Preliminary Evaluation of the First NOAA Demonstration Network Wind Profiler

B. L. WEBER, D. B. WUERTZ, R. G. STRAUCH, D. A. MERRITT AND K. P. MORAN

Wave Propagation Laboratory, ERL/NOAA, Boulder, Colorado

D. C. LAW, D. VAN DE KAMP, R. B. CHADWICK, M. H. ACKLEY, M. F. BARTH AND N. L. ABSHIRE

Profiler Program, Forecast Systems Laboratory, NOAA, Boulder, Colorado

P. A. MILLER AND T. W. SCHLATTER

Program for Regional Observing and Forecasting Services, Forecast Systems Laboratory, NOAA, Boulder, Colorado

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ABSTRACT

The first wind profiler for a demonstration network of wind profilers recently passed the milestone of 300 h of continuous operation. The horizontal wind component measurements taken during that period are compared with the WPL Platteville wind profiler and the NWS Denver rawinsonde. The differences between the network and WPL wind profilers have standard deviations of 2.30 m s^{-1} and 2.16 m s^{-1} for the u- and v-components, respectively. However, the WPL wind profiler ignores vertical velocity, whereas the network radar measures it and removes its effects from the u- and v-component measurements. The differences between the network wind profiler and the NWS rawinsonde (separated spatially by about 50 km) have standard deviations of 3.65 m s^{-1} and 3.06 m s^{-1} for the u- and v-components, respectively. These results are similar to those found in earlier comparison studies. Finally, the new network wind profiler demonstrates excellent sensitivity, consistently reporting measurements at all heights msl from 2 to nearly 18 km with very few outages.

1. Introduction

In the late 1970s, NOAA's Aeronomy Laboratory built and began testing a 50 MHz Doppler radar near Platteville, Colorado. In 1980, NOAA's Wave Propagation Laboratory (WPL) joined the Aeronomy Laboratory in operating this radar and in attempting to measure tropospheric winds. Early successes in producing detailed hourly profiles of tropospheric winds prompted the establishment of a small network of five wind profilers in Colorado in the mid-1980s. Many meteorologists have investigated the diagnostic utility of these data. (See, for example, Shapiro et al. 1984; Schlatter 1985; Zamora et al. 1987.) Profiler data have been used on an experimental interactive workstation at the Denver National Weather Service Forecast Office for several years (Dunn 1986), and the prospect of a larger network of wind profilers led Kuo et al. (1987) to conduct observing system simulation experiments.

On the basis of evidence that a network of profilers providing winds aloft every hour could improve mesoscale nowcasts, short-range forecasts, and services to aviation (Strauch et al. 1989), the National Weather Service (NWS) has funded the installation of a wind profiler demonstration network at 30 sites in the central United States (Chadwick 1986). It will be used for meteorological research and to evaluate the utility and feasibility of a national network of wind profilers for operational use by the NWS (Hassel and Hudson 1989). The national network would provide wind data spatially comparable with those from the rawinsondes currently launched twice a day by NWS (Hogg et al. 1980; Strauch 1981; Strauch et al. 1983), but continuous in time.

Deployment of most of the demonstration network will occur in 1990. However, the first wind profiler was installed at Platteville, Colorado, in 1989 and recently passed its 300-h reliability test for continuous operation. The satisfactory completion of the 300-h test is an important step in the acceptance of this wind profiler before others like it are built and installed in the network. This wind profiler was designed and built by Unisys under contract with the U.S. Department of Commerce and with technical guidance from the profiler program and WPL.

The first Unisys wind profiler is about 50 km east of the Continental Divide near Platteville, Colorado,

Corresponding author address: Dr. Bob L. Weber, NOAA/ERL, Mail Code R/E/WP4, 325 S. Broadway, Boulder, CO 80303.

the site of another wind profiler belonging to WPL. Since 1983, WPL has continuously operated a small network of UHF and VHF wind profilers in Colorado (Strauch et al. 1984) to provide hourly-averaged vertical profiles of horizontal winds. The Unisys wind profiler operates at a frequency of 404 MHz (UHF), and the WPL profiler operates at a frequency of 50 MHz (VHF); thus simultaneous operations are possible without interference.

We compared the horizontal wind component measurements of the Unisys profiler with those by the WPL profiler and the NWS rawinsonde in Denver, Colorado, for 300 h from 1500 UTC 3 August to 0200 UTC 16 August 1989, the period of the reliability acceptance test. Good agreement is expected between the two wind profilers because they are collocated (Strauch et al. 1987); also expected is reasonable agreement between rawinsonde and wind profiler data (Weber and Wuertz 1990) even though the profilers are about 50 km north of the rawinsonde launch site. The Denver rawinsonde site is also about 50 km east of the Continental Divide.

Hourly-averaged winds were reported by both the Unisys and WPL wind profilers at fixed levels in the vertical. Measurements were at the center of range resolution cells along the axis of each of three antenna beams every 6 min (Unisys) or two antenna beams every 5 min (WPL). Both profilers used two oblique beams tilted about 15° off the vertical toward the east and the south (WPL) or north (Unisys) in order to measure the horizontal wind components. The Unisys profiler also used a third beam pointed upward to measure vertical motion so that its effects could be removed from the measurements on the other two beams. The WPL wind profiler did not use a vertical beam.

The wind profilers measured a reflectivity-weighted average of radial velocity in their resolution cells, where reflectivity depends upon the spatial distribution of refractivity fluctuations with a spatial scale of half the radar wavelength. This reflectivity can be different at different radar frequencies, so the Unisys (UHF) and the WPL (VHF) wind profilers may give different measurements. For example, precipitation is more readily observed at UHF than at VHF (Gossard and Strauch 1983, 1988). Therefore, when convective storms occurred, it was necessary to use the zenith antenna beam measurements in order to remove vertical motion effects from the horizontal wind component estimates of the network UHF wind profiler. Failure to correct for vertical motion dramatically increases the variance in the horizontal wind component measurements in precipitation (Wuertz et al. 1988), but it can also increase the variance of the measurements in clear air (Strauch et al. 1987). Also, specular reflections from layers in the atmosphere have been observed at times at VHF, but so far not at UHF. These can cause erroneous wind estimates when the specular radar echo entering an antenna sidelobe dominates the clear-air turbulent echo in the main antenna beam.

At the end of each hour, up to 10 (Unisys) or 12 (WPL) samples were used to produce hourly-averaged radial velocities on each antenna beam. Those in turn were converted to the horizontal wind components u, v, and the vertical wind w (Unisys only) using trigonometry. The hourly averages did not always include all measurements, particularly at higher altitudes where the signal-to-noise ratio is typically lower. The Unisys wind profiler required a consensus of at least 4 of 10 measurements, and the WPL wind profiler required a consensus of at least 4 of 12 measurements when deriving the hourly averages. Therefore, although the profiler winds are not always strictly 1-h averages, they are still temporally representative if the winds do not change significantly over an hour. On the other hand, when the winds are highly variable within an hour, only a few of the estimates may be used in computing the averaged winds (i.e., only a small number of measurements pass the consensus). In such cases the average of the measurements may not be representative of the actual average winds over the hour. Sometimes the Unisys wind profiler achieved a larger consensus number when the effects of vertical motion were removed from the individual 6-min radial velocities on the oblique beams prior to averaging, for example, in precipitation (Wuertz et al. 1988). In such cases, these results were used instead of the results obtained with consensus averaging before correction for vertical motion.

The rawinsonde obtains wind profiles twice daily. It gives measurements that are time averaged over the balloon trajectory, corresponding normally to layers 300–400 m thick in the troposphere (WMO 1983), and observations are assigned to the center of the layer. As the balloon rises toward the lower stratosphere during an hour or so, it drifts with the wind at each level. In strong winds, the rawinsonde is carried many kilometers from the point of release, and the measurements at different heights are not made directly above one another and are far from the location of the wind profilers. As a result, the rawinsonde and the wind profilers often obtain measurements at widely separated locations where the winds may be very different. A tracking system on the ground follows the balloon, and its horizontal displacement per unit time is converted into an estimate of the wind. The last portion of the rawinsonde flight may occur at low elevation angles, increasing errors due to radar reflections from terrain (Vockeroth 1975). As a result, one generally expects the largest errors at the greatest heights. Also, the wind profiler is expected to have its largest errors at the upper heights because the signal-to-noise ratio is usually lowest there. Either instrument is capable of an occasional large error, but it is also possible that the wind profiler and rawinsonde may measure very different winds aloft. No attempt was made to distinguish between these two situations, and all measurements from both instruments are included in these comparisons.

Wind profilers and rawinsondes measure winds in very different ways. The wind profilers make Eulerian measurements by sensing the radial component of turbulent eddies passing through the antenna beams, whereas the rawinsonde makes a Lagrangian measurement. Furthermore, the rawinsonde balloon responds to the winds on a scale related to its size, which increases with altitude, while the individual sample volume of the wind profiler increases with height in relation to the antenna beam width. The profiler effectively samples a much larger volume than the rawinsonde because of the time integration involved in an individual sample and in an hour average.

Nevertheless, one expects good agreement in cases of uniform winds, that is, when there are no significant differences in the winds over an hour and over the distance separating the two instruments. Conversely, discrepancies are expected when the winds are changing rapidly over an hour, for instance, during disturbed conditions. In the lee of the Continental Divide, temporal and spatial variability can be significant, sometimes rendering individual comparisons meaningless. For example, vertical velocity varies markedly over short distances in mountain lee waves. Under such conditions, comparison of measurements gives no information on the accuracy of either the wind profilers or the rawinsonde.

With 657 comparisons between the Unisys wind profiler and the NWS rawinsonde, the differences in the horizontal wind components had a standard deviation of about 3.4 m s^{-1}. With 10 520 comparisons between the Unisys and WPL wind profilers, the differences in the horizontal wind components had a standard deviation of about 2.2 m s^{-1}. Since rawinsonde winds are available only every 12 hours, one would expect about 12 times as many profiler–profiler comparisons as rawinsonde–profiler comparisons; however, the number of data points in each vertical profile is greater for the profilers, so there are actually about 16 times as many profiler–profiler comparisons.

2. Comparisons

Figures 1, 2, and 3 show the winds measured at 24-h intervals during the 300-h acceptance test period by the Unisys wind profiler, the WPL wind profiler, and the NWS rawinsonde, respectively. The reported times for the wind profilers are 1 h after the initiation of measurements. The NWS rawinsondes are launched twice daily, once between 1100 and 1300 UTC and again between 2300 and 0100 UTC. The Denver rawinsondes are typically released as soon as possible after 1100 and 2300 UTC. They are compared with the profiler measurements averaged from 1100 to 1200 and from 2300 to 0000. Only one in 24 of the hourly wind profiler measurements are displayed because of limited space. All three instruments show similar flow patterns.

At the start of the testing period, a short-wave trough extended from an upper-air closed low in Alberta to the Pacific Ocean off California. This system progressed slowly eastward across the northern tier of the states from 3 to 5 August, causing west-southwesterly to westerly flow at 15–35 m s^{-1} in the upper troposphere over Colorado (Fig. 1). On 6–7 August, the trough deepened as it approached the northeastern United States. At the same time, a ridge developed northward from the desert Southwest through the Great Basin and into western Canada. Thus, the flow aloft veered to the northwest over Colorado and weakened. The ridge line was over the central Rockies from 11 to 13 August but retrograded slowly during 14–16 August. Weak wave disturbances moving through the ridge from 11 to 16 August are evident between 600 and 300 mb in Fig. 1.

An examination of 700 mb analyses by the National Meteorological Center led to the conclusion that lower tropospheric winds were controlled as much by topographical influences as by the weak pressure gradient. On time scales of a few hours, the winds were also influenced by convection, if not directly, at least by thunderstorm outflows. During 6–7 August, a center of surface high pressure moved south from Saskatchewan and temporarily strengthened the low-level pressure gradient over eastern Colorado. This had the effect of bringing moist air upslope toward the foothills. Thundershowers formed near the profiler on the afternoons of 6–7 August. Low-level moisture was plentiful again from 11 to 14 August and helped trigger afternoon and early evening thunderstorms. It is not

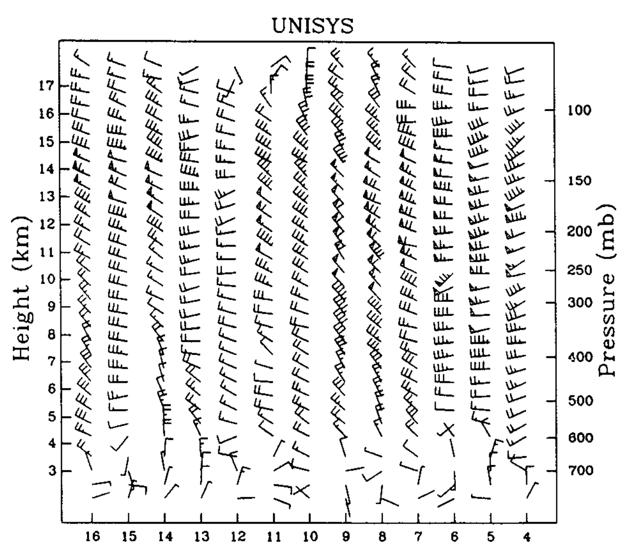

FIG. 1. Horizontal winds measured by the Unisys wind profiler at Platteville, Colorado, from 0000 UTC 4 August to 0000 UTC 16 August 1989. The data are shown at 500-m height intervals and at 24-h intervals although measurements were made every hour from 1500 UTC 3 August to 0200 UTC 16 August 1989.

known whether these storms directly affected the 0000 UTC observations at Platteville.

The Unisys wind profiler consistently gave more measurements at all heights than did the WPL wind profiler or the NWS rawinsonde. This is partly due to oversampling with the network profiler. The Unisys profiler reported measurements each hour from 2.02 to 17.77 km(msl), uniformly spaced at 250 m intervals in both the low and high modes of operation. The low mode extends from 2.02 to 10.77 km(msl) and has a height resolution of about 375 m. The high mode extends from 9.02 to 17.77 km (msl) and has a height resolution of about 1000 m. Thus, there is oversampling by a factor of 4 in the high mode. Note that the low and high modes overlap from 9.02 to 10.77 km(msl). The WPL profiler reported measurements each hour from 3.31 to 9.98 km(msl) with 290 m spacing in the low mode, and from 5.73 to 18.77 km(msl) with 870 m spacing in the high mode. Its resolution is 300 m in the low mode and 1350 m in the high mode. The first Unisys measurements are made about 500 m above ground level and the first WPL measurements are made about 1500 m above ground level. (Platteville is 1524 m above sea level.) We expected the Unisys profiler to measure winds to greater heights and with better accuracy than the WPL wind profiler because it has about 7 dB greater sensitivity. The Denver rawinsondes (see Fig. 3) reported measurements every 12 h from about 1.8 to 17.0 km(msl) with nonuniform sampling in height of about 300–400 m. The first winds are reported near ground level, which is 1611 m above sea level.

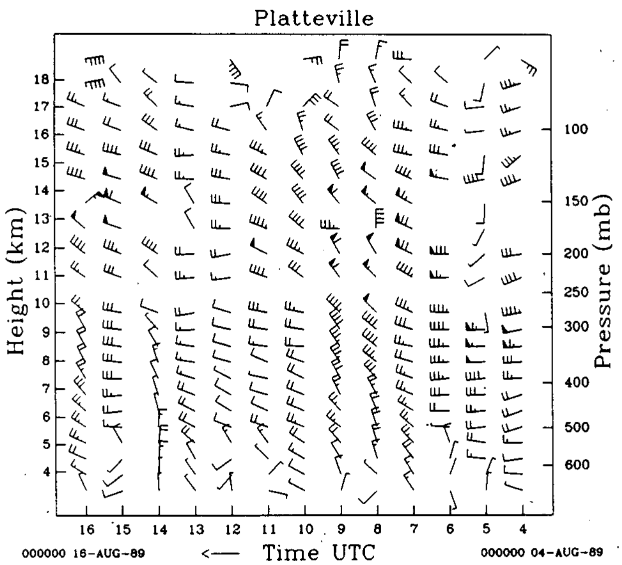

FIG. 2. Horizontal winds measured by the WPL wind profiler at Platteville, Colorado, from 0000 UTC 4 August to 0000 UTC 16 August 1989. The data are shown at 500-m height intervals and at 24-h intervals although measurements were made every hour.

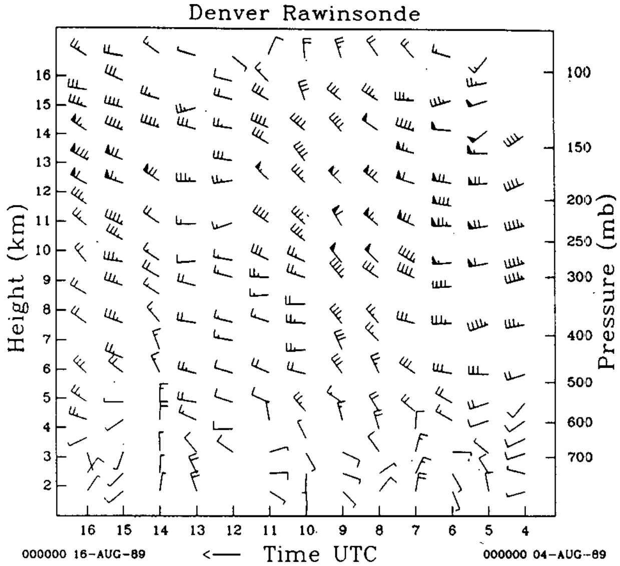

FIG. 3. Horizontal winds measured by the NWS rawinsonde at Denver, Colorado, from 0000 UTC 4 August to 0000 UTC 16 August 1989 every 24 h and 500 m.

Separate comparisons were made between the Unisys wind profiler and the WPL wind profiler and between the Unisys wind profiler and the NWS rawinsondes. Measured values were directly compared whenever the instruments gave measurements within 30 min and 125 m in vertical measurement level of each other. Figure 4 compares all Unisys and WPL measurements of horizontal wind components. If the measurements from both instruments are equal, then the points will lie on a diagonal line going from lower left to upper right. Therefore, any point positioned off this diagonal indicates that the two instruments are in disagreement. We obtained a total of 18 650 Unisys profiler measurements and 10 705 WPL profiler measurements; 11 298 measurements fell within the 30-min and 125-m window of one another and were compared. (The number of comparisons is larger than the total number of measurements from the WPL wind profiler because both profilers report more than one measurement within 125 m in the height region where the low and high modes overlap.) The differences between the u-component measurements of both profilers versus the differences between their v-component measurement are plotted in Fig. 5. A point located precisely at the center of the graph indicates perfect agreement between the Unisys and WPL wind profilers. Clearly, some of the data are outliers, possibly caused by errors with one of the profilers.

Representing only a small percentage of the data points, these outliers can nonetheless bias the comparisons. Therefore, the more obvious outliers were removed using an editing algorithm developed by Wuertz and Weber (1989). The consensus-averaged

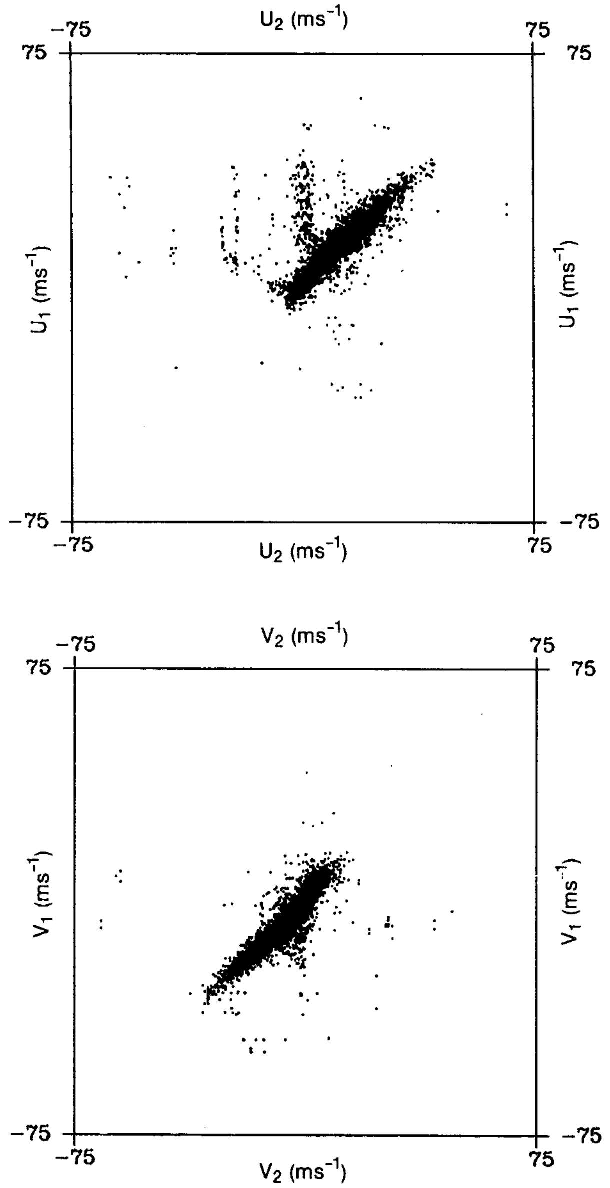

FIG. 4. Scatter plots of unedited u- and v-components for the Unisys and WPL wind profilers from 1500 UTC 3 August to 0200 UTC 16 August 1989. The Unisys wind profiler measurements are given by the vertical coordinates (U_1 and V_1), and the WPL wind profiler measurements are given by the horizontal coordinates (U_2 and V_2). Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Correlation statistics are given in Table 1.

data from each profiler were edited separately. Figures 6 and 7 show the comparisons with the outliers removed. Only 398 Unisys data points (about 2%) and 753 WPL data points (about 7%) were eliminated in this way. Since the editing algorithm removed a greater percentage of the WPL profiler data, and since subsequent comparisons between the Unisys profiler and the NWS rawinsonde (Figs. 8 and 9) do not demonstrate any such large discrepancies, it is believed that most of these large differences are due to errors in the WPL VHF wind profiler measurements and not the Unisys UHF wind profiler measurements.

The statistics for the Unisys–WPL comparisons are given in Table 1. With 10 520 comparisons, the u- and v-components for the Unisys and WPL wind profilers had correlations of 0.94 and 0.95, respectively, after the outliers were removed. These high correlations are also indicated by the linear least-squares technique, which gives straight-line slopes of 0.90 and 1.03 for both the u- and v-components with least-squares errors of 2.19 and 2.15 m s^{-1}. (A least-squares fit to data in exact agreement would yield slopes of 1.0 passing through the origin in Fig. 6.) The differences in the wind component measurements made by the two profilers (Fig. 7) had standard deviations of 2.30 and 2.16 m s^{-1} for the u- and v-components. These results are similar to results from earlier side-by-side comparisons in clear air (Strauch et al. 1987) and in precipitation (Wuertz et al. 1988). Recall that only the Unisys radar measures the vertical velocity and uses it to derive the horizontal components from the radial velocity measured on the oblique beams.

Figures 8 and 9 show the comparisons of Unisys wind profiler and NWS rawinsonde measurements of

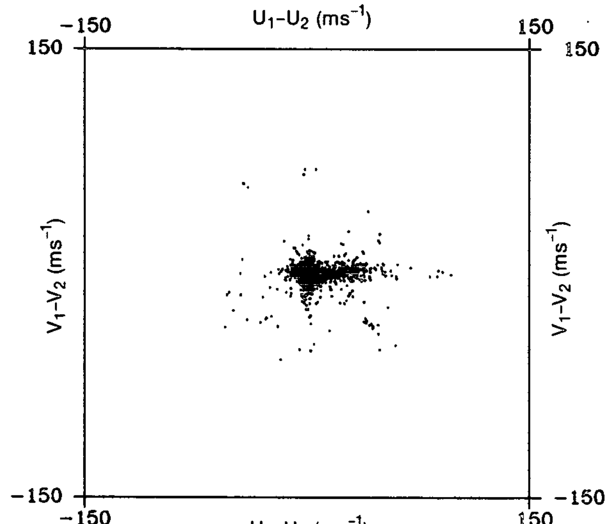

FIG. 5. Scatter plot of the differences between unedited Unisys and WPL wind component measurements from 1500 UTC 3 August to 0200 UTC 16 August 1989. The v-component differences between the Unisys and WPL wind profilers ($V_1 - V_2$) are given by the vertical coordinates, and the u-component differences ($U_1 - U_2$) are given by the horizontal coordinates of each point. Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Statistics are given in Table 1.

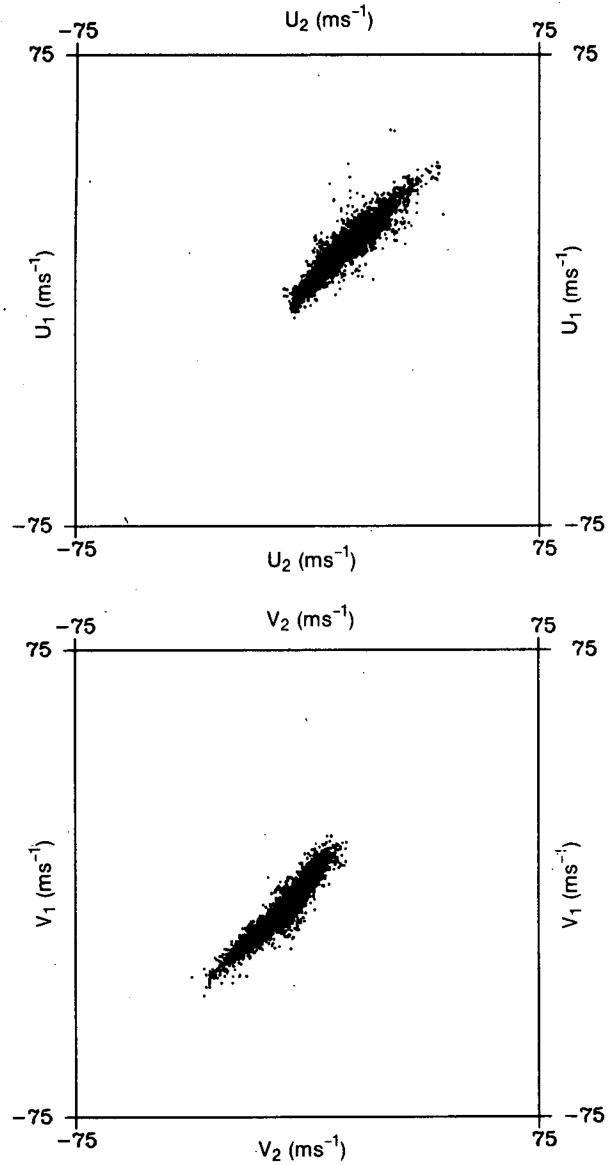

FIG. 6. Scatter plots of edited *u*- and *v*-components for the Unisys and WPL wind profilers from 1500 UTC 3 August to 0200 UTC 16 August 1989. The Unisys wind profiler measurements are given by the vertical coordinates (U_1 and V_1), and the WPL wind profiler measurements are given by the horizontal coordinates (U_2 and V_2). Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Correlation statistics are given in Table 1.

horizontal wind components. These data have not been edited. The results after editing show only negligible differences (with few points being edited), so only the unedited comparisons are given here. The statistics for the Unisys–NWS comparisons are given in Table 2. The Unisys wind profiler has 1637 total measurements at times corresponding to weather balloon launches, and the Denver rawinsonde has 607 total measurements during the 300-h test. Comparisons are made with 657 pairs of components from each instrument that fall within the required time–height window. The *u*- and *v*-components for the Unisys wind profiler and NWS rawinsonde have correlations of 0.93 and 0.91. Their least-squares-fitted slopes are 0.84 and 0.86, respectively. The differences had standard deviations of 3.65 and 3.06 m s^{-1} for the *u*- and *v*-components. These results are similar to results from earlier wind profiler–rawinsonde comparisons (Weber and Wuertz 1990).

Contrast the correlation diagrams for the Unisys–WPL comparisons (Fig. 6) with those for the Unisys–NWS comparisons (Fig. 8). Although it is true there are far fewer rawinsonde measurements (once every 12 hours) than wind profiler measurements (once every hour), the wind graphs (Figs. 1, 2, and 3) clearly show that the WPL VHF wind profiler measured low wind speeds on some occasions at upper heights [between 10 and 15 km(msl)] when the Unisys UHF wind profiler and the NWS rawinsonde both reported strong winds. We attribute the weak winds reported by the VHF wind profiler to measurement errors caused by specular reflections in an antenna sidelobe of one of the oblique beams.

Consider the winds reported on one particular day during the test. Figure 10 shows the Unisys UHF and Fig. 11 shows the corresponding WPL VHF wind pro-

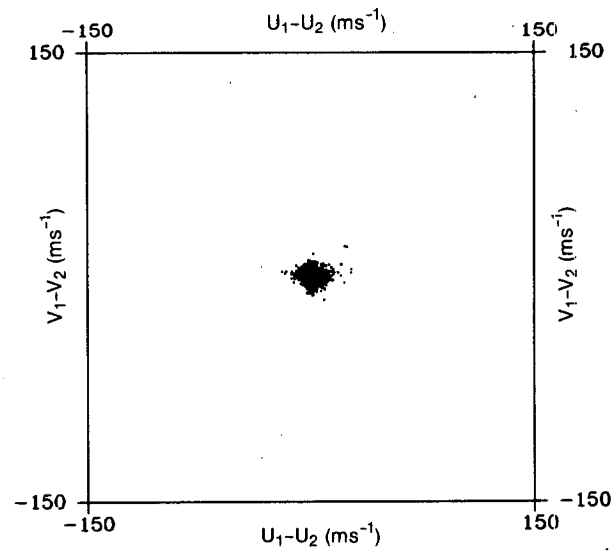

FIG. 7. Scatter plot of the differences between edited Unisys and WPL wind component measurements from 1500 UTC 3 August to 0200 UTC 16 August 1989. The *v*-component differences between the Unisys and WPL wind profilers ($V_1 - V_2$) are given by the vertical coordinates, and the *u*-component differences ($U_1 - U_2$) are given by the horizontal coordinates of each point. Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Statistics are given in Table 1.

TABLE 1. Unisys wind profiler—WPL wind profiler comparisons.[1]

	Pairs	Correlation	lsf[2]	Intercept[3]	Slope[4]	Mean[5]	Std dev[6]
u, all	11 298	0.71	5.10	4.72	0.66	1.65	5.75
u, edited	10 520	0.94	21.9	2.03	0.90	1.04	2.30
v, all	11 298	0.86	3.52	−0.66	0.93	−0.30	3.55
v, edited	10 520	0.95	2.15	−0.06	1.03	−0.22	2.16

[1] Comparisons were made between 1500 UTC 3 August and 0200 UTC 16 August 1989 at heights between 3.31 and 17.90 km(msl) whenever the two wind profiler measurements were within 30 min (in time) and 125 m (in height) of each other. The first line for each wind component is for all measurements, while the second line is for edited measurements with outliers removed.

[2] Root-mean-square (rms) difference (m s^{-1}) between data and least-squares-fit (lsf) straight line.

[3] Intercept (m s^{-1}) on the vertical (Unisys) axis of lsf straight line.

[4] Slope of lsf line.

[5] Average difference (m s^{-1}) between Unisys and WPL wind profiler measurements.

[6] Standard deviation (m s^{-1}) of differences between Unisys and WPL wind profiler measurements.

filer measurements on 5 August. Note the large number of missing data for the VHF wind profiler between 8 and 15 km(msl). A number of weak winds were also reported at those heights. The 24-h period depicted in these figures was meteorologically uneventful. The 35 m s^{-1} westerlies in the upper troposphere were part of a broad zonal flow across the United States at about 40° latitude. At the surface, a trough of lower pressure extended from northwest Minnesota to central Kansas. The low-level pressure gradient strengthened between 0600 and 1200 UTC, resulting in brisk northerly flow. At the surface, a surge of north to northeast winds (15 m s^{-1}) developed over the northeast Colorado plains between 1200 and 1500 UTC and diminished slowly later in the day. These winds lay below the lowest level observed by the profiler. As the profiler observations show, the wind between 2 and 3 km(msl) veered slowly from north through east and weakened. By late on 5 August, the low-level pressure gradient had slackened considerably and winds were light.

It is believed that the turbulent structure parameter of refractive index (C_n^2) was weak in the middle of the jet stream, causing the less-sensitive VHF wind profiler to fail the consensus test (missing data) or to mistake the specular-reflection echo (small velocities) for the clear-air return, which may have been present but was weaker. Such pervasive specular reflection at UHF has yet to be observed. Although a few erroneous measurements reported by the Unisys profiler can be seen in Fig. 10, these figures illustrate that more of the disagreement between the two profilers was due to errors on the WPL VHF profiler than on the Unisys UHF profiler. Quality control algorithms are currently being tested that will automatically remove such erroneous measurements from the data available on the operational wind profiler network.

3. Performance

The performance of any wind profiler is limited by its sensitivity, which improves with higher transmitted power levels and larger antennas. The signal strength is also a function of C_n^2, which tends to decrease with height and is smaller for certain meteorological conditions. If turbulence is weak, the power may be insufficient to produce a clear-air echo distinguishable from noise, thereby precluding a meaningful measurement of wind.

An important indicator of profiler performance is the percentage of the time wind measurements are reported (Fig. 12). This percentage is shown for the low mode (leftmost two curves) and the high mode (rightmost two curves) as a function of height for both 1-h (lower curve) and 3-h (upper curve) reporting periods. Hourly-averaged winds are reported in each 1-h reporting period. Thus, the lower curves give the percentage of time that hourly averaged winds were actually reported. The difference between 100% and the lower curves at any height gives the percent of hours that a measurement was not reported (for any reason) during the 300-h test period. There are no restrictions placed upon the quality of the wind measurements for these performance computations. A 3-h reporting period is defined as any three consecutive hours when the wind profiler is expected to be operating. If no winds are reported during any given 3-h period, for whatever reason, an outage is said to occur. Thus, the difference between 100% and the upper curves gives the percent of the time that outages occurred during the 300-h test. Note that outages occurred in the low mode above 10 km(msl) at least 10% of the time. They occurred less than 6% of the time between 8 and 10 km(msl) and they occurred far less than 1% of the time at all heights below 8 km(msl). The high mode, meanwhile, experienced far fewer than 1% outages at all heights from 9 to 18 km(msl). Combining the low and high modes, which overlap between 9 and 11 km(msl), shows that there was a wind measurement reported in any given 3-h period at least 97% (usually greater than 99%) of the time at all heights from 2 to 18 km(msl). Of course, there were more missing hourly-averaged measurements, but even those occurred less than 5% of the time at all heights in the high mode and at all heights

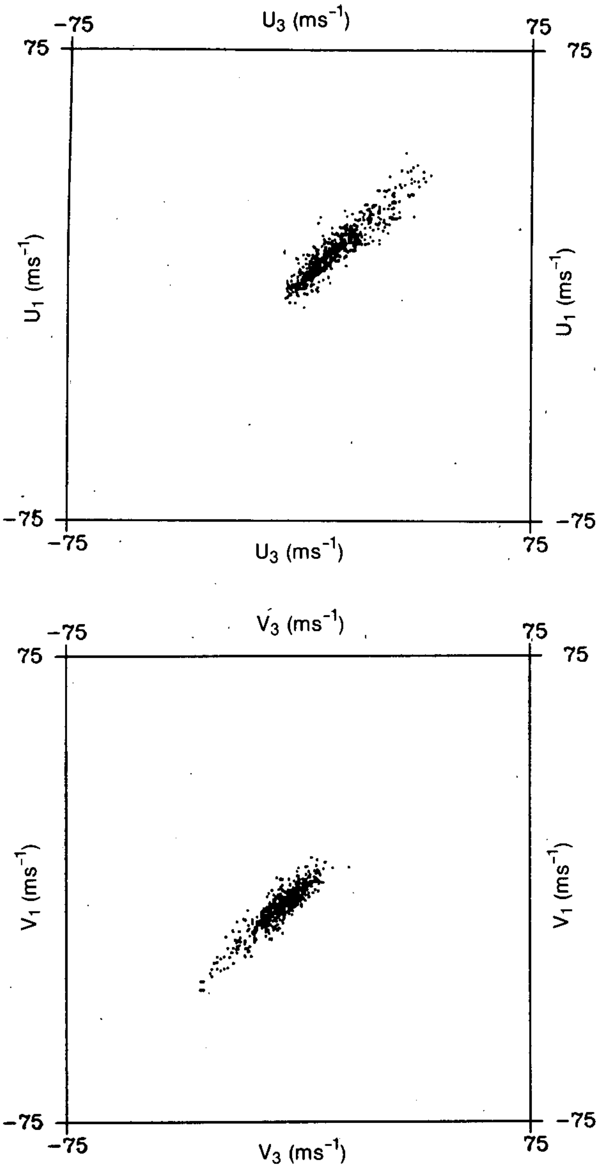

FIG. 8. Scatter plots of unedited u- and v-components for the Unisys wind profiler and the NWS rawinsonde from 0000 UTC 4 August to 0000 UTC 16 August 1989. The Unisys wind profiler measurements are given by the vertical coordinates (U_1 and V_1), and the rawinsonde measurements are given by the horizontal coordinates (U_3 and V_3). Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Correlation statistics are given in Table 2.

below 8 km (msl) in the low mode. The outages above 8 km (msl) in the low mode were no doubt due to its reduced sensitivity, about 11 dB less than that of the high mode.

4. Conclusions

The Unisys UHF wind profiler measurements compared very well with the WPL VHF wind profiler measurements and with the NWS rawinsonde measurements of horizontal wind components. The two wind profilers were collocated at Platteville, Colorado, and therefore close agreement was expected. However, since

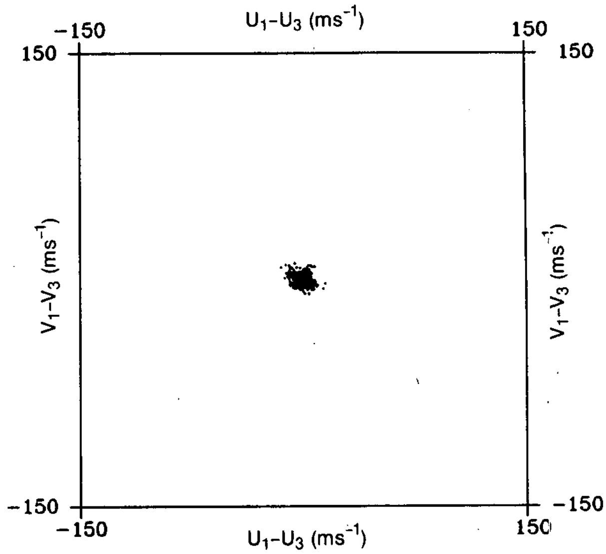

FIG. 9. Scatter plot of the differences between unedited Unisys and NWS rawinsonde wind component measurements from 0000 UTC 4 August to 0000 UTC 16 August 1989. The v-component differences between the Unisys wind profiler and the rawinsonde ($V_1 - V_3$) are given by the vertical coordinates, and the u-component differences ($U_1 - U_3$) are given by the horizontal coordinates of each point. Each point corresponds to a pair of measurements that were obtained by the two instruments within 30 min (in time) and 125 m (in height) of one another. Statistics are given in Table 2.

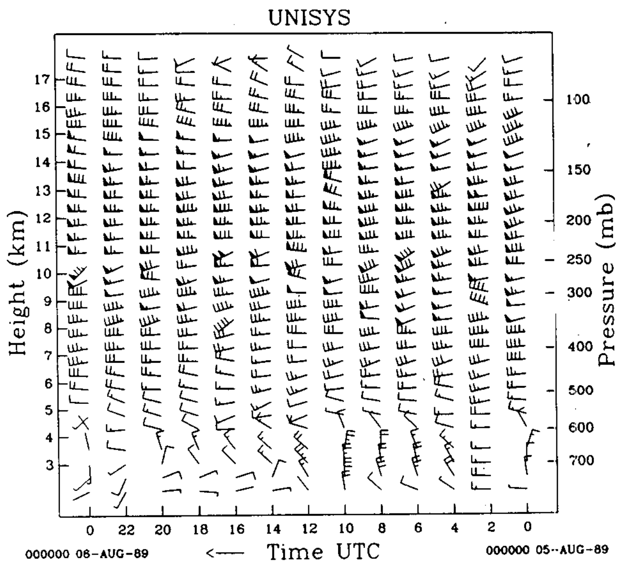

FIG. 10. Horizontal winds measured by the Unisys UHF wind profiler at Platteville, Colorado, from 0000 UTC 5 August to 0000 UTC 6 August 1989 every other hour at 500-m height intervals.

TABLE 2. Unisys wind profiler—NWS rawinsonde comparisons.[1]

	Pairs	Correlation	lsf[2]	Intercept[3]	Slope[4]	Mean[5]	Std dev[6]
u	657	0.93	3.31	1.50	0.84	−0.37	3.65
v	657	0.91	2.90	−0.66	0.86	0.10	3.06

[1] Comparisons were made between 0000 UTC 4 August and 0000 UTC 15 August 1989 at heights between 1.83 and 16.73 km(msl) whenever the Unisys wind profiler and rawinsonde measurements were within 30 minutes (in time) and 125 m (in height) of each other. No editing was necessary.
[2] Root-mean-square (rms) difference (m s^{-1}) between data and least-squares-fit (lsf) straight line.
[3] Intercept (m s^{-1}) on the vertical (Unisys) axis of lsf straight line.
[4] Slope of lsf line.
[5] Average difference (m s^{-1}) between Unisys wind profiler and rawinsonde measurements.
[6] Standard deviation (m s^{-1}) of differences between Unisys wind profiler and rawinsonde measurements.

the NWS rawinsonde was about 50 km south at Denver, Colorado, a degree of uncertainty was present.

The differences in the two wind profiler measurements of horizontal wind components had a standard deviation of about 2.2 m s^{-1}. This is somewhat larger than the 1.3 m s^{-1} observed in side-by-side comparisons of identical UHF wind profilers in clear air when correction for the vertical component was made, but it is similar to the standard deviation in those same side-by-side comparisons when the correction was not made (Strauch et al. 1987). It is less than the standard deviation of 2–4 m s^{-1} observed in precipitation (Wuertz et al. 1988). It is known that there was some precipitation during the period of the present comparisons. However, it has not yet been determined how much of the difference between the two wind profiler measurements is due to precipitation. Some of the more obvious outliers appear to be due to errors in the VHF wind profiler measurements, probably caused by specular reflections entering through antenna sidelobes.

The differences in horizontal wind components between measurements by the Unisys wind profiler and the NWS rawinsonde had a standard deviation of about 3.4 m s^{-1}. This is somewhat larger than the 2.5 m s^{-1} observed in a two-year comparison study between a WPL UHF wind profiler and the NWS rawinsonde, both of which were operating at Denver, Colorado (Weber and Wuertz 1990). The larger number is almost certainly due to meteorological variability, since the Unisys wind profiler was about 50 km north of the NWS rawinsonde, both being about 50 km east of the Continental Divide.

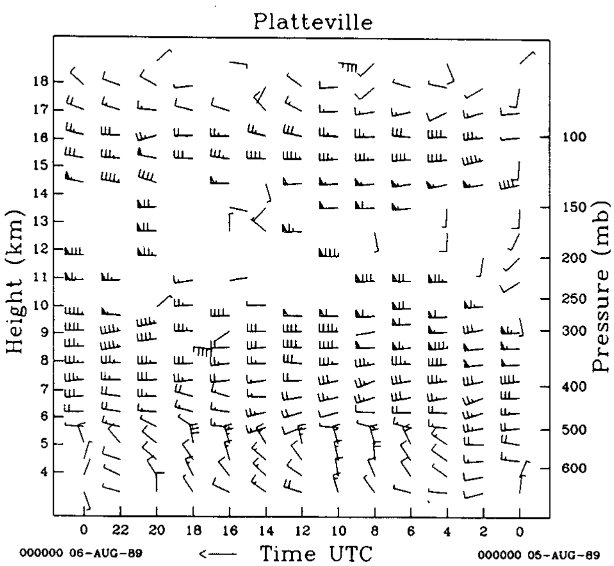

FIG. 11. Horizontal winds measured by the WPL VHF wind profiler at Platteville, Colorado, from 0000 UTC 5 August to 0000 UTC 6 August 1989 every other hour at 500-m height intervals.

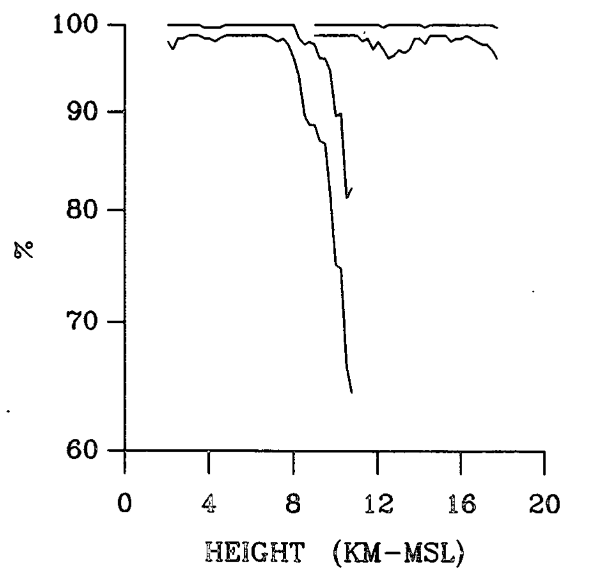

FIG. 12. Percentage of time horizontal wind measurements were reported as a function of height by the Unisys wind profiler from 1500 UTC 3 August to 0200 UTC 16 August 1989. The two curves at the left are for the low mode and the two curves at the right are for the high mode. In each case, the lower curve gives the percentage of time that wind measurements were reported and the upper curve gives the percentage of the time that wind measurements were reported at least once within any given three consecutive hours.

The Unisys wind profiler reported wind component estimates with very few outages. An outage was defined to be 3 consecutive hours of missing data when a minimum consensus of 4 was required for an hourly average. Outages occurred less than 1% of the time at all heights in the high mode [from 9 to 18 km(msl)] and less than 2% of the time at all heights in the low mode except above 9 km(msl). There the high mode, with 11 dB greater sensitivity, readily filled in the missing data.

This comparison does not attempt to present an error analysis of any of the three instruments. Past studies provide analyses of rawinsondes (Hoehne 1980; WMO 1983) and wind profilers (Lawrence et al. 1986; Strauch et al. 1987; Wuertz et al. 1988; Weber and Wuertz 1990). Future studies will continue to address the magnitude and sources of error in this important wind profiling tool. The present study does, nevertheless, offer reassurance that the new wind profilers perform as well as some older wind profilers and probably better. The development of the wind profiler network can proceed with confidence.

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