The Altitude Coverage of the Colorado Wind Profilers at 50, 405 and 915 MHz

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ABSTRACT

The maximum height performance of the 50, 405 nd 915 MHz Colorado wind profilers is computed from the wind profiler database. Results show that even though the 50 MHz profiler has the largest seasonal variation in the maximum height coverage, it also has the greatest height coverage. In addition, it also has a greater increase in height for the same increase in sensitivity. On the basis of these measurements we predict the height coverage of the 405 MHz wind profiler for the proposed wind profiler network.

1. Introduction

Doppler radars operating at VHF (very high frequency, 30–300 MHz) and UHF (ultra high frequency, 300–3000 MHz) can be used to measure vertical profiles of horizontal winds in nearly all weather conditions. These "*wind profiling*" radars, which are *lower-sensitivity versions of MST* (mesosphere–stratosphere–troposphere) radars, typically measure winds from near the ground to about 15 km. Much of the recent interest in wind profiling stems from technology developed in the Aeronomy Laboratory (AL) of NOAA's Environmental Research Laboratories (ERL) (Ecklund et al., 1979). Relatively low-cost VHF radar hardware was used to demonstrate that continuous wind profiles could be measured throughout the troposphere. Strauch et al. (1984) at the Wave Propagation Laboratory (WPL) built a mesoscale wind profiler network in Colorado, using the VHF radar technology developed in the AL (50 MHz) and standard UHF (915 MHz) radar technology.

The Colorado profiler network consists of four VHF radars (50 MHz) and two UHF radars (the 915 MHz and a newer 405 MHz). Hourly averaged wind profiles are measured by each radar, and their data are automatically sent by telephone to a central computer once per hour. Studies by Shapiro et al. (1984a,b) used data from this network to demonstrate the utility of automated, continuously operating wind profiling systems to provide a detailed spatial and temporal view of the evolving upper atmospheric wind field. If, as proposed, wind profilers are to become operational meteorological tools, with 100–1000 radars deployed across the continental United States, then relatively low cost radars must be used. A major concern is whether a low cost (and therefore low-sensitivity) radar can reliably measure wind profiles throughout the troposphere, particularly at upper altitudes (10–16 km) where the signals received by clear-air radar are weak. The performance of the radars in the Colorado network can be used to infer the radar sensitivity needed to measure winds throughout the troposphere. The database available from operating the Colorado network allows a statistical assessment of how often data can be obtained at a given altitude, using a radar of given sensitivity.

In this paper we present the results of an analysis of the height coverage of radar wind profilers operating at 50, 405 and 915 MHz, concentrating on the results at 405 MHz because of its proposed use in an operational network. Monthly statistics of height coverage are computed on the basis of 1984–85 data from the Colorado network. These statistics are an important part of an assessment of potential operational wind profilers, since they pertain to radars with quite modest sensitivity. In this study we do not evaluate the accuracy of the wind data (which will be discussed in a forthcoming paper), but concentrate on the frequency of occurrence and duration of "outages."

2. Profiler description

The radar wind profilers are described by Strauch et al. (1984, 1985). Their charactertistics are summarized in Tables 1–3. The 915-MHz radar is a three-beam system in which data obtained on a vertically pointing antenna position are used to estimate corrections for the effects of vertical motion in the two oblique pointing positions (east and north) that are used to measure horizontal wind components. The 50- and 405-MHz radars had only two beams, and with these radars the vertical velocity is assumed to be negligible when averaged for 1 hour. (Since both the 405- and the 915-MHz radars will detect nearly all types of precipitation, the 405-MHz radar will eventually also have a zenith-pointing antenna position so that during precipitation the effects of particle fall speed can be estimated. The effects of precipitation on the statistical description of

TABLE 1. Parameters of the 50-MHz profiler.

Radar		
Frequency	49.8 MHz	
Authorized bandwidth	0.4 MHz	
Peak power	30 kW	
Average power	400 W	
Pulse width	3, 9 μs	
Pulse repetition period	238.67, 672 μs	
Antenna aperture	50 m × 50 m	
Antenna pointing	15° off-zenith to north and east (2 antennas)	
Antenna type	fixed phase array of colinear-coaxial dipoles	
Two-way beamwidth	5°	
Data processing	3-μs pulse	9-μs pulse
Time domain averaging	419 pulses	124 pulses
Spectral averages	8	16
Maximum radial velocity	±15.05 m s^{-1}	±18.06 m s^{-1}
Spectral resolution (64 points)	0.47 m s^{-1}	0.56 m s^{-1}
Height sampling	3-μs pulse	9-μs pulse
First height	1.7 km AGL	2.6 km AGL
Height spacing	290 m	870 m
Number of heights	24	18

height coverage of the radars will be negligible, since the radars measure to heights above the top of precipitation.)

The UHF radars operate with 1-, 3- and 9-μs pulse durations; the VHF radar operates with 3- and 9-μs pulse durations. If the radar reflectivity is uniformly distributed along the beam, then the sensitivity of the radars operating with 9-μs pulse durations is greater than the sensitivity with 3-μs pulse duration by the values given in Table 4. Note that all three radars have about equal increase in sensitivity when operating with 9-μs pulses as compared with 3-μs pulses. When the 405- and 915-MHz radars are compared with the 50-MHz radar, and scattering from homogeneous isotropic turbulence in the inertial subrange is assumed, the relative sensitivity (derived from the power-aperture product, dwell time, etc.) of the radars, all operating with 9-μs pulses, is shown in Table 5. Even the most sensitive of these wind-profiling radars is 10–20 dB less sensitive than typical MST radars.

3. Data processing and archiving

The radar signals are sampled at intervals of two-thirds of the pulse duration. Data processing includes time domain averaging, power spectral analysis, and averaging of spectra before the spectral moments (signal power, mean Doppler velocity, and Doppler spectrum width) are estimated. Each pulse duration mode is used 12 times each hour; the 12 mean Doppler velocity estimates from each pulse width and each antenna pointing direction (east, north, and zenith) are averaged by applying a random sample consensus (Fischler and Bolles, 1981). At least 4 of the 12 values must form a consensus, in that they must lie within a window that is 1/16 of the Nyquist velocity interval (see Tables 1, 2 and 3 for maximum, minimum radial velocities). If fewer than 4 of the 12 velocity measurements pass this consensus test, the data for that height, pulse length, and antenna pointing position are rejected and the event is counted as an outage. (In general, if a consensus was not reached, it means that there was inadequate signal.) If a velocity consensus is found, the signal power and spectral width are averaged for that consensus set. For a vector wind to be calculated, both horizontal wind components from the oblique antennas must pass

TABLE 2. Parameters of the 915-MHz profiler.

Radar			
Frequency		915 MHz	
Maximum bandwidth		2 MHz	
Peak power		5.6 kW	
Duty cycle		≤25%	
Antenna aperture		≈10 m × 10 m	
Antenna pointing		zenith, 15° off-zenith to north and east	
Antenna type		offset paraboloidal reflector with offset horn feeds	
Two-way beamwidth		1.7°	
System, noise temperature		240 K	
Data processing	1-μs pulse	3-μs pulse	9-μs pulse
Pulse repetition period	50 μs	64 μs	110 μs
Average power	110 W	260 W	450 W
Time domain averaging	136 pulses	80 pulses	46 pulses
Spectral averages	8	32	32
Maximum radial velocity	13.2 m s^{-1}	17.7 m s^{-1}	17.7 m s^{-1}
Spectral resolution (64 points)	0.41 m s^{-1}	0.55 m s^{-1}	0.55 m s^{-1}
Height sampling	1-μs pulse	3-μs pulse	9-μs pulse
First height	0.3 km AGL	1.64 km AGL	2.7 km AGL
Height spacing	100 m	290 m	870 m
Number of heights	24	24	18

TABLE 3. Parameters of the 405-MHz profiler.

Radar			
Frequency		405.25 MHz	
Authorized bandwidth		1.00 MHz	
Peak power		30 kW	
Average power		0.4 kW maximum	
Pulse width		1, 3, 9 μs	
Pulse repetition period		100, 150, 300 μs	
Antenna aperture		9 m × 9 m	
Antenna pointing		15° off-zenith to north and east	
Antenna type		phased array of Yagi-Uda elements	
Two-way beamwidth		4.3°	
Data processing	1-μs pulse	3-μs pulse	9-μs pulse
Time domain averaging	120 pulses	75 pulses	35 pulses
Spectral averages	8	16	24
Maximum radial velocity	± 15.41 m s^{-1}	± 16.44 m s^{-1}	± 17.62 m s^{-1}
Spectral resolution (64 points)	0.48 m s^{-1}	0.51 m s^{-1}	0.55 m s^{-1}
Height sampling	1-μs pulse	3-μs pulse	9-μs pulse
First height	0.4 km AGL	2.4 km AGL	4.0 km AGL
Height spacing	100 m	290 m	870 m
Number of heights	24	24	14

the consensus test. If the signal-to-noise ratios for a given range gate are below that needed to obtain reliable velocity estimates, then there is about a 1% chance that the consensus test will select a false value. If there is a signal from an aircraft or strong radio interference that dominates one of the 12 hourly observations, the probability is 1/16 that the velocity will be accepted in the consensus and therefore become averaged with the atmosphere signals. These data processing steps are performed at the radar site prior to transferring the data to a central computer. At the central computer further tests can be made to eliminate points that are obviously not valid. We have calculated the statistical height coverage based on the hourly data supplied by the profilers without any other data editing.

4. Profiler outages

To compute statistics of the times that no radar return was observed at a specific height, we used the database available from a 915-MHz wind profiler located at Denver's Stapleton Airport, a 405-MHz profiler located at Platteville, and 50-MHz profilers located at Fleming, Cahone, Platteville, and Flagler, Colorado.

Figures 1a and 1b are samples of the time–height history, for the same time period, of the Platteville 405-MHz profiler for the 3- and 9-μs pulse modes. Each vertical dash represents a measurement. If there was no measurement at a particular height and time, no symbol was plotted. The periods that show no data at any height are due to equipment outages such as power failures, data transmission problems, etc.; these outages are not included in the statistics. Between days 4 and 7 at 9 km we see fewer outages in the 9-μs mode (Fig. 1b) than in the 3-μs mode (Fig. 1a). In this particular example, the decrease in the outages is due to an increase in sensitivity (~7 dB) of the 9-μs mode over the 3-μs mode. Where both radars show outages due to insufficient signal, we know there is insufficient scattering from refractive irregularities in the pulse-volume at one-half the radar wavelength (Tatarski, 1961). This lack of scattering can be due to two things. Either the strength of the refractive irregularities at one-half the radar wavelength is so small that a 7 dB increase in sensitivity is inadequate to detect the scattering, or there are no irregularities at all at one-half the radar wavelength. This could happen if the inner scale of turbulence increases due to the turbulence levels getting very small (Tatarski, 1961). If this is the reason for an outage, then increasing the sensitivity would have no effect on the outage.

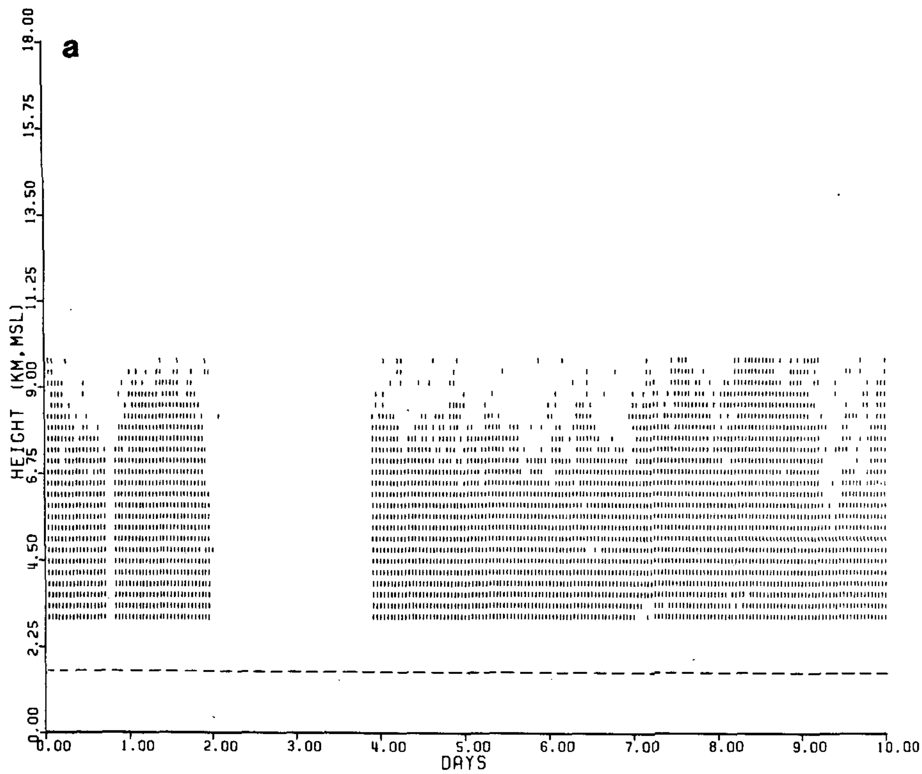
Another possible cause of an outage might occur when there is adequate signal, but the variance in the measurement is great enough that its data will not pass

TABLE 4. Sensitivity increases of profilers operating in the 9-μs mode compared with the 3-μs mode.

Profiler	Sensitivity increase
50 MHz	+6.4 dB
405 MHz	+7.3 dB
915	+7.1 dB

TABLE 5. Sensitivity of the 50-MHz profiler relative to the 405- and 915-MHz profilers, all operating in the 9-μs mode.

Profiler	Relative sensitivity of 50-MHz profiler
405 MHz	+6.5 dB
915	+7.0 dB



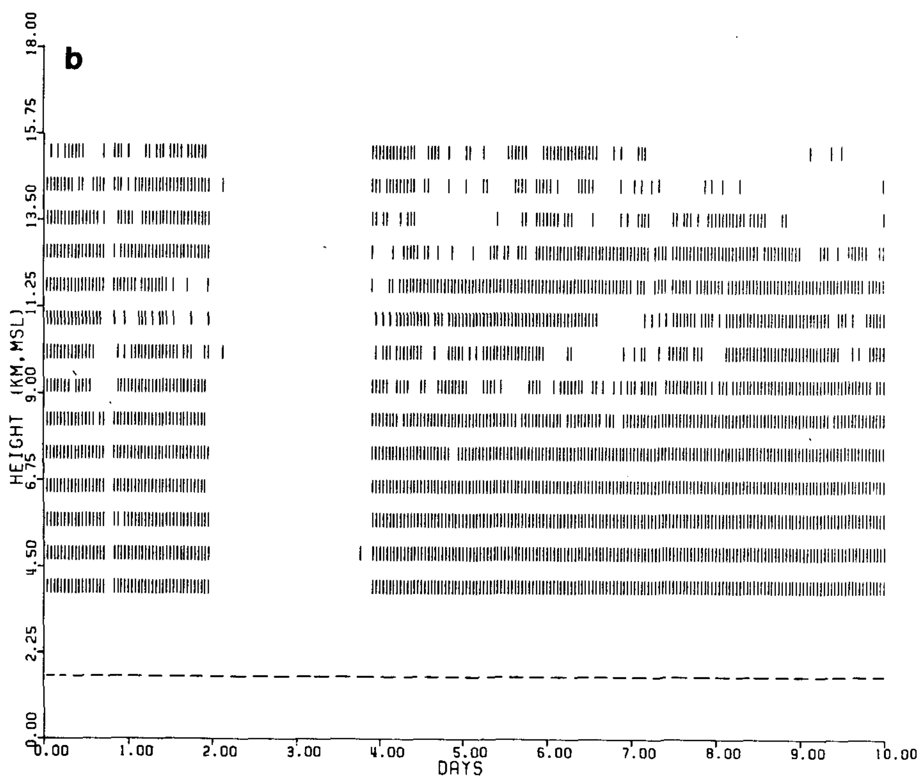


FIG. 1. Time–height display of the (a) 3-μs mode and (b) 9-μs mode for the Platteville 405-MHz wind profiler. Vertical dashes indicate that there was a wind measurement passing the consensus test at that time and height. The display starts at 0000 UTC on 1 April 1985 and ends at 0000 UTC on 11 April 1985. The lower horizontal dashed line represents the elevation of the Platteville site. Notice in (a) that the outages occur as low as 5 km on day 9.

the consensus test. This might happen if there were strong gravity waves with wide fluctuations in velocity, but all our evidence indicates that it is primarily the loss of signal that causes the outage. This can be seen in the increased height coverage and decreased outages when one increases the sensitivity. However, the possible meteorological causes for the outages are being investigated more thoroughly. Since, the outage is caused by weak scattering that is part of a known echo-intensity distribution, then we can infer how much the outages will be decreased with increased sensitivity.

a. Cumulative distribution of outages

The cumulative distribution of outage times was computed as a function of time and height. We define this as the percentage of time we had 1-hour outages, the percentage of 1-hour plus 2-hour outages, and so on up to the maximum outage time. Figure 2a is a sample of the July 1984 statistics for the 3- and 9-μs modes between 9 and 10 km at 915 MHz. In the 3-μs mode the longest outage length was about 50 hours, and at 9 μs the longest was 10 hours, indicating that the 7-dB increase in sensitivity decreased the maximum outage length by a factor of 5 for this height and month. Similar results are shown in Fig. 2b for January 1985. Comparing Figs. 2a and 2b, we can see very little difference in the outage distribution at 915 MHz for these two samples of a summer and a winter month.

The July 1984 statistics for the 50-MHz profiler (Fig. 3a) show that the maximum outage at 10 km was about 50 hours in the 3-μs mode. Increasing the sensitivity by 7 dB (9-μs mode) decreased the maximum outage length to 4 hours. In January 1985 (Fig. 3b), the maximum outage length for the 50-MHz radar (between 9 and 10 km) was about 30 hours in the 3-μs mode, whereas the maximum was 1 hour at 9 μs, reflecting a very substantial improvement in performance in both modes in this winter month compared with the summer month.

The database for the 405-MHz wind profiler at Platteville began in January 1985. Figure 4 shows outage duration distribution for January 1985 at the 10-km height. With this radar the maximum outage duration was 31 hours in the 3-μs mode and 5 hours in the 9-μs mode.

b. Height of outages

One of the statistics used to measure the performance of the profilers was the height at which the profiler was "out" (no wind data, given that the radar was operating) for 3 or more consecutive hours. Samples of these outage statistics for January 1985 at the three frequencies are shown in Figs. 5a–c. The 50-MHz wind profiler at Fleming (Fig. 5a) 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 (Fig. 5b) profiler had no outages until 6 km in the 3-μs mode, and none until 9 km in the 9-μs mode; the 915-MHz profiler

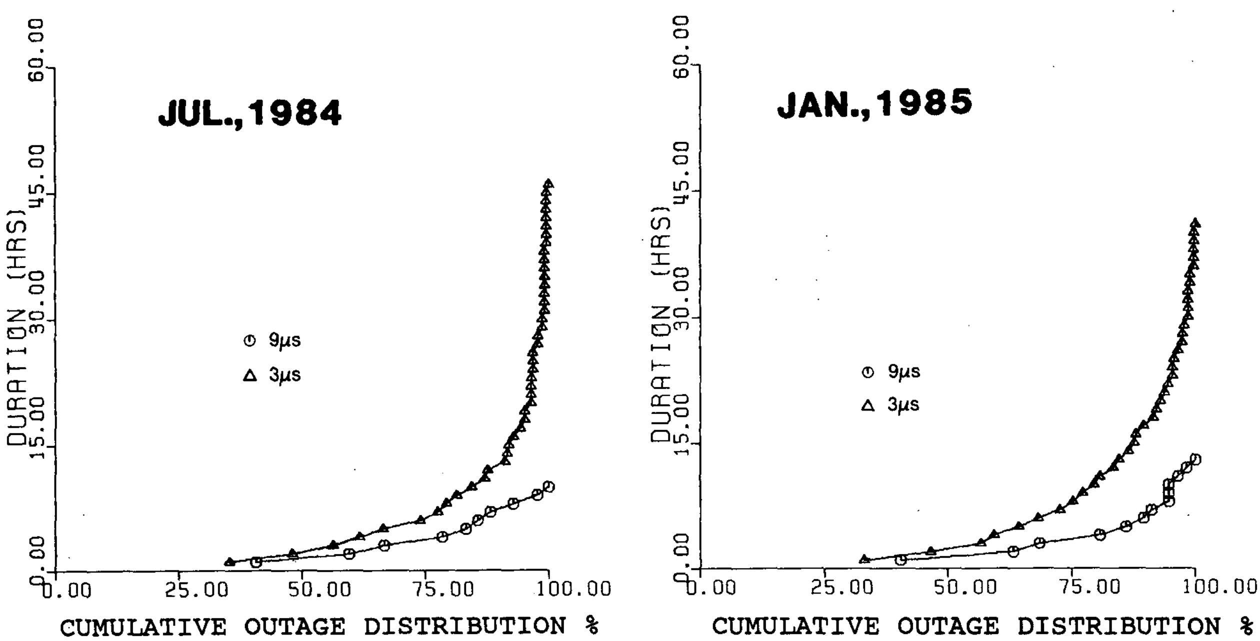


FIG. 2. Distribution of outage durations for the 3- and 9-μs modes at 915 MHz at Denver. The data had to pass the consensus test four out of 12 times in 1 hour on both east and north beams or it was counted as an outage. (a) Data were averaged between 9 and 10 km for July 1984. Notice that the longest outage with the 9-μs mode is 10 hours whereas the maximum outage with the 3-μs mode is 46 hours. This is because the 9-μs mode is 7 dB more sensitive than the 3-μs mode. (b) Data were taken between 9 and 10 km in January 1985.

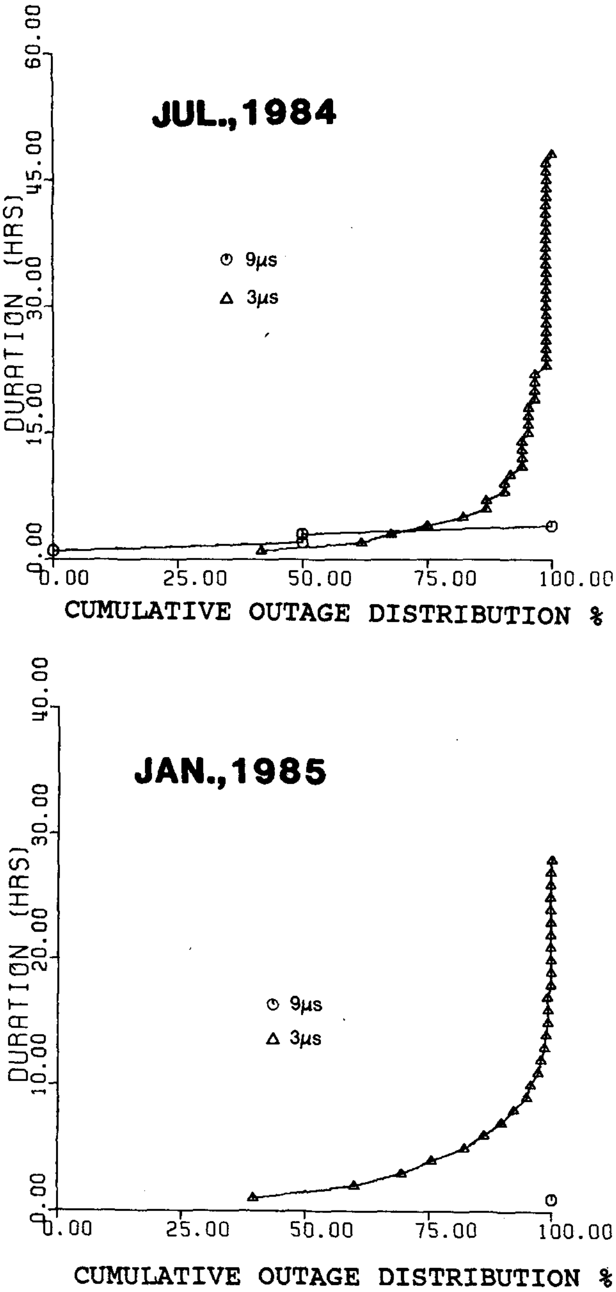


FIG. 3. Distribution of outage durations for the 3- and 9-μs modes at 50 MHz at Fleming. Data were taken between 9 and 10 km in (a) July 1984 and (b) January 1985.

(Fig. 5c) had no outages until a little over 5 km in the 3-μs mode and none until 6 km in the 9-μs mode.

When we compare the outages at 50 MHz (Fig. 5a), 405 MHz (Fig. 5b), and 915 MHz (Fig. 5c) for the same month, the 50-MHz radar had a much greater increase in height coverage for the 9-μs mode versus the 3-μs mode than did the 915-MHz radar, even though the increase in radar sensitivity between the two modes was roughly the same for the two radars (~7 dB). These outage statistics reveal several things. Both 405 and 915 MHz show a maximum in outage times at about 10 km, and less outage time above this height. This implies a minimum in the backscattered power at about 10 km and an increase above. Since the 50 MHz profilers are more sensitive in the 9 μs mode than either the 405 and 915 MHz profilers, it may be that the apparent larger increase in height between the 3- and 9-μs modes at 50 MHz is due to the increase in backscattered power with height rather than any differences of backscattered power with frequency. In addition, comparing the outages in the modes with equal sensitivity vs. frequency (3 μs, at 50 MHz, 9 μs at 405 and 915 MHz), we see that up to 10 km there were more outages at 50 MHz than at 405 or 915 MHz. This indicates that there was no loss of inner scale at least to 10 km.

A report on all the monthly statistics in this way would be too detailed, so we plotted the lowest height, defined as H_{10}, at which the different modes had a probability of an outage as high as 10% for 3 or more consecutive hours for each month. These statistics are shown in Fig. 6a for the Fleming 50-MHz, in Fig. 6b for the Platteville 405-MHz, and Fig. 6c for the Denver 915-MHz wind profilers, as a function of month. The top of the dotted area in the bar graph denotes that height at which the wind data from the 9-μs mode show an outage of 10% for ≥3 consecutive hours. The top of the slashed area is the height at which the 3-μs mode has an outage of 10% for ≥3 consecutive hours. (In

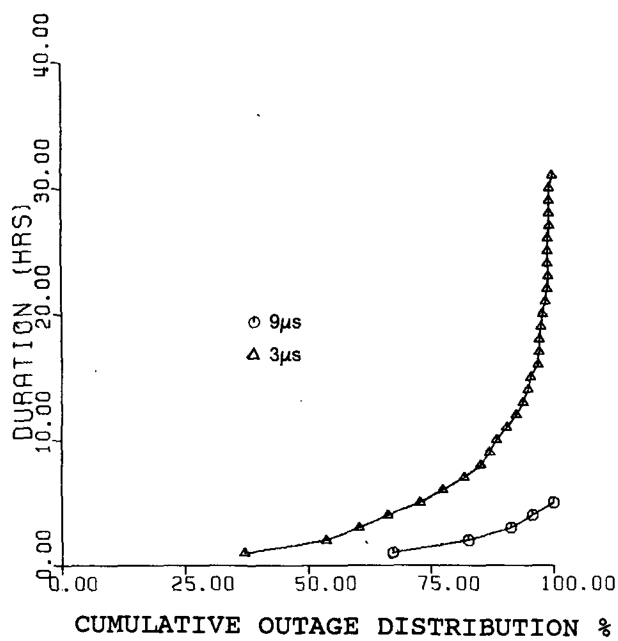


FIG. 4. Distribution of outage durations for the 3- and 9-μs modes at 405 MHz at Platteville. Data were taken between 9 and 10 km in January 1985.

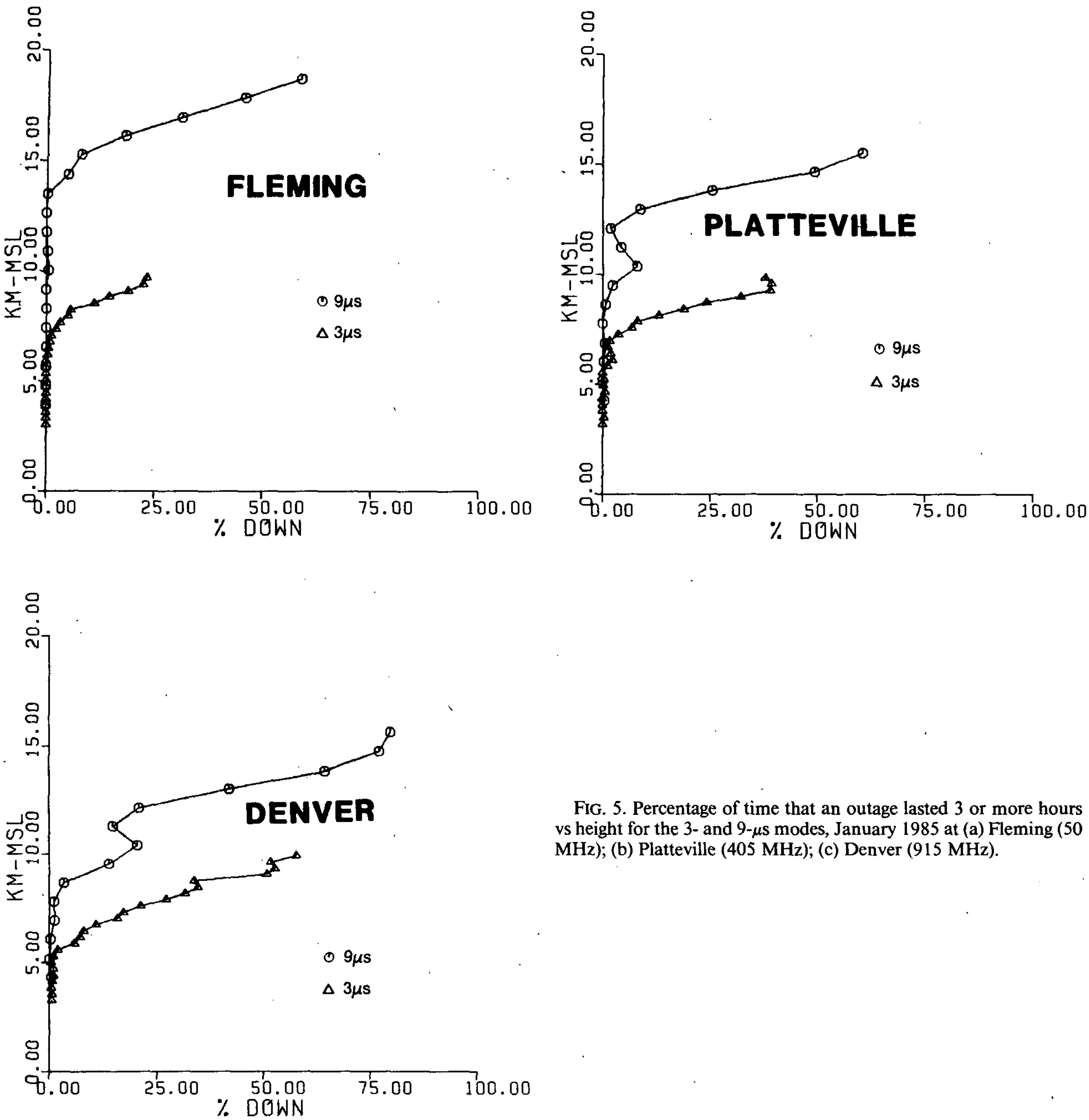
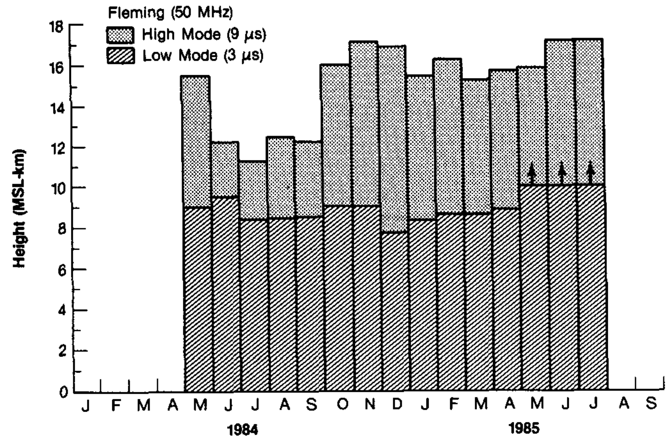
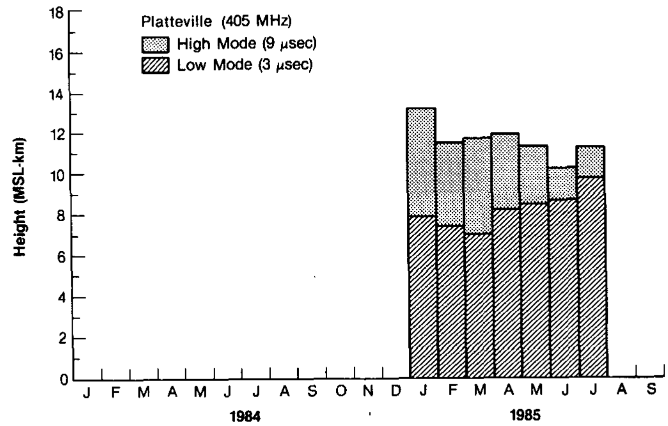


FIG. 5. Percentage of time that an outage lasted 3 or more hours vs height for the 3- and 9-μs modes, January 1985 at (a) Fleming (50 MHz); (b) Platteville (405 MHz); (c) Denver (915 MHz).

May, June and July 1985, the 3-μs mode at 50 MHz did not have a 10% outage below its maximum height range of 9.71 km.)

From these figures we can see that the monthly variations of H_{10} at 9 μs and 50 MHz (Fig. 6a) are greater, going from 11.5 km in July 1984 to 17 km in November 1984, when compared with H_{10} for either the 405- or 915-MHz profilers. The variation in H_{10} at 405 MHz (Fig. 6b) was from a low of 10 km in June 1985 to a high of 13 km in January 1985. The variation in H_{10} at 915 MHz (Fig. 6c) was comparable: from 9 km in July 1985 to 12 km in September 1984. The drop in H_{10} for the Platteville 405 MHz in June and July 1985 may be related to variables other than changes in the backscattering cross section; we discuss this in some detail later in this section. We have less data on the other Colorado 50-MHz profilers. Cahone (Fig. 7a) has about four months of data, and in May, June and July 1984 had a value of H_{10} in excess of 15 km, dropping to a little over 10 km in August. This is in contrast to Fleming (Fig. 6a), which had an H_{10} drop in June 1984. Cahone is in the western part of Colorado, but it is unknown at this time if differences in meteorology and consequently backscatter cross section caused this dis-





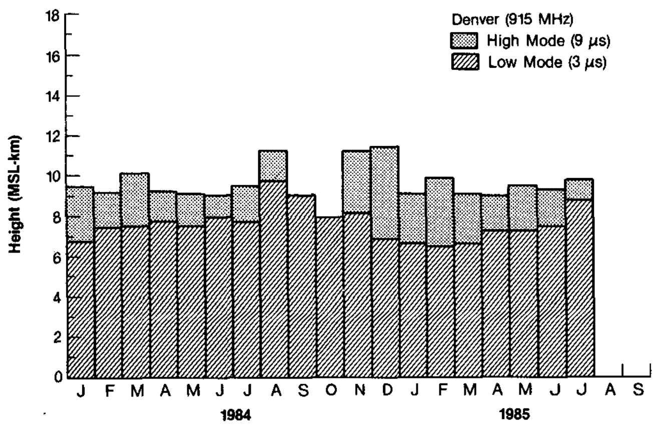


FIG. 6. Lowest height (H_{10}) at which the outage time for 3 or more consecutive hours was less than 10%, for the 3- and 9-μs modes. (a) At Fleming (50 MHz); note that in May, June and July 1985, the outage for the 3-μs mode at 9.71 km (the highest height recorded at this range) was less than 10%. (b) At Platteville (405 MHz). (c) At Denver (915 MHz).

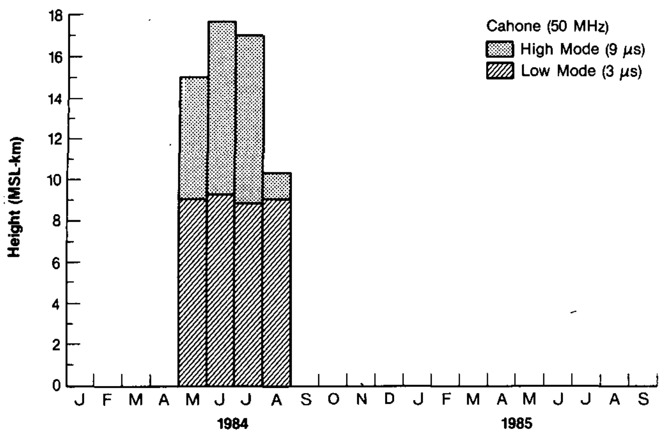
similar behavior compared with Fleming (eastern Colorado) in June and July 1984, or whether the system sensitivity changed, thus causing the difference in performance.

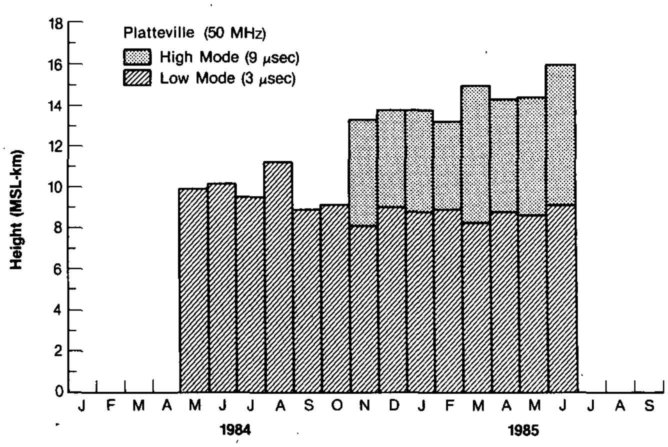
The measurement of H_{10} for the Platteville 50-MHz profiler is shown in Fig. 7b. The present data-archiving system started in May 1984 with one 3-μs mode; in November 1984, the two modes at 3- and 9-μs were started. One can see that the 9-μs mode has values of H_{10} similar to the 9-μs mode at Fleming, although Fleming's values are about 1 km higher. These larger values of H_{10} are consistent from November 1984, when both 3- and 9-μs modes were recorded at Platteville, to June 1985. The Platteville 50-MHz profiler should have more sensitivity (~7 dB) (Strauch, personal communication, 1985); consequently there is probably some degradation in either the antenna or other hardware to make its performance less than that of Fleming.

The performance of the latest 50-MHz profiler to be installed in the Colorado network (Flagler) is shown in Fig. 7c. Here again, the performance of the 9-μs mode is similar to both the Fleming and Platteville 50-MHz profilers, and the values of H_{10} are between those of the Fleming and Platteville 50-MHz profilers.

When we change the sensitivity by changing the scattering volume, we can look at the incremental gain in height performance (ΔH_{10}) of the profilers as a function of frequency and month (Fig. 8) by comparing the 3- and 9-μs modes. This enables us to see what increase in performance of a profiler one might expect with a given increase in sensitivity. From Fig. 8, we can see that the seasonal changes in ΔH_{10} occurred from May through October 1984, where it went from 7 km in May to 3 km in August, and back to 7 km in October. After October 1984, ΔH_{10} varied from 5.5 to 7 km through July 1985. The values of ΔH_{10} for the 405-MHz profiler varied from 4.5 to 6 km in the period January through April 1985, and then dropped rather suddenly to 2 km in July 1985. At 915 MHz ΔH_{10} changed from less than 1 km in July 1985 to 4.5 km in December 1984.

Because of the importance of the 405-MHz profiler performance to the eventual network, we want to look at it in some detail. From Fig. 8, we can see that ΔH_{10} of the 405-MHz profiler drops from midway between the 50- and 915-MHz profilers to about the same level as the 915-MHz system. This is particularly noticeable for the months of June and July 1985. Since these statistics require that the data on both beams must pass





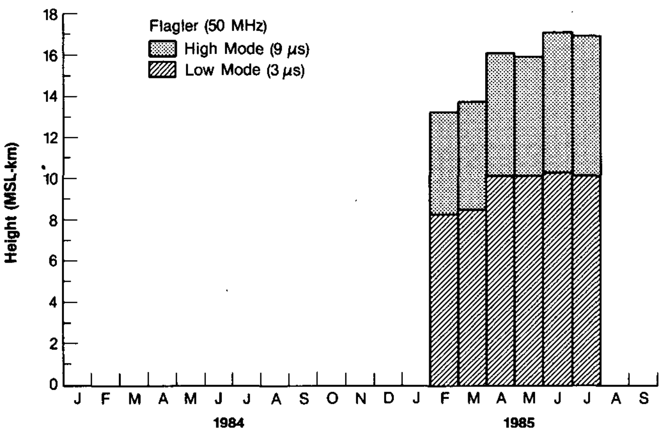


FIG. 7. Lowest height (H_{10}) at which the outage time for 3 or more consecutive hours was less than 10% for the 3- and 9-μs modes at (a) Cahone (50 MHz); (b) Platteville (50 MHz); (c) Flagler (50 MHz).

the consensus simultaneously, we can look at the individual performances of each beam of the 405-MHz profiler to see if this overall drop in performance is related to a drop in the performance of one of the beams. Figure 9a shows the results of this analysis for each beam in the 9-μs mode in July 1985. Here it is apparent that the north beam had significantly better performance than the east beam. We can check H_{10} for each beam. For the north beam, this was at a height of 15 km; for the east beam at about 12 km, a 3-km difference in height. For the east beam, at 13 km, there was an outage maximum of 15%. This was not true for April (Fig. 9b). Returning to the monthly statistics, we can use the north and east beams for computing

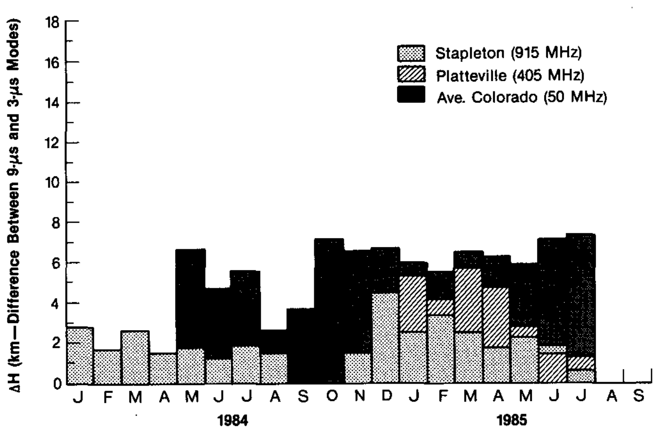


FIG. 8. Increase in height (ΔH_{10}) for an increase of 7 dB in sensitivity.

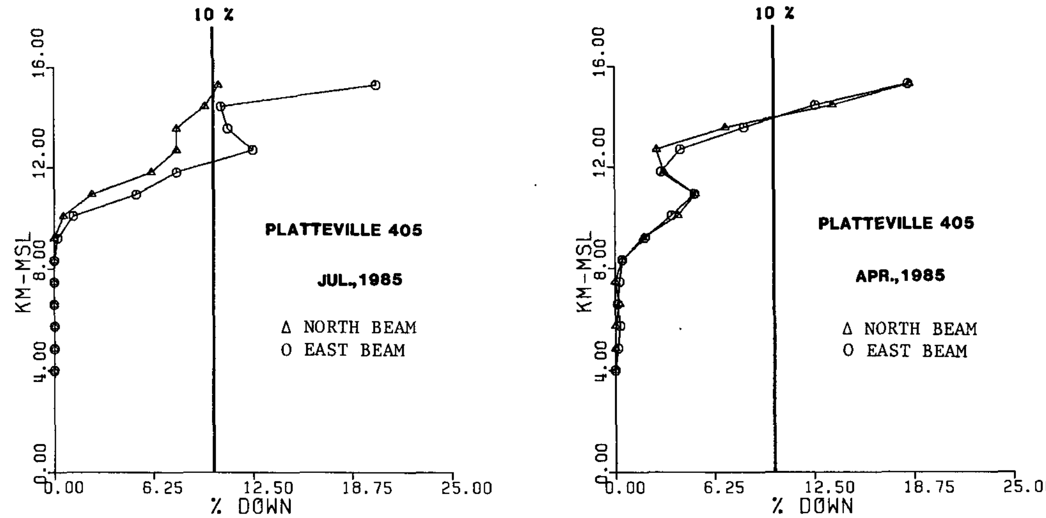


FIG. 9. Comparison of the east and north beams, in the 9-μs mode, for 3 or more consecutive hours of down time at Platteville (405 MHz). (a) For July 1985; note that the east beam has a higher percentage of outages compared with the north beam (b) for April 1985.

H_{10} (Fig. 10). Here the performance "outage" height H_{10}, of the north beam is significantly higher, and is on the order of 14 km for the seven months. Using the difference in height between the 3- and 9-μs modes for the north beam, we see a significant difference between the 7-month interval (Fig. 11) compared with the combined north and east outage statistics (Fig. 8); in fact, the north beam values are relatively unchanged for the 7-month interval. Since the echo power is only recorded on the east beam (Strauch et al., 1985), we cannot get a direct measurement of this performance difference based on the echo power difference. However, we can use the fact that the distribution of backscattered power is approximately normally distributed, and that the difference in sensitivity of the 3- and 9-μs modes is 7 dB, to see how large the sensitivity difference between the two beams must be for the difference in performance.

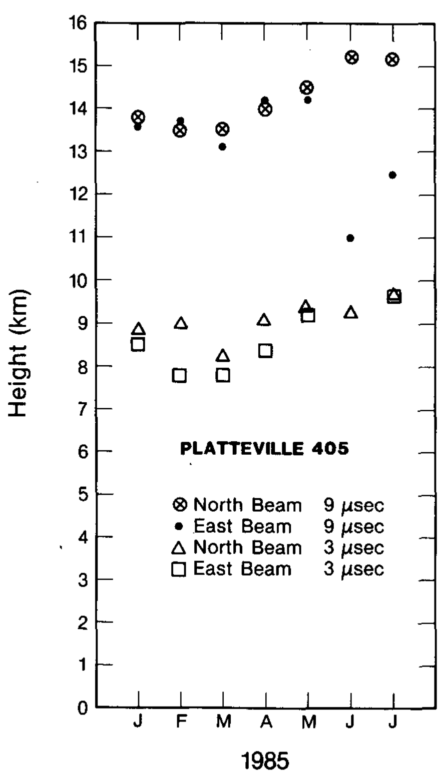


FIG. 10. H_{10} for the 3- and 9-μs modes for the east and north beams at Platteville (405 MHz). Note the drop in H_{10} for the east beam 9-μs mode in June and July 1985.

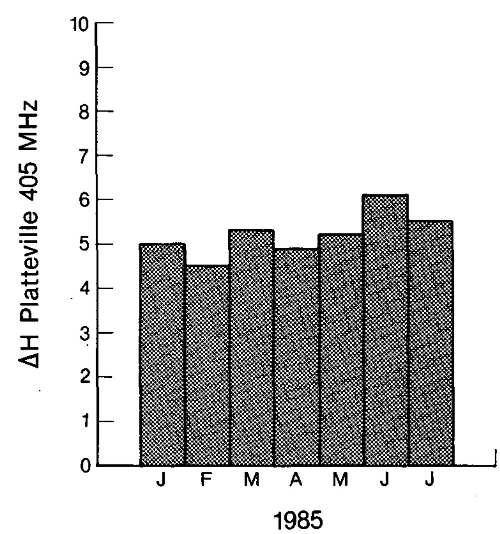


FIG. 11. Change in H_{10} for an increase in sensitivity (7 dB change in sensitivity between the 3- and 9-μs modes) for the north beam of the 405-MHz profiler at Platteville.

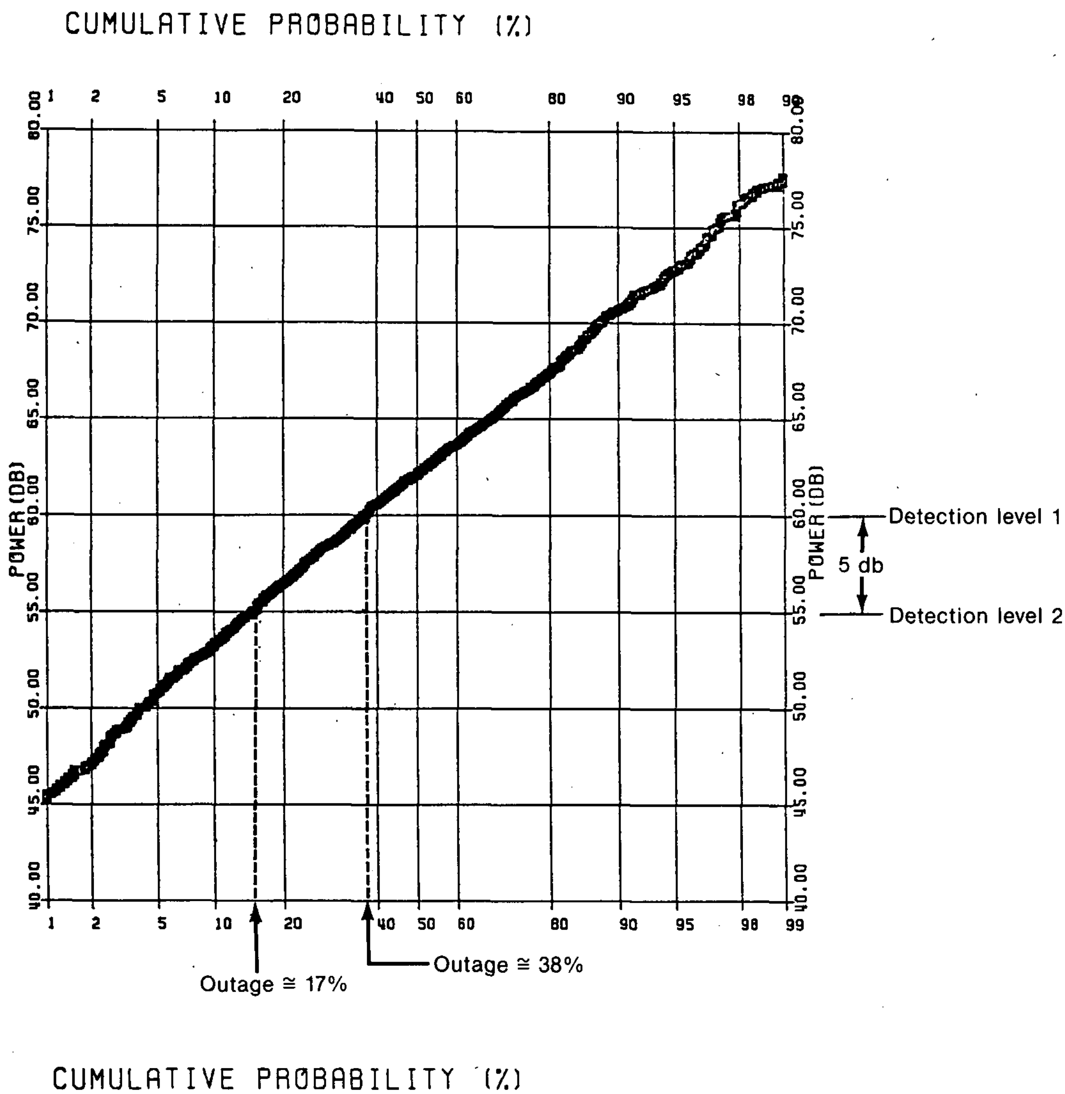


FIG. 12. Cumulative power distribution at 5.7 km for the Platteville 405-MHz wind profiler, April through June 1985. Detection levels are discussed in the text.

Figure 12 shows a sample of the cumulative distribution function for backscattered power at 405 MHz and 4.3 km. Note that the power is loglinear between the 1% and 99% levels.

We use the following technique to see how a change in sensitivity affects the outage time:

Figure 12 represents the cumulative backscattered power, which is proportional to C_n^2, the refractive index structure constant (Tatarski, 1961), from the 405-MHz wind profiler at 5.7 km MSL (1 April to 1 July 1985). If we assume that the detection level was 60 dB then the outage would be 38%; if we add 5 dB sensitivity, our detection level would correspond to a signal of 55 dB and the corresponding outage would be reduced to 17%. It is helpful to note that the flatter the power curve is, the less variance in backscattered power, and the greater decrease in outage time for a given increase in sensitivity.

Since the 3- and 9-μs modes overlap to 10 km, and since there is a 7 dB difference in their sensitivities, we can use them to evaluate the variance of the backscattered power at 405 MHz. To do this we use the outage statistics for the total outage versus height for the two modes and see what value of variance will bring the two curves closest to coincidence. Nastrum et al. (1985) used the 50-MHz radar at Poker Flat (Alaska) and Platteville (Colorado) to evaluate the distribution of power from 6.0 to 16.9 km and thus the variation in backscattered power above sea level. The standard deviation of backscattered power was in a range from 4 to 6 dB. The distribution was approximately Gaussian.

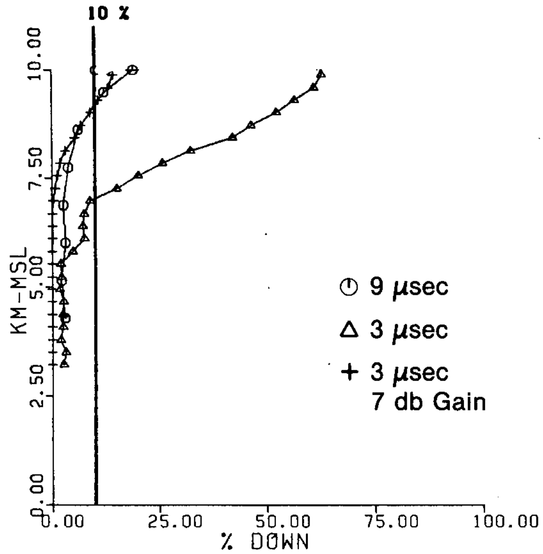


FIG. 13. Use of the 9- and 3-μs modes in January 1985 Platteville VHF to determine the variation in C_n^2. The pluses show the 3-μs mode with a 7-dB increase in sensitivity and a σ value of 8 dB for C_n^2. The fit using σ = 7 dB is best in the range from 8 to 10 km. The 3-μs mode is not recorded above 10 km.

Figure 13 shows the effective improvement in the 3 μs mode at Platteville (405 mHz) when the 7-dB sensitivity between modes is accounted for (8-dB standard deviation is assumed in the backscattered power). This gave us the best fit between 8 and 10 km, the highest measurement in the 3-μs mode. With the standard deviation in backscattered power equal to 8 dB, we can modify the sensitivity factor of the east beam until the performances of the north and east beam are the same. A value of 2.0-dB change in sensitivity was sufficient to make the performances of the two beams virtually identical (Fig. 14). Thus we can see that only a slight change in sensitivity is enough to change H_{10} significantly. Furthermore we can use this technique to estimate the performance of the planned 405-MHz network of profilers, which will have at least 8 dB more sensitivity than the present 405-MHz profiler. If we assume that the inner scale of turbulence exists at wavelengths smaller than the Bragg wavelength for the 405 MHz profiler (and we see no evidence of the inner scale being larger than this below 10 km), then we can use the lognormal model to see what the performance of the proposed network profiler would be. To do this, we can use a sensitivity increase of 8 dB for the network profiler, the statistics of the present 405 MHz profiler and estimates of what we believe is the standard deviation of backscattered power.

The critical parameter is the backscattered power variance. Our estimates for April through June indicate a variance of 8 dB. However, this is below 10 km, and other estimates at other frequencies and at higher altitudes indicate a variance of 4 or 5 dB (Nastrum et al., 1985).

Figure 15 shows the Platteville 405 outage performance for February 1985, or the performance modified with an 8 dB gain and a "pessimistic" backscattered power variance of 8 dB, and what we believe is a more realistic 8 dB gain and 5 dB backscattered power variance. These results show that for the 3 or more consecutive hours down time that the outage should be less than 5% to 14 km even with the more pessimistic power variance of 8 dB and less than 2% of the times for a backscattered power variance of 5 dB.

5. Summary and conclusions

We have examined the archived wind profiler database and computed a performance statistic for the 3- and 9-μs pulse width modes at 50, 405 and 915 MHz. The statistics indicate that there is more seasonal variation of the 50-MHz wind profiles than of the UHF profiles, and that the 405-MHz system performance lies between those of the 50- and 915-MHz systems. The 50-MHz profiler has the greatest height change for the same increase in sensitivity, the 405-MHz the next greatest, and the 915-MHz the least. The average increase in height performance for similar sensitivity changes (7 dB) was approximately 7 km at 50 MHz, 5 km at 405 MHz, and 2 km at 915 MHz. Our analysis indicates that the profiler of choice for the proposed

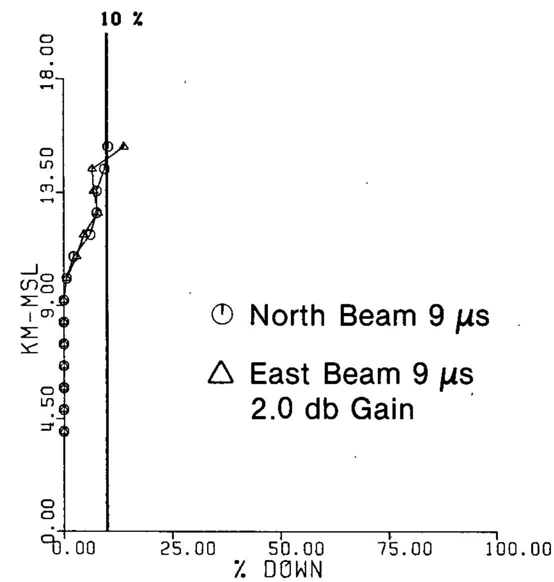


FIG. 14. Comparison of the east and north beam performance for 3 or more consecutive hours down with σ = 8 dB and an increase in sensitivity of 2.0 dB for the east beam for July 1985 at Platteville (405 MHz).

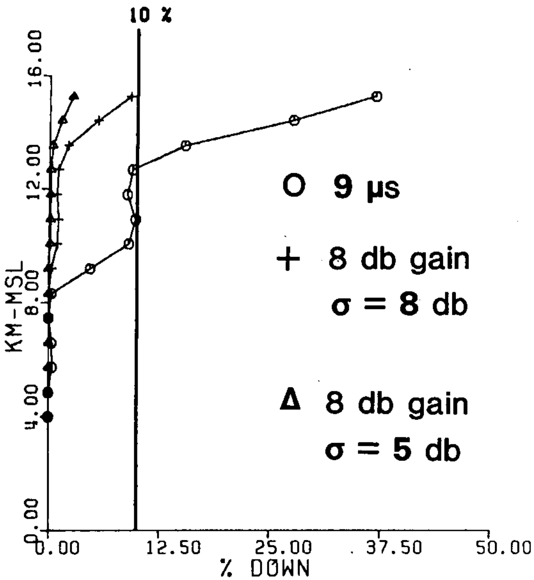


FIG. 15. Three-hour outage performance in April 1985 of the Platteville 405 MHz wind profiler in the 9 μs mode (circles). The same type of performance projected for the proposed network 405 MHz profiler with an 8 dB gain in sensitivity and an 8 dB standard deviation in C_n^2 (crosses) and projected performance with 8 dB gain in sensitivity and 5 dB standard deviation in C_n^2.

expanded network (405 MHz) will have almost no outages for 3 or more consecutive hours to a height of 14 km, providing that the inner scale of turbulence is smaller than the Bragg wavelength at all times for the 405-MHz system.

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