NOAA Technical Memorandum ERL ETL-290

USER'S GUIDE FOR THE SERDP MOBILE METEOROLOGICAL MONITORING SYSTEM

M.R. Mulhern
B.D. Templeman
G.H. Crescenti

Environmental Technology Laboratory
Boulder, Colorado
June 1998

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

NOAA Technical Memorandum ERL ETL-290

USER'S GUIDE FOR THE SERDP MOBILE METEOROLOGICAL MONITORING SYSTEM

Martin R. Mulhern

Meteorological Applications and Assessment Division
Environmental Technology Laboratory

Brian D. Templeman

Cooperative Institute for Research in Environmental Sciences
The University of Colorado at Boulder

Gennaro H. Crescenti

Field Research Division, Air Resources Laboratory
Idaho Falls, Idaho

Environmental Technology Laboratory
Boulder, Colorado
June 1998

UNITED STATES
DEPARTMENT OF COMMERCE

William M. Daley
Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

D. JAMES BAKER
Under Secretary for Oceans
and Atmosphere/Administrator

Environmental Research
Laboratories

James L. Rasmussen
Director

Notice

This document is an account of work sponsored by an agency of the United States Government. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the federal government. Neither the United States Government or any of its employees make any warranty, express or implied, or assume any legal responsibility or liability for the accuracy, completeness, or usefulness of this information or any product or process discussed, or represent that use of any product or process mentioned would not infringe privately owned rights. Mention of a commercial company or product does not constitute an endorsement by NOAA. Use of information from this publication concerning proprietary products or the tests of such products for publicity or advertising purposes is not authorized.

The purpose of this document is to provide an overall system description and guidance for installation, setup, and operation of the Mobile Meteorological Monitoring System. Excellent information regarding the individual sensors and each element of the system is also available from the manufacturers. It is assumed that readers will also refer to information provided by the manufacturers, particularly concerning safety and operating guidelines, before operating the system and its various components.

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, DC 20402

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report is a detailed description and user guide of a Mobile Meteorological Monitoring System (MMMS) designed to characterize the vertical structure of the atmosphere from the surface up to 2 to 3 km, in the vicinity of open burning and open detonation of surplus military munitions. This report describes tower-mounted in situ sensors and ground-based remote sensors, their respective data acquisition systems, quality control algorithms and data processing routines, setup procedures, and data formats. The development of the MMMS, a joint project of the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA), was funded by the Strategic Environmental Research and Development Program (SERDP).

1. INTRODUCTION

During the Cold War the United States military accumulated a vast arsenal of warfare materials. These included explosive munitions, propellants, and various pyrotechnic materials. Now that the Cold War has ended, the U. S. is faced with the task of disposing of these energetic materials in an environmentally safe manner. The surplus inventory is currently estimated to be 500,000 tons and to be growing at a rate of 40,000 tons per year (U. S. Army, 1995). These materials are located at several hundred Department of Defense (DOD) and Department of Energy (DOE) installations throughout the country. Disposal of the demilitarized stockpile will be a momentous undertaking.

The most common disposal methods now in use are open burning (OB) and open detonation (OD). OB/OD activities are a relatively simple and cost-effective means for stockpile reduction. However, these activities can generate air pollutants such as SO_2, NO_x, CO, particulates, metals, cyanides, and volatile and semi-volatile organic compounds. Any facility that intends to use OB/OD disposal methods must meet permit requirements under Part 264, Subpart X of the Resource Conservation and Recovery Act (U. S. Environmental Protection Agency, 1993).

Subpart X permits are issued by an Environmental Protection Agency (EPA) Regional Office only if the facility demonstrates that the OB/OD activities pose no significant threat to either human health or the surrounding ecosystem. With the request for a Subpart X permit the facility must provide information on the materials being destroyed, the type and quantity of pollutants being released, a description of how these pollutants will be dispersed in time and space, and an assessment on the potential impact on human health and the surrounding ecosystem by these emissions both on short-term and long-term bases.

Very few Subpart X permits have been granted, and the few permits that have been granted are very restrictive in scope. This is due, in part, to the lack of an EPA-approved model specifically designed to simulate OB/OD transport and dispersion. In many other instances, the facility applying for a permit does not have enough data to demonstrate compliance.

To address these issues, the Strategic Environmental Research and Development Program (SERDP) has funded EPA's National Exposure Research Laboratory (NERL) and the National Oceanic and Atmospheric Administration's (NOAA) Environmental Technology Laboratory (ETL) to develop an OB/OD air pollution dispersion model and a Mobile Meteorological Monitoring System (MMMS) that may be used to provide the necessary information needed for evaluation of a Subpart X permit request. The air pollution dispersion model being developed by Weil et al. (1995, 1996a, 1996b) is a Gaussian puff model which considers source emissions, plume rise, transport, and dispersion from disposal by either OB or OD. The MMMS that has been developed is used to provide a detailed characterization of the structure and dispersive state of the atmospheric boundary layer (ABL). Data acquired by the MMMS may also be used by the model for predicting transport and dispersion of emissions released into the atmosphere by an OB or OD.

It is important to accurately characterize the state of the ABL because the plumes released from OB/OD activities rise quickly. To accomplish this, the MMMS includes a suite of in situ and remote sensors to characterize the vertical structure of the atmosphere from the surface up to 2 to 3 km.

The design specifications for a measurement system were first presented at an OB/OD workshop in February 1995 (Banta, 1996), where a consensus was reached on the measurements needed to characterize the ABL and for input into the OB/OD dispersion model. The integrated system was designed to be mobile to be easily and quickly moved from one OB/OD site to another.

This report describes the MMMS system, including the meteorological sensors and their respective data acquisition systems, quality control algorithms, data processing routines, setup procedures, and data formats.

2. MMMS SYSTEM DESCRIPTION

The MMMS system consists of tower-mounted in situ meteorological sensors to acquire surface layer measurements, a suite of ground-based remote sensors mounted on a flatbed trailer to obtain vertical profile data, and accompanying electronics and data acquisition systems located nearby in an enclosed climate-controlled trailer. The in situ meteorological sensors include a propeller anemometer, sonic anemometer, air temperature and relative humidity probe, net radiometer, barometer, and rain gauge. The remote sensing systems include a radar wind profiler, sodar equipped with RASS, and ceilometer. Some system components have been customized for the purpose of this installation.

2.1 In Situ Tower-Mounted Sensors

A 10-m open-lattice aluminum tower serves as a measurement platform for a number of in situ sensors. The variables measured include horizontal wind speed and wind direction, air temperature, relative humidity, net (shortwave and longwave) radiation, barometric pressure, precipitation, and turbulence. If sensors are required at additional locations to adequately observe the surface layer wind field due to complex terrain or other local conditions, the MMMS data acquisition system is designed to accommodate as many ancillary tower systems as required. Each ancillary 10-m tower would usually be equipped with sensors to measure only the horizontal wind speed and wind direction, air temperature, and relative humidity.

2.1.1 Propeller anemometer

An R. M. Young wind monitor (model 05305-AQ) is used to measure the horizontal wind speed and wind direction at 10 m above the ground. The 20-cm diameter, 4-blade propeller used for wind speed measurement is composed of a carbon fiber thermoplastic. The wind vane is lightweight expanded polystyrene, and the main housing, nose cone, and other internal parts are injection molded plastic. Propeller rotation produces an AC sine wave signal with frequency proportional to wind speed. The manufacturer-specified measurement range is for wind speed from 0 to 40 m s^{-1} and wind directions from 0 to 360°. The propeller pitch is 30 cm with a starting threshold of 0.4 m s^{-1}, and the distance constant is 2.7 m for a 63% recovery. The wind vane position is transmitted by a 10-k ohm precision conductive plastic potentiometer. The damping ratio is 0.45 with a delay distance of 1.2 m for a 50% recovery. The starting threshold for wind direction is 0.5 and 0.7 m s^{-1} for a 10° and 5° displacement, respectively.

2.1.2 Sonic anemometer

A Metek sonic anemometer (model USA-1) is mounted on the main tower at 10 m. It is a fast-response instrument that acquires mean (u, v, w, T_v) and standard deviation (σ_u, σ_v, σ_w, σ_{Tv}) of the three-component wind velocity and virtual air temperature. Using eddy correlation techniques, turbulence parameters such as the kinematic heat flux ($\overline{w'T_v'}$), kinematic momentum flux ($\overline{u'w'}$), friction velocity (u_*), temperature scale (T_*), the Monin-Obukhov length (L), drag coefficient (C_D), the longitudinal (I_x), lateral (I_y), and vertical (I_z) turbulence intensities can also be determined from the sonic anemometer data. The sonic anemometer transmits its data via an RS-232 serial line to a computer. The manufacturer-specified measurement range is from 0 to 60 m s^{-1} with a resolution of ±0.01 m s^{-1} for velocity, 0.4° for wind direction, and 0.01 K for temperature.

2.1.3 Air temperature and relative humidity probe

A Vaisala HMP35C probe is used to measure air temperature and relative humidity 10 m above the ground. The probe is housed in an R. M. Young Gill-aspirated radiation shield (model 43408) in order to minimize errors associated with solar heating. Temperature measurement is achieved with a simple thermistor. The humidity sensor is a small capacitor consisting of a thin-film polymer sandwiched between a pair of electrodes that is mounted on a glass substrate. Absorption of water molecules into the polymer matrix results in an increase in sensor capacitance which is proportional to relative humidity. The thermistor and thin-film polymer are enclosed by a membrane filter which protects the sensor elements from particulates. The manufacturer-specified accuracy for temperature measurement is ±0.4 °C over a range of -33 to 48 °C. The manufacturer-specified accuracy for relative humidity is ±2% from 0 to 90% and ±3% from 90 to 100%.

For many meteorological purposes the standard height above the ground for temperature and relative humidity measurements is about 2 m. The purpose for mounting this Vaisala T/RH probe at 10 m is to provide a comparison with the Metek sonic anemometer. If T/RH data are needed at 2 m, the sensor could be mounted at that level or another sensor could be added.

2.1.4 Net radiometer

Net radiation (combined downwards and upwards shortwave and longwave radiation) is acquired with a Radiation Energy Balance Systems net radiometer. This sensor is a 62-junction upward- and downward-facing thermopile protected by polyethylene domes. The manufacturer-specified accuracy is ±5% with a spectral response of 0.3 to 60 μm.

2.1.5 Barometer

Barometric pressure is acquired by a Vaisala PTB-100B analog transducer. The Vaisala sensor is composed of two pieces of silicon with one piece acting as a pressure sensitive diaphragm and the other as a rigid support plate. The two silicon pieces are isolated by a glass layer, which also seals the vacuum reference chamber. Pressure variations deflect the diaphragm and change the sensor's capacitance, which is proportional to the barometric pressure. The manufacturer-specified accuracy is ±0.5 hPa over a measurement range of 600 to 1060 hPa.

2.1.6 Rain gauge

Precipitation is measured by a Texas Electronics model 6118-1 tipping bucket rain gauge. Rainfall is intercepted by a 26-cm diameter orifice which is funneled down to a tipping bucket mechanism. When 0.25 mm of precipitation has fallen, the bucket tips which triggers a mercury switch thereby sending an electric pulse to the data acquisition system. The manufacturer-specified accuracy is 1% for rainfall rates less than 5 cm hr^{-1}.

2.2 Ground-Based Remote Sensors

Several ground-based remote sensors permanently mounted on a flatbed trailer are used to obtain information on the vertical structure of the atmospheric boundary layer (ABL). Wind profiles are obtained with a Doppler sodar and radar wind profiler. Temperature profiles are acquired by a Radio Acoustic Sounding System (RASS), which is comprised of the sodar and radar working in unison. A ceilometer provides cloud heights and vertical visibility measurements.

The radar, Doppler sodar, and ceilometer are mounted on a 7-m-long flatbed trailer (figure 1). The radar is mounted near the front end of the trailer, the sodar near the rear, and the ceilometer at the rear corner. A rack has been installed on the front end of the trailer to store the radar antenna clutter fence during transport.

2.2.1 Doppler sodar

A Radian phased-array Doppler sodar (model 600PA) is used to acquire wind profiles in the first several hundred meters of the ABL. A Doppler sodar operates on the principle of acoustic backscattering. Electronic sound drivers (often referred to as transducers) are used to generate an acoustic pulse which is directed into the atmosphere. As the sound wave propagates through the atmosphere, a small fraction of that energy is scattered by small-scale (~ 10 to 30 cm) temperature inhomogeneities whose scale is one-half the wavelength of the acoustic pulse. These temperature inhomogeneities are produced by turbulence in regions of larger-scale potential temperature gradients, inversion layers, wind shear layers, or thermal plumes produced by surface heating.

After the acoustic pulse is transmitted into the atmosphere, the transducers receive and amplify (by a factor of up to 10^7) the backscattered signal. The signal is sampled and digitally recorded at a rate of several thousand Hz over a period of several seconds. The time series is then divided up into a number of smaller data blocks. Each block is directly related to a discrete layer in the atmosphere at a particular height. A number of different algorithms may be employed (Neff and Coulter, 1986) to determine the mean frequency of the backscattered signal, although a Fast Fourier Transform (FFT) is commonly used. The Doppler shift, the difference between the transmitted and backscattered frequency, is directly proportional to the radial wind velocity along the acoustic beam axis. Determination of the horizontal, vertical, and total wind vectors requires a minimum of three independent radial wind velocities. The sodar transducers are sequenced slightly out of phase to electronically steer the acoustic beam at angles of 15 ° from the vertical.

This sodar employs an array of 120 vertically pointing transducers, each about 10 cm in diameter. The frequency of the acoustic pulse of a sodar usually ranges from 1 to 4.5 kHz, which corresponds to a wavelength of 34 to 8 cm, respectively. The acoustic pulse length (i.e., pulse duration) may vary from 50 to 300 ms, with power outputs ranging from 2 to 300 W. For the Radian 600PA the frequency is nominally set to 2.125 kHz and the pulse length is nominally set at 250 ms.

Horizontal wind speed and direction, and vertical wind speed are acquired from heights of 50 to 800 m over 30-m intervals. However, the backscatter received isn't always sufficient to provide wind data at every level, especially at the higher intervals. The vertical range of a Doppler sodar is a function of acoustic frequency, power output, and atmospheric stability. A convective ABL is conducive to acoustic backscatter and therefore produces a high data return rate. However, a neutral ABL lacks the thermal turbulence that is necessary for acoustic backscatter to the surface. Therefore, a low data return rate is expected for a neutral ABL.

2.2.2 Radar wind profiler

A Radian 924-MHz phased-array Doppler radar wind profiler (modified model LAP-3000) is also used to obtain wind profiles. This UHF radar was originally developed as a boundary-layer profiler by researchers at NOAA's Aeronomy Laboratory as a companion for their 50-MHz VHF deep tropospheric profiler (Ecklund et al., 1988). The 924-MHz radar wind profiler acquires wind data with a vertical resolution of 60-to-100 m over a vertical range from about 125 m to 3 to 4 km with suitable atmospheric conditions. Commercial versions of this UHF profiler have been used in air quality studies and related applications since 1991.

The principles behind the radar profiler are similar to the sodar except the wind profiler uses electromagnetic (EM) waves instead of acoustic pulses to sense turbulent fluctuations in the atmosphere. Because EM signals do not attenuate as quickly as acoustic pulses, a radar wind profiler has a greater vertical range than a sodar. Radar wind profilers rely on scatter from clear-air turbulence to measure the wind, and the signal strength is typically weak when compared to the more well-known weather radars which detect scatter from hydrometeors (i.e., rain, snow, hail). Wind measurements from the radar profiler are based on the assumption that the turbulent eddies that induce EM scattering are carried along by the mean wind. The energy backscattered by these eddies is orders of magnitude smaller than the energy transmitted. However, if sufficient samples can be obtained, then the amplitude of the energy scattered by these eddies can be clearly identified above the background noise level. The mean wind speed and direction within the volume being sampled can be determined from the observed Doppler shift of the backscattered signal.

The 924-MHz radar profiler antenna transmits an EM pulse along a minimum of three (and sometimes five) independent directions. One beam is aimed vertically to directly measure vertical wind velocity. The other two beams are tilted 15° from the vertical and are orthogonal to each other in azimuth. These oblique-angle beams are necessary to measure the horizontal wind components. A microstrip phased-array antenna is used to electronically steer the radar beams. The antenna is enclosed by clutter suppression screens which are designed to minimize the reception of signal returns from ground clutter.

The pulse length (i.e., duration of the EM pulse) determines the volume of air illuminated by the radar beam. Small amounts of the transmitted energy are scattered back towards the surface and are received by the radar antenna. Delays or fixed intervals are built into the data processing system so that the radar receives scattered energy from discrete altitudes, referred to as range gates. The Doppler-shifted frequency of the backscattered energy is determined and then used to calculate the velocity of the air toward or away from the radar along each beam as a function of altitude. The source of the backscattered energy is small-scale turbulent fluctuations that induce irregularities in the radio refractive index of the atmosphere. The radar is most sensitive to scattering by turbulent eddies whose spatial scale is one-half the wavelength of the radar, or approximately 16 cm for a 924-MHz profiler. Simple trigonometric equations are employed to obtain profiles of the horizontal and vertical wind velocity components from the radial velocities.

Boundary-layer radar profilers are often configured to sample in more than one mode. For example, in a so-called "low mode," the pulse of energy transmitted by the profiler may be 60 m in length. The pulse length determines the depth of the column of air being sampled and thus the vertical resolution of the data. The lowest altitude at which winds can be measured in this low mode is about 95 to 105 m. With a 60-m pulse length, the maximum altitude to which data can be collected is typically 1 to 2 km.

In a "high mode" the pulse length is increased to 100 m. The longer pulse length means that more energy is being transmitted for each sample and improved signal-to-noise ratio of the data. The longer pulse length increases the depth of the sample volume but decreases the vertical resolution. Thus, in the high mode greater energy output increases the maximum altitude to which the profiler can sample, but at the expense of coarser vertical resolution and an increase in the altitude at which the first winds are measured. High mode data collected with 100-m vertical resolution can be collected to 3 to 4 km or higher, depending on atmospheric conditions and sampling configuration.

The profilers can also often operate in dual mode (both "low" and "high"). When a profiler is operated in dual mode, the data are often combined into a single overlapping data set by alternating the low- and high-mode samples to simplify post-processing and data-validation procedures.

2.2.3 Radio Acoustic Sounding System (RASS)

A Radian Radio Acoustic Sounding System (RASS) is included, which combines the radar and sodar to acquire profiles of virtual air temperature (T_v). The virtual temperature of an air parcel is the temperature that dry air would have if its pressure and density were equal to those of a parcel of moist air. The definition for virtual temperature is $T_v = T(1 + 0.61q)$, where T is the absolute ambient air temperature and q is the specific humidity. Thus, T_v is always higher than the ambient air temperature. Under hot and humid conditions, T_v may be 2 to 3 °C higher than T.

The principle of operation on which RASS is based is that when acoustic energy is transmitted into the radar beam, Bragg scattering occurs when the wavelengths of the acoustic signals match the half-wavelength of the radar. By varying the frequency of the acoustic signal over a range likely to encompass the appropriate frequencies for current or expected temperature conditions, strongly enhanced scattering of the radar signal occurs when the Bragg match takes place. When this occurs, the Doppler shift of the radar signal produced by the Bragg scattering can be determined as well as the atmospheric vertical velocity. Therefore, the speed of sound as a function of altitude can be measured, from which virtual temperature profiles can be calculated after appropriate corrections for vertical motion have been applied.

Ordinarily, when RASS is added to a radar profiler, four vertically pointing acoustic sources are placed around the radar's antenna, and electronic subsystems are added that include the acoustic power amplifier and the signal generating circuit boards. The acoustic sources are used only to transmit sound into the vertical beam of the radar. The acoustic sources are usually encased in noise suppression enclosures to minimize disturbance to nearby neighbors or others working around the instrument. Instead of using four separate acoustic sources surrounding the radar, in the MMMS configuration the sodar acts as the acoustic source. The phased-array design allows the acoustic beam to be steered slightly upwind of the vertical radar beam, which optimizes data-capture efficiency.

The vertical resolution is determined by the pulse length(s) used by the radar. RASS sampling is usually performed with a 60- to 100-m pulse length. The altitude of the first range gate is typically 100 to 120 m. Because of atmospheric attenuation of the acoustic signals at the RASS frequencies used by the radar, the maximum height above the system that can be sampled is usually 1 to 2 km. The maximum height is also affected by other atmospheric conditions including wind speed, with the maximum decreasing as the wind speed increases.

During the first 25 minutes of a 30-minute sampling interval, the radar and sodar operate independently from each other, acquiring their respective wind profile and backscatter data. During the last 5 min of a 30-min sampling interval, the RASS mode is initiated. The sodar and radar work together to determine a mean profile of T_v.

2.2.4 Ceilometer

A Vaisala laser ceilometer (model CT25K) is used to determine cloud height and vertical visibility. This instrument employs lidar technology and uses a pulsed diode laser with a wavelength of 905 nm. The laser pulses are reflected by haze, clouds, precipitation, fog, mist, and virga and the profile of the backscatter is observed, stored, and processed. The accuracy specified by the manufacturer is ±2% over a range of 7.5 km and a resolution of 15 m.

2.3 Data Acquisition System

A schematic of the data acquisition system is shown in figure 2. Three data acquisition computers are interconnected by a local area network. The computers are labeled "SERDP" (or called the "hub"), "sodar," and "radar." A fourth computer for modeling may also be networked to the system. The radar computer uses the DOS operating system, the sodar computer system is operating in Windows 3.1, and the SERDP computer utilizes the Windows 95 operating system. A new Windows 95 version of the software is under development for the radar system computer.

In addition to the PC computer systems, the data acquisition system includes a Campbell Scientific CR10 data logger located at the meteorological tower. The CR10 acquires data from the in situ instruments including the propeller anemometer, temperature and relative humidity sensors, net radiometer, barometer, and tipping bucket rain gauge, i.e. all of the instruments mounted on or near the tower except the sonic anemometer.

The data-averaging cycle times for the radar and sodar computer systems could individually be set to different lengths, but in practice they are usually set to the same period. The length of the "common" cycle time can also be varied by the operator, but is usually selected to be 30 minutes.

The Campbell Scientific CR10 data logger interrogates its sensors at a rate of 1 Hz and averages over 15-minute intervals. A similar meteorological monitoring system, if used for climate studies, would probably have a much slower sampling rate. However, for the air quality studies served by this system, the relatively rapid sampling rate of 1 Hz is required. The averages computed by the CR10 are stored until copied to the radar/RASS computer once during each radar averaging cycle.

The sodar computer controls the sodar data acquisition, computations, and storage. Once per the sodar's averaging cycle the sodar computer copies the data to the SERDP/hub computer.

The radar/RASS computer acquires the radar data and computes the consensus wind profiles from the data. Once per averaging cycle the radar/RASS computer also directs the sodar computer to initiate RASS observations for a 5-minute period, and then processes the RASS data. Once per averaging cycle it also acquires the meteorological data from the Campbell CR10 data logger. The radar, RASS, and "Campbell" data are all stored on the radar/RASS computer and once per cycle copied to the SERDP/hub computer.

The "SERDP" computer is the network hub of the system. It directly acquires and stores the data from the sonic anemometer and the ceilometer, and periodically acquires copies of the data previously stored on the radar and sodar computers. All of the data are stored on the SERDP PC hard drive and/or backed up locally on a JAZ drive. At the discretion of the operator data can then be transferred automatically via a modem and telephone line or via the Internet to a remote site.

The ceilometer and sonic anemometer write data directly to the SERDP/hub computer and aren't affected by the averaging cycle times of the other systems. The ceilometer instrument computes consensus data internally and writes the information to the SERDP computer once each cycle. The default cycle time for the ceilometer is 30 seconds. The sonic anemometer is controlled by software that resides on the SERDP/hub computer. The length of the averaging period for the sonic anemometer can be set by the operator, and is usually 30 minutes.

2.3.1 Tower-mounted data logger

A Campbell Scientific CR10 data logger as shown in figure 3 is used to acquire data from the tower-based in situ sensors. These data are telemetered via a radio frequency (RF) line-of-site link, or by an RS-232 cable to the radar processing computer on a regularly scheduled basis (typically once per hour) or on demand. Using Campbell Scientific instructions, the data logger is programmed to record scalar-averaged wind speed, vector-averaged wind speed, vector-averaged wind direction, standard deviation of the horizontal wind direction, precipitation, and mean values of air temperature, relative humidity, net radiation, and barometric pressure. A Campbell Scientific model CR10X data logger could be used in place of the CR10 if desired.

2.3.2 Sodar computer

The sodar is operated by a dedicated 486 PC operating under Windows 3.11. Upon startup, the program **TakeData.exe** is executed and acquires data from the sodar antenna. Wind profiles are typically obtained as 30-min averages and displayed in standard meteorological wind barb format for a 24-hour time period.

2.3.3 Radar and RASS computer

The radar data acquisition is controlled by a 486 PC operating under DOS 6.2. Upon startup, the radar computer executes Radian Corporation's version of the acquisition and processing program (**POP4.exe**). The wind profiles are usually obtained as 25-min averages every 30 min. Usually once per hour the meteorological data from the Campbell data logger is also copied to the radar computer via an RF link or an RS-232 cable.

An RS-232 serial line between the radar and sodar computers enables these two systems to work in unison when the RASS data acquisition mode is initiated. When RASS mode is initiated, the radar computer sends a package of information to the sodar computer which switches to RASS mode and emits continuous, variable frequency sound waves. The RASS temperature profiles are obtained as 5-min averages once per designated averaging period (usually 30 minutes).

2.3.4 Sonic anemometer and ceilometer computer

In this installation, the SERDP hub computer is also used to obtain data from the sonic anemometer located on the meteorological tower and ceilometer located on the flatbed trailer using RS-232 serial lines. However, a separate computer could be utilized for the sonic anemometer and ceilometer data if preferred. The program **Metek.exe** acquires the data from the sonic anemometer. It also computes turbulence parameters from the sonic anemometer data, which are recorded as 30-min averages. The program **CeiloWin32.exe** is used to acquire data from the ceilometer. The cloud heights and visibility from the ceilometer are recorded as 30-s samples.

2.3.5 SERDP hub computer

The hub computer has been referred to by several different names: "The Gateway System" is Radian Corporation's terminology for the system computer in its reference information and "SERDP" is the label given to this computer for this project. It is a Pentium system running the Windows 95 operating system. Remote access to the hub computer is possible via a telephone line and a high-speed modem. Data from the hub computer can also be downloaded by File Transfer Protocol (FTP) through an Internet connection. The 486 PC sodar and radar computers are networked to the "hub" computer using NodeRunner 2000/C self-describing Internet cards with LANtastic 7.0 network software.

The hub computer employs a clock card to keep accurate system time. It periodically checks the other computers and resets their respective clocks should they differ by more than 5 seconds. All of the computers and electronics require standard 110/120 AC, 60-Hz voltage. These systems are protected against power surges and outages with an uninterruptible power supply.

The hub computer receives and records all meteorological data from each computer. These data are recorded on a 2 GB hard drive, where data are stored in directories labeled RADAR, SODAR, etc. Under typical conditions the hard drive can accommodate data for about five months.

2.3.6 Model computer

A separate computer for modeling can also be linked to the hub computer using the network connection. This modeling computer could be dedicated to run the OB/OD dispersion model developed by Weil et al. (1995, 1996a, 1996b). The hub computer sends the meteorological data required by the OB/OD model to this workstation.

3. SITE SELECTION AND PLACEMENT OF SENSORS

Guidance for making surface meteorological measurements is provided in a number of EPA documents. They include: *Ambient Monitoring Guidelines for Prevention of Significant Deterioration* (EPA, 1987a); *On-Site Meteorological Program Guidance for Regulatory Modeling Applications* (EPA, 1987b); *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements* (EPA, 1989); and *On-Site Meteorological Instrument Requirements to Characterize Diffusion from Point Sources* (EPA, 1981). Additional information is provided in the *Instructor's Handbook on Meteorological Instrumentation* (NCAR, 1985) and *Guide to Meteorological Instruments and Methods of Observation* (WMO, 1983).

For both the in situ and remote sensing instrumentation the primary objective of instrument siting (horizontal and vertical probe placement) and exposure (spacing and direction from obstructions) is to place each sensor in a location where it can make precise measurements that are representative of the general state of the atmosphere in the region under study. Local flow distortion because of the presence of other sensors, the tower, and the trailers, as well as from other artificial and natural obstructions must be considered. Air temperature may be affected by the proximity of such features as paved parking lots.

Practical logistical considerations such as availability of electrical power, permission from landowners to establish the monitoring site, and security to assure safety of both the public and the station equipment must be considered as well. The site should ideally have limited access by the public and animals and should be fenced if necessary.

To prevent damage by rodents and other small animals, it may be necessary to protect the cables by enclosing them in PVC pipes or suspending the cables above ground. Burying the cables in a shallow trench is usually sufficient to protect them from occasional vehicular traffic and similar disturbances but not from small animals.

For the remote sensing systems in particular, nearby obstructions and "interferences" can affect the character of the backscattered signal and significantly degrade the data product. Some of these effects can be reduced with post-processing software, but it is preferable to identify potential interferences in advance and to avoid them if possible.

Because of the varied instrument characteristics and practical logistical considerations, site selection can be challenging. In addition to the guidelines listed above and comments that follow, the user guides for particular instrumentation also provides invaluable detailed instruction.

3.1 Site Selection for In Situ Tower-Mounted Sensors

Ideally, the 10-m meteorological tower (figures 4 and 5) should be located in an open level area representative of the surrounding terrain. Sometimes the representative terrain includes topographic features or other unusual characteristics that may affect the local meteorological conditions. If such features cannot be avoided they should be well documented. Considerations such as accessibility and security are very important but must not be allowed to override factors that affect data quality.

The standard height of the wind monitor over level, open terrain is 10 m above the ground. Open terrain is defined as an area where the horizontal distance between the instrument and any obstruction is at least ten times the height of that obstruction. The tower should also be a sufficient distance from the trailers to avoid local flow distortions.

The wind sensor is mounted on a boom projecting horizontally out from the tower at a height of 10 m. Precautions must be taken to ensure that the wind measurements are not unduly influenced by the tower, as turbulence in the wake of a tower can be severe. The sensor should be located at a horizontal distance of at least twice the maximum width of the tower, and the boom should be aligned to minimize distortion for the most important wind directions. For example, the boom should project in a northwesterly or southeasterly direction if the predominant wind is from the southwest.

The Vaisala temperature and humidity probe is mounted inside the Gill-aspirated radiation shield, which is mounted on the tower 10 m above the ground, and should be located away from obstructions at a distance equal to at least four times their height. The inlet for the radiation shield should be at least a distance of one tower width from the closest point on the tower. The temperature and humidity measurement should be made over a location representative of the surrounding area. Usually, a plot of open, level ground at least 9 m in diameter is desirable. Any conditions not representative of the surrounding area should be avoided. Provided it is typical of the surroundings, the ground surface should be covered with non-irrigated short grass or with natural earth in areas that lack a vegetation cover. The surface must not be concrete, asphalt, or oil-soaked. If there is a large paved area nearby, the sensor should be at least 30 m away from it. Also to be avoided are large industrial heat sources, roof-tops, steep slopes, hollows, high vegetation, swamps, snow drifts, standing water, and air exhausts. However, if one of these characteristics (e.g. a large paved area) is in fact representative of the larger surrounding area, then it would be an appropriate characteristic of the site selected.

Net radiation measurements should be taken in a location with an unobstructed view of the sky. There should be no object above the horizontal plane of the sensor that will cast a shadow or reflect light on it (including the tower). In addition, it should not be placed near light-colored walls or artificial sources of radiation. In practice, the horizon should not exceed 5°, especially from the east-northeast through the south to the west-northwest. A 5° horizon will obstruct only about 1% of the global radiation and thus can be considered negligible. The net radiometer should be mounted at a height of 2 to 3 m above the ground so that the downward-looking thermopile is acquiring a representative upward flux of short- and long-wave radiation. It is critically important that the instrument be level with the horizontal plane to better than 1°. Any tilt from the horizontal plane may introduce significant errors (Katsaros and DeVault, 1986). This radiometer has a circular spirit level attached so that proper leveling may be achieved.

The pressure sensor is mounted inside a weatherproof fiberglass box that also houses the Campbell Scientific data logger. This enclosure is usually mounted near the base of the tower. Tygon tubing connects the barometer to a “quad disc” outside of the enclosure to dampen high-frequency pressure fluctuations in high winds.

The tipping bucket rain gauge should be mounted over level ground with its orifice horizontal. The minimum distance to obstructions (including the tower) should be at least four times the height of the obstruction, if possible. The ground surface around the rain gauge should be natural vegetation and the orifice of the gauge should also be at least 1 m above the ground to minimize the possibility of rain splashing into the gauge. The gauge could be mounted on a post, on top of a fence, or anywhere there will be a good catch of rain.

3.2 Site Selection for Remote Sensing Equipment

3.2.1 Sodar

An excellent reference for information related to siting of the sodar is the *User's Reference Manual Volume II: Technical Handbook, Revision 3.0, January 1995* by the Radian Corporation. Because of the volume of the sound it should be located away from nearby residences and populated areas (1 km minimum is recommended). The sodar sound volume can be reduced at night if necessary to avoid disturbance to surrounding neighbors. The site should be level and firm, with nearby objects removed, if possible.

Avoid proximity to features such as roads, airports, large trees, buildings, power lines, and hills, and any other objects or surface configuration that may distort the local airflow and/or temperature, such as large paved parking lots. Also avoid any significant local audible noise sources. The manufacturer recommends that the ambient noise level at the site should be less than 50 dBA, when averaged over a representative period. A noise level survey can be performed if there are doubts about the suitability of the site. Crescenti (1998), provides an overview of noise interference on the performance of Doppler sodars.

3.2.2 Radar

When selecting the site for the radar it is important to minimize interferences that affect the backscattered signal, assure that the site is representative of the local meteorology, and meet logistical requirements. The radar system user guide, "*The Lap-3000, A Lower Atmosphere Profiling Radar, Operator's Manual,*" provides excellent information related to these issues.

A site with excessive clutter targets will cause the radar to generate erroneous data. To decrease interferences the site should be level and cleared such that other objects are not greater than 5° above the horizon. Interferences include nearby towers, structures, vertical antennas, power lines, things that sway in the wind such as trees, highway traffic adjacent to the site, and frequent air traffic. Cattle can also be a major problem. Birds flying through the area also affect the data. The site should also be secure and dry, with good drainage, vehicular access, AC power, and telephone.

In general, if the radar antenna has a square cross section the maximum sensitivity of the radar signal is along the principal axes of the antenna and the minimum sensitivity along the diagonal axes, i.e. aligned with the corners of the antenna. The radar profiler is therefore most susceptible to interferences along the axes of beams that are in use.

There are up to five beams available from this radar, vertical plus the 4 "horizontal" axes. It is unusual to find a site that does not have some local interferences and possible clutter sources. The number and character of the potential sources determine the most appropriate orientation of the equipment at the site. If there is one major clutter source, such as a commercial radio antenna, it would be desirable to align one of the "horizontal" axes directly toward that source. The beam that points toward the obstruction would be suppressed. Data in that plane would be acquired only from the corresponding beam on the opposite side of the radar. If there were two interference sources orthogonally placed, it would be ideal to align the instrument axes directly toward both sources. Only the beams on the opposite sides of the radar and the vertical beam would be used. If there are many potential sources of clutter, it would be good to utilize all five beams and to the extent possible site the trailers such that the clutter sources expected to be the most prominent lie along the diagonals of the antenna.

4. FIELD DEPLOYMENT

Deploying the MMMS involves several steps which include transport and leveling of the trailers and instrumentation, erecting the tower, and wiring of the meteorological sensors to their respective data acquisition systems.

4.1 Trailering and Transportation

> *Note*: The following is an overview of experience acquired trailering this equipment to field sites. It is not a comprehensive summary of all information needed to assure safe trailer transportation. Each operator should also refer to the trailer information manuals provided with the system and assure that the towing setup is safe, appropriate, and in accord with applicable state and federal regulations.

There are two MMMS system trailers, a flatbed trailer for the remote sensing equipment and an enclosed "electronics" trailer to house the data acquisition system and related equipment. The flatbed and electronics trailers are transported from site to site using standard ball-hitch towing equipment. The flatbed trailer is equipped with a 5' tongue. The load is distributed such that the tongue weight is quite heavy. It has not been weighed, but it is calculated to be about 1,000 lbs. This trailer is equipped with a 2 5/16" ball and should only be towed using an appropriate truck with a proper hitch. A class III hitch is rated to 5,000 lbs total trailer weight and 500 lbs tongue weight, or 10,000 lbs total and 1,000 lbs tongue weight if a leveling hitch is utilized. A class IV hitch, sometimes found on heavier trucks, is rated at 10,000 lbs total and 1,000 lbs tongue weight.

The electronics trailer is also equipped with a 2 5/16" ball and can be easily towed using a ¼ ton or larger vehicle. Specifications for the flatbed and electronics trailer are given in Appendix B.

A heavy-duty truck would be ideal for towing either of these trailers if available. However, both trailers have also been successfully trailered with smaller vehicles that were equipped with appropriate hitches. For example, the Pace American electronic equipment trailer was towed without difficulty with a standard full-size pickup, and the Superior flatbed remote sensing equipment trailer has been towed successfully with both a dual-wheel standard-size pickup and a 4WD Chevy Suburban.

For the flatbed trailer, the trailer tongue weight is an issue that must be considered. With a 1/4- or 1/2- ton pickup or equivalent a load-leveling hitch is recommended for towing the remote sensing trailer. When towing with such a hitch, the trailer was very stable, the vehicle was level, and the load distribution was correct.

At the field site, the trailers should be parked parallel, about 3 meters apart. The power cable port through the floor of the trailer is at the back corner on the right side, and the ports for cabling to the instrumentation are on the left side of the trailer, about one-third of the way back from the front of the trailer. It is desirable to have the left ("road") side of the enclosed electronic equipment trailer toward the radar/sodar trailer to minimize the cable distance as much as possible. This arrangement shortens the cable run to the minimum required, and minimizes the risk of accidentally walking on the cables unnecessarily. Positioning the trailers such that the trailer door is on the opposite side from the radar also increases the safe distance from the radar and sodar for personnel when entering the trailer.

4.2 Setup of Flatbed Remote Sensing Trailer

Inspect the site for surrounding interferences and position the trailers accordingly. Select a site with adequate security and provide for fencing, if necessary. Arrange for power and phone line connections in advance. The sodar cables are shorter than the radar cables and therefore limit the maximum distance between the trailers.

4.2.1 Level the flatbed trailer and sodar

Figure 6 shows the sodar antenna, which is permanently mounted on the flatbed trailer and is leveled by leveling the trailer. Pick a ground surface that is firm and reasonably level. Block the tires to prevent the trailer from rolling. Then locate the six side jacks and one tongue jack on the flatbed trailer. Place a foot pad under the jacks unless the surface is concrete or otherwise very firm. With the side jacks clear of the surface, adjust the level along the center line of the trailer by adjusting the winch near the front of the trailer.

Next, the six side jacks are used to accomplish horizontal leveling to within ±0.5°. This should only take a few iterations of raising and lowering of the jacks. Extend all of the side jacks to the surface (or footpads) until all six jacks just make contact, and then extend each jack by two turns. If the terrain is uneven additional cement or wooden blocks beneath some of the jacks may be required. Double-check the level along the centerline. It should be unchanged. If necessary, readjust the level along the centerline and double-check the transverse level. On the low side, take the same number of turns on all jacks, e.g. four turns. Observe the change in the level indicator; then continue to adjust. The tolerance of ±0.5° is required to meet the specification of the sodar antenna.

The bottom plate of the sodar, which is used as the reference plane, is not precisely parallel to the bed of the trailer. Carefully double-check the level of the sodar and if it is not correct readjust the jack stands until it is. After the sodar antenna is level it is possible to level the radar antenna.

4.2.2 Level the radar

Figure 7 shows the radar antenna on the flatbed trailer. Check and adjust the radar level. Each corner of the radar antenna base is equipped with a threaded leveling adjustment and inflatable air shocks. The air shocks are designed to protect the antenna elements during transit. On arrival at a site release the pressure from the air shocks to let the profiler frame rest on the threaded leveling adjustment. Lower the air shocks far enough so the frame is supported solely by the threaded rods.

The level of the radar initially can be checked by placing the level on the top of the frame at the base of the antenna. However, the most accurate check is to hold the level against the underside of the stainless plate that forms the bottom of the radar. Neither the plate nor the top of the frame is precisely flat, so some slight variation from perfectly level will be apparent and is unavoidable.

The radar is leveled using four leveling bolts located at each corner of the radar base, numbered 1, 2, 3, 4 in figure 8. Place a digital level on the frame and adjust the adjacent bolts to level that side. Adjust each side until all sides are within tolerance (better than ±0.5°).

4.2.3 Install the sodar clutter screen

During transit the sodar clutter screen is carried in the electronics trailer. It consists of two fiberglass semicircles. They are light enough to be handled by one person, although installation is easier with two. Place each semicircle near the sodar antenna and lift in place one by one. Insert several bolts to hold them in place. If the screens are installed such that the "joint" between the two screens is aligned along the axis of the trailer, it will provide a good baseline along which to check alignment of the trailer.

4.2.4 Install the radar clutter fence and corrugations

Figure 9 shows the radar antenna with the clutter screens partially installed. The radar clutter fence is stored in a rack at the front of the flatbed trailer during transport. Otherwise, the clutter fence might be damaged during transport because of wind resistance and vibration. The clutter fence is separated into twelve sections that are labeled alphabetically. The lettering on the bottom-outside of each section matches a corresponding letter stenciled on the radar frame.

There are many possible approaches for installation of the sections of the screens. Because it is necessary to hold each element in alignment while the fasteners are placed, it is recommended to have at least two people available. However, one person can accomplish this with a little practice. Installation of the clutter screens should take about an hour, and installing the support bracket for the corrugation sections along the top of the antenna should require about an hour.

One approach for assembling the clutter screens is to attach the eight corner sections to the frame first. Hold a corner panel level with the ground or at a slight angle and align it with the matching hinge on the frame. Insert a pin into the hinge to hold the two pieces together. One person can slip the pins into the hinge while holding the panel, but it is easier with two. Connect each of the corner panels to the frame. Then, using a stepladder, raise two adjoining corner sections until the edges are aligned and place pins into the corner hinges. Continue around the fence until all the corners are connected, and then install the remaining elements.

Finally, add the aluminum support brackets along the top of the panels and install the corrugations with the "open" side up (i.e. the side with the foam material exposed). Covers are provided for the corrugations, which should be applied before installing the corrugations on the antenna. Installation of the brackets and corrugations also requires a step ladder. To prevent the bolts from seizing, it is recommended that any of the commercially available "never-seize" products be applied to the bolts before installation. On each of the brackets for the corrugations the left-hand fastener is a large eye bolt to be used to guy the installation in case of high winds.

4.2.5 Install the ceilometer

Before the flatbed trailer is moved the ceilometer (figure 10) is always removed from the trailer because it is not shock-mounted. After arrival at a new site install the ceilometer in its proper location at the rear of the flatbed trailer.

4.3 Setup of Tower and In Situ Instruments

A Metek sonic anemometer, an R. M. Young wind speed and direction anemometer, and a Vaisala temperature and relatively humidity (T/RH) sensor are mounted on top of the meteorological tower. The R. M. Young and T/RH sensors create turbulence that will greatly affect the sonic anemometer, hence the sonic is mounted well above the flow from the other sensors. The R. M. Young sensor is also affected by turbulence from the other sensors and the tower, but less so than the sonic. Typically, the sonic anemometer is located at the center of the stand with the R. M. Young on one side and the T/RH on the other. The net radiation sensors are located on the tower two meters above the ground.

To avoid damaging the R. M. Young sensor it is best not to put the propeller on the anemometer until the unit can be mounted on the tower. There is a risk of damage to the propeller or injury if the propeller is spinning. To reduce the possibility of damaging the vanes, it is also helpful to grasp the instrument frame such that one or two fingers can prevent the sensor from rotating.

The R. M. Young must be installed with the terminal box located on the south side of the unit. For convenience, that box is normally aligned with the boom on which it is supported because the boom can easily be seen from ground level and aligned with the N-S axis. The R. M. Young sleeve fits over the vertical mounting pipe and is tightened into place.

The Vaisala T/RH is connected to a dedicated horizontal pipe. Usually the T/RH is mounted in line with the horizontal support boom, and on the "outboard" side. The T/RH sensor is inserted in the radiation shield about halfway into the hexagonal fitting. Hand tighten the retainer on the shield. Note that the body of the T/RH sensor can be damaged if gripped or tightened excessively.

All of the data cables from the tower instruments and rain gauge are connected to the Campbell data logger except the cables for the sonic anemometer, which run directly to the SERDP computer. The sonic-to-computer data cable is three-conductor, RS-232 protocol, and is connected to the computer with DB9 connectors. The power supply to the sonic cable is two-conductor (12-18V, and G).

The Campbell data logger is typically mounted at the base of the met tower, about 1.5 m off the ground for convenient access.

As a simple field check, the sonic anemometer wind speed readings should be compared with the R. M. Young wind speed measurement. When it is mounted the sonic anemometer should be aligned using the reference arrows on the sonic.

4.4 Setup of the Electronics Trailer

The electronics trailer is shown in figure 11. It is leveled by first blocking the tires and then using the winch at the front of the trailer to lower/raise the trailer to a level position. Scissor jacks placed under the frame of the trailer are recommended for long-term use. Two of the jacks should be mounted at the rear of the trailer near the rear doors.

Power requirements for the entire system are 120 VAC at 60 amps, which should be supplied to the trailer using the three-conductor electrical cable located at the rear of the trailer. Optionally, the trailer may be configured to accept a four-conductor cable by rewiring the sub-panel located in the back inside the trailer. The electrical connections to bring power to the site and the connections at the trailer should be completed by a certified electrician.

Run the cables from the electronics trailer to the radar, sodar, and ceilometer on the remote sensing flatbed trailer, to the sonic anemometer and Campbell data logger at the meteorological tower, and to the electrical power source.

Arrangement of the displays and equipment in the electronics trailer (other than the rack-mounted PCs and controllers) is at the discretion of the operator. The system will be delivered with the cables that are inside the electronics trailer fully connected. After the system is transported it is a good idea to double check that all of these connectors are still tightly in place. After all of the connectors to the external equipment (e.g. to the sodar and radar) are in place, the computers can be powered up.

4.4.1 Power supply

An Uninterruptable Power Supply (UPS) is provided. Power strip protection is also provided for each electronic rack.

4.4.2 LAN and computer connections

The data acquisition computers are linked by a local area network using commercially available software called LANtastic. All of the local area network cabling utilize BNC connectors.

Connect the cables, monitors, keyboards, and mouse for each PC. The monitors provided for the three data acquisition computers are also labeled “SERDP”, “sodar,” and “radar”. The front panel of each PC opens to reveal “reset” and “keyboard lock” function keys. Because it is difficult to reach the back of the computers when they are in the equipment racks, cables have been connected to each computer and run to a more accessible location. Thus, cables from the monitors, etc., need only be connected to the cables already in place rather than directly to the PC. The keyboard can be connected to the front or rear panel of each PC at the convenience of the operator. All of the cables are labeled.

The sonic anemometer, ceilometer, mouse, and modem are connected to serial ports on the SERDP computer. The radar and Campbell data logger are connected to serial ports on the radar computer (periodically, the radar computer sends the radar, RASS, and Campbell data to the SERDP computer). The sodar is connected to a serial port on the sodar computer. All of the ports and cables are labeled for easy identification.

4.5 Wiring, Start-up, and On-line Operations

The wiring for the sodar, radar, and ceilometer is connected from the computers in the electronic equipment racks located in the electronics trailer to the appropriate instruments located on the flatbed trailer. The Campbell data logger and sonic cables connect from computers located in the instrument trailer to the respective equipment at the meteorological tower.

The connectors, sockets, and locking rings for the sodar and radar cables should be checked carefully for dirt before being connected, and cleaned if necessary. Tighten the locking rings fully, being careful not to cross thread them. The connectors should tighten easily if they are clean and properly aligned,

4.5.1 Tower, Campbell Scientific data logger, and in situ tower instruments

The 10-m (30-ft) tower is composed of three triangular 10-ft aluminum sections. To construct the tower, the tower base is first "set" into the ground with a sledgehammer. Attach the lower tower section to the base plate by setting the tower section onto the three pipes located on the tower base, and bolt the tower section to the base. Three guy wires with their respective anchors are used to keep the tower vertical and in place. The 10-m tower can easily be erected by two people working together.

A Campbell Scientific data logger acquires data from all of the in situ meteorological sensors from the primary 10-m tower. The data logger is mounted inside a white fiberglass enclosure which, in turn, is mounted to the base of the tower by means of several U-bolts. A Campbell Scientific PS12 12-volt DC regulated power supply with backup battery is also mounted inside the box. It provides continuous power to the data logger and is charged by a solar panel that is also located at the tower or by an AC adapter connected to a power outlet.

The Campbell is a fully programmable data logger that can accept a wide variety of sensor configurations and types. All of the meteorological instrumentation except the sonic are connected to the Campbell. When the station is deployed it is necessary to program the Campbell and to make all of the necessary data logger-to-sensor connections.

There are two modes of connecting sensors to the Campbell data logger. The single-ended mode will allow 12 channels (i.e. sensors) to be recorded, while the differential mode will allow only six channels. The advantage of differential operation is increased resolution of the signals, and the disadvantage is that a reduced number of sensors that can be recorded by one data logger. The radiation sensors require the differential mode because of low signal levels.

A sample program for the data logger is provided for use with the standard configuration of sensors for the MMMS. Any changes in the suite of sensors installed, however, requires that the program be changed. Programming is described in detail in the Campbell Scientific, Inc. user manual. Campbell also provides a "Prompt Sheet", which lists all of the information necessary for an experienced operator to program the data logger. With the variety of sensors normally being recorded, developing the program is fairly complicated and is best done by experienced personnel before the station is to be deployed.

The Campbell data logger can be programmed utilizing either a "program keypad" or programming software on a PC. If a PC is used the program can be developed and edited before being downloaded to the CR10. The program box approach has the disadvantage that the program must be entered sequentially through the keypad. It is more difficult to review and inspect the program with the keypad, and entry errors are more likely.

Analog (i.e. analog voltage), pulse code (RS232), and counter data may be recorded by the Campbell data logger. The program controls sampling of the input voltages, setting the output flags, calculations, and final storage of processed data. It is recommended that the system battery voltage be recorded, because it is a good indicator of whether the data logger is functioning properly. A battery voltage below 12V may cause some sensors to malfunction.

Theoretically, the sensors could be connected to any Campbell channel. However, once the channels are designated in the program the leads from the sensors must be matched with the corresponding channel numbers. For example, in the example programs listed in the T/RH sensor manual, asterisks in the program listings indicate channel numbers that must correspond to whichever channel is connected on the CR10. Different channel numbers may be selected as long as the designation in the program is changed correspondingly.

Assemble and install the sensors on the tower including the propeller anemometer, T/RH sensor, and radiometers, install the pressure sensor in the Campbell enclosure, and assemble the rain gage. See section 3 for information about placement of the instruments. After attaching the meteorological sensors and fiberglass enclosure to the tower, connect the wires from the sensors to the Campbell CR10 data logger as outlined in Table 1.

When connecting cables from the sensors to the connection blocks in the CR10 loosen the set screw, insert the wire into the slot vertically, and tighten the screw. It is important that all connections are securely fastened to both the sensors and data logger to prevent short circuits or bad data values. Pull gently on the wire after connecting to be sure it is secure.

Table 1
CR10 Wiring Information

R. M. Young Wind Monitor-AQ
(single-ended analog signal)

wire	CR10	Wind Monitor
green	2H (3 Blue)	AZ Signal
black	AG	AZ Reference
red	P1	WS Signal
brown	G	WS Reference
white	E3	AZ Excitation

Vaisala HMP35C T/RH Probe
(differential analog signal)

wire	CR10	Probe
white	AG	prewired
orange	1H (1 Blue)	
green	1L (2 Blue)	
purple	AG	
black	E1	
yellow	E2	
red	12V	
clear	G	

Net Radiometer
(differential signal)

wire	CR10	probe
black	3L	prewired
white	3H	
clear	G	

Tipping Bucket Rain Gauge
(switch closure pulse signal)

wire	CR10	Rain Gauge
black	P2	prewired
white	G	

Pressure Sensor, Vaisala PTB-110B
(analog signal)

wire	CR10	PTB-110B
blue	4H	Pressure (VOUT)
yellow	4L	Signal ground
red	12V	12VDC (supply)
black	G	Pwr Grnd (GND)
green	E3	Control (Ext. Trig.)
clear	G	Clear Shield

note: E3 is shared with the R. M. Young Wind monitor

It is also important that the data logger is properly grounded. A one-meter copper rod should be driven into the ground near the base of the tower. A heavy copper cable should be connected from an Earth ground terminal to the copper rod. The instrument ground circuit should be connected to the blocks labeled G on the CR10, and the external ground should be connected to Earth ground from the external copper strap on the CR10. The analog ground (AG) terminals are all connected internally, so it does not matter which AG terminal is used. The same is true for the ground (G) terminals.

Note that some of the connections on the panel of the CR10 are labeled with both blue and white letters. The blue letters refer to single-ended circuits and the white to differential circuits. It is also useful to be aware that instruction 3 on the Campbell is always a "pulse" code signal.

Assuming the sensors have been mounted on the tower, and the necessary cabling from the sensors has already been connected to the Campbell CR10 data logger, the following describes connecting the data logger and power supply. Power for the CR10 is provided by a Campbell Scientific Model PS12 12 V power supply that contains a battery. The battery in the power supply can be recharged with a solar panel or an 18 VDC charger connected to an electrical outlet.

Turn "off" the switch on the power supply before making the other power supply connections. Remove the cover plate from the PS12 power supply, and connect the red and black leads from the solar panel or the leads from the Arstan AC adapter (color may vary because several manufacturers and models are in use) into the two terminals labeled CHG and CHG next to the battery. The connection of these leads is independent of polarity. If the AC adapter is being used, plug it into an AC outlet. This will provide continuous charging of the power supply battery.

When all of the system connections are completed turn the switch on the power supply to the On position to provide power to the Campbell CR10. With either the solar panel or AC adapter connected the red light will be on. Leave this switch on for the entire study. Turning this switch off any time in the study will result in the loss of the program and all data in the CR10 memory buffer. Replace the battery cover plate. This will ensure that the power switch is not accidentally turned off.

The connections linking the Campbell data logger and the radar computer in the electronics trailer can be completed before or after the data logger is connected to the sensors and power supply, but the power should be secured while the connections are made. To connect the Campbell data logger to the radar computer, first connect an SC12 cable to the CR10 serial I/O port which resides on the wiring panel of the data logger. The other end of the SC12 cable is connected to the SC32A Optically Isolated RS-232 Interface box. Then connect an RS-232 cable between the other end of the SC32A Optically Isolated RS-232 Interface box and serial port number one in the back of the radar computer.

The CR10 data acquisition and management programs reside in a subdirectory named RADAR on the C drive of the radar computer. In DOS mode, access the RADAR subdirectory by typing RADAR and then CD/RADAR.

Then access GT (Graph Term), a DOS-based menu-driven program that allows communication between the computer and data acquisition system, by typing GT SERDP. The GT software presents a menu of several options to control communications between the hub computer and data logger. Several of the necessary options are:

D - download program to data logger
K - set data logger time to PC time
U - collect uncollected data
Q - quit
M - display the data
G - will graph the data

Selecting option **K** will initially set the data logger clock (day and time) using the PC clock as a reference. Then select option **D**, which will download the program **serdp.dld** from the PC to the CR10. It will request a destination file name. Once the time has been set and the program downloaded to the data logger, the data logger immediately begins collecting and recording data with the proper date and time stamps. Data from the CR10 can be manually downloaded by selecting option **U**. The data is downloaded as the file named **serdp.dat,** which resides in the subdirectory RADAR. After the GT software is executing, **U** is called automatically by the batch file on startup and automatically executed once per averaging period. Each time this option is selected, new data is simply appended to the end of the data file. To exit Graph Term select option **Q**, which closes communication between the PC and CR10.

GT is located in the RADAR subdirectory because that is where all of the executable files referenced in **POP4.bat** reside, i.e. the radar batch file runs the **POP4** software, collects the meteorological tower data from the Campbell data logger, and writes the data to the SERDP computer.

Software that acquires the Campbell data automatically is presently available only in DOS and Windows 3.1. For that reason, the Campbell data are written to the radar computer first and then sent to the SERDP computer.

4.5.2 Sodar

Connecting the sodar cables from the electronics trailer to the sodar antenna is straightforward. A photograph of the electronics box underneath the sodar phased array antenna on the flatbed trailer is shown in figure 12. Eight large grey cables are required for the sodar. At the sodar all of the connectors are identical, but the cables and sockets are all labeled. Match the cable number with the appropriate connector on the large grey box found at the bottom of the sodar antenna. Note that the locking rings on these connectors require only a partial turn, but when properly tightened they will "snap" into place.

The procedure to boot up the sodar computer for data acquisition is straightforward but is fairly lengthy, and the operator must be patient. The software will automatically bring up two windows when the boot-up is complete, one presenting backscatter return and the other displaying wind speed and direction. The wind speed and direction data aren't displayed until a full averaging cycle has been completed.

The "start menu" on the sodar computer uses a shareware program called "**WCHRON**", which also automatically runs the data copy program called "**SODARCOPY,**" and copies the data from the sodar computer to the hard drive in the SERDP hub computer. All sodar data is thus stored on both the sodar computer and the SERDP hub computer. There is also a JAZ drive on the SERDP computer for system backup or to transport data to other locations. Periodically, the SERDP computer also collects the sodar data.

To report data results via the Internet requires a phone line and specified locations on the hard drive where the data directories are stored. The naming of the data directories is intended to be as self-explanatory as possible, and includes: CEILO, COMMS, DOWNLOAD, JAS4DGS, MET, RADAR, and SODAR.

There is a difference between how the radar and sodar data are stored. The radar data may be filed in one of three modes: CNS, MOM, and RASS, depending on the operating and data processing software in use. Each type of data creates a separate sub-directory. The sodar data may be saved in up to about nine different modes, but all are stored in the same directory. Thus, the different modes of the radar data are stored in separate directories, whereas the different modes of the sodar data are all stored in one directory.

4.5.3 Radar and RASS

The manufacturer user's guide for the radar is *The Lap-3000, A Lower Atmosphere Profiling Radar, Operator's Manual.* It provides a system description including information for setup and parameter selection and is an excellent resource.

Figure 13 shows the radar electronics box located under the radar antenna. The radar transceiver is first bolted in place under the radar antenna. Next, the cables can be connected. Unlike the sodar, each radar cable connector is unique.

There are four cables for the radar. Two cables are thin coax, one with a BNC connector and the other with an RF screw connector. Attach these connectors to the matching connectors on the white box located underneath the radar antenna. Two larger cables with green military connectors also connect to the white box.

Booting up the radar computer is a step-by-step process. The description that follows assumes the sodar system and sodar computer are already running, and the local area network software is in place and running on the SERDP hub computer. Turn on the radar computer. As the **autoexec.bat** file executes, it will log the radar computer onto the SERDP computer, and will also execute a batch file called **POP4.bat** This **POP4.bat** batch file is essentially an infinite loop that cycles once each averaging period. The batch file runs the **POP** version 4 software and acquires the radar and RASS data, performs some computations, and then transfers data to the SERDP hub computer. "**RADARCOPY.exe**" copies the radar data automatically to the 2-GB hard drive on the SERDP computer. The data is copied automatically once per hour, at 45 minutes after the hour.

During each averaging period the radar computer executes a similar sequence of events controlled by **POP4.bat.** The RASS system automatically acquires data for five minutes each hour. However, the length of acquisition time for the radar data varies, depending on the length of the averaging period selected. The radar computer operates in DOS, so it is a sequential process. The averaging period is usually set to 15 or 30 minutes, but sometimes longer periods such as an hour are selected.

For example, if a 30-min averaging period is selected, wind observations begin a minute or two into the cycle and continue to the end of the first 25-min period, after which RASS data are acquired for 5 minutes. After the end of that 30-min data-collection period and during the first minute or two of the "next" averaging period the consensus of the radar and sodar data is computed and stored on the radar computer. Then the **POP4.bat** file pauses the POP 4 software. It next copies the meteorological data stored on the Campbell data logger to the radar computer, and then the Campbell data, radar data, and RASS data to the SERDP computer, all of which may take a minute or two. Finally it restarts the POP 4 program and begins to acquire new radar data perhaps a minute or two into the new cycle. At this point, the data from the previous cycle are on both the radar and SERDP computers.

Selection of the optimum parameter values is determined by site and hardware characteristics, meteorological conditions expected, and the limitations of the hardware. Consideration of all of the optional combinations exceeds the scope of this manual. Parameters should be selected, if possible, after the environmental conditions at the site are known but before deploying to the field.

It is desirable that the operator be familiar with the radar and sodar system operating parameters, but it is necessary to be very cautious about changing any of the radar and RASS operating parameters (e.g. pulse length). **Inappropriate combinations of parameters can seriously damage the radar.** Changing the prescribed parameters should be done only by someone fully experienced with this aspect of the system.

Figures 14 through 23 provide examples of the **POP4** computer monitor screens that display and allow for setting of the site, RASS, and radar parameters. The principal computer screens displayed when the radar, RASS, and sodar are operating are fairly straightforward. However, examples of the setup screens for the radar and RASS are provided here because they are not as straightforward and because of possible system damage if incompatible parameters are entered. The parameters displayed in these figures are a satisfactory combination for safe and effective system operation and are a good starting point for typical site and meteorological conditions. The operator's manual for the radar further describes the parameter sets and defines terms. In figures 15 through 23, fields where the operator may change entries are highlighted in white.

When the radar data acquisition program (**POP4**) is initialized at a new site and before the system is operated, it is usually necessary only to set some of the site parameters and to double-check the system operating parameters for the radar and RASS. Site-specific parameter files include station name, latitude, longitude, Universal Time Coordinated (UTC), antenna height, and antenna orientation. The zenith angle is measured as a deviation from the vertical.

To display the parameter screens, press alt-Q while the POP program is running to pause the program. Then press F1 to bring up the setup screens, beginning with the main operational setup screen image (figure 14). This screen displays basic information about the current system configuration.

On the main setup screen click on "build parameter file" to bring up the build parameter files screen (figure 15). Then click on "edit" to display a menu for selection of parameters related to the site, sampling, wind, RASS, I/O, or display. Figure 16 displays the site-specific parameters. Note that entering the azimuth angle for one beam automatically sets the azimuth for all beams.

The wind processing parameters screen (figure 17) enables the operator to specify the requirements for satisfactory consensus determination of the wind speed, selection of the "bird algorithm" (ICRA) and highest altitude to which the clutter rejection algorithm will be applied. The RASS parameters screen (figure 18), which is analogous to the wind processing parameter screen displayed in figure 17, allows the operator to specify parameters affecting the consensus computation, anticipated atmospheric temperatures, etc.

Figure 19, parameter sets and beam sequencing, allows selection of the consensus timing and specification of electronic parameters for the radar and RASS beams. This figure displays four parameter sets for the radar in columns at the bottom of the screen. If "RASS" is selected in the pull down menu on the right hand side above "edit set 4", the fourth column will display the RASS parameters. If "wind" is selected in the pull down menu, the fourth column will display a fourth set of radar wind parameters. The radar and RASS consensus timing is displayed (and selected) in the upper left corner of the screen. The grid in the upper right displays the sequence of beam selection, the parameter set applicable to each beam, and the number of repetitions of the “averages” for each radar beam (specified in the parameter sets reached with the “edit set” buttons). This example specifies the first set of radar wind parameters, with a beam sequence of X-vertical, southeast, and northeast. This is a “normal” operating configuration for an MMMS deployment; however it would not be unusual to also sample the beams using another parameter set. This screen also allows the RASS to be turned on or off.

Figure 20 is the screen displayed if “edit set 1" is chosen in figure 19. It is particularly important for the operator to be careful if any changes are made to the radar parameters selected on this screen, to avoid incompatible selections and system damage. Figure 21 is analogous to figure 20 but displays the RASS parameters. It is also selected in figure 19.

Figure 22 displays input/output parameters and file names. The file names and paths are determined by the system requirements to be compatible with other software and ordinarily aren’t changed. Figure 23 displays the run time display parameters, which also ordinarily won’t be changed.

When the site (or other) parameters have been modified, click on “file,” then “save” or “save and run.” Clicking “save” will save the parameters but not change the presently operating program configuration. The POP program can be restarted with the new parameters by either exiting the program and restarting, or clicking on “save and run.”

> *Note*: It is important to double-check one more feature. Return to the main “operational” screen (figure 14), and check to see if the “pause on” feature is active. Click to change it to “pause off,” or the radar will collect only one profile and quit. Click “run” to continue the program.

4.5.4 Ceilometer

There are two cables from the electronics trailer to the ceilometer. An orange AC electric cord with a black molex connector is used to supply power to the unit. Connect the black connector to J2 (power input) found on the bottom of the ceilometer. The second cable, a grey (RS-232) data cable, should be connected from the SERDP/hub computer to J3 (data line), which is also found on the bottom of the ceilometer.

There are three switches in the ceilometer that are reached through an access panel in the side of the ceilometer enclosure, the main circuit breaker (on/off), a circuit breaker for the window conditioner (on/off), and battery on/off. Before connecting any cables be sure that all three switches are in the “off” position. After all cables are connected, turn on the main circuit breaker and battery switch, and the window conditioner. In normal operation all three switches are on. There are two light-emitting diodes on the DC converter; D2 should be steady green and D1 should be blinking yellow after the switches are on. If the internal battery were discharged, the D2 light may not go on immediately. The processor board DMC50A “LED STATUS” will also be blinking at regular intervals. Finally, the ceilometer interface board DCT51 LED labeled D4 will be on during the laser pulse train. If these LEDs do not have this configuration the system isn't working properly. Refer to the manufacturer user manual.

The ceilometer must be vertical. Initially, this can be checked by placing a level next to the housing of the ceilometer. A more precise method is to run the terminal emulator software, which includes a field for the vertical angle. The ceilometer vertical angle should be between plus and minus one degree.

The ceilometer data are recorded at 30-s intervals. After the connections are completed and the hub computer booted up, the hub should begin acquiring the ceilometer data at each 30-s period.

4.5.5 Computer wiring

Attach a keyboard, mouse, and monitor to each computer located in the instrument racks. An RS-232 cable should be connected between the sodar and radar computers to the serial ports labeled RASS. The network connections should already be attached.

If remote meteorological towers are used, connect the Campbell RF base-station to a serial port located on the back of the hub computer labeled SERDP.

5. QUALITY CONTROL ALGORITHMS AND DATA PROCESSING

The hub computer also performs certain quality control and data processing functions. A real-time QA/QC editor (Weber et al., 1993) is employed to check for the quality and consistency of the radar wind profiler data. Newly developed mixed-layer height determination algorithms (White, 1993; Angevine et al., 1994) have also been incorporated which estimate z_i using data acquired by the radar, sodar, ceilometer and sonic anemometers. The hub computer also contains algorithms that process the data in a format needed by the OB/OD model for real-time forecasts of transport and dispersion of released pollutants.

A consensus-averaging (Strauch et al., 1984) or pattern-recognition scheme (Weber et al., 1993) is applied to a sequence of first-moment profiles, thereby eliminating outlying data points. The first averaged moments from each of the beams are then combined to form an average (typically 1 h) wind vector.

6. SOFTWARE AND SAMPLE DATA FORMATS

6.1 Main Tower Data Logger Program and Data

Listed below is the Campbell Scientific CR10 program needed for the acquisition of meteorological data from the standard MMMS suite of sensors at the meteorological tower. If other sensors are substituted or added, modification of this program is required. The sensors are sampled at a rate of 1 Hz and averaged over 15-min intervals.

Program: SERDP CR10 Met Tower Program

Output Array: wss (scalar wind speed, m/s), wsv (vector wind speed, m/s), wd (wind direction, Deg), sig (standard deviation of the wind direction, Deg), t (temperature,°C), rh (relative humidity, %), nr (net radiation, Wm^{-2}), pr (pressure, mb), rg (rain gauge, mm), and v (battery voltage, volts)

```
*    1 Table 1 Programs
 01: 1                    Sec. Execution Interval

01:  P3                   Pulse
  01: 1                   Rep
  02: 1                   Pulse Input Chan
  03: 21                  Low level AC; Output Hz.
  04: 1                   Loc : ws (m/s) R. M. Young model # 5305, wind speed
  05: .1024               Mult (multiplier dependent on model #)
  06: 0.0000              Offset

02:  P4                   Excite, Delay, Volt (SE)
  01: 1                   Rep
  02: 5                   2500 mV slow Range
  03: 3                   IN Chan (Channel 2H)
  04: 3                   Excite all reps w/EXchan 3
  05: 2                   Delay (units .01sec)
  06: 2500                mV Excitation
  07: 2                   Loc : wd (DEG), R. M. Young model # 5305, wind dir., degrees true
  08: .1420               Mult (multiplier for model # 5305 with CR10 data logger)
  09: 0.0000              Offset

03:  P11                  Temp 107 Probe
  01: 1                   Rep
  02: 1                   IN Chan (Channel 1H)
```

```
   03: 1          Excite all reps w/EXchan 1
   04: 3          Loc : T (°C) Vaisala HMP35C
   05: 1          Mult
   06: 0.0000     Offset

04:  P4           Excite, Delay, Volt (SE)
   01:1           Rep
   02: 5          2500 mV slow Range
   03: 2          IN Chan (Channel 1L)
   04: 2          Excite all reps w/EXchan 2
   05: 15         Delay (units .01sec)
   06: 2500       mV Excitation
   07: 4          Loc : R.H. (%) Vaisala HMP35C
   08: .1         Mult
   09: 0.0000     Offset

05:  P2           Volt (DIFF)
   01: 1          Rep
   02: 14         250 mV fast Range
   03: 3          IN Chan (Channels 3H, 3L)
   04: 5          Loc : REBS Q7.1 net radiometer (W/m**2)
   05: 9.24       Mult (multiplier specific to individual sensor)
   06: 0.0000     Offset

06:  P89          If X<=>F
   01: 5          X Loc
   02: 4          <
   03: 0          F
   04: 30         Then Do

07:  P37          Z=X*F
   01: 5          X Loc
   02: 1.246      F (multiplier specific to individual sensor)
   03: 5          Z Loc :

08:  P95          End

09:  P2           Volt (DIFF)
   01: 1          Rep
   02: 25         2500 mV 60 Hz rejection Range
   03: 4          IN Chan (Channels 4H, 4L)
   04: 6          Loc : Pressure (mb) Vaisala PTB-110B
   05: .184       Mult
```

```
 06: 200          Offset *Must add +400 to pr values in post-processing!

10: P3            Pulse
 01: 1            Rep
 02: 2            Pulse Input Chan (P2)
 03: 2            Switch closure
 04: 7            Loc : precipitation (mm) tipping bucket rain gauge.
 05: .254         Mult
 06: 0.0000       Offset

P10               Battery Voltage
 01: 8            Loc : Battery voltage in Volts

12: P92           If time is
 01: 0            minutes (seconds--) into a
 02: 15           minute or second interval (averaging period)
 03: 10           Set high Flag 0 (output)

13: P77           Real Time
 01: 1110         Year, Julian day, hour-minute

14: P78           Resolution
 01: 1            High Resolution

15: P69           Wind Vector
 01: 1            Rep average ws, wd
 02: 0            Samples per sub-interval
 03: 2            Polar Sensor/(S, U, DU, SDU)
 04: 1            Wind Speed/East Loc
 05: 2            Wind Direction/North Loc

16: P71           Average
 01: 4            Reps average t, rh, nr, pr
 02: 3            Loc

17: P72           Totalize
 01: 1            Rep total precipitation amount
 02: 7            Loc

18: P70           Sample
 01: 1            Reps sample battery voltage
 02: 8            Loc
```

```
19: P                   End Table 1

*    2                  Table 2 Programs
  01: 0.0000            Sec. Execution Interval

01: P                   End Table 2

*    3                  Table 3 Subroutines

01: P                   End Table 3

*    A                  Mode 10 Memory Allocation
  01: 28                Input Locations
  02: 64                Intermediate Locations
  03: 0.0000            Final Storage Area 2

*    C                  Mode 12 Security
  01: 0000              LOCK 1
  02: 0000              LOCK 2
  03: 0000              LOCK 3
```

Input Location Assignments (with comments):

Key:
T=Table Number
E=Entry Number
L=Location Number

```
T:  E:  L:
1:  1:  1:  Loc: wind speed (m/s) R. M. Young model # 5305
1:  2:  2:  Loc: wind direction (DEG) R. M. Young model # 5305
1:  3:  3:  Loc: temperature (°C) Vaisala HMP35C
1:  4:  4:  Loc : R.H. (%) Vaisala HMP35C
1:  5:  5:  Loc : REBS Q7.1 net radiometer (W/m**2)
1:  7:  5:  Z Loc :
1:  9:  6:  Loc : pressure (mb) Vaisala PTB-110B
1: 10:  7:  Loc: precipitation (mm) tipping bucket rain gauge
1: 11:  8:  Loc: battery voltage in Volts
```

The following several lines are an example of a comma-delimitated ASCII data file generated by the CR10 data logger. Note data file values are not fixed field.

```
107,1995,147,1500,1.895,1.473,41.959,38.124,18.121,23.967,50.23,1013.2,0.1,12.5
107,1995,147,1515,1.934,1.542,55.924,35.274,18.012,25.984,55.32,1013.1,0.1,12.5
107,1995,147,1530,2.121,1.981,60.125,38.441,18.001,27.267,54.23,1012.9,0.1,12.5
107,1995,147,1545,2.455,2.147,70.221,30.934,17.872,29.432,48.01,1012.9,0.2,12.5
```

Variable 1: Data logger identification number
Variable 2: Year
Variable 3: Julian Day
Variable 4: Time (HHMM), where HH is the hour, MM is the minute
Variable 5: scalar-averaged wind speed (m s^{-1})
Variable 6: vector-averaged wind speed (m s^{-1})
Variable 7: vector-averaged wind direction (deg)
Variable 8: standard deviation of the wind direction (deg)
Variable 9: air temperature (°C)
Variable 10: relative humidity (%)
Variable 11: net radiation (W m^{-2})
Variable 12: barometric pressure (mb)
Variable 13: precipitation (mm)
Variable 14: battery voltage (v)

6.2 Sonic Anemometer Data

The following lines display the averaged data using a fixed format from the Metek sonic anemometers. Four values per line are given, each preceded by its name (five characters, right-aligned), a space character, an equal sign, and an eight-character (right-aligned) floating-point number with a fixed number of decimal digits (possibly with trailing zeros). This number will be replaced by eight space characters in case of invalid data. The values are separated by a space character. The names of the data and their order are given in the following example:

```
SNC 940815090000 UTC AVE      900 SMP       10 AZI        0 XCL        0
 YCL        0 ZCL        0 TCL        0 SDQ      100 HTR
    x =    1.74     y =   -0.93     z =   -0.14     T =    0.62
 xsig =    0.91  ysig =    0.89  zsig =    0.43  Tsig =    0.47
xycov = -0.3911 xzcov = -0.2010 xTcov = -0.1801
yzcov =  0.0961 yTcov =  0.2170 zTcov =  0.1200
psig  =    1.07  qsig =    0.70  rsig =    0.40
  tp  =    0.54    tq =    0.35    tr =    0.20
ustar =    0.39 Tstar =    0.31    Cd =    0.04
  MOs =   -0.03    mf =   -0.19    hf =  144.60
    u =   -0.93     v =    1.74     w =   -0.14
  vel =    1.98   dir =   151.9
```

Every data record starts with a header line that consists of the string **SNC** followed by a space and twelve characters for the date/time, another space, and finally the string **UTC**. In this example, the year is 94, the month is 08, the day is 15, the hour is 09, the minute is 00, and the second is 00. The data names and their respective units are listed below:

SMP	sampling rate (Hz) as defined by *SF* / 1000
AZI	device azimuth as defined by *AZ*
AVE	averaging time as defined by *AT*
XCL	no special meaning
YCL	no special meaning
ZCL	no special meaning
TCL	no special meaning
SDQ	sonic data quality derived from the quotient of the number of valid instantaneous data sets to the expected number of sets (percentage of valid data compared to the expected number)
HTR	sensor head heating was turned on or off while averaging the data
x	Mean x wind component in the sensor-related orthogonal coordinate system (parallel to the black arrow on the electronics box) (m s^{-1})
y	Mean y wind component in the sensor-related orthogonal coordinate system (horizontally perpendicular to x) (m s^{-1})
z	Mean z wind component in the sensor-related orthogonal coordinate system (vertical) (m s^{-1})
T	Mean temperature (°C)
xsig	Standard deviation of x (m s^{-1})

ysig	Standard deviation of y (m s^{-1})
zsig	Standard deviation of z (m s^{-1})
Tsig	Standard deviation of T (K)
xycov	Covariance of x and y (m^2 s^2)
xzcov	Covariance of x and z (m^2 s^2)
xTcov	Covariance of x and T (m K s^{-1})
yzcov	Covariance of y and z (m^2 s^2)
yTcov	Covariance of y and T (m K s^{-1})
zTcov	Covariance of z and T (m K s^{-1})
psig	Standard deviation of the wind component parallel to the mean wind direction (m s^{-1})
qsig	Standard deviation of the wind component horizontally perpendicular to the mean wind direction (m s^{-1})
rsig	Standard deviation of the wind component vertically perpendicular to the mean wind direction (m s^{-1})
tp	Longitudinal turbulence intensity
tq	Transversal turbulence intensity
tr	Vertical turbulence intensity
ustar	Friction velocity (m s^{-1})
Tstar	Characteristic temperature scale (K)
Cd	Drag coefficient
MOs	Monin-Obukhov stability parameter (m^{-1})
mf	Vertical momentum flux (N)
hf	Vertical heat flux (W m^{-2})
u	Mean easterly wind component (m s^{-1})
v	Mean northerly wind component (m s^{-1})
w	Mean vertical wind component (m s^{-1})
vel	Mean horizontal wind velocity (m s^{-1})
dir	Mean horizontal wind direction (deg)

6.3 Sodar Data

The following is an example of a data file **ech70105.cdf** generated by the Radian phased-array Doppler sodar. The first three characters in the filename (ech) refer to the name of the sodar (i.e., echosonde). The next number (7) refers to the year, which in this case is 1997. The next two numbers represent the month (01), and the last two numbers represent the day (05). The suffix (cdf) is an abbreviation for Radian's common data format. The sodar data files are stored in ASCII format. Listed below are the header information and data for only one 15-min averaged interval (out of a possible 96) for January 5, 1997.

```
CDF Type:  Wind             Program:   echosonde             Version:  3.0.31
      bao tower

Station:                 echosonde
Date:                    01/05/97             Julian Day:          5
Filename:                c:\echo\dmc.cdf      Validation Level:    0.0
Created by:              echosonde V. 3.0.31  Created on:          01/05/97    0000
Elev. (m msl):           1630                 Elev. (ft msl):      5320
Lat (dec deg):           40.05000 n           Long (dec deg):      105.03000 w
UTMN (km):               0000.000             UTME (km):           0000.000
Time Zone:               mst                  Diff. to UTC (hr):   6
Mode Number:             2                    Mode Title:          Low Mode Winds
Avg. Int. (min):           15                 Time Convention      End
Pulse Len. (m):          0043                 Spacing (m):           20
Max.Samples:             000 000 000          Req. Samples:        000 000 000
Ant. Azimuth (deg):      315 225 225          Ant. Elev. (deg):    075 075 090

QC Code Definition:      0=Valid,    1=Estimated,    7=Suspect,    8=Invalid
Data Code Definition:  -940=Failed QC,    -950=Failed Consensus,
                       -960=Exceeded Nyquist Vel., -980=Flagged by Reviewer
                       -999=Missing or Not Reported

Time     # of Gates  Radar Parameter Changes
HHMM     NNN         N
QC    Height    WS     WD       u        v         w     No. in Cns       SNR (db)
Code  (m agl)  (m/s)  (deg)    (m/s)    (m/s)    (m/s)    7   1   0     7    1    0
0000     34           0
 0      50       6.9   47.    -5.01    -4.69     0.04   37  37  37     8    8    8
 0      70       8.5   47.    -6.19    -5.76    -0.10   37  37  37     9    9    8
 0      90       8.7   44.    -6.06    -6.23    -0.03   37  37  37     8    8    8
 0     110       9.0   44.    -6.19    -6.51    -0.09   37  37  37     9    8    8
 0     130       9.2   43.    -6.24    -6.81    -0.13   37  37  37     9    9    9
 0     150       9.3   40.    -6.03    -7.12    -0.09   37  37  37     8    8    8
 0     170       9.0   36.    -5.28    -7.32     0.01   37  37  37     8    9    7
 0     190       9.5   37.    -5.71    -7.55    -0.04   37  37  37     8    7    6
 0     210       9.7   39.    -6.14    -7.51    -0.09   37  37  37     6    4    4
 0     230      10.0   38.    -6.21    -7.86    -0.10   37  37  37     4    3    4
 0     250       8.2   15.    -2.06    -7.93     0.64   37  37  37     5    2    2
 8     270    -950.0 -950.     9.32    -7.56     2.75   37  37  37     3    1    1
 8     290    -950.0 -950.     9.41    -7.72     2.72   37  37  37     2    1   -1
 0     310       8.9   26.    -3.96    -8.00     0.10   37  37  37     1   -1    1
 0     330       9.3  346.     2.31    -8.96     1.34   37  37  37     0   -3    0
 8     350    -950.0 -950.     9.38    -8.76     2.69   37  37  37    -1   -1   -2
 0     370       9.1   27.    -4.06    -8.09    -0.03   37  37  37     1    0   -2
 0     390       9.6   27.    -4.30    -8.58    -0.05   37  37  37    -1   -2   -2
```

```
8     410     -950.0 -950.    10.19     -8.70     2.76  37  37  37   -1   -2    0
0     430        9.8  337.     3.92     -9.03     1.53  37  37  37   -2   -2   -1
8     450     -950.0 -950.     8.53     -9.11     2.52  37  37  37   -2   -2   -1
8     470     -950.0 -950.     9.96     -8.69     2.89  37  37  37   -1   -4   -1
8     490     -950.0 -950.     9.87     -8.37     2.84  37  37  37   -2   -3    1
8     510     -950.0 -950.     6.76     -7.32     2.18  37  37  37   -2   -3   -1
8     530     -950.0 -950.     6.14     -6.66     2.00  37  37  37   -7   -3   -2
8     550     -950.0 -950.     4.24    -12.23     2.17  37  37  37   -4   -7    0
8     570     -950.0 -950.    15.08     -4.98     2.79  37  37  37   -5   -9    0
8     590     -950.0 -950.    -1.07      4.95     2.39  37  37  37   -5   -4   -1
8     610     -950.0 -950.     3.22      1.58     2.81  37  37  37   -6   -4   -1
8     630     -950.0 -950.    11.17    -12.42     2.83  37  37  37   -8   -7    0
8     650     -950.0 -950.     0.38     -0.52     2.87  37  37  37   -7   -6    1
8     670     -950.0 -950.     1.27     -2.49     2.81  37  37  37   -9   -5    0
8     690     -950.0 -950.    -1.01      0.87     2.70  37  37  37   -6   -9    0
8     710     -950.0 -950.     3.92      0.94     2.78  37  37  37  -11   -7    2
```

6.4 Radar Data

The following is an example of a data file **bao97074.08w** generated by the Radian radar wind profiler. The first three characters in the filename (bao) refer to the name of the station location, which in this case is the Boulder Atmospheric Observatory. The next two numbers (97) refer to the year, which in this case is 1997. The next three numbers represent the Julian day (074), which in this case is March 15. The first two numbers of the suffix (08) represent the hour, and the last letter (w) identifies the file as a set of wind profiles. The radar data files are stored in ASCII format. In this example, two data sets are given. The first set was acquired when the radar was set in a high-resolution mode, while the second set was acquired when the radar switched over to a low-resolution mode.

```
BAO
WINDS    rev 4.1
 40.05  105.03   1630
 97 03 15 08 05 18   0
 54  3  38
10:19 (2.0) 10:19 (2.0) 10:19 (2.0)
 320 320 50 50 400 400 20 20
 12.7  12.7  1  2100 2100 38 38 400 400
 226 90.0   46 66.4   316 66.4
  HT   SPD DIR  Radials...
0.179  6.3  16   0.6   2.8   1.8 19 19 19  14  16  13
0.234  7.0   6   0.5   2.6   2.3 19 19 17   6  12  12
0.289 9999 999   0.6   2.9  -2.4 19  8  6   7  -8 -10
0.344 9999 999   0.7   3.2  -2.8 18 12  8   4  11  -7
0.399 9999 999   0.4   2.8   2.4 17  7 17  -0  -1   2
0.454  7.6   6   0.9   3.1   2.7 19 15 16  10  12  12
0.509  6.2 303   0.3  -0.3   2.7 15 10 16  -3  -3  11
0.564 11.3 252   0.7  -3.4   2.6 17 13 16   7 -10  10
0.618  7.4   6   0.7   2.9   2.6 18 14 16   8   8   9
0.673  7.1   4   0.7   2.7   2.5 18 15 17   8   7   8
0.728  6.4   2   0.7   2.5   2.4 19 14 17   7   6   7
0.783  5.8 354   0.6   2.0   2.4 18 14 17   6   4   6
0.838  5.3 352   0.6   1.8   2.3 18 15 18   5   5   4
0.893  3.6 337   0.6   1.1   1.9 18 14 18   4   3   3
0.948  3.7 309   0.6   0.4   2.0 18 16 16   4   2   3
1.003  5.9 297   0.7  -0.2   2.9 19 16 12   3   0   1
1.058  9.4 306   0.8   0.1   4.4 19 17 10   3   3   1
1.113 13.6 304   0.8  -0.4   6.1 19 13 15   3   3   1
1.168 15.6 306   0.8  -0.4   6.9 19 15 18   3   2   1
1.223 16.5 304   0.9  -0.6   7.2 18 16 16   3   1   2
1.278 17.2 305   0.8  -0.5   7.5 18 15 16   2   2   1
1.333 17.5 302   0.9  -0.8   7.7 19 15 15   2   0   1
1.388 18.5 301   1.0  -1.1   8.0 18 15 14   2  -0   1
1.443 19.3 301   1.0  -1.1   8.4 19 17 13   1   2   0
1.498 18.9 300   1.0  -1.2   8.1 18 17 13   2   2   1
1.553 19.7 299   0.9  -1.5   8.4 19 17 13   2   1   0
1.608 20.5 300   1.0  -1.4   8.8 19 18 13   2   2  -0
1.663 21.4 301   0.9  -1.4   9.1 19 17 11   2   2   1
1.718 21.2 299   0.9  -1.7   8.9 19 19 14   2   2  -1
1.773 22.1 298   0.9  -1.9   9.3 18 17 13   1   2  -1
1.828 22.4 298   0.9  -2.0   9.3 19 18 12   1   1  -1
1.883 22.9 298   0.9  -2.0   9.5 19 18 14   0   1  -2
```

```
1.938 23.4 298   0.9   -2.1    9.7 18 18 12   0    1   -2
1.993 23.9 297   0.9   -2.2    9.9 19 16 11  -0    1   -1
2.048 24.4 296   0.9   -2.5   10.0 19 17 13  -1    0   -2
2.103 25.1 298   0.8   -2.4   10.3 19 19 12  -1   -1   -2
2.158 24.8 297   0.8   -2.5   10.1 18 17 11  -1   -1   -3
2.213 25.8 297   0.8   -2.6   10.5 18 17 11  -2   -2   -4

BAO
WINDS    rev 4.1
 40.05  105.03   1630
 97 03 15 08 05 18   0
 54  3  30
09:18 (2.0) 10:19 (2.0) 10:19 (2.0)
 270 270 50 50 700 700 30 30
 10.0  10.0  1  2200 2200 30 30 700 700
 226 90.0   316 66.4   46 66.4
  HT   SPD DIR  Radials...
0.186  8.3   9   0.1    2.0    2.7 17 14 19   1    3    8
0.282  8.6   6   0.2    2.4    2.8 17 16 18   5    5   12
0.378  7.4   7   0.9    2.7    3.1 18 17 18  21   19   19
0.474 10.2   6   0.1    2.7    3.2 17 16 17   4    6   15
0.570  7.7  11   0.9    2.6    3.3 18 17 17  20   19   19
0.667  7.4   9   0.8    2.5    3.1 18 19 17  18   18   18
0.763  6.5   2   0.8    2.5    2.6 18 19 16  17   16   17
0.859  4.8 352   0.7    2.2    1.8 18 18 18  15   14   17
0.955  4.8 321   0.8    2.6    0.9 18 17 19  14   15   15
1.051 10.1 308   0.8    4.7    0.2 18 14 17  13   13   11
1.148 14.8 306   0.8    6.6   -0.3 18 17 16  13   11   12
1.244 17.0 306   0.9    7.5   -0.4 18 19 15  13   10   13
1.340 18.2 303   0.9    7.9   -0.9 18 19 15  13   10   12
1.436 18.9 302   0.9    8.2   -1.0 18 19 15  12   10   12
1.533 19.6 302   0.9    8.5   -1.0 18 19 17  12    9   13
1.629 20.4 300   0.9    8.7   -1.5 18 17 19  12    9   12
1.725 21.1 298   0.9    8.9   -1.8 18 17 19  12    8   12
1.821 21.9 298   0.9    9.2   -1.9 18 17 19  12    7   11
1.917 22.5 298   0.9    9.4   -2.0 18 14 19  11    6   11
2.014 22.8 297   0.9    9.4   -2.1 18 11 19  10    3   11
2.110 27.0 152   0.8   -9.6   -2.3 18 11 18  10    6   11
2.206 26.9 152   0.7   -9.7   -2.3 18 15 19   9    4   10
2.302 26.6 152   0.7   -9.6   -2.4 18 15 18   7    3   10
2.398 26.3 153   0.6   -9.6   -2.5 18 15 19   6    2    9
2.495 25.9 153   0.5   -9.4   -2.6 18 14 19   5    1    8
2.591 25.9 154   0.6   -9.3   -2.6 18 16 19   5    1    8
2.687 25.9 154   0.6   -9.3   -2.6 18 17 19   4   -0    6
2.783 25.0 154   0.5   -9.1   -2.6 18 17 18   3   -1    6
2.879 24.5 154   0.4   -9.0   -2.6 18 17 19   2   -2    5
2.976 24.0 154   0.4   -8.8   -2.7 18 18 18   0   -3    4
```

Line 1: Blank line
Line 2: Station identification letters
Line 3: Software version number
Line 4: Latitude (N), longitude (W), and elevation above mean sea level (m)
Line 5: Year, month, day, hour, minute, second, and UT offset (min)

Line 6:	Consensus averaging time (min)
	Number of beams
	Number of range gates
Line 7:	Number of records required to make consensus for beam 1
	Total number of records for beam 1
	Consensus window size (m s^{-1}) for beam 1
	Number of records required to make consensus for beam 2
	Total number of records for beam 2
	Consensus window size (m s^{-1}) for beam 2
	Number of records required to make consensus for beam 3
	Total number of records for beam 3
	Consensus window size (m s^{-1}) for beam 3
Line 8:	Number of coherent integrations (oblique and vertical)
	Number of spectral averages (oblique and vertical)
	Pulse width (ns) (oblique and vertical)
	Inner pulse period (ns) (oblique and vertical)
Line 9:	Full-scale Doppler value (m s^{-1})
	Vertical correction applied to oblique (0=no, 1=yes)
	Delay to first gate (ns) (oblique and vertical)
	Number of gates (oblique and vertical)
	Spacing of gates (ns) (oblique and vertical)
Line 10:	azimuth (deg) and elevation (deg) (for each beam)
Line 11:	Labels for columns of data that follow
Column 1:	Height above ground level (km)
Column 2:	Wind speed (m s^{-1})
Column 3:	Wind direction (deg)
Column 4:	Radial velocity of beam 1 (m s^{-1})
Column 5:	Radial velocity of beam 2 (m s^{-1})
Column 6:	Radial velocity of beam 3 (m s^{-1})
Column 7:	Number of records that made consensus for beam 1
Column 8:	Number of records that made consensus for beam 2
Column 9:	Number of records that made consensus for beam 3
Column 10:	Average signal-to-noise ratio (dB) of records in consensus for beam 1
Column 11:	Average signal-to-noise ratio (dB) of records in consensus for beam 2
Column 12:	Average signal-to-noise ratio (dB) of records in consensus for beam 3

6.5 RASS Data

The following is an example of a data file **bao97081.08t** generated by the Radian radio acoustic sounding system. The first three characters in the filename (bao) refer to the name of the station location, which in this case is the Boulder Atmospheric Observatory. The next two numbers (97) refer to the year, which in this case is 1997. The next three numbers represent the Julian day (081), which in this case is March 22. The first two numbers of the suffix (08) represent the hour, and the last letter (t) identifies the file as a set of temperature profiles. The RASS data files are stored in ASCII format.

```
BAO
RASS     rev 4.1
 40.05  105.03    1630
 97 03 22 08 01 05    0
  4  1  20
06:12 (2.0)
 10 20 400 20
405.6  1700 20 400
 226 90.0
   HT        T       Tc        W       CNT             SNR
 0.135    21.8     21.3     0.3     10    7    9    -21 -21 -26
 0.195     6.8      6.9    -0.1     12    8    8    -15 -14 -21
 0.255     6.3      6.1     0.3     12    8    7    -11 -10 -22
 0.315     5.8      6.0    -0.1     12    6    6    -11 -10 -24
 0.375     5.4      5.1    -0.0     12    8    9    -13 -12 -26
 0.435     5.5      5.1     0.4     11    8    7    -14 -13  -4
 0.495     5.9   9999.0     0.1     12    4    4    -14 -18 -24
 0.555     5.9      4.8     0.6     12    6    6    -15 -13 -27
 0.615     5.3   9999.0     7.4     12    4    2    -18 -21 -31
 0.675     4.8   9999.0     0.9     12    3    3    -19 -22 -30
 0.735     4.5      3.8     0.4     12    6    6    -20 -18 -29
 0.795     4.2   9999.0     0.0     12    5    5    -22 -24 -28
 0.855     4.1   9999.0     0.5     11    2    3    -22 -25 -27
 0.915     4.1      3.9     0.1     11    8    8    -23 -24 -26
 0.975     4.0   9999.0     0.6     10    2    3    -22 -25 -25
 1.035     3.8   9999.0    -0.3     11    4    4    -22 -22 -12
 1.095     4.6   9999.0    -0.2     10    5    7    -24 -25 -10
 1.155     4.8   9999.0     0.1      9    5    6    -26 -26 -15
 1.215     4.7      4.8    -0.1     10    7    7    -28 -28 -16
 1.275     4.5   9999.0    -9.5      7    3    2    -28 -30 -29
```

Line 1:	Blank line
Line 2:	Station identification letters
Line 3:	Software version number
Line 4:	Latitude (N), longitude (W), and elevation above mean sea level (m)
Line 5:	Year, month, day, hour, minute, second, and UT offset (min)
Line 6:	Consensus averaging time (min) Number of beams Number of range gates

Line 7:	Number of records required to make consensus
	Total number of records
	Consensus window size (m s^{-1})
Line 8:	Number of coherent integrations
	Number of spectral averages
	Pulse width (ns)
	Inner pulse period (ns)
Line 9:	Full-scale Doppler value (m s^{-1})
	Delay to first gate (ns)
	Number of gates
	Spacing of gates (ns)
Line 10:	Azimuth (deg) and elevation (deg)
Line 11:	Labels for columns of data that follow
Column 1:	Height above ground level (km)
Column 2:	Uncorrected temperature consensus (°C)
Column 3:	Corrected temperature consensus (°C)
Column 4:	Vertical wind velocity consensus (m s^{-1})
Column 5:	Number of records that made consensus for uncorrected temperature
Column 6:	Number of records that made consensus for corrected temperature
Column 7:	Number of records that made consensus for vertical wind velocity
Column 8:	Average signal-to-noise ratio of records in consensus for uncorrected temperature
Column 9:	Average signal-to-noise ratio of records in consensus for corrected temperature
Column 10:	Average signal-to-noise ratio of records in consensus for vertical wind velocity

6.6 Ceilometer Data

The following is an example of a data file generated by the Vaisala CT25K ceilometer:

```
09/29/97 10:40:34
☺CT61023☻

OW ///// ///// ///// 00010200

100 N  98 +26 169  219  +1    9 SF7LN1   0

000F91D005EFFFCFFEDFFDEFFD1FFE4FFE1FFD7FFADFFC1FFD7FFEB00050019FFE9
016FFD50016000F00540046OO25FFF80016OO14001B00A600290004FF9BFFD30039
032FFF1FFDC0066FFDEFF9100050035005E00240011FFD4FFCC0039FFEAFFA0FF9F
048001DFFEDFFD8FFA0FF9FFF8DFFDD0003FFC1FFF8FFEEFFDEFFD600220013001F
0640016FFC9002BFFABFFE5003FFFFB00470014002BFFB80011FFF5FFACFFBCFFD2
080FFE200310007001100 27FFD2004000540021000300320011FFF100220023FFFF
096000E0079FFE9FFF8FFB30051FFE20069002CFFFE000FFFECFFDE005EFFF0FFEA
11200130000FFBD003C0035FFD4000100130027000BFFE30000FFE100060028FFE1
128003B0021000FFFB20043FFF6FFD30008000DFFD8FFD30043001CFFE4FFA3000F
144FFE3004BFFF700000022FF730065FFC2FFCFFFF6FFEA001EFFE5FFE5FFC4FFD8
160FFF900320041FFEC002500200013FF87000CFFF80013FFEF004A001F000AFFE5
176FFD4FFF9FFB5FFEDFFA3001BFF7B0036FFD4FFBAFFDD00230036002CFFB9001B
192FFF1FFF4FFD9FFB20002000C005AFFA60017FFE2FFBD002DFFC8002CFFBE0054
208004DFFECFFCAFFFBFFE8FFF4FFCF0025FFF3FFA70011FFCD0002FFF9001E0008
224FFCA00050067FFC8FFF3002E0023FFE1FFEAFFFF001D002FFFEFFFC4FFA10011
24000640039001CFFCBFFEEFF8C0037001BFF8F000F0026000000000000000000000
```

Line 1:	Date (mm/dd/yy) and time (hh:mm:ss)
Line 2:	Ceilometer's identification string
Line 3:	Status byte
	Warning/error byte
	Lowest cloud-base information
	Second lowest cloud-base information
	Highest signal detected
	Highest cloud-base information
	4 2-byte error/warning indicators
Line 4:	Scale parameter (0 to 999), %
	Measurement mode
	Laser pulse energy, % of normal
	Receive sensitivity, % of normal
	Window contamination (0-2500)
	Tilt angle
	Background light
	Measurement parameter codes
	Sum of detected backscatter
Line 5-20:	Backscatter profile in hexadecimal pair (00-FF)

7. SAFETY AND MAINTENANCE CONSIDERATIONS

The following provides an overview to highlight certain safety and maintenance requirements for various MMMS instruments. It is anticipated that such a listing will help field teams to quickly become familiar with the operating requirements. However, this is NOT intended to be a comprehensive listing of all such information or to replace the need to refer to documentation provided by the manufacturers regarding safe operation and proper maintenance. The information contained in this section is largely based upon the manufacturer user's guides and technical manuals.

All of the sensors, cabling, and other equipment should be visually inspected on a routine basis. All guy wires should be periodically checked, and adjusted when necessary.

7.1 Tower-mounted in Situ Sensors

Periodic maintenance of the R. M. Young wind sensor requires checking the bearings in both the propeller and the vertical shaft. There are two approaches to this check. A qualitative check is possible by spinning the propeller and observing as it slows to a stop. When badly worn, the propeller will slow gradually but then will stop abruptly. A correctly operating bearing will gradually slow to a stop. A more accurate method is to obtain a torque reading with the device provided for this purpose by the manufacturer. This device measures the torque required to start rotating the shaft from a dead stop.

The temperature/relative humidity (HMP35C) probe requires minimal maintenance, but should be calibrated annually. A single-point calibration technique to eliminate the temperature offset is described in the manual.

7.2 Sodar

The following suggestions for safe operation and maintenance are largely drawn from the manufacturer user manual, *User's Reference Manual Volume II: Technical Handbook, Revision 3.0, January 1995*. It provides excellent guidance regarding safety and maintenance issues.

Warning signs noting the hazard of electrical shock and hearing damage must be located and periodically inspected to assure they are readable and readily apparent to anyone approaching. The warnings should include the following: "When approaching the sodar antenna, BE SURE TO SHUT DOWN THE SODAR." and "Looking over and into the acoustic enclosure while the sodar is operational IS HAZARDOUS TO YOUR HEARING."

A variety of maintenance items must be performed periodically. In addition, if system performance degrades or if changes are observed in the sound of the acoustic pulse, it is recommended that the "quarterly" maintenance checks be carried out.

The manufacturer also recommends that the antenna self-test module should be run weekly. If bad transducers are found replacement can be delayed as long as the number of unsatisfactory transducers is less than 10% of the total and they are randomly located. However, at least quarterly unsatisfactory transducers should be replaced, followed by an antenna self-test. The system should be routinely inspected for damage to the cables and debris on the array.

The air filters in the host PC should be checked, cleaned and/or replaced, and all wiring connections should be checked to see they are firmly connected. The system should be backed up periodically. Periodically inspect the vicinity of the data acquisition site and all equipment for obstructions and/or damage.

Periodically, check the level of the array, and readjust the leveling jacks on the trailer if necessary. The array should be level to +/- 0.3 degrees. If there is any concern the trailer may have been moved, recheck the orientation of the installation and verify the compass direction.

7.3 Radar

The Radian Corporation's radar operator's manual provides information regarding safety and maintenance (*The Lap-3000, A Lower Atmosphere Profiling Radar, Operator's Manual*). The operator's manual recommends signs be placed on the receiver/modulator, on the antenna structure, and along the cables warning of risk of electrical shock, and on the clutter screen designating it as a restricted area. The manual also recommends that the following warning should be posted: "Do not lean over the top of the clutter screen, open the clutter screen, or spend long periods of time near the profiler while the profiler is operating. Doing so endangers your well-being."

The Radian Corporation operator's manual also recommends, "Periodically clean the air filters in the computers, remove the dust from the electronic components, check cables and connections, and backup/copy data from the hard disk. All of the equipment exposed to the weather should be inspected for wear, damage and debris. The manufacturer recommends that all hinges, turnbuckles, and leveling screws should be lubricated with WD-40 or something equivalent."

7.4 Ceilometer

The CT25K uses pulsed diode laser LIDAR technology, in which short, powerful laser pulses are sent out in a vertical or near-vertical direction. The invisible laser radiation may seriously harm human eyes if one looks at the beam. Avoid looking at the unit toward the beam direction, and never look directly into the transmitter with magnifying optics (glasses, binoculars, etc). Be certain the LASER WARNING labels are in place on the ceilometer and clearly visible to anyone approaching.

> *Note*: **If the battery switch is on, the laser is operating even if the master circuit breaker is off.** Therefore, it is mandatory to turn off both the master circuit and the battery circuit to prevent eye exposure to the laser, e.g. before maintenance. When the system is operating, all three switches are normally on. When not in use all three switches should be off.

The instrument chassis and cabinet must be grounded. Review the manufacturer user guide, "Safety Summary" for further information including a list of the warning labels displayed.

Detailed instructions for assembly of the pedestal, measuring unit, and shield are provided in the user's guide. In particular, when lifting the measurement unit, note handles are provided for this purpose. Again, if the unit is operating and is tilted for any reason, be sure that there is no one looking toward it with binoculars or other magnifying optics.

A listing of factory settings for the user programmable parameters is provided in the manufacturer user guide. In normal operation this ceilometer samples the atmosphere every 100 nano-seconds, providing a spatial resolution of 50 feet from the ground up to 25,000 feet.

Periodically the operator should (1) be sure windows are clean, (2) check to make sure the alarms and messages are operating properly, and (3) be sure the air blower is functioning properly. The window should be cleaned with a soft, lint-free cloth moistened with mild detergent. Be careful not to scratch the window surface.

7.5 Computers

There are air filters in the front of each PC that must be cleaned periodically. No standard interval is specified, as operating conditions will vary widely. However, it is recommended this be done on a routine basis at least monthly and more frequently as conditions warrant.

8. SHIPPING

There are many ways to pack the equipment for shipment, and any approach that assures safe transport and easy assembly is acceptable. However, after moving the system several times, a pattern has developed that works well.

During shipment the instrument cables from the instrument trailer to the radar, sodar, and ceilometer on the equipment trailer are disconnected from each instrument. They are pulled back into the instrument trailer. Rather than piling the cables under the 19" computer racks, the cables can be coiled neatly on the floor of the trailer, with as much of the weight as possible near the back of the trailer. Similarly, the electrical power cable should be disconnected from the power source, fed through the cable port at the right-rear corner of the trailer, and laid on the trailer floor.

Cardboard shipping boxes are provided for the PC monitors. During shipping, these have been usually placed under the tables along the left side of the electronics trailer.

The sonic anemometer should be wrapped in foam packing material and placed in the wooden crate at the forward-left side of the trailer.

Profiler corrugations (i.e. corrugated edge treatment) should be handled carefully. During shipment this can be easily stowed on top of the benches on the right side of the trailer. While not terribly expensive, it is important to treat this material with care as it is difficult to replace or repair if damaged.

The support brackets for the corrugations can be removed and placed in the electronic trailer on the floor along the centerline. Clutter Screens for the radar are stored in the rack at the front end of the remote sensing equipment trailer. Fasteners for the sodar and profiler installation may be placed in the box on the tongue of the equipment trailer or in any of the drawers in the electronics trailer.

The tower sections, cabling, and related equipment may all be placed on the floor in the electronics trailer. The large semi-circular screens for the sodar can be placed in the rear of the electronics trailer during shipment, on top of the cables and frames used for the profiler edge treatment.

> Note: The ceilometer is not shock-mounted on the equipment trailer. Hence, it is recommended that the ceilometer be removed from the flatbed trailer when transporting the equipment between sites. It should be carefully enclosed in foam packing material in the electronics trailer. Also, the ceilometer could be carried in the towing vehicle to provide a smoother ride.

9. ACKNOWLEDGMENTS

The successful completion of this manual would not have been possible without the contributions of many professionals. The authors first wish to thank Dr. William J. Mitchell for his vision and leadership, and Dr. William D. Neff and Dr. John E. Gaynor for their contributions. The authors are very appreciative of the comments and recommendations received from Catherine A. Russell, and for her assistance developing the program for the Campbell Scientific, Inc. data logger. This work has been supported by the Strategic Environmental Research and Development Program, project number 251.

10. REFERENCES

Angevine, W. M., A. B. White, and S. K. Avery, 1994: Boundary-layer depth and entrainment zone characterization with a boundary-layer profiler. *Bound.-Layer Meteor.*, **68**, 375-385.

Banta, R. M., 1996: ETL/EPA workshop on open burning/open detonation (OB/OD). NOAA Tech. Memo. ERL ETL-267, Boulder, CO, 54 pp.

Crescenti, G. H., 1998: The degradation of Doppler sodar performance due to noise: a review. *Atmos. Environ.*, **32**, 1499-1509.

Ecklund, W. L., D. A. Carter, and B. B. Balsley, 1988: A UHF wind profiler for the boundary layer: Brief description and initial results. *J. Atmos. Oceanic Technol.*, **5**, 432-441.

Katsaros, K. B., and DeVault, J. E., 1986: On irradiance measurement errors at sea due to tilt of pyranometers. *J. Atmos. Oceanic Technol.*, **3**, 740-745.

Neff, W. D., and R. L. Coulter, 1986: Acoustic remote sensing. *Probing the Atmospheric Boundary Layer*, D. H. Lenschow, Ed., Amer. Meteor. Soc., 201-239.

National Center for Atmospheric Research, 1985: *Instructor's Handbook on Meteorological Instrumentation.* NCAR/TN-237+IA, Boulder, Colorado.

Strauch, R. G., D. A. Merritt, K. P. Moran, K. B. Earnshaw and D. van de Kamp, 1984: The Colorado Wind-Profiling Network. *J. Atmos. Oceanic Technol.*, 1, 37-49.

U. S. Army, 1995: *Joint Demilitarization Study, Joint Ordnance Commanders Group.* Demil Technology Office, U. S. Army Defense Ammunition Center and School, Savanna, IL, 128 pp.

U. S. Environmental Protection Agency, 1981: *On-Site Meteorological Instrumentation Requirements to Characterize Diffusion from Point Sources.* EPA-600/9-81-020, Research Triangle Park, North Carolina.

U. S. Environmental Protection Agency, 1987a: *Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD).* EPA-450/4-87-007, Research Triangle Park, North Carolina.

U. S. Environmental Protection Agency, 1987b: *On-Site Program Guidance for Regulatory Modeling Applications.* EPA-450/4-87-013, Research Triangle Park, North Carolina.

U. S. Environmental Protection Agency, 1989: *Quality Assurance Handbook for Air Pollution Measurement Systems. Volume IV: Meteorological Measurements.* EPA-600/4-90-003, Research Triangle Park, North Carolina.

U. S. Environmental Protection Agency, 1993: *RCRA 40 CFR Part 264, Subpart X Draft Permit Writers Technical Resource Document.* Code of Federal Regulations, Title 40, Part 264, Office of the Federal Register, Washington, D. C.

Weber, B. L., D. B. Wuertz, D. C. Welsh, and R. McPeek, 1993: Quality controls for profiler measurements of winds and RASS temperatures. *J. Atmos. Oceanic Technol.*, **10**, 452-464.

Weil, J. C., B. Templeman, R. Banta, and W. Mitchell, 1995: Atmospheric dispersion model development for open burn/open detonation emissions. Proc., *88th Annual Meeting & Exhibition*, San Antonio, TX, Air & Waste Management Assoc., paper 95-MP22A.05.

Weil, J. C., B. Templeman, R. Banta, R. Weber, and W. Mitchell, 1996a: Dispersion model development for open burn/open detonation sources. Preprint, *9th Joint Conference on the Applications of Air Pollution Meteorology*, Atlanta, GA, Amer. Meteor. Soc., 610-616.

Weil, J. C., B. Templeman, and W. Mitchell, 1996b: Progress in developing an open burn/open detonation dispersion model. Proc., *89th Annual Meeting & Exhibition*, Nashville, TN, Air & Waste Management Assoc., paper 96-TA35.01.

White, A. B., 1993: Mixing depth detection using 915-MHz radar reflectivity data. Preprints, *8th Symposium on Meteorological Observations and Instrumentation*, Anaheim, CA, Amer. Meteor. Soc., 248-250.

World Meteorological Organization, 1983: *Guide to Meteorological Instruments and Methods of Observation (Fifth edition).* WMO No. 8, Geneva, Switzerland.

FIGURES

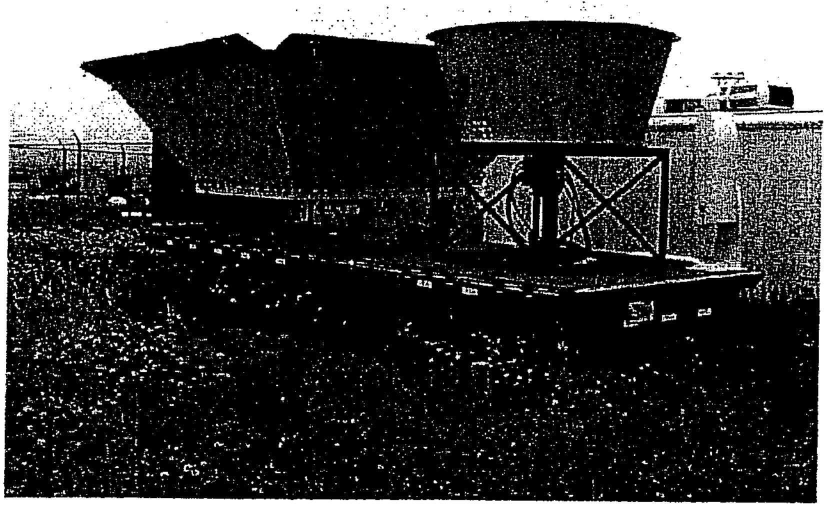


Figure 1. Photograph of remote sensors on the flatbed trailer (l to r: wind radar, sodar, ceilometer)

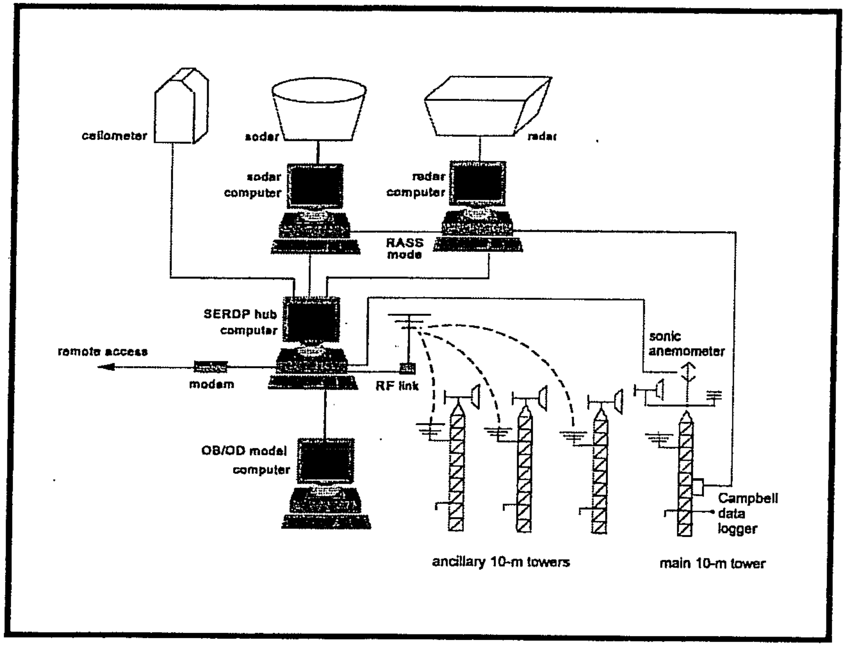


Figure 2. Schematic of Mobile Meteorological Monitoring System.

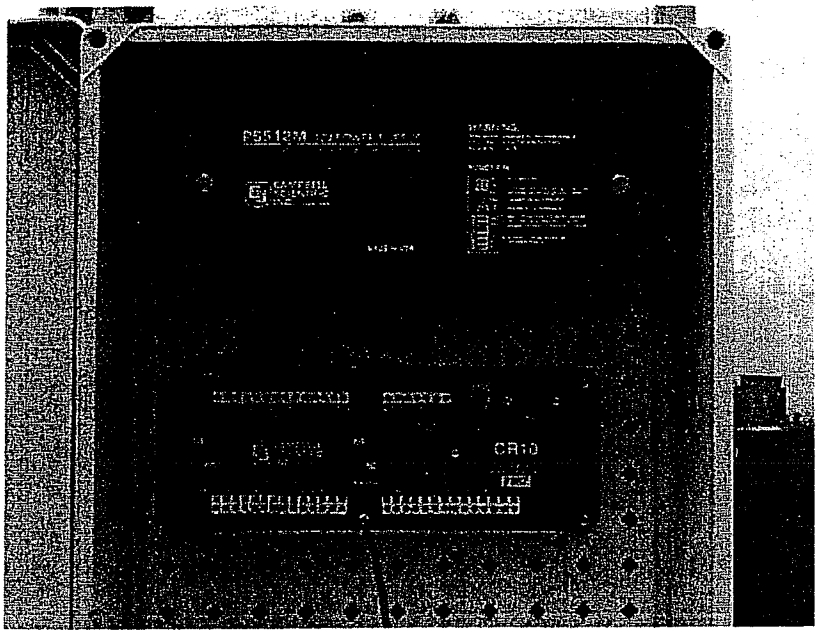


Figure 3. Campbell Scientific CR10 datalogger and 12V power supply

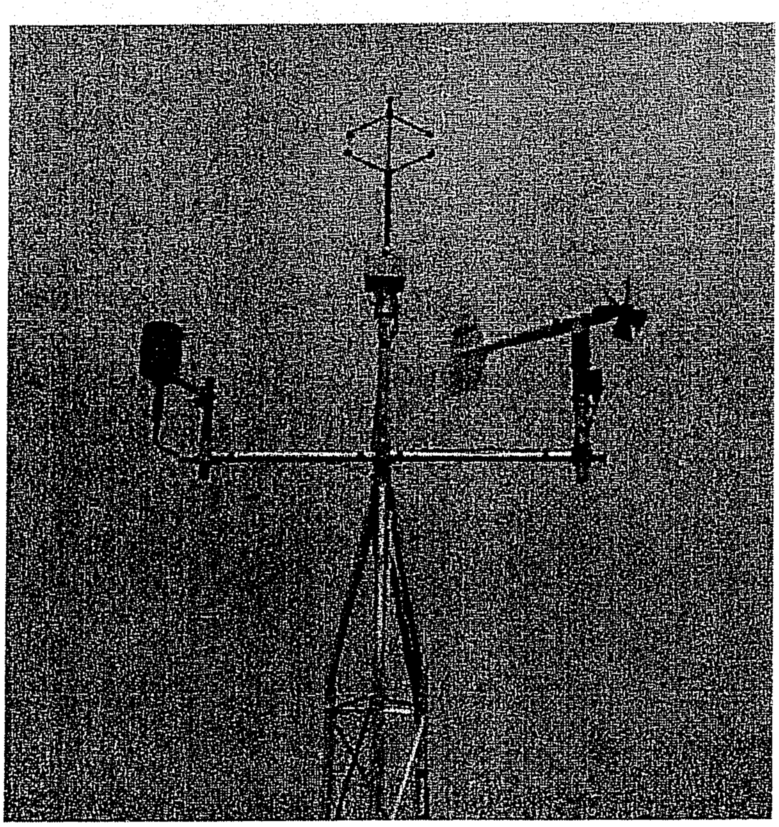


Figure 4. Top of the 10-m tower and met sensors (T/RH, sonic anemometer, and R.M. Young anemometer.

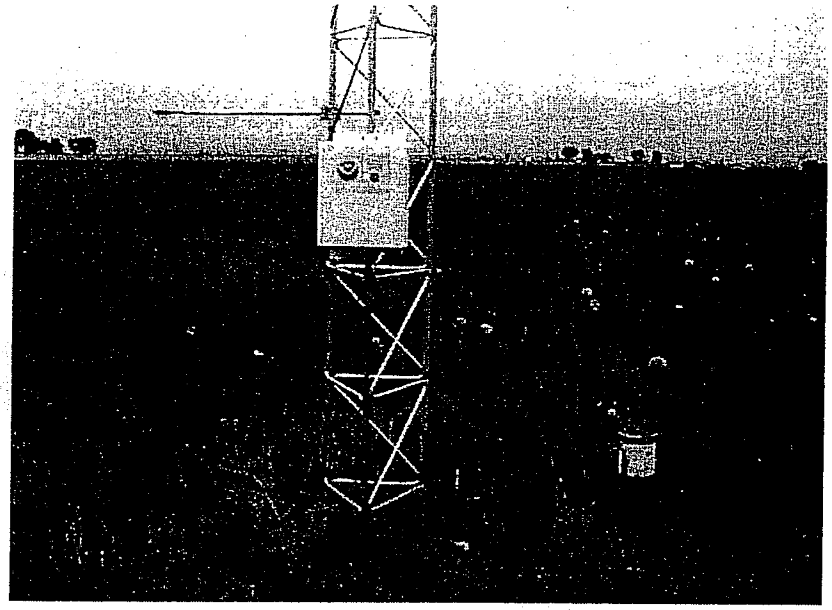


Figure 5. Campbell Systems data logger enclosure and net radiometer on tower, and rain gauge

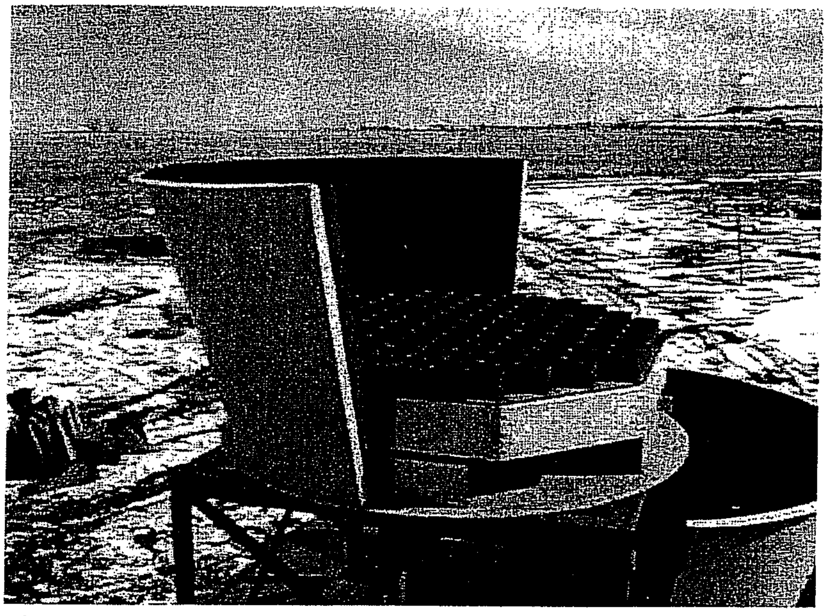


Figure 6. Attaching enclosure on Radian's phased array sodar.

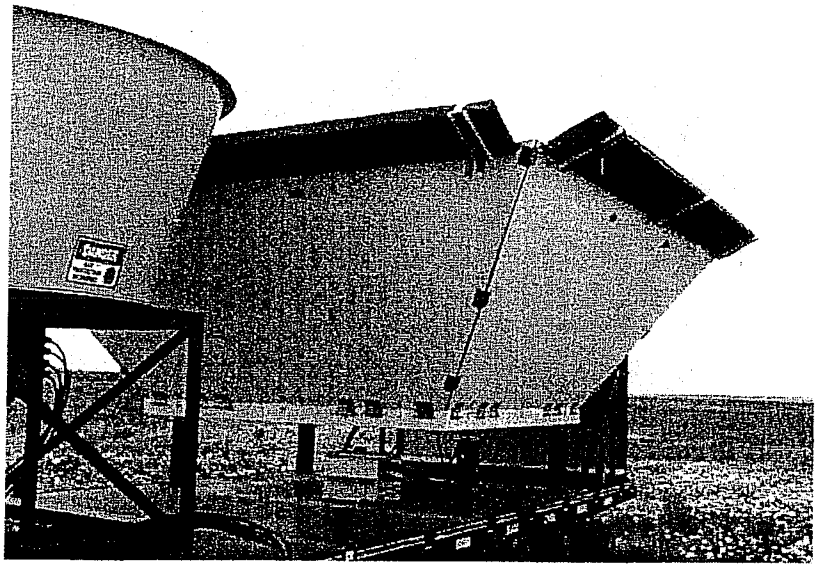


Figure 7. Radian radar wind profiler with clutter screen and corrugations in place

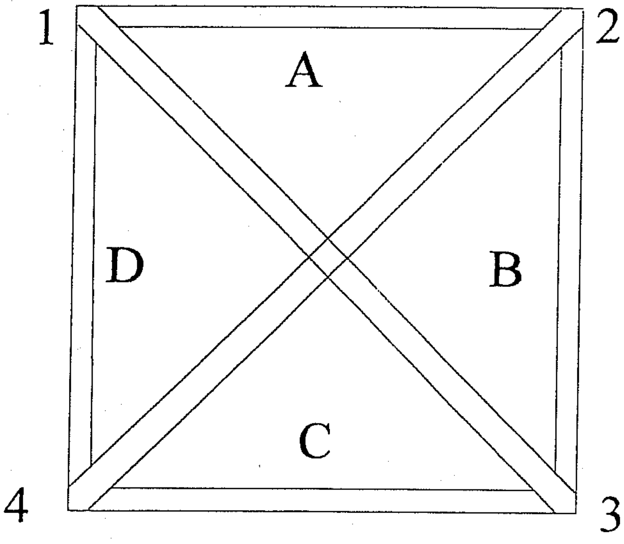


Figure 8. Locations on radar frame for placement of level (A, B, C, D) and location of leveling bolts (1, 2, 3, 4).

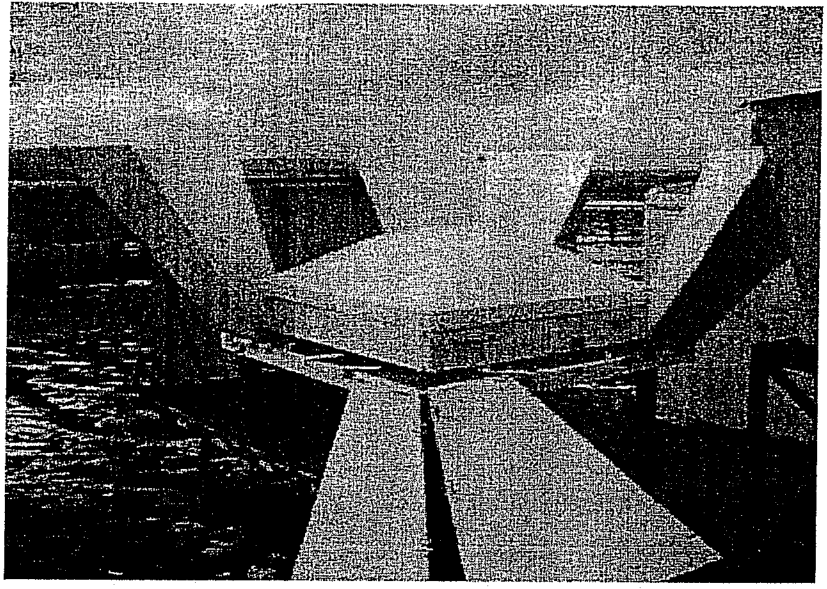


Figure 9. Attaching clutter fence to Radians's 924 MHz radar

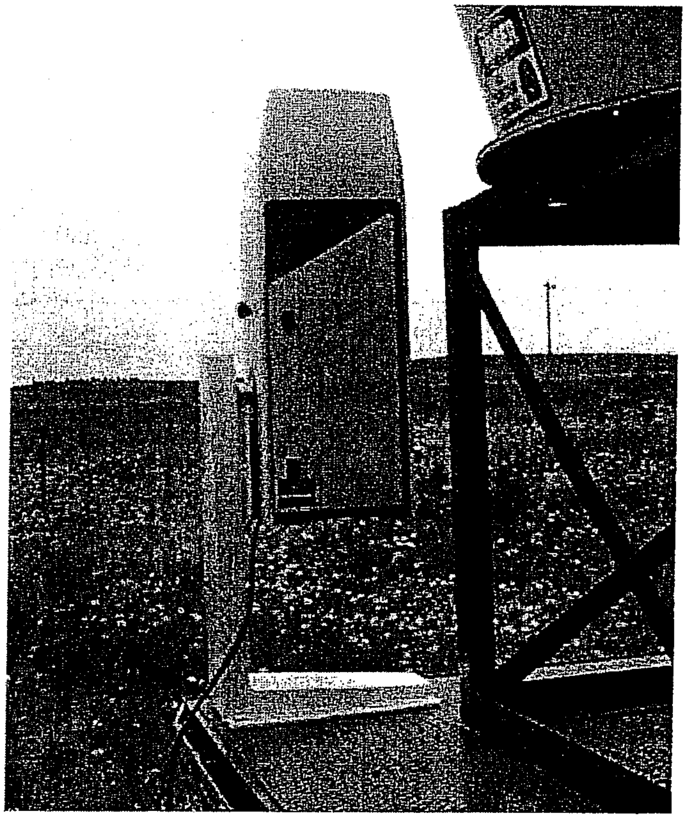


Figure 10. Ceilometer

Figure 11. System electronics trailer

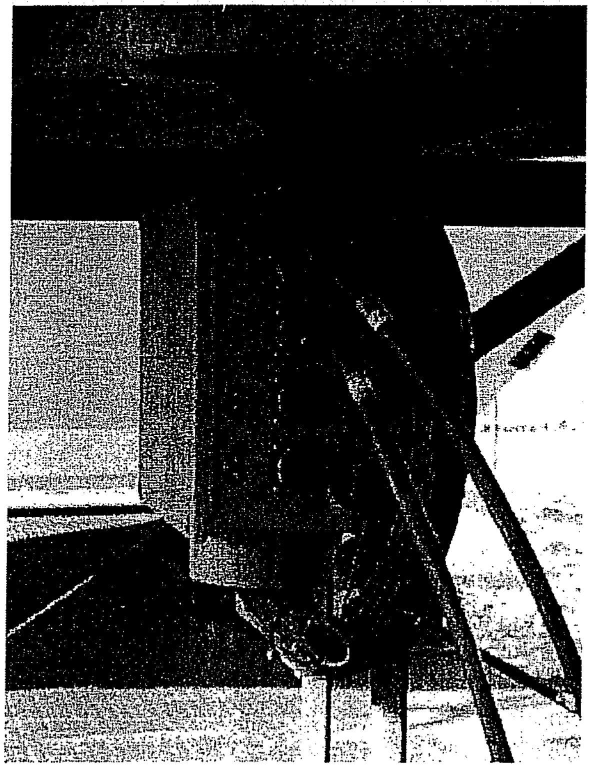


Figure 12. Sodar electronics box located under the sodar (with 2 of the 8 cables connected).

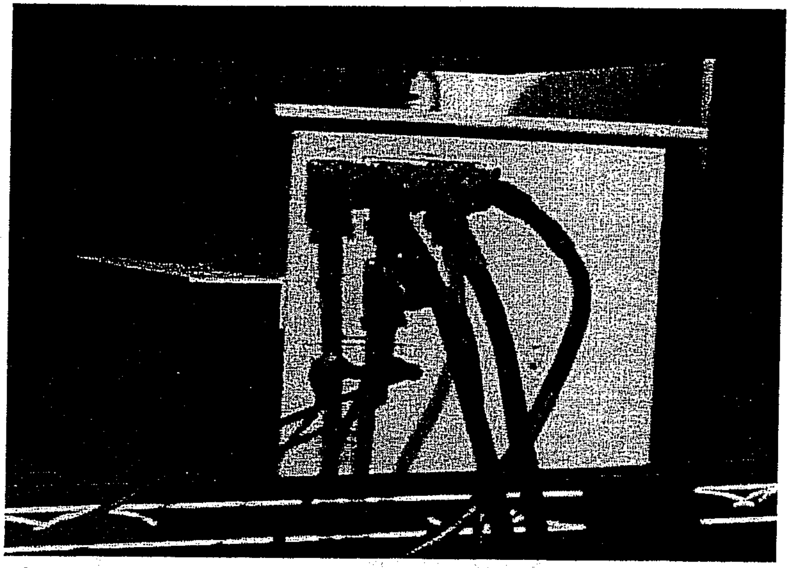
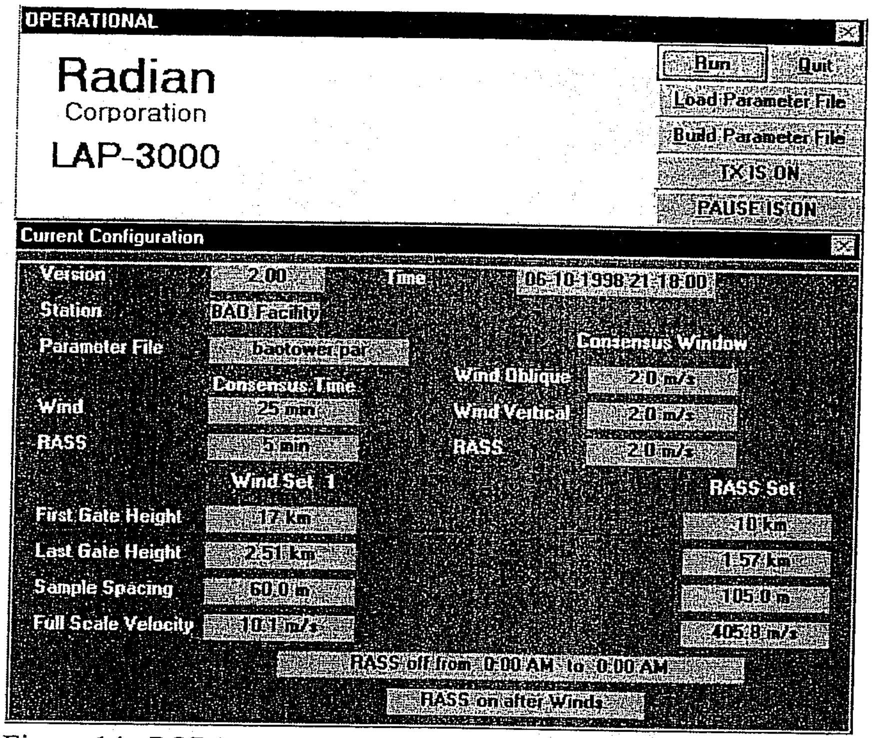


Figure 13. Radar electronics box located under the radar antenna.



Version 2.00 Time 06-10-1998 21:18:00

Station BAD Facility

Parameter File baotower.par

Consensus Time

Wind 25 min

RASS 5 min

Consensus Window

Wind Oblique 2.0 m/s

Wind Vertical 2.0 m/s

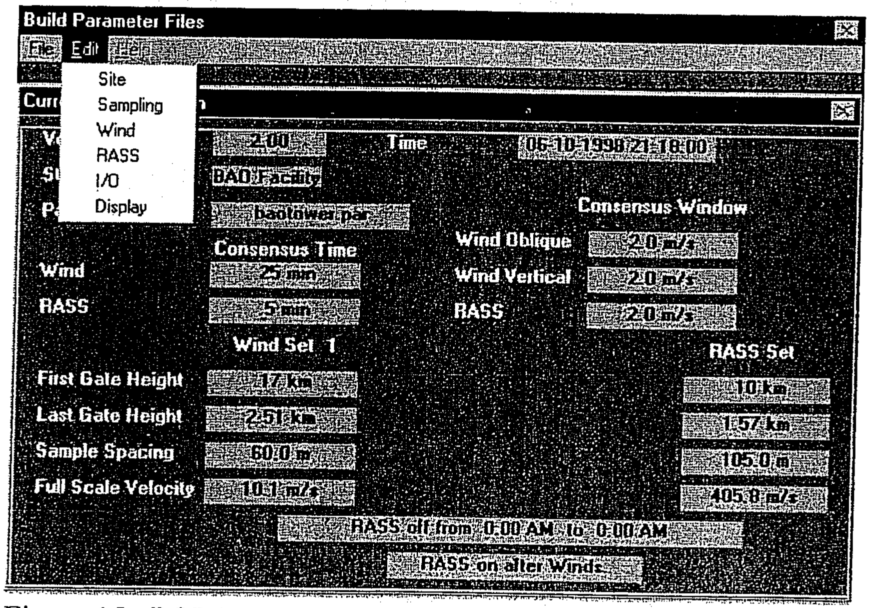
RASS 2.0 m/s

	Wind Set 1	RASS Set
First Gate Height	17 km	10 km
Last Gate Height	2.51 km	1.57 km
Sample Spacing	60.0 m	105.0 m
Full Scale Velocity	10.1 m/s	405.8 m/s

RASS off from 0:00 AM to 0:00 AM

RASS on after Winds

Figure 14. POP4 screen, operational setup



Version 2.00 Time 06-10-1998 21:18:00

Station BAD Facility

Parameter File baotower.par

Consensus Time

Wind 25 min

RASS 5 min

Consensus Window

Wind Oblique 2.0 m/s

Wind Vertical 2.0 m/s

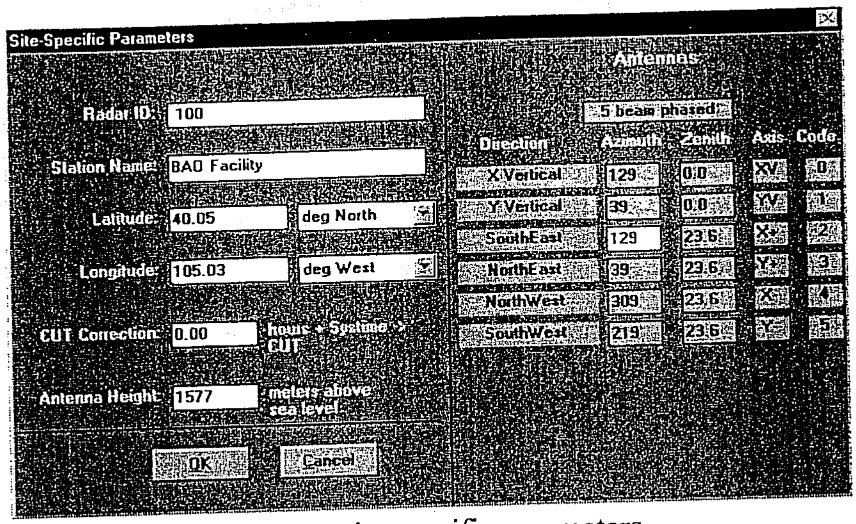
RASS 2.0 m/s

	Wind Set 1	RASS Set
First Gate Height	17 km	10 km
Last Gate Height	2.51 km	1.57 km
Sample Spacing	60.0 m	105.0 m
Full Scale Velocity	10.1 m/s	405.8 m/s

RASS off from 0:00 AM to 0:00 AM

RASS on after Winds

Figure 15. POP4 screen, build parameter files



Radar ID: 100

Station Name: BAO Facility

Latitude: 40.05 deg North

Longitude: 105.03 deg West

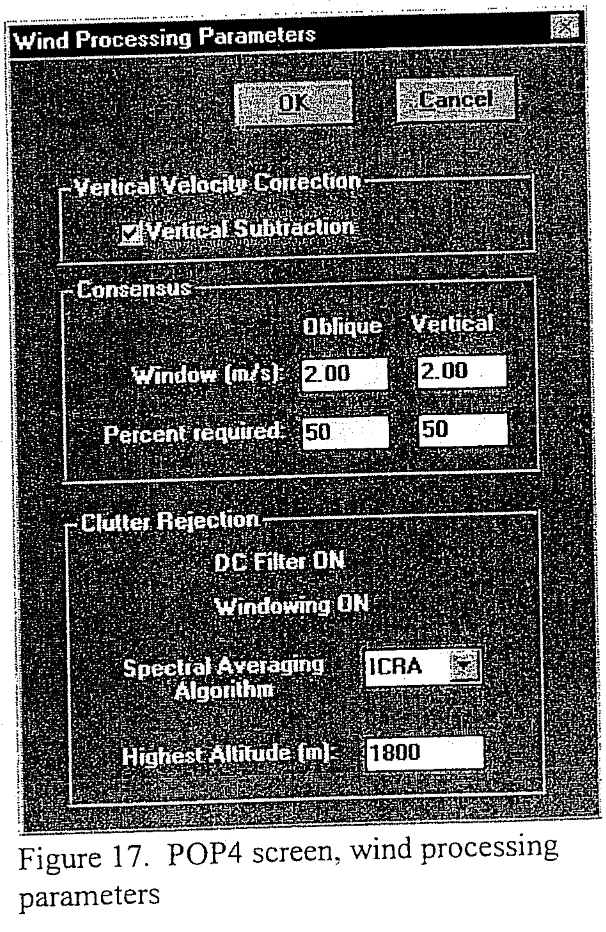
CUT Correction: 0.00 hours + Systime -> CUT

Antenna Height: 1577 meters above sea level

5 beam phased

Direction	Azimuth	Zenith	Axis	Code
X Vertical	129	0.0	XV	0
Y Vertical	39	0.0	YV	1
SouthEast	129	23.6	X+	2
NorthEast	39	23.6	Y+	3
NorthWest	309	23.6	X-	4
SouthWest	219	23.6	Y-	5

Figure 16. POP4 screen, site specific parameters



☑ Vertical Subtraction

	Oblique	Vertical
Window (m/s):	2.00	2.00
Percent required:	50	50

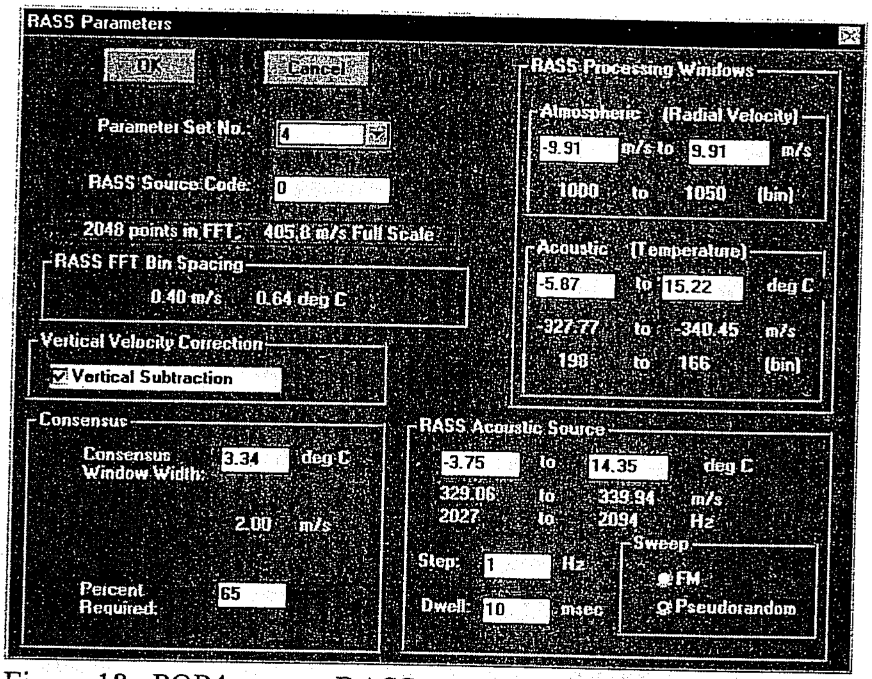
DC Filter ON

Windowing ON

Spectral Averaging Algorithm: ICRA

Highest Altitude (m): 1800

Figure 17. POP4 screen, wind processing parameters



Parameter Set No.: 4

RASS Source Code: 0

2048 points in FFT, 405.8 m/s Full Scale

RASS FFT Bin Spacing: 0.40 m/s 0.64 deg C

Vertical Velocity Correction: ☑ Vertical Subtraction

Consensus

Consensus Window Width: 3.34 deg C

2.00 m/s

Percent Required: 65

RASS Processing Windows

Atmospheric (Radial Velocity): -9.91 m/s to 9.91 m/s

1000 to 1050 (bin)

Acoustic (Temperature): -5.87 to 15.22 deg C

-327.77 to -340.45 m/s

198 to 166 (bin)

RASS Acoustic Source: -3.75 to 14.35 deg C

329.06 to 339.94 m/s

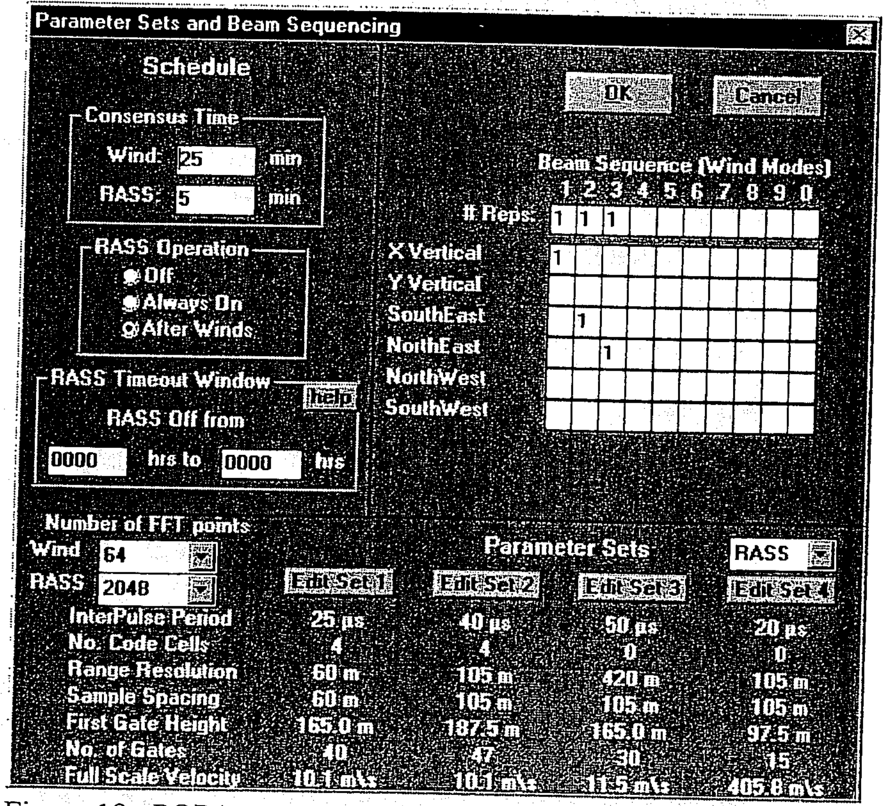
2027 to 2094 Hz

Step: 1 Hz

Dwell: 10 msec

Sweep: ● FM ○ Pseudorandom

Figure 18. POP4 screen, RASS parameters.



Schedule

Consensus Time

Wind: 25 min

RASS: 5 min

RASS Operation: ● Off ● Always On ○ After Winds

RASS Timeout Window

RASS Off from 0000 hrs to 0000 hrs

Beam Sequence (Wind Modes)

	1	2	3	4	5	6	7	8	9	0
# Reps:	1	1	1							
X Vertical	1									
Y Vertical										
SouthEast		1								
NorthEast			1							
NorthWest										
SouthWest										

Number of FFT points

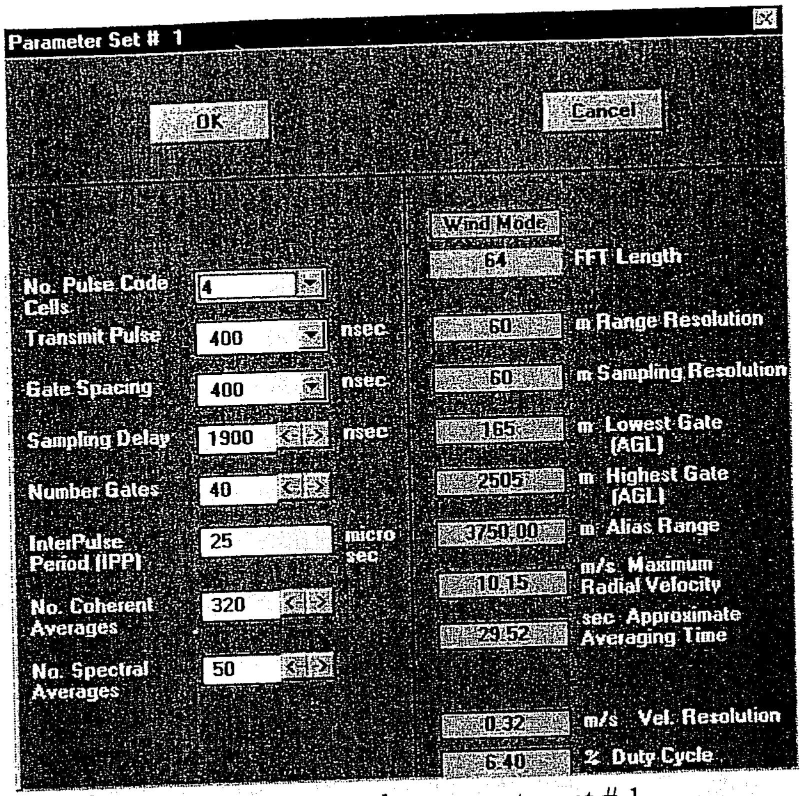
Wind: 64

RASS: 2048

Parameter Sets: RASS

	Edit Set 1	Edit Set 2	Edit Set 3	Edit Set 4
InterPulse Period	25 µs	40 µs	50 µs	20 µs
No. Code Cells	4	4	0	0
Range Resolution	60 m	105 m	420 m	105 m
Sample Spacing	60 m	105 m	105 m	105 m
First Gate Height	165.0 m	187.5 m	165.0 m	97.5 m
No. of Gates	40	47	30	15
Full Scale Velocity	10.1 m\s	10.1 m\s	11.5 m\s	405.8 m\s

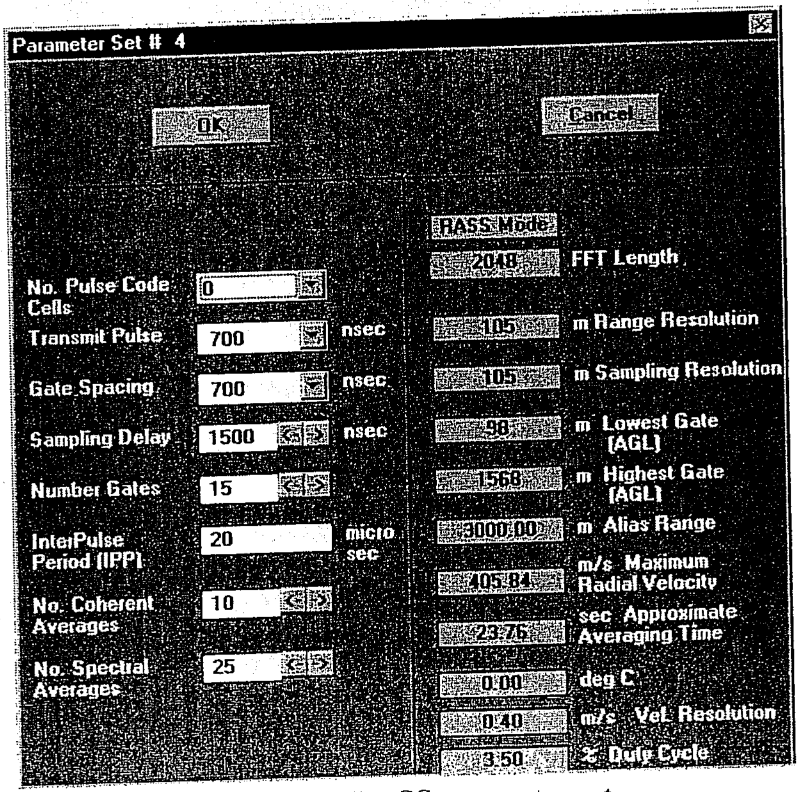
Figure 19. POP4 screen, radar and RASS parameter sets and beam sequencing



No. Pulse Code Cells: 4
Transmit Pulse: 400 nsec
Gate Spacing: 400 nsec
Sampling Delay: 1900 nsec
Number Gates: 40
InterPulse Period (IPP): 25 micro sec
No. Coherent Averages: 320
No. Spectral Averages: 50

64 FFT Length
60 m Range Resolution
60 m Sampling Resolution
165 m Lowest Gate (AGL)
2505 m Highest Gate (AGL)
3750.00 m Alias Range
10.15 m/s Maximum Radial Velocity
29.52 sec Approximate Averaging Time
0.32 m/s Vel. Resolution
6.40 % Duty Cycle

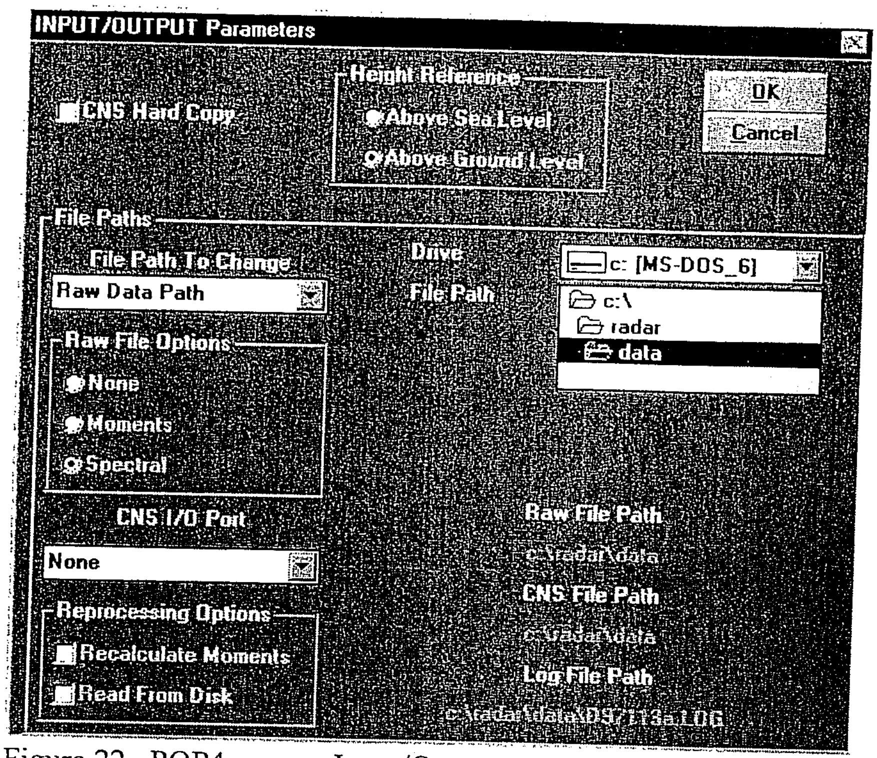
Figure 20. POP4 screen, radar parameter set # 1



No. Pulse Code Cells: 0
Transmit Pulse: 700 nsec
Gate Spacing: 700 nsec
Sampling Delay: 1500 nsec
Number Gates: 15
InterPulse Period (IPP): 20 micro sec
No. Coherent Averages: 10
No. Spectral Averages: 25

2048 FFT Length
105 m Range Resolution
105 m Sampling Resolution
98 m Lowest Gate (AGL)
1568 m Highest Gate (AGL)
3000.00 m Alias Range
405.84 m/s Maximum Radial Velocity
23.76 sec Approximate Averaging Time
0.00 deg C
0.40 m/s Vel. Resolution
3.50 % Duty Cycle

Figure 21. POP4 screen, RASS parameter set


INPUT/OUTPUT Parameters

☐ CNS Hard Copy

Height Reference
- ● Above Sea Level
- ○ Above Ground Level

File Paths

File Path To Change: Raw Data Path

Drive: c: [MS-DOS_6]

File Path:
- c:\
  - radar
    - data

Raw File Options
- ● None
- ● Moments
- ○ Spectral

CNS I/O Port: None

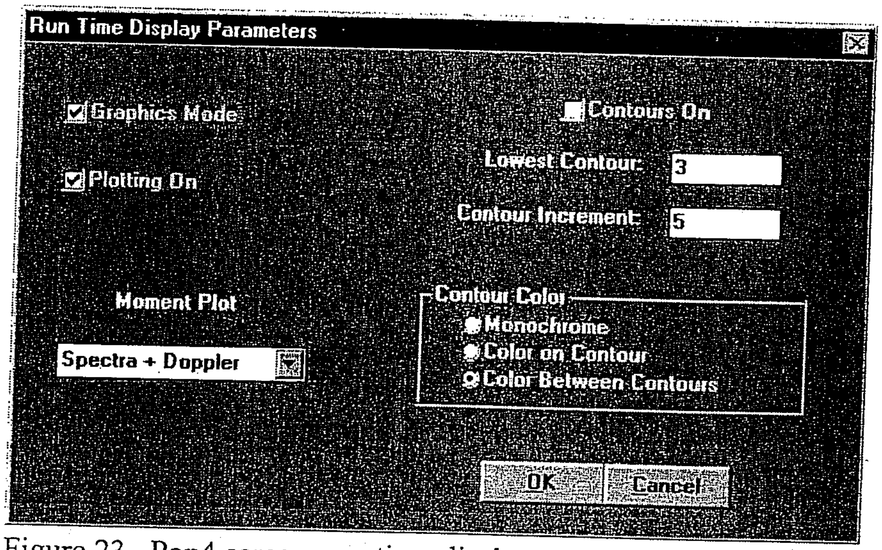
Reprocessing Options
- ☐ Recalculate Moments
- ☐ Read From Disk

Raw File Path: c:\radar\data

CNS File Path: c:\radar\data

Log File Path: c:\radar\data\D97113a.LOG

Figure 22. POP4 screen, Input/Output parameters


Run Time Display Parameters

☑ Graphics Mode

☑ Plotting On

Moment Plot: Spectra + Doppler

☐ Contours On

Lowest Contour: 3

Contour Increment: 5

Contour Color
- ● Monochrome
- ● Color on Contour
- ○ Color Between Contours

Figure 23. Pop4 screen, run time display parameters

APPENDIX A

LIST OF EQUIPMENT MANUALS AND USER'S GUIDES

Ceilometer: Vaisala, 1995: *Ceilometer CT25K User's Guide.* Vaisala Corp.

Data Logger: Campbell Scientific, Inc., 1995: *CR10X Operator's Manual.* Campbell Scientific, Inc., Logan, Utah.

Local Area Network: Artsoft, Inc., 1996: *LANtastic for Windows 95 User's Manual.* Artsoft, Inc., Tucson, Arizona.

Radar: Radian Corporation, Electronics Systems Department Staff, 1993: *The LAP(TM)-3000 Operators Manual.* Radian Doc. Control No. 80018001, Rev. 1

Radiotelemetry: Campbell Scientific, Inc., 1995: *Radiotelemetry Network Instruction Manual.* Campbell Scientific, Inc., Logan Utah.

Rain Gauge: Campbell Scientific, Inc., 1991: *TE525 Tipping Bucket Rain Gage.* Campbell Scientific, Logan, Utah.

Sodar: Radian Corporation, 1995: *USER's REFERENCE MANUAL, VOLUME II: Technical Handbook for Echosonde (Reg) PC/486, Model 600PA, Revision 3.0.* The Radian Corporation.

Solar Panels:

Campbell Scientific, Inc.: *MSX10, MSX10R and MSX20R Solar Panels Instruction Manual.* Campbell Scientific, Inc., Logan, Utah.

Sonic Anemometer: METEK GmbH, 1995: *USA-1 user manual.* METEK Corp.

Temperature/RH probe: Campbell Scientific, Inc., 1996: *Model HMP35C Temperature and Relative Humidity Probe Instruction Manual.* Campbell Scientific, Inc., Logan, Utah.

Uninterruptible Power Supply: American Power Conversion Corporation, 1995: *APS Smart-UPS, Uninterruptible Power Source, User's Manual.* American Power Source Corporation, West Kingston, Rhode Island.

Wind monitor: Campbell Scientific, Inc. 1994: *05103 and 05305 R. M. Young Wind Monitor Instruction Manual.* Campbell Scientific, Inc., Logan, Utah.

APPENDIX B

TRAILER SPECIFICATIONS

Flatbed Trailer

Purchased from:
Superior Trailers
A-J Sales and Service
5530 E. 52nd Ave.
Denver, CO 80022
303 287-0223

GVWR:	13,500#
tare weight:	3,500#
capacity:	10,000#
overall length:	approx. 22'
height:	NA
brakes:	electric
coupler size:	2 5/16"
scissor jacks (6)	The Hammerblow Corp "Bulldog", model 190, lift capacity 7,000#

Electronics Trailer

Manufactured by:
Pace American, Inc.
11550 Harter Dr..
Middlebury, IN 46540
800 247-5767

model L818TA2

GVWR:	7000#
tare weight:	2750#
overall length:	21' 9"
height:	6' 8"
brakes:	electric
coupler size:	2 5/16"

Purchased from:
Classic Car Care Center & Trailer Sales
4415 Ward Rd.
Wheat Ridge, CO 80033
303 467-0601