An Overview of the Mobile Profiler System: Preliminary Results from Field Tests during the Los Angeles Free-Radical Study

David Merritt,* David Wuertz,* David Welsh,* David Merritt,* David Welsh,* Richard Fritz,* Ken Moran,* Melinda Simon,* Anthony Simon,* James Cogan,* DeWitt Littell,* and Edward Measure*

Abstract

The System Demonstration and Integration Division of the U.S. Army Research Laboratory have designed and built the Mobile Profiler System (MPS). The MPS is an integrated system of ground-based and satellite-borne remote sensors that measure nearly continuous wind and temperature profiles from the surface up through the troposphere. Ground-based sensors include a 924-MHz phased-array wind and temperature profiler, a four-channel microwave radiometer, a surface meteorological tower, and a balloon sounding system. Although MPS was initially developed for military applications, the nonmilitary environmental applications are numerous and significant.

This paper provides an overview of the instrumentation, software networking, data processing, data integration, and near real-time data display capabilities currently incorporated into the MPS. Initial results from the first field tests (Los Angeles Free-Radical Study, 3–24 September 1993) demonstrate the ability of MPS to observe the complex meteorological structures associated with high-pollution events within the Los Angeles Basin.

1. Introduction

The System Demonstration and Integration Division of the National Oceanic and Atmospheric Administration’s Environmental Technology Laboratory in conjunction with the Battlefield Environment Directorate of the U.S. Army Research Laboratory designed and built the Mobile Profiler System (MPS) (Moran and Weber 1993). The purpose of MPS is to improve meteorological forecasts used by the U.S. Army during artillery operations. This task was to be accomplished by replacing existing rawinsonde thermodynamic and wind data with nearly continuous integrated data from an array of ground-based and satellite-borne sensors. These sensors include a 924-MHz phased-array wind and temperature profiler, a four-channel microwave radiometer, a surface meteorological tower, and a balloon sounding system. Although MPS was initially developed for military applications, the nonmilitary environmental applications are numerous and significant.

This paper provides an overview of the instrumentation, software networking, data processing, data integration, and near real-time data display capabilities currently incorporated into the MPS. Initial results from the first field tests (Los Angeles Free-Radical Study, 3–24 September 1993) demonstrate the ability of MPS to observe the complex meteorological structures associated with high-pollution events within the Los Angeles Basin.
aspect of MPS is another important consideration in its design. Any field system can technically be described as mobile, but because of requirements by the U.S. Army, one of the final goals of MPS was to construct a highly compact system that could be set up quickly and used to collect data almost anywhere in the world. This paper provides an overview of the instrumentation, the networking of individual data collection systems, the real-time QC, and some of the processing and data display software currently incorporated into the MPS.

A field experiment was undertaken to test the data collection and integration software and to demonstrate the ability to provide high-quality integrated soundings in the field. Initial results from the first field tests during the Los Angeles Free-Radical Study (LAFRS) (3–23 September 1993) show how marine air influences the thermal and wind structures within the Los Angeles Basin. Three-minute RASS (radio acoustic sounding system) virtual temperature ($T_v$) profiles reveal complicated thermal structures generated by the differential heating of complex terrain. High-resolution wind profiler data show how the convective boundary layer develops within the marine layer and the daily evolution of the land–sea breeze and drainage flow generated by the surface heating and cooling. Integrated profiles combine the high-resolution boundary layer profiler, RASS, and radiometer data with upper-level satellite radiometric data. These data provide valuable information on the interaction between both the smaller- and larger-scale meteorology and the air pollution levels in this region.

2. Instrumentation

Rawinsonde data systems furnish reliable thermodynamic and wind profiles. Their primary limitations are spatial and temporal sampling capabilities (Weber and Wuertz 1990). Releases made more often than every 6 to 12 h require substantial manpower and expendables. Even when high temporal resolution flights are made, the parameters measured often represent meteorological conditions many tens of km downwind of the area of interest. Ground-based and satellite-borne remote sensors provide the means to monitor meteorological conditions nearly continuously in the same volume. Typically the highest spatial- and temporal-resolution measurements are made in the lower troposphere. Figure 1 is an artist’s conception of the MPS.

2. Wind profiler/RASS

A 924-MHz phased-array boundary layer radar wind profiler with RASS (Ecklund et al. 1988, 1990; Strauch et al. 1988), referred to in this paper as a wind profiler or profiler, serves as the focal point of the MPS. Wind profilers of this type with RASS are capable of measuring wind and $T_v$ profiles every few minutes with a 1 m s$^{-1}$ accuracy for winds (Strauch et al. 1987) and 1°C accuracy for temperature (May et al. 1990). Typical vertical resolution is 100 m with a height coverage from near the surface (0.1 km) to 3–5 km for winds and 1–2 km for temperature, depending on the meteorological conditions. Actual temporal resolution depends on the profiler sampling parameters. The ability to measure winds generally improves in turbulent and humid conditions, while for temperature the height coverage is limited by acoustic attenuation and strength of the horizontal winds. Current MPS operating parameters produce wind and $T_v$ profiles every 3 min with a vertical resolution of 100 m using pulse coding. The technique of pulse coding (Schmidt et al. 1979) allows the wind profiler to operate in a single 100-m vertical-resolution mode without sacrificing average power and therefore height coverage.

Improved methods of wind profiler and RASS sampling, processing, and real-time QC have been implemented in the MPS. The MPS phased-array profiler sampling is configured to cycle through four orthogonally directed beams offset 21° from vertical and a fifth beam directed vertically (RASS). This five-beam method of sampling has been shown to be more effective than a three-beam system because of the redundancy in measurements (Wuertz et al. 1988; Weber et al. 1992). In this configuration, two independent measurements of each of the three wind components (east–west, north–south, and vertical) are made for every cycle through the four oblique beams. A third independent measurement of vertical air motion is made by the fifth vertically pointed beam used for RASS. The vertical component used to correct the acoustic signal on the MPS system is the average of
the computed vertical air velocity calculated from the four orthogonal radial velocities and not the directly measured vertical air motion. This method is used since the measured vertical wind is often contaminated by ground clutter. Note that with the MPS sampling scheme, temperature measurements are made with the same temporal resolution as the winds, 3 min each for the current sampling parameters. This method of sampling, with redundant horizontal wind measurements and increased temperature temporal resolution, is important especially when operating in highly convective conditions. Furthermore, it provides better information for more sophisticated QC processing and allows error estimates to be computed for each wind measurement.

The spectral averaging algorithm normally running on the wind profiler has been replaced by a new algorithm (Merritt 1994) for MPS. This algorithm is employed to better distinguish atmospheric signals from migrating birds by using the statistical difference in the distribution of the return-signal power for the two targets providing QC at a much earlier stage in the data collection process and preserving more of the original data. Bird signatures in profiler data are not unexpected (Eastwood 1967; Gauthreaux 1970), but vertically pointing wind profilers operating continuously present a special situation in the presence of flocks of migrating birds (Wilczak et al. 1994).

b. Radiometer

A four-channel scanning microwave radiometer (nominally 50–60 GHz) extends temperature coverage to heights above those of RASS. Retrieval of a temperature profile from the radiometer brightness temperature (Askne and Westwater 1986) produces 15 heights of layer-averaged temperatures every 3 min with 30-m vertical resolution in the lowest layers, decreasing in resolution and accuracy at higher ranges. A two-channel microwave radiometer, planned as a part of the original MPS design to provide total precipitable water vapor and total cloud liquid-water measurements, was not available.

c. Surface sensors

Surface meteorological measurements (at 4 m) include temperature, relative humidity, wind speed, wind direction, and surface pressure. Five-min average values were assimilated into the radiometer, profiler, and integrated data to provide more complete profiles and serve as calibration data where needed.

d. Rawinsonde systems

A Vaisala MARWIN® (MW-12) and a Radian Corporation/NCAR Cross-chain Loran Atmospheric Sounding System (CLASS) (Lauritsen et al. 1987) provided rawinsonde wind and thermodynamic profiles for comparison with the MPS instrumentation. Both systems use a Vaisala RS-80 rawinsonde package with Loran wind-tracking capabilities. A single sonde was launched and tracked simultaneously and independently by both systems. The purpose behind simultaneous, independent tracking was to compare the wind calculations made in each system. Data from the MW-12 system are smoothed and weighted to fit an Ekman-spiral profile in the lowest levels. Increasing weight is given to the measured data with increasing height above the surface. On the other hand, data from CLASS have minimal smoothing and no Ekman-spiral fitting. Only data from the MW-12 were ingested in real time, while CLASS data were ingested after the flight for comparison purposes.

e. Satellite radiometry and imagery

Satellite wind and temperature profiles are retrieved using the SeaSpace Corporation satellite system. A total of 15 mandatory pressure layers of temperature (Smith et al. 1979) and 10 layers of winds are generated from polar-orbiting satellite passes. Winds are estimated from the temperature profile using the geostrophic wind relations. Standard visible and IR images can be viewed using the satellite work station and available display software. Also included as part of the satellite receiving system is a global positioning system (GPS) that provides accurate positioning information and a time standard.

f. Weather maps

National Weather Service weather maps are obtained using an Alden Electronics, Inc., DIFAX Ku-band satellite receiving system. These maps provide valuable forecasting capabilities in the field along with real-time confirmation. These data are not stored in the database or saved at this time.

3. Instrumentation networking

Instrumentation networking is a crucial step to building an easily accessible, integrated dataset. Figure 2 shows an overall schematic of how the individual systems are linked together using a local area network (LAN) for computer-to-computer communication. A major requirement for a field-ready version of MPS is to reduce the number of computers or processing systems required to operate and collect data from the various instruments. The multitasking operating system OS/2 V2.1 (486DX/33MHz; MPSRADAR) allows MPS the flexibility of operating the wind profiler as well as ingesting data from the surface meteorological datalogger, MARWIN® rawinsonde system, and the
four-channel radiometer from a single personal computer (PC). Data from the OS/2 computer are sent every 15 min across the LAN to the main database computer (HP-9000/735; MPSHUB) operating under UNIX via file transfer protocol. Satellite temperature and wind profiles are passed to MPSHUB from the satellite computer (HP-9000/720; MPSSAT, UNIX) via a network file system volume mount and direct-disk write. Once on MPSHUB, all data are ingested into the Informix® relational database management system database. Design and development of the database subsystem began prior to the physical installation of any hardware and then proceeded in parallel with the building of MPS. The database is configured in such a manner that additional new sensors can be incorporated into MPS.

All clocks are synchronized on a regular basis using the GPS time through an automated software routine on each computer, insuring consistent time throughout the database. Three printers (a dot matrix, a color Postscript, and a laser) are also on the network, providing hard copy.

4. Data processing and display

As stated earlier, the wind profiler served as the primary instrument around which MPS was built. More than 90% of the data going into the database, and therefore a majority of the data processing, deals with the profiler. Wind profilers produce much more information than just consensus-averaged profiles of wind and temperature. This information includes the first three moments of the Doppler spectra (returned-signal power, radial velocities, spectral width) and signal-to-noise ratio (SNR) for each profiler beam at all heights every 3 min.

On earlier systems, these data were routinely stored in files on the profiler system disk. Recent improvements in QC have been implemented by reprocessing the radial velocities and virtual temperatures returned from the field in these files using a pattern recognition QC method (Wuertz and Weber 1989; Weber and Wuertz 1991; Weber et al. 1993; Wolfe et al. 1993). This method of profiler QC is taken one step further with near real-time quality control performed by MPS. All of the profiler data, including the Doppler spectra, are now ingested into the database. Every 15 min the Weber and Wuertz (1991) QC process is executed for each wind and RASS radial velocity measurement. All raw and quality-controlled radial velocities along with their corresponding QC indicators are saved in the database. This allows the user to utilize these indicators in later processing stages to produce nearly any level of final wind and temperature profiles desired.
pling rates and/or spatial resolution can quickly be displayed or compared in like formats. This capability is available as soon as the data have been stored in the database. As a unique part of the MPS five-beam, phased-array profiler processing, error estimates are calculated. These error estimates are differences in vertical velocities calculated from two independent pairs of orthogonal profiler beams; they represent an estimate of the atmospheric variability measured across the wind profiler sampling volumes.

The integration process did not stop with data collection and storage in the database. Integration algorithms (Cogan and Izaguirre 1993) have been implemented to blend data from the various instruments into single profiles of temperature, wind speed, and wind direction. This set of algorithms can also merge other types of data (e.g., humidity) as they become available. Although still in the early stages of development, these are the very first integrated real-time profiles from a common database for both temperature and winds. Satellite data consist of gridded profiles produced from continuous scans for each satellite pass. Currently, only the closest satellite profile, at a single grid point, within a 6-h window is integrated with profiler, RASS, and radiometer data. This satellite profile is weighted based on its distance from MPS and its time staleness from the requested integration time. Satellite temperature data below 2.5 km above ground level (AGL) are not used, and RASS data are given priority over radiometer data in the lowest levels. These integrated profiles may then be used to generate new profiles from a user-defined structure of heights or layers (Cogan 1990). The intent of this integration routine is to produce final profiles that take advantage of each individual instrument’s strengths (i.e., altitude coverage and time–height resolution).

Not to be overlooked are the data display capabilities of MPS, which are critical for inspecting the data in real time and for post analysis. These graphical routines connect the user not only to the database, but also to the data processing (averaging and integration). Below we briefly describe the graphical display and analysis tools available on MPS to date. Several examples are shown in the following section. All user interaction with the database and display programs are executed through MPSHUB.

One feature of the graphics package is its ability to display spectral moment data from every wind profiler antenna beam. Signal power, radial velocity, spectral width, and SNR can be displayed in color for any time period and height range. The color scale can be easily modified to investigate features of interest in greater detail. Data with and without QC editing are plotted to ensure that the database ingestion and processing are functioning properly.
Integration of these three datasets is described by Cogan and Izaguirre (1993) along with a list of differences in and accuracies of the remote sensors. These integrated and rawinsonde $T_c$ profiles show good agreement below 1 km AGL in the presence of an elevated temperature inversion (Fig. 3, see inset). The integrated profile below 1.6 km consists of RASS 3-min measurements averaged over a 15-min period. Differences in the overall structure of the temperature inversion are a result of averaging, spatial separation as the balloon drifts downwind, and different vertical resolutions. The integrated profile above 1.6 km includes, first, ground-based radiometer, and then, satellite radiometer measurements. Although the ground-based radiometer measurements are not $T_c$, the fact that these data are from the drier region above the marine layer means there will be less moisture contribution. The rawinsonde $T$ profile, added to the insert in Fig. 3, shows the magnitude of the differences between $T$ and $T_c$ (1.5°C) and the height of the moist marine layer. Above this height, the mixing ratio drops from approximately 9 to 0.5 g kg$^{-1}$. Both the satellite and ground-based radiometer temperature measurements include layer averaging, which can contribute to significant differences when the integrated profile is compared to the rawinsonde profile. Spatial separation, due to balloon drift and the large sample volumes of the remote sensors, may also contribute to the differences seen at higher altitudes.

5. Field testing MPS during LAFRS

LAFRS was sponsored by the California Air Resources Board to study the formation of ozone ($O_3$) in the Los Angeles Basin. The MPS provided meteorological support for the air-chemistry portion of the study and meteorological data for input to air pollution models and comparison with a collocated $O_3$ lidar. Operations were conducted in Claremont, California, 5 km south of the San Gabriel Mountains and 20 km east of downtown Los Angeles, a major source region for precursors to $O_3$. The MPS site was located on the eastern edge of the Los Angeles Basin, some 60 km from the Pacific Coast.

Atmospheric conditions measured within the Los Angeles Basin during LAFRS are characterized by three fairly distinct meteorological periods. Figures 4–5 show time series of hourly averaged temperature, calculated mixing ratio, wind speed, and wind direction from the MPS surface meteorological tower for the LAFRS experiment (3 September–22 September 1993, Julian day 246–265). The first 8 days of the study had clear skies, daytime maximum temperatures of 30°–38°C, and diurnal temperature cycles approaching...
15°C. After an upper-level trough passed to the east, the next 7 days were characterized by persistent onshore flow, cooler temperatures (25°C maximum), weaker diurnal temperature cycles (<10°C), clouds, and light drizzle. The end of the study was a transition period back to clear skies and warmer temperatures.

Keith (1980) describes climatological conditions typically found within the Los Angeles Basin. The Los Angeles Basin is characterized by a marine air influence and temperature inversion, especially during the hot summer months. Strong diurnal heating generates a consistent land–sea breeze (Fig. 5). The westerly sea breeze increases in strength toward midafternoon to around 4–6 m s\(^{-1}\). Transition to a weak and shallow easterly land breeze begins after sunset, combined with a northerly drainage flow off the San Gabriel Mountains (<2 m/s).

Onshore flow from the Pacific Ocean is modified as it moves inland toward the MPS site. Therefore, the strength of the marine inversion is highly dependent on the strength and duration of the westerly winds. Evidence of a marine layer exists throughout LAFRS, varying in depth from 0.5 km AGL during the first part of the study to nearly 2.0 km AGL when the onshore flow was strongest. Coinciding with the period of synoptically forced onshore flow are a deeper marine layer, a stronger (6°–7°C) capping inversion, and an increase in the mixing ratio (moisture). Wind speeds within the boundary layer maintain a persistent diurnal cycle throughout the study. Upper-level winds are decoupled from the marine layer and dominated by south–southeasterly and west–northwesterly flow.

Figure 6 shows a 24-h time series plot of hourly averaged profiler winds from 0.0 to 3.0 km AGL from the MPS graphics package, at 0700 UTC 6 September 1993 until 0700 UTC 7 September 1993. There is a 7-h offset from local time (i.e., 1900 UTC = noon local), and wind data have been quality controlled. Below 0.6 km AGL we find evidence of the land–sea breeze. A weak land breeze continues until about 1800 UTC, when the winds switch to westerly (beginning of the sea breeze), gradually increasing in strength throughout the afternoon. Not long after sunset (0300 UTC) the winds begin to die down and shift around to a land breeze and/or drainage flow off the San Gabriel Mountains. The top of the marine boundary layer (MBL) is not clearly defined by the winds, but appears as a shear layer around 0.6 to 1.0 km.

Figure 7 is a plot of the radial velocities (a) and SNRs (b) for a single wind-profiler beam corresponding in time to Fig. 6. Each plot represents approximately 480 individually measured profiles for the northwest-pointing beam prior to any QC. An elevated layer is depicted by a horizontal band of higher SNR, 15–20 dB, at around 1 km AGL visible from 0700 UTC to 2000 UTC. This layer is believed to be the remnants of the boundary layer from the previous day and shows up in the 1600 UTC balloon sounding as a weak elevated inversion. A second, stronger (30 dB) layer develops and begins to rise around 1900 UTC. This
second layer has the appearance of a convective boundary layer (CBL) and corresponds in time to the transition period from the land to sea breeze. Enhancement of thermal convection during this period is possible because of the light winds and the potential for decreased vertical stability. Notice how the growth of the CBL stops when it reaches the height of the elevated layer. Temperature and relative humidity profiles (Fig. 8) from an MPS rawinsonde flight confirm these observations and indicate that thermal heating within the CBL did not break through the capping inversion on this day. White et al. (1991) have shown that the SNR can be used to successfully identify and track the mixed-layer depth.

By examining these data on a finer timescale we are able to observe even more detail in both the wind and temperature structure. Figure 9a is a color display of 10-min-averaged $T$, from RASS at 1800 UTC 6 September 1993 until 0700 UTC 7 September 1993. Note the warming trend beginning after 1900 UTC corresponding to the growth of the CBL seen in Fig. 7. Using the calculated error estimates (variability) described previously in section 4, we are further able to identify the region of strong thermal activity within the CBL (Fig. 9b). Another region with larger variability, 0300–0500 UTC 7 September 1993, corresponds to a period of migrating bird interference and is discussed in more detail later in this section.

Figures 10 and 11 show profiler winds, radial velocities, and SNR data at 0700 UTC 16 September 1993 until 0700 UTC 17 September 1993, a strong onshore flow period. The main meteorological differences between this day and the day corresponding to the data shown in Figs. 6–7 are the absence of any land breeze at night or any well-defined CBL growth during the day, and a deeper and more continuous MBL (1.6 km AGL). On both days the winds are very complex within the marine layer. Rawinsonde temperature and relative humidity profiles (Fig. 12) on 16 September 1994 do show a classic marine-layer profile with a strong capping inversion, high relative humidities beneath the inversion, and an abrupt drop (>80% to <20%) in relative humidity above the MBL that is consistent with large-scale subsidence. Comparing the temperature
and relative humidity profiles (Fig. 12) to the profiles of
SNR (Fig. 11b), observe how the inversion corresponds
to a brighter band of high SNR and the dry region above
the inversion corresponds to a sharp drop in SNR.

The 2 days shown above have a small amount of
bird interference. Note 0300–0400 UTC in Figs. 7a,b
and the brighter, speckled structure seen on top of the
MBL during most of the evening hours, 0700–1200
UTC 16 September and 0300–0600 17 September in
Fig. 11b. Wilczak et al. (1994) describe in detail the
effect migrating birds have on wind profilers, showing
examples of contaminated radial velocities, winds,
and SNR data. A total of 15 of the 21 days during
LAFRS had bird contamination of varying strengths,
lasting anywhere from 1 to 10 h. The majority of the wind
contamination exists above 2 km AGL in the northwest-
erly flow. Two points should be noted. First, the prelimi-
nary version of the Merritt algorithm used with MPS ran
on a PC rather than on a digital signal processor board,
which constrained how the profiler parameters could be
set and still maintain high-temporal resolution and ver-
tical coverage. Second, bird contamination occurred
during the night, while the focus of LAFRS was the early
morning to early afternoon hours. A more detailed
examination of the wind data indicates that less than
5% of these data show evidence of unrealistic jumps
in the wind speed or changes in the wind direction.
Wilczak et al. (1994) also describe a method of
thresholding on various profiler moment parameters,
including SNR, to identify periods affected by birds.
This postprocessing is not able to recover the winds,
it can only remove periods of contaminated data. Error
estimates calculated from the MPS five-beam profiler
are also a possible tracer of bird contamination.

6. Summary

The Mobile Profiler System was designed and built
for the U.S. Army as an integrated system of both
satellite and ground-based remote sensors and in situ
sensors to provide nearly continuous temperature and
wind profiles from the surface up through the tropo-
sphere. The integration process is accomplished by
utilizing a central data collection computer and data-
base. Once collected and stored in the database,
these data can then be combined to form single
temperature and wind profiles. This concept provides
not only real-time visualization of the data, but opera-
tional output of integrated profiles from remote sen-
sors of widely differing sampling characteristics and
spatial resolutions. The user needs to be familiar with
the operation of the various sensors and how the
temporal or spatial averaging affects the results. The
approach of MPS is comparable to many new mea-
surement systems such as ISS, but it differs signifi-
cantly in the utilization of a new profiler spectral-
averaging algorithm, real-time QC, integration of
ground-based and satellite radiometers, and near
real-time integrated wind and temperature profiles.

Although developed for military applications, MPS
demonstrated its value to the environmental commu-
nity during LAFRS. Storage of the high-temporal
resolution profiler data provided continuous wind and
$T_{\text{a}}$ profiles characterizing the complex meteorology
associated with pollution events in the Los Angeles
Basin. Integrated profiles improved the temporal and
spatial resolution and vertical coverage by employing
the strengths of each sensor.

Future plans for MPS and its technology involve
improving the existing instrumentation and techniques
for integrating data from ground-based and satellite-
borne sensors. Work is underway to redesign the wind
profiler antenna to increase transmitted power, en-
hance vertical coverage, and improve antenna beam
patterns. The equipment used for the MPS were
primarily commercial off the shelf. Future integrated-
profile plans consist of investigating additional algo-
rithms (Stankov et al. 1993) and modifying current
integration routines to combine satellite profiles from

![Fig. 8. Rawinsonde profiles (0–4 km) of temperature (solid line) and relative humidity (dashed line) at 2235 UTC 6 September 1993. Solid line with open circle represents the dry-adiabatic lapse rate.](image)
several grid points surrounding the actual measurement location through time and space weighting. Incorporation of additional sensors, such as a cloud-detecting ceilometer, and new techniques—including implementing GPS to sense atmospheric water vapor (Bevis et al. 1992)—are also recognized as methods to further improve the capabilities of MPS. The real impact of MPS may not be as a replacement for the rawinsonde system but as an innovative tool to supplement rawinsonde data and provide new ways of observing the atmosphere on multiple time and spatial scales. It is hoped that further development would also include combining the strengths of ISS and MPS.

Acknowledgments. The authors would like to acknowledge the California Air Resource Board for allowing us to field test MPS during LAFRS. Thanks also go to Norbert Szczepczynski and Paul Schmidt for their help in designing the MPS trailer and equipment installation.

References


Fig. 10. Hourly averaged profiler winds, 0–3 km, from 0700 UTC 16 September 1993 to 0700 UTC 17 September 1993. Time runs from right to left with wind barbs plotted at the end of the averaging period. Data are quality controlled.

Fig. 11. Radial velocity (a) and SNR (b) color profiles for a single antenna beam, Az = 311°, for the same time period as in Fig. 10. Time runs from right to left. Radial velocities toward the radar (from the northwest) are positive.
FIG. 12. Rawinsonde profiles (0–4 km) of temperature (solid line) and relative humidity (dashed line) at 2243 UTC 16 September 1993. Solid line with open circles represents the dry-adiabatic lapse rate.


