A Field Evaluation of NOAA Remote Sensor Measurements of Wind, Temperature, and Moisture

B. E. Martner
National Oceanic and Atmospheric Administration
Wave Propagation Laboratory
Boulder, CO 80303

The Atmospheric Radiation Measurement (ARM) program goals are ambitious, and its schedule is demanding. Many of the instruments, proposed for operations at the first Cloud and Radiation Testbed (CART) site as early as 1992 represent emerging technology and exist only as special research prototypes. Therefore, an important preparatory step for ARM was an intensive field project in Colorado in 1991 to assess the suitability of instruments and techniques for profiling the thermodynamic and kinematic structure of the troposphere and lower stratosphere. The field work was designed to provide ARM with a head start by gathering practical information for the design and operation of the CART sites. Additional longer term research, also fundamental to ARM goals, will use the 1991 data to design an optimized combination of diverse profiling instruments. The data will also be used to extrapolate single site data to dynamically consistent, four-dimensional fields at general circulation model (GCM) subgrid scales using a data assimilation mesoscale model. The result will be an integrated system for atmospheric profiling tailored to ARM's needs. This ARM Science Team research is being conducted by a partnership that includes the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA) the Wave Propagation Laboratory (WPL), the Aeronomy Laboratory, and the University of Wisconsin.

NOAA has also conducted shorter range infrastructure research for ARM/CART in which the performance of the NOAA remote sensors used in the 1991 field project was examined. Recommendations for CART instrumentation were derived from these evaluations and from the experience that NOAA scientists and engineers have obtained by designing and operating these instruments over the years. This research is reported in a NOAA Technical Memorandum by Martner et al. (1991). The report also contains examples of the remote sensor routine data products for three intensive operating periods during the 1991 field project.

Instruments operated during the 1991 field work included 5 different NOAA Radio Acoustic Sounding System (RASS) units, three of which (50-, 404-, and 915-MHz) were collocated with an NCAR cross-chain Loran Atmospheric Sounding System (CLASS) radiosonde and microwave radiometers. This allowed the remote sensor measurements to be compared with each other and with the in situ data of the sondes. Accuracies and height coverages were examined. Height overlaps and gaps in the wind and temperature profiles obtained from various combinations of the three frequencies were studied. The primary findings from analysis of the field project data are listed below along with recommendations for CART.

Accuracies

Before the RASS signal was corrected for the vertical air speed, the RASS measurement of virtual temperature had about 1.0°C rms difference from nearby measurements with radiosondes. After correction, the differences are expected to be close to 0.5°C. With the Aeronomy Laboratory's innovative 2048-point Fast-Fourier Transform (FFT) radar processor, the vertical air speed and the speed of the acoustic pulse can be measured simultaneously, thus allowing the 0.5°C accuracies to be obtained in real time in most conditions. In earlier studies, the horizontal wind speeds measured by wind profilers were shown to have 2-3 m/s rms differences from nearby radiosonde data. The dual-channel microwave radiometers (20.6- and 31.65-GHz) are passive remote sensors which provide measurements of the total water vapor content and liquid water content along their beam directions. When the instrument is pointed vertically, the vapor measurement gives the precipitable water vapor (PWV) content of the atmosphere. The theoretical accuracy of these instruments is about 0.7 mm for vapor and 0.03 mm for liquid. Comparisons with National Weather Service radiosondes have shown a 1.7 mm rms difference in the PWV measurements. Comparisons against CLASS radiosondes, which use a better humidity sensor, show rms differences of only 1.1 mm, which is very close to the radiometer's theoretical limit of accuracy.

Height Coverage

The combination of 915-MHz and 50-MHz RASS, which ARM has selected for the first CART site, will generally provide accurate profiles of virtual temperature from 100 or 200 m above the surface to 5 km, and often higher. However, there will usually be a serious gap in these profiles between about 0.7 and 2.0 km. The NOAA Demonstration Network 404-MHz wind profilers manufactured by Unisys, Inc., would completely fill this gap if they are equipped with RASS capability. ARM should ingest data from the NOAA Demonstration Network 404-MHz wind profilers in the CART vicinity. NOAA will add RASS capability to two of these profilers in 1992; ARM may want to help equip others in the area with RASS.

Most of the time, the 915/50-MHz combination will provide wind profiles from 100 or 200 m to over 12 km without gaps. The height coverage of temperature and wind measurements of the CART wind profiler/RASS can and should be extended beyond that of the NOAA systems. This can be accomplished by increasing the sensitivity of the profiler radars with the use of larger antennas, greater transmitted power (for the 50-MHz system), and pulse compression (for the 915-MHz system). Several acoustic sources are recommended for each RASS. The 915-MHz system should use 5 or more acoustic sources, each of which produces 25 W of acoustic power (continuous), and the 50-MHz system should use 3 or more of 200 W each. It is desirable to make one acoustic source mobile for each RASS, so it can be moved somewhat upwind of the profiler antenna. To obtain a more accurate virtual temperature measurement, both the 915- and 50-MHz systems should use processors that permit simultaneous measurement of the vertical air speed and the speed of the acoustic pulse.

Other

The path-integrated vapor and liquid measurements of the microwave radiometers by themselves provide useful information for radiative transfer calculations. In combination with other instruments such as ceilometers, infrared radiometers, or 8 mm wavelength radars, the radiometer data can be even more valuable because vertical distributions, or at least localizations, of the vapor and liquid contents can be obtained. In combination with wind data, vapor flux and convergence can be obtained over the CART domain. We recommend that one microwave radiometer be located at the center of the CART and that as many as four others be deployed at perimeter locations.

RASS-derived temperature profiles will have minimum and maximum heights. Infrared spectrometer devices such as High-resolution Interferometer Sounder (HIS) and Fourier-transform Infrared Sounder (FIRS) offer a promising way to provide temperature profiles below the RASS minimum height, and satellite radiometers can extend the temperature profiles above the RASS maximum height. WPL has demonstrated that optimized combinations of RASS and satellite data can provide accurate composite temperature profiles throughout the troposphere.

The remote sensor evaluations conducted for this study have relied almost entirely on empirical methods of testing. Instrument behavioral modeling is another complementary method which has been beneficial in the case of radiometer design and might be even more helpful for more complex instruments such as RASS. We recommend that ARM continue its efforts on this approach.

Reference

Martner, B. E., E. R. Westwater, R. G. Strauch, B. B. Stankov, D. B. Wuertz, W. L. Ecklund, K. S. Gage, D. A. Carter, J. B. Snider, J. C. Churnside, J. A. Shaw, K. P. Moran, and J. C. Reynolds. 1991. A Field Evaluation of Remote Sensor Measurements of Wind, Temperature, and Moisture for ARM Integrated Sounding System Research. NOAA Technical Memorandum, ERL WPL-211, Boulder, Colorado, 110 pp.