CHAPTER 3

APPLICATIONS

UHF Doppler systems have a number of different uses; all rely on the basic technique described in section 2.2 and differ mainly in their sensitivity and cost. Improved sensitivity is obtained by higher average transmitted power (peak power is not important) and larger antenna effective apertures, and sensitivity determines the altitude coverage and/or averaging time needed to measure the radial velocity. Three general categories of profilers are described below and typical characteristics are listed in Table 3-1.

Table 3-1. Typical characteristics of UHF Doppler profilers.*

		Boundary Layer	Lower Tropospheric	Tropospheric
Minimum altitude	(m)	60–100	100–200	250–500
Maximum altitude	(km)	1–3	5–8	12–16
Altitude resolution	(m)	60–100	100–300	250–1000
Time resolution	(min)	10–15	20–30	30–60
Average power	(W)	10–50	100–500	1000–2000
Antenna aperture	(m^2)	3–10	10–25	100–200

*Characteristics listed in this table are typical for midlatitude Continental United States (CONUS) operation. In other regimes the maximum altitude can be quite different. For example, in the tropics the boundary layer systems will typically measure to 5–6 km altitude, whereas in the Arctic the minimum altitude may be less than 200 m.

3.1. **Boundary Layer Profilers**. These systems, operating primarily at 915 MHz (Ecklund et al. 1988), are commonly used for air quality or urban-scale studies. They are also used to complement profilers whose minimum observing altitude or range resolution cannot portray the boundary layer winds. Their small size allows them to also be deployed on ships (e.g., Fairall et al. 1997), as part of integrated sounding systems (ISSs) (e.g., Parsons et al. 1994) and mobile profiling systems (MPSs) (Cogan 1995). Several universities are using them in research and in a teaching role. RASS, for measuring temperature profiles, is a popular addition because it can provide high-temporal-resolution temperature soundings with the same height resolution as for wind measurements.

3.2. **Lower Tropospheric Profilers**. These systems, with more sensitivity and higher cost than the boundary layer profilers, have not been widely used. They have a number of potential applications including monitoring airport winds, and transport and diffusion of hazardous materials, and for wind corrections for artillery. A 404-MHz system was used for several years to aid in the safe operation of a tethered balloon (Moran et al. 1989). Although the profiler may provide valuable data for airport operations, it should not be envisioned as a "wind-shear" warning device; the profiler will measure vertical shear of the horizontal wind, but because of the inhomogeneity associated with convective storms, profilers are not appropriate for detecting and warning of the wind shears from downdrafts that lead to dangerous conditions for takeoff and landing of large aircraft.

3.3. **Tropospheric Profilers**. The best example of tropospheric UHF Doppler wind profilers is the instruments used in NOAA's Wind Profiler Demonstration Network (WPDN) (Chadwick 1986; Beran 1991). These profilers were installed in the early 1990s to provide data for weather forecasting, both for local forecasts and for input to numerical models. The network data are available on the Web (http://www-dd.fsl.noaa.gov). Another application for wind profilers is for tropospheric/lower stratospheric height coverage for rocket launch support (Beran 1985; Beran and Kaimal 1989). However, UHF half-wavelength turbulent scales that cause radar scattering may be damped by viscosity in the stratosphere; this uncertainty argues for using longer wavelength systems.

Longer wavelength (VHF) profilers, often referred to as stratospheric-tropospheric (ST) profilers, were developed earlier than UHF profilers; the pioneering work at Poker Flat, Alaska (see Balsley and Gage 1980), set the stage for the Eastern Range (ER) system and White Sands Missile Range (WSMR) system described in sections 3.5.1 and 3.5.3, respectively.

3.4. **NOAA Profiler Network**. In 1980, the NOAA Wave Propagation Laboratory (WPL), now the Environmental Technology Laboratory (ETL), extended earlier profiler research in the NOAA Aeronomy Laboratory by beginning a program that made wind profilers practical for routine meteorological measurements. The Colorado wind profiler network, consisting of three VHF and one UHF profiler (Strauch et al. 1984), demonstrated the ability of profiling systems to portray the winds aloft over a large area with automated, unattended systems. This work was the precursor to NOAA's initiative to build the current national wind profiler network.

In the early 1990s, the WPDN, consisting of 32 commercially produced 404-MHz wind profilers, was deployed in the central third of the United States (Fig. 3-1). This network, later renamed the NOAA Profiler Network (NPN), has been operating since 1992. In 1994, the 404-MHz experimental frequency was replaced by a permanent 449-MHz frequency allocation for wind profilers. New systems must comply with this standard. In 1995, NOAA began a cooperative effort with the Air Force to replace the 404-MHz profiler at Vandenberg Air Force Base (AFB), California, with a 449-MHz system. NOAA is installing three 449-MHz profilers in Alaska and deactivating the existing Alaskan 404-MHz system.

Details of the NPN operation are described by Barth et al. (1994a). Data from the network profilers are gathered in near-real time at a hub in Boulder, Colorado. Data include both wind measurements and details regarding the health and status of various components of the radars. After quality control at the hub, the data are distributed within NOAA, to universities, and to other government agencies and the general public (Fig. 3-2). The staff in the Profiler Control Center (PCC), where the hub is located, are responsible for remotely monitoring the operation of each profiler in the NPN. This includes responding to profiler reported faults, coordination of repair logistics, communications monitoring, and the subjective monitoring of engineering and meteorological data.

The impact of the NPN has been studied by several authors (Weber et al. 1990). Both theoretical studies and analyses of actual situations have demonstrated its value to numerical models (Kuo and Guo 1989; Smith and Benjamin 1993). One important contribution has been the ability to observe the role of the nocturnal low-level jet in the rapid transport of moisture-laden warm air northward from the Gulf of Mexico (Shiyuan et al. 1996). NPN data have been key to predicting the occurrence of nocturnal thunderstorms caused by this low-level jet (Leftwich and Beckman 1991; Miller et al. 1993). In subjective evaluations, wind profiler data have been found to be useful in numerous forecasting tasks including aviation forecasts, precipitation onset and termination, and severe weather warnings and advisories. To date, the most comprehensive study of the NPN is contained in the "Wind Profiler Assessment Report" edited by Schlatter and Zbar (1994).

3.5. **Space Launch and Test Range Activities**. During the early 1990s, wind profilers were introduced at national space launch and test range facilities. Today, they are being used to support operations at the Eastern and Western Space Launch Ranges, and research at WSMR.

3.5.1. **The Eastern Space Launch Range**. The use of wind profilers to directly support space launch operations began in 1990 when the National Aeronautics and Space Administration (NASA) installed a 50-MHz profiler at Kennedy Space Center (KSC) to evaluate the applicability of the technology for assessing launch wind conditions (Wilfong et al. 1993). Like an identical 50-MHz system at the WSMR, this profiler has an effective aperture of 13,500 m^2 with a peak power of 250 kW and a maximum average power of 12 kW. Two modes of operation provide range resolutions of 150 or 600 m for 110 gates. In practice only the 150-m range resolution mode is used, with the lowest gate at 2 km and the highest gate at 18.5 km.

The standard consensus-average technique delivered with the system was judged inadequate for launch support. To produce high-quality wind profiles in minimal time, NASA replaced the conventional signal processing with one that uses a median filter to remove spurious echoes from the averaged Doppler spectral data and constrains the search by a first guess (Wilfong et al. 1993; Shumann et al. 1998).

The KSC 50-MHz profiler is now integrated into the prelaunch wind evaluation process at the ER. NASA uses the data to evaluate wind persistence for Shuttle launches, but does not use the data to compute expected Shuttle loads during launch. The Titan IV program uses the profiler data to compute expected loads, but continues to use balloon-derived winds as the primary data source. This conservative approach is expected to continue until the use of profiler data in launch support is fully validated. The 50-MHz system has recently been used to study the probability distribution of short-period upper-air wind changes. Merceret (1997) found the distribution is lognormal, which implies that large wind changes may occur much more frequently than if the distribution were Gaussian, as is now assumed during the prelaunch vehicle risk assessment (Merceret 1998).

The National Weather Service (NWS) Spaceflight Meteorology Group (SMG) at Johnson Space Center, Houston, Texas, is required to provide wind profile forecasts from the surface to 80,000 feet (24,384 m) for Space Shuttle landings (Bellue et al. 1996). These forecasts are used to calculate Space Shuttle vehicle performance during descent and landing at KSC. The 50-MHz data are routinely transmitted from the Cape Canaveral Air Station to forecasters at Johnson Space Center. These data are used in conjunction with Jimsphere and rawinsonde data, and numerical model output, to produce the forecast wind profile. The 50-MHz profiler data are also used for analysis and forecasts that support ground operations.

In 1996, the ER completed installation of a network of five 915-MHz radars with RASS (Heckman et al. 1996). This network is designed to provide three-dimensional wind direction and speed estimates in the boundary layer from 120 m to 4 km AGL and virtual temperature (T_v) estimates from 120 m to 1.5 km AGL. It was installed to provide wind data with high spatial and temporal resolution in the gap between the top of the local wind tower network (150 m) and the lowest gate (2 km) of the 50-MHz wind profiler. The five profilers are arranged in a diamond pattern with an average spacing of 10–15 km (see Fig. 3-3). Although the systems are capable of generating five beams, they are operated in a three-beam mode to accommodate a 10-min wind measurement cycle followed by a 5-min RASS temperature measurement cycle.

A primary launch-specific use for the 915-MHz profilers is for characterization of the wind and temperature fields for toxic hazard assessment. When fully operational, the network will support forecasts of low-level winds for launch analyses on all vehicles and for Space Shuttle landings. The network will also enhance general forecasting capability for such problems as thunderstorms and high winds.

3.5.2. **The Western Space Launch Range**. The Western Range (WR), located at Vandenberg AFB, California, hosted one of the original NPN profilers until 1997. As mentioned in section 3.4, this NPN 404-MHz system is being replaced with a new 449-MHz profiler. The new profiler incorporates features such as (1) five beams, (2) four modes with range resolutions of 125 m, 250 m, 500 m, and 1 km, and (3) flexible operating modes. Its capability to retrieve high-resolution low-altitude data is shown in Fig. 3-4.

The WR now has two mobile 915-MHz low-altitude profilers. One is collocated with the new 449-MHz radar; the second is located near the space launch complexes. Both profilers are currently operating in dual mode on a 30-min cycle. Winds are sampled for 25 min and temperature is sampled for 5 min. In addition, during the wind-sampling period, each radar operates in two different modes that provide two overlapping profiles for each site. One mode provides 100-m vertical resolution from 120 m AGL to 2 km. The other mode provides 200-m vertical resolution from 320 m AGL to about 3–4 km. Temperature profiles provide data at 60-m vertical resolution from 120 m AGL to 1 km. All three systems (the 449-MHz radar and the two 915-MHz radars) employ the same data system and thus provide a common interface for data collection at the local Air Force weather station, where the wind and temperature data can be viewed independently.

3.5.3. **The U.S. Army Atmospheric Profiler Research Facility**. The U.S. Army Research Laboratory's Battlefield Environment Directorate (ARL-BED) at WSMR, New Mexico, operates the Atmospheric Profiler Research Facility (APRF). This facility uses remote sensors to measure high-resolution vertical profiles of refractive index (C_n^2), wind speed, wind direction, and ambient temperature. The measurements are continuous and provide high resolution from the surface up to about ~19 km AGL. The APRF systems include (1) two high-performance clear-air atmospheric profilers (50 MHz and 2900 MHz), (2) a specialized independent optical turbulence measurement system, (3) a suite of three supporting standard atmospheric profilers operating at 404 and 924 MHz, (4) RASS, (5) an array of specialized tower and surface-mounted point and integrated-path instrumentation, and (6) tethered and free-flight balloon capability.

The 50-MHz profiler provides high-resolution calibrated C_n^2 values, winds, and virtual temperature. Specialized spectral processing converts the total received power into calibrated C_n^2 values at 150-m resolution. Calibrated C_n^2 values, based on a first-principles calibration approach (Eaton et al. 1988), are obtained for both the 50- and 2900-MHz radar profilers.

The 2900-MHz profiler obtains continuous measurements of radar power return with ultra-high range resolution (1–2 m) from 50 to 2200 m AGL. When hydrometeor-type backscatter is being observed, radar hardware gains can be adjusted to obtain similar resolution for Rayleigh scattered precipitation. These frequency modulated-continuous wave (FM-CW) radar measurements are used to study boundary layer dynamics, hydrometeors, radio wave propagation, insect interference, imaging, and laser propagation. Slow-rate azimuth scans can be made for velocity-azimuth display (VAD) wind profiling with lower space and time resolution, or the antennas can be directed vertically for temperature profiling at lower height resolution or for backscatter profiling at high resolution (McLaughlin 1992). The radar is used predominantly for high-height-resolution C_n^2 profiling. In this mode the antennas are directed vertically, and typically, the data are averaged over 6–10 s, with a 2.15-m resolution from 0 to 2200 m AGL.

The APRF provides high-resolution (spatial/temporal) C_n^2, wind speed, wind direction, and ambient temperature measurements needed for micrometeorological, boundary layer, and upper atmospheric research, optical sensor evaluations, transport and diffusion studies, scintillation studies, satellite ground truth, and propagation studies. Features in the atmosphere, including insect migrations in the New Mexico Tularosa basin and the different backscatter return signatures derived from the different operating frequencies of the various radar profilers, have also stimulated new research interests.

3.6. **Mobile Profiler Systems**. An MPS called the Profiler is being developed by the ARL Information Science and Technology Directorate (ISTD), with the assistance of NOAA's ETL. The system is designed to provide complete meteorological soundings from the surface to more than 30 km as often as once every 3 to 5 min by integrating data from a number of sources, including meteorological satellite sounders, a microwave radiometer, RASS, and a 924-MHz wind profiler. The radar processing algorithms developed by ETL for the wind profiler (Wolfe et al. 1995) allow for higher data quality at faster data rates than were previously possible. A more advanced prototype Meteorological Measuring Set-Profiler (MMS-P) is expected to be ready for initial field testing in the summer of 1998. A shelter on a standard pickup truck, or equivalent, plus a small trailer will contain the MMS-P equipment.

The Profiler has certain elements in common with fixed-site systems described by Parsons et al. (1994) and Stokes and Schwartz (1994), but it has additional features such as a microwave radiometer, a combined radar/RASS antenna, and software for processing and quality control of data from the ground-based sensors and for combining satellite soundings with ground-based profiles in near-real time. Wolfe et al. (1995) provide details on the Profiler as configured and operated during the Los Angeles Free Radical Experiment (LAFRE) in Claremont, California, along with examples of the various products. Cogan (1995) presents additional samples of output and gives preliminary quantitative results. Wolfe et al. (1995) and Cogan (1995) briefly describe the method for merging data from satellite and ground-based sensors. A more complex description of the merging algorithms, and a fuller, quantitative presentation and discussion of test results, are given in Cogan et al. (1997).

The future MMS-P will have a variety of military and civilian applications, including timely support for airfield operations, and near-real-time indications of potentially hazardous wind conditions. Mesoscale models will have access to detailed, near-real-time, atmospheric soundings within and somewhat above the boundary layer. Through access to data from environmental satellites, and potentially from airborne sensors and dropsondes, the MMS-P could potentially obtain meteorological data throughout the domain of a mesoscale model.

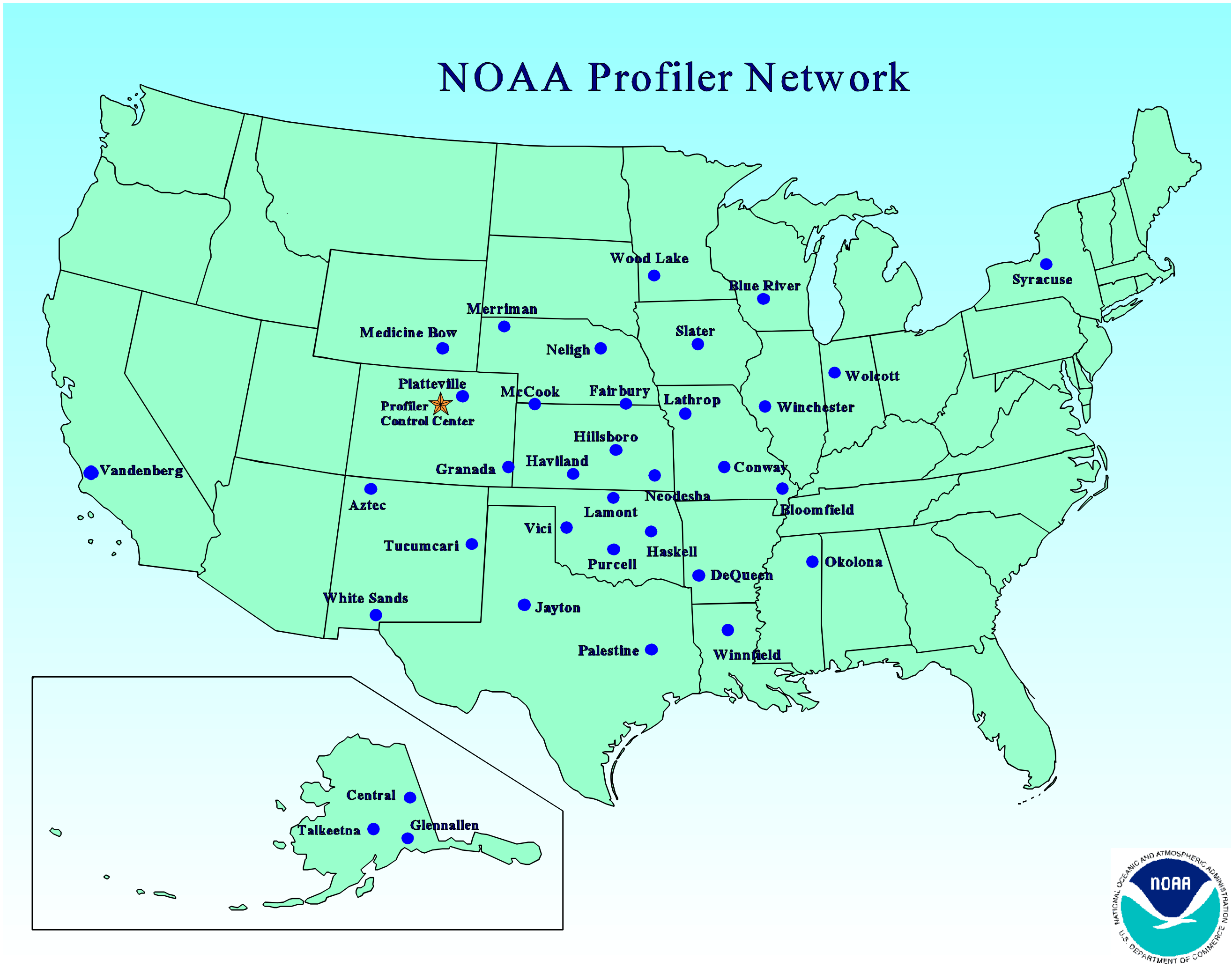

Figure 3-1. Locations of wind profilers in the NOAA Profiler Network. There will be three sites in Alaska after 1998.

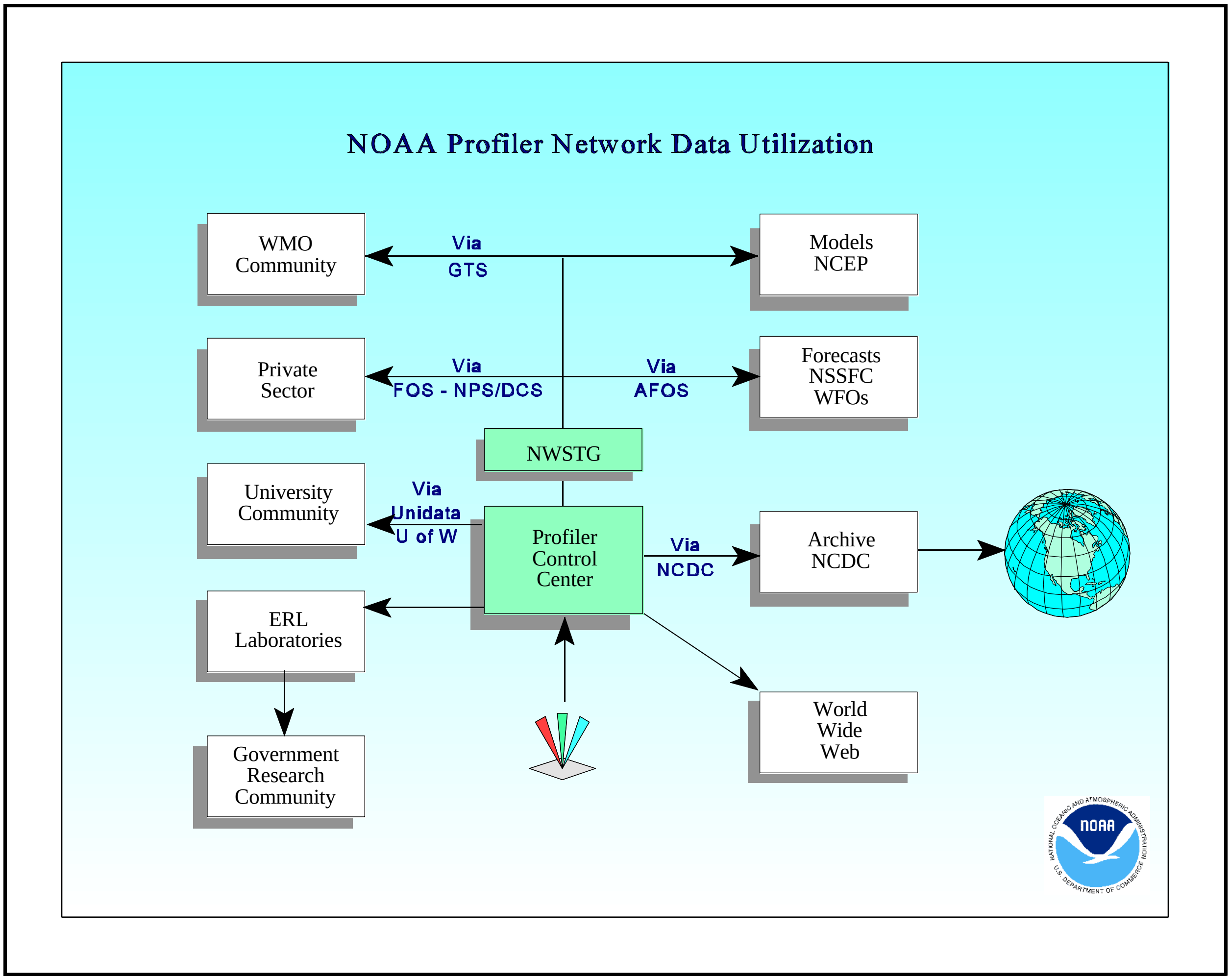

Figure 3-2. Data distribution from the NOAA Profiler Network [World Meteorological Organization (WMO), Environmental Research Laboratories (ERL), National Centers for Environmental Prediction (NCEP), National Severe Storms Forecast Center (NSSFC), Weather Forecast Office (WFO), and National Climatic Data Center (NCDC)].

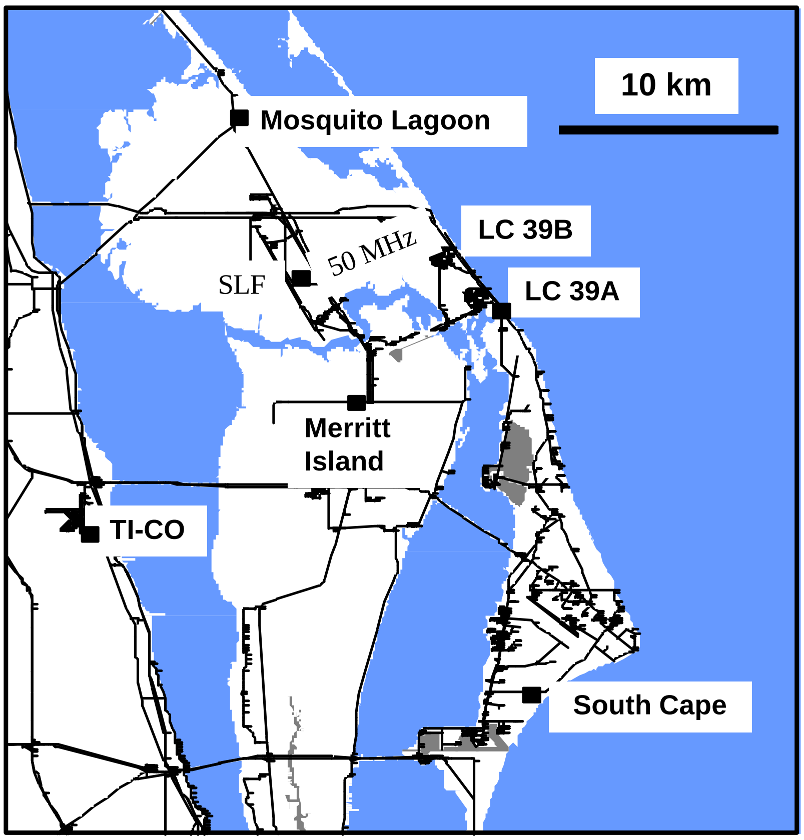

Figure 3-3. Wind profiler locations at Cape Canaveral Air Force Station and Kennedy Space Center, Florida. The 915-MHz and 50-MHz profiler locations are indicated by solid squares. The names of the locations are printed next to the sites, and a scale is provided in the upper right. Also shown are the Shuttle launch complexes (LC 39A,B), the Shuttle Landing Facility (SLF), and Titusville Corporate Airport (TI-CO).

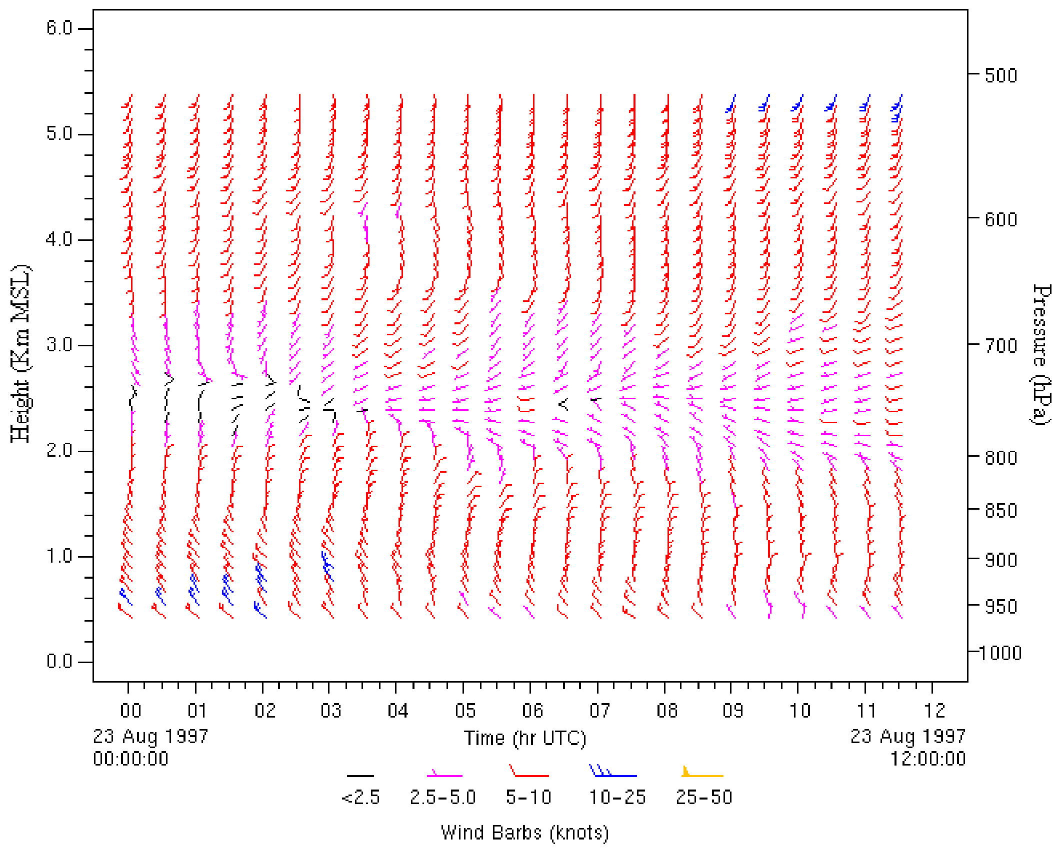

Figure 3-4. Data sample from the Vandenberg AFB 449-MHz wind profiler for 23 August 1997.