homogeneous, isotropic turbulence in the optically clear atmosphere with the radar half-wavelength in the inertial subrange, then relative sensitivity is proportional to

$$\frac{\overline{P}_t A_e \Delta R \sqrt{T_o} \lambda^{1/6}}{(T_{op}) L}$$

where A_e is the effective antenna aperture, λ is the radar wavelength, T_{op} is the system noise temperature and L is the total loss (rf losses and receiver losses). For the 9-μs pulse mode, the 50-MHz radar is 6.5 dB more sensitive than the 405-MHz radar. These numbers are important in comparing the performances of the different radars.

PROFILER OUTAGES

Figure 1 shows an example of the outage in hourly-averaged wind profiles for the 3- and 9- s modes of the 405-MHz radar. Each vertical dash represents available data for that height and hour; no symbol is printed if data are not available. The periods that show no data at all heights are due to equipment failures including loss of power, loss of telephone transmission, etc.; these outages are not included in the statistics. The 9-μs mode shows fewer outages below 10 km than does the 3-μs mode because the sensitivity of the 9-μs mode is about 7 dB greater. Where both modes show outages the scattering is too weak to detect. Since there is no signal the "depth of fade" is unknown. If the loss of signal is related to an increase in the inner scale of turbulence, the fade could be very large and increased radar sensitivity could yield little reduction of outages. If the loss of signal is related to weak scattering where the fade is on the lower tail of a normal distribution, then the reduction of outage with increased sensitivity can be inferred.

One of the statistics used to measure the performance of the profilers is the percent of time that the profiler was "down" at each height (no wind data, given that the radar is operating) for three or more consecutive hours. Samples of these down-time statistics for January 1985 at the three frequencies are shown in Figures 2-4. The 50-MHz profiler at Fleming (Figure 2) had no outages to 6 km in either the 3- or 9-μs mode, and none until almost 14 km in the 9-μs mode. In comparison, the 405-MHz (Figure 3) Profiler had outages starting at 6 km in the 3- s mode, and at 9 km in the 9-μs mode; the 915-MHz Profiler (Figure 4) had outages starting at a little over 5 km in the 3-μs mode and at 6 km in the 9-μs mode. All radars are in the same geographical area and all radars have about the same sensitivity increase for the 9-μs pulse mode relative to the 3-μs pulse mode (the 50-MHz radar has the least sensitivity increase). However, the 50-MHz radar has a 6-7 km increase in height coverage for the 9-μs mode compared to the 3-μs pulse mode whereas the 915-MHz radar and 405-MHz do no show nearly as much increase. This difference in performance indicates a frequency-dependent profile of backscattering cross section.

To evaluate the height performance of the profilers and determine whether this frequency-dependent difference in height performance for the two modes was consistent, the lowest height where the probability of an outage for three or more consecutive hours reached 0.1 was calculated based on monthly statistics. These heights for the two modes are shown in Figures 5-7. The 915-MHz Profiler consistently shows the smallest height difference for the two modes (Figure 5).

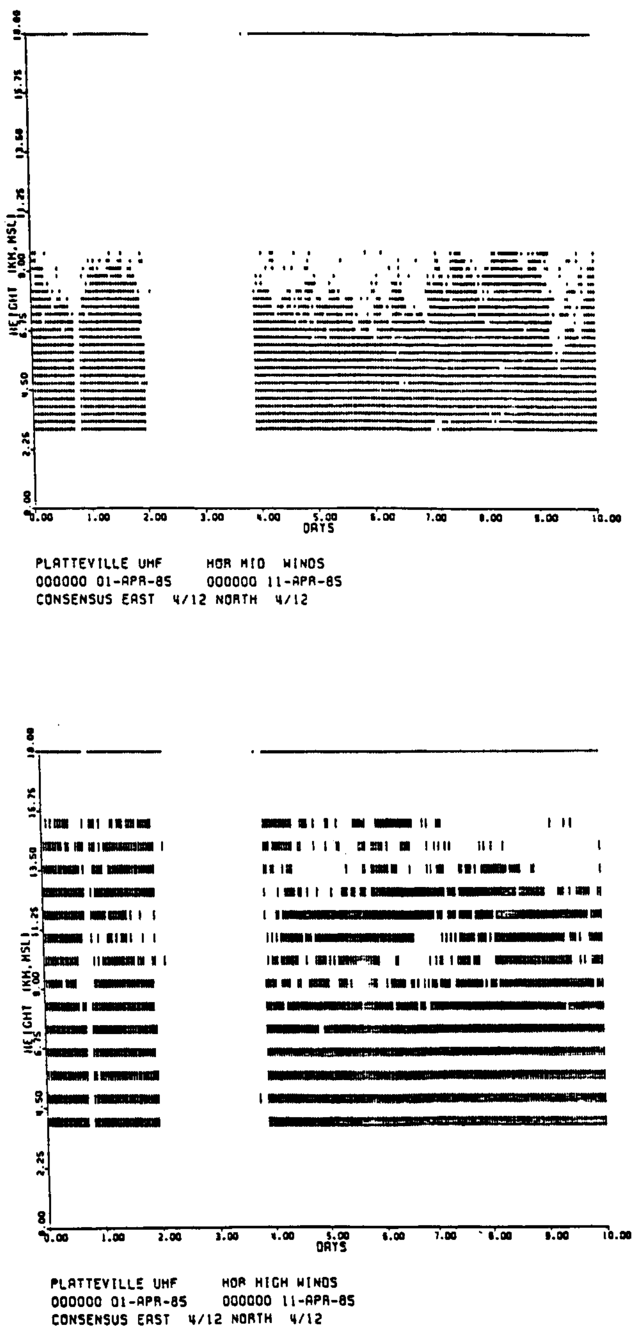

Figure 1. Height-time display of 3- (top) and 9-μs (bottom) modes for Platteville 405-MHz wind profiler. Vertical dashes indicate that there was a wind measurement at that time and height.

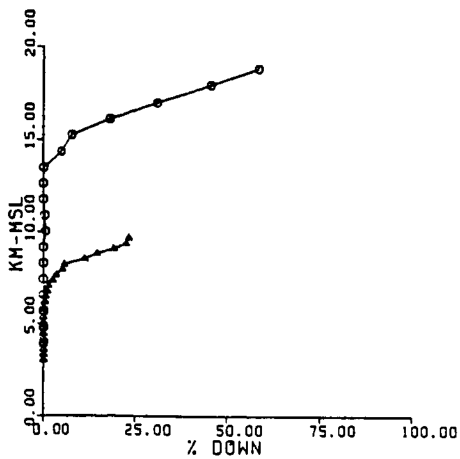

Figure 2. Probability that an outage will last 3 or more consecutive hours vs height at 50 MHz for the 3-μs (triangles) and 9-μs (circles) modes based on January 1985 statistics.

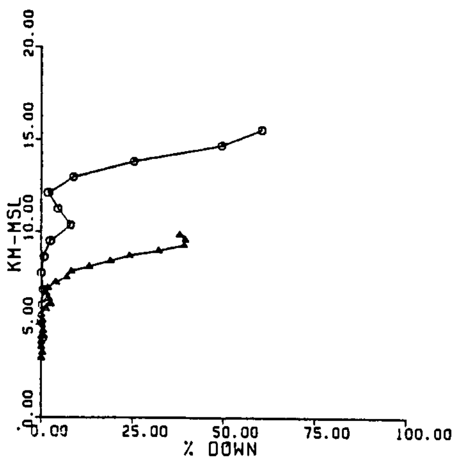

Figure 3. Probability that an outage will last 3 or more consecutive hours vs height at 405 MHz for the 3-μs (triangles) and 9-μs (circles) modes based on January 1985 statistics.

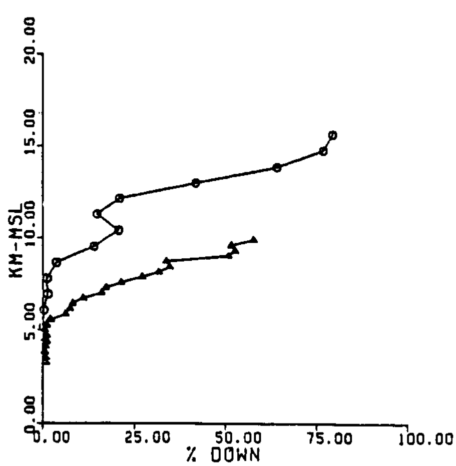

Figure 4. Probability that an outage will last 3 or more consecutive hours vs height at 915 MHz for the 3-μs (triangles) and 9-μs (circles) modes based on January 1985 statistics.

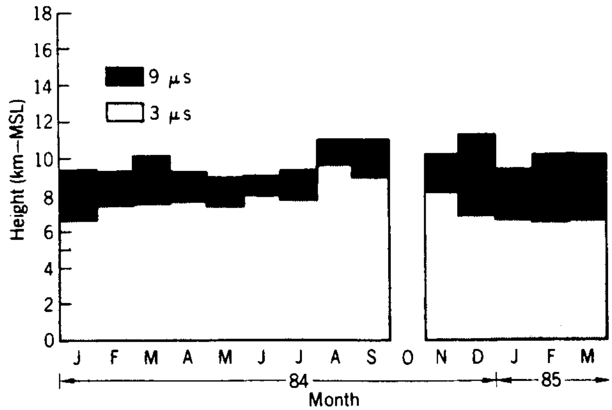

Figure 5. Lowest height where the probability of an outage for $\geq$ 3 consecutive hours is 0.1 for the 3- and 9-μs modes (915 MHz).

(The radar did not operate with a 9-μs pulse width in October 1984.) Note that the difference in height resolution for the two modes is about 900 m; therefore an increase of about 500 m would occur in the data even if there were no actual height increase. The actual height difference for the 915-MHz Profiler for the summer of 1984 is therefore very small. The height difference for the 50-MHz radar (Figure 6) shows a small height increase for the 9-μs mode for the summer of 1984 and 6-7 km for other months. Preliminary analyses of summer data for 1985 also shows a 6-7 km difference. The 405-MHz radar started operating in January 1985, and its height coverage and the difference between the two pulse widths falls between the other two radars (Figure 7).

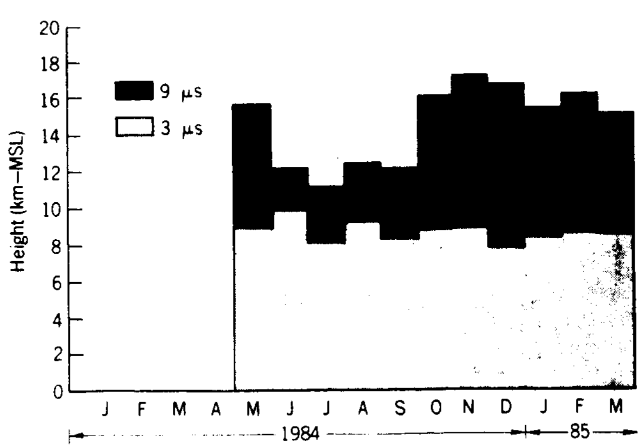

Figure 6. Lowest height where the probability of an outage for $\geq$3 consecutive hours is 0.1 for the 3- and 9-μs modes (50 MHz).

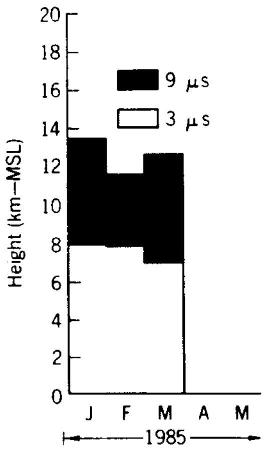

Figure 7. Lowest height where the probability of an outage for $\geq$ 3 consecutive hours is 0.1 for the 3- and 9-μs modes (405 MHz).

CONCLUSIONS

The height performance of radar wind profilers at upper-tropospheric and lower-stratospheric altitudes is important because the radar sensitivity required to measure winds at these altitudes is a major factor in determining the cost of the profiler. The profilers must reach these altitudes to provide the wind data needed for synoptic meteorology and commercial aviation. The specification of performance of a wind profiler must be a statistical specification because of the variability of backscatter cross section; if a profiler is required to measure winds to height H with height resolution of ΔH in time T under all meteorological conditions, the cost would be prohibitive for H, ΔH, and T needed for operational applications.

The upper-tropospheric/lower-stratospheric performance of wind profilers operating at 50-, 405-, and 915-MHz has been evaluated according to statistical criteria. The results of the evaluation indicate a wavelength-dependent backscatter cross section profile that favors longer wavelength radars for upper tropospheric wind measurement. For years it has been noted that 10-cm wavelength radars are not very useful clear-air radars above the boundary layer. The 33-cm (915-MHz) radar (with less sensitivity than that of a 10-cm wavelength meteorological Doppler radar) has dramatically different performance in that it can measure winds routinely to 9-10 km MSL. However, the 915-MHz radar has a much lower increase in height coverage when the sensitivity is increased compared to the height increase found with lower frequency radars. Both the fact that the 915-MHz radar can measure winds to much greater altitude than 3-GHz radars with equal sensitivity, and the fact that increased sensitivity with the 915-MHz radar does not produce the same increase in height coverage that is found with lower frequency radars, support the concept of a frequency-dependent backscatter cross section that is related to the increase in the length of the inner scale of turbulence as height increases, or that the wavelength dependence in theory of scattering is incomplete. The 405-MHz radar, with sensitivity equivalent to the 915-MHz radar, was able to obtain wind data to about 3 km greater altitude. The 50-MHz radar, with 6-7 dB more sensitivity than the UHF radars was able to measure winds to 15-16 km except during the summer months of 1984. (Summer data from 1985 show measurement capability to 16 km.) In case studies it has been noted that the 50-MHz profiler has marginal sensitivity for some meteorological conditions; a 3-dB increase in sensitivity should be sufficient to satisfy most requirements.

The 405-MHz radars being procured for a 30-station network (CHADWICK, 1986) will be about 9 dB more sensitive than the 405-MHz radar used in this study. The performance of these network radars would exceed that of the 50-MHz radar used in this study if the backscatter cross section is not frequency dependent. However, the data from this study indicate a frequency dependence that may limit the increased height coverage due to increased sensitivity, so a conservative statement regarding the upper altitude performance of the network radars is that they will clearly exceed the performance of the 405-MHz radar analyzed here and should be able to measure wind profiles to greater than 14 km MSL using statistical criteria similar to those used here.

REFERENCES

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