

## Temperature Sounding with Wind Profiler Radars

K. P. MORAN, D. B. WUERTZ AND R. G. STRAUCH

*Wind Profiler Research Group, NOAA/ERL, Wave Propagation Laboratory, Boulder, Colorado*

N. L. ABSHIRE AND D. C. LAW

*Profiler Program, NOAA/ERL, Forecast Systems Laboratory, Boulder, Colorado*

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### ABSTRACT

A network of 31 radar wind profilers is being installed in the central United States by the National Oceanic and Atmospheric Administration (NOAA). The radars are expected to measure the vertical profile of horizontal and vertical wind starting at 500 m above the surface (AGL) and extending to about 16 km AGL. These 404.37-MHz radars can also be adapted to measure virtual temperature profiles in the lower troposphere by the radio acoustic sounding system (RASS) technique. RASS experiments were conducted using the prototype radar of the NOAA network, and results showed that virtual temperature profiles can be measured starting at 500 m AGL (the lowest height observed with this radar) and extending to 3.5–5.2 km AGL.

### 1. Introduction

Radar wind profilers were used in numerous research programs during the 1980s; their ability to measure vertical profiles of vertical and horizontal winds throughout the troposphere holds promise for improved meteorological observations in the 1990s. Röttger and Larsen (1990) summarize the significant developments for this technology. The National Oceanic and Atmospheric Administration (NOAA) is installing a network of 31 wind profilers in the central United States during 1990–1991 to evaluate the utility of the nearly continuous wind data they provide. The same radars that measure the wind can be adapted to measure virtual temperature profiles in the lower troposphere using the radio acoustic sounding system (RASS) method. Spatial and temporal resolution of RASS temperature profiles can be the same as that of wind profiles.

RASS has received renewed attention in the United States since 1987 because wind profiler radars are now available, and these radars are well suited for RASS. The wind profiler Doppler radar measures the speed of sound with its zenith-pointing antenna; the speed of sound  $C_a$  and virtual temperature  $T_v$  are related by  $C_a = 20.047\sqrt{T_v}$ . Acoustic energy is transmitted vertically by loudspeakers at wavelengths  $\lambda_a$  that encompass the Bragg condition,  $\lambda_a = \lambda_r/2$  where  $\lambda_r$  is the radar wavelength, at all heights that give detectable radar return. The acoustic frequency required for the

Bragg match varies from about 840 to 940 Hz for the 404.37-MHz wind profilers. The RASS technique used with wind profilers is well understood (May et al. 1990), and methods for installing RASS on wind profilers are documented (Strauch et al. 1989). The accuracy of RASS temperature measurements has been verified by radiosonde comparisons (May et al. 1989), and RASS temperature data are being used in meteorological research studies (e.g., Neiman et al. 1991; Stankov and Bedard 1990). The purpose of this note is to show results of RASS experiments with the prototype radar of the NOAA wind profiler network that demonstrate that these profilers can measure temperature starting at 500 m above the surface AGL and extending to 3.5–5.2 km AGL.

### 2. Experimental results

A series of RASS tests was conducted with a 404.37-MHz wind profiler at Platteville, Colorado, in April and May 1990. This profiler is the prototype system for the NOAA wind profiler network. The purpose of the tests was to demonstrate that virtual temperature profiles in the lower troposphere could be measured by these wind profilers with little or no degradation of wind measurements. Experiments were conducted during nine days under generally similar meteorological conditions, insofar as RASS performance is concerned. Height coverage of virtual temperature measurements started at 500 m AGL, the lowest height observed by the prototype radar. The results shown here are examples of the data obtained (Moran et al. 1990). Height coverage was typically to 4.25 km: the minimum height was 3.5 km, and the maximum height was 5.25 km.

*Corresponding author address:* Mr. Kenneth P. Moran, NOAA/ Wave Propagation Laboratory, Mail Code R/E/WP4, 325 Broadway, Boulder, CO 80303.

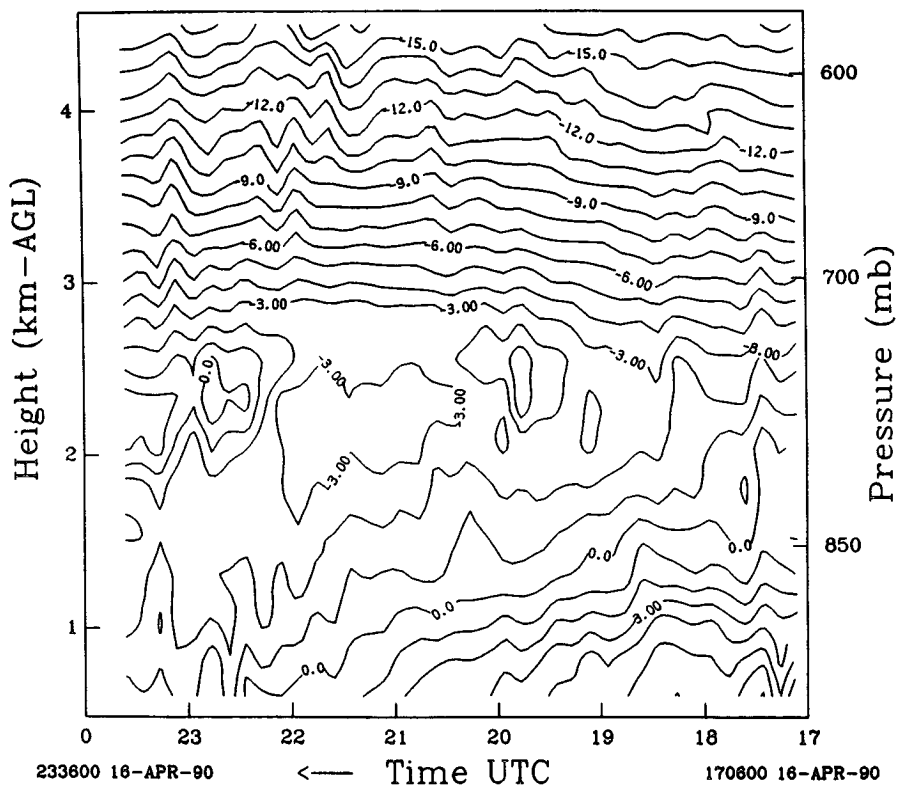


FIG. 1. Contours of virtual temperature ( $^{\circ}\text{C}$ ) measured by RASS on 16 April 1990.

Figure 1 shows virtual temperature contours measured during a 6.5-h test on 16 April 1990. Temperature profiles were measured each time the wind profiler cycled to vertical antenna-pointing in the high-resolution mode, i.e., once every 6 min with a 1-min dwell time. Measurements were made every 250 m in altitude. During this test 66 profiles were measured; 2 were lost because the radar transmitter is automatically turned off to prevent radio interference with satellites. Below 4.3 km only one measurement had to be edited (deleted) before contouring the data. During this time a cold front was moving through the area, and the surface temperature decreased from  $13^{\circ}$  to  $5^{\circ}\text{C}$ . There was little cooling above 2.5 km associated with the frontal passage. Figure 2 shows time-averaged temperature profiles for this test. The profile at 1800 UTC 16 April is an average of 10 profiles measured from 1700 to 1800 UTC when the surface temperature had just started to decrease. The profile at 0000 UTC 17 April is an average of six profiles measured from 2300 to 2336 UTC (16 April), after the cold front had passed. These profiles show the depth of the cold air and the temperature inversion after frontal passage when cold air displaced the lower-level warm air and lifted the upper-level air by about 300 m.

Another test was conducted on 10 April 1990 during a 1.5-h period when the temperature changed very little with time. Figure 3a shows the averaged profile (13 measurements for each height), and Fig. 3b shows the

root-mean-square (rms) difference between the 13 measured values and a straight-line fit to these values for each height. The average rms temperature difference for individual measurements was  $0.31^{\circ}\text{C}$ . The rms difference includes atmospheric temperature fluctuations

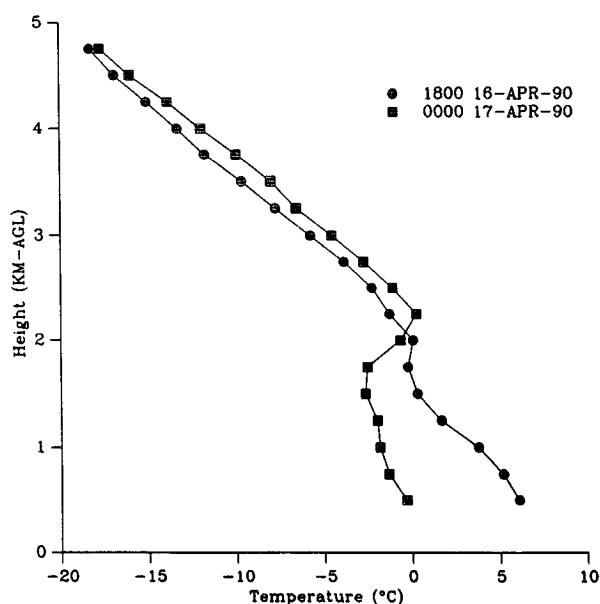


FIG. 2. Averaged temperature profiles for RASS contours near the beginning (circles) and the end (squares) of the data for Fig. 1.

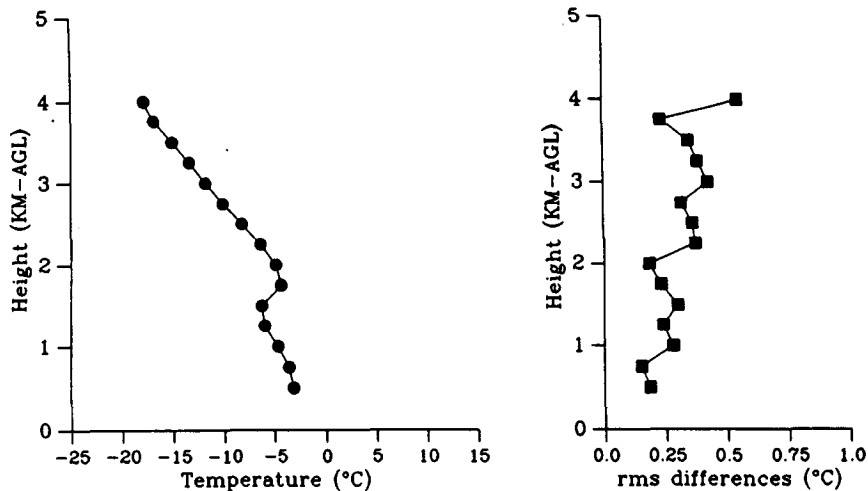


FIG. 3. (a) Average temperature profile (13 measurements for each height) measured by RASS on 10 April 1990. (b) Root-mean-square temperature differences between the 13 temperature measurements averaged for each height in (a) and a straight-line fit to those values.

as well as measurement error. Temperature measurements for routine operation will be an average of 10 individual measurements obtained each hour. It should be noted that vertical wind was neglected for these tests; however, vertical wind must be measured and a correction included for operational RASS. The vertical wind and  $C_a$  must be measured during the same dwell time because low-altitude vertical wind fluctuations can be significant during the 1-min dwell time used to measure the temperature profile. The data system used for these tests was only able to measure either  $C_a$  or the vertical wind; new data systems under construction will be able to measure both simultaneously. If the correction for vertical wind is made, the measurement uncertainty would increase because the temperature measurement error would result from independent measurements of the speed of sound and the vertical wind. Measurement errors of  $w$  will be comparable to those of  $C_a$  (Strauch et al. 1987).

### 3. Significance

The tests conducted with the prototype system of the NOAA wind profiler network demonstrate that it will be possible to obtain lower-tropospheric temperature profiles with the same time and space resolution with which winds are obtained, that is, profiles measured every 6 min starting at 500 m AGL and extending to 3–5.2 km in altitude with data every 250 m. These data should be useful to local weather forecasters and research meteorologists who will be evaluating the profiler network in the 1992–1995 time period. However, the most significant result of having lower tropospheric RASS data may be in the way that they complement temperature profiles measured by passive satellite radiometers (Schroeder et al. 1991). Temperature profiles derived from satellite radiometers have poor height resolution, and their accuracy is poor near the surface where the meteorologist needs the best information.

The RASS–satellite combination may provide remotely sensed temperature profiles throughout the troposphere for many meteorological applications. It should be noted, however, that a major problem with RASS is that acoustic energy at the Bragg frequency ( $\sim 900$  Hz for 404-MHz radars) is audible; therefore, acoustic sources that do not annoy nearby residents must be developed.

### REFERENCES

- May, P. T., K. P. Moran and R. G. Strauch, 1989: The accuracy of RASS temperature measurements. *J. Appl. Meteor.*, **28**, 1329–1335.
- , R. G. Strauch, K. P. Moran and W. L. Ecklund, 1990: Temperature sounding by RASS with wind profiler radars: A preliminary study. *IEEE Trans. Geosci. Remote Sens.*, **28**, 19–28.
- Moran, K. P., D. B. Wuertz, R. G. Strauch, N. L. Abshire and D. C. Law, 1990: RASS demonstration on a NOAA network wind profiler. NOAA Tech. Memo., ERL WPL-184, 24 pp. [Available from NOAA Environmental Research Laboratories, Boulder, CO 80303.]
- Neiman, P. J., P. T. May, B. B. Stankov and M. A. Shapiro, 1991: Radio acoustic sounding system observations of an arctic front. *J. Appl. Meteor.*, **30**, 881–892.
- Röttger, J., and M. F. Larsen, 1990: UHF/VHF radar techniques for atmospheric research and wind profiler applications. *Radar in Meteorology*, D. Atlas, Ed., American Meteorological Society, 235–281.
- Schroeder, J. A., E. R. Westwater, P. T. May and L. M. McMillin, 1991: Prospects for temperature sounding with satellite and ground-based RASS measurements. *J. Atmos. Oceanic Technol.*, **8**, 506–513.
- Stankov, B. B., and A. J. Bedard, Jr., 1991: Remote sensing observations of winter aircraft icing conditions: A case study. *J. Appl. Meteor.*, submitted.
- Strauch, R. G., B. L. Weber, A. S. Frisch, C. G. Little, D. A. Merritt, K. P. Moran and D. C. Welsh, 1987: The precision and relative accuracy of profiler wind measurements. *J. Atmos. Oceanic Technol.*, **4**, 563–571.
- , K. P. Moran, P. T. May, A. J. Bedard and W. L. Ecklund, 1989: RASS temperature sounding techniques. NOAA Tech. Memo., ERL WPL-158, 12 pp. [Available from NOAA Environmental Research Laboratories, Boulder, CO 80303.]