Improved Humidity Profiling by Combining Passive and Active Remote Sensors at the Southern Great Plains

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Introduction

In the past few years, ground-based microwave radiometry has proven extremely reliable for accurately measuring atmospheric integrated water vapor content. More recently, the development of multispectral microwave radiometers has opened the possibility of humidity profile estimates by passive instruments, thanks to the vertical features of weighting functions at different frequencies. Although, the inversion of humidity profiles from passive observations is an ill-posed problem. Thus, the vertical resolution of such estimates is limited by the number of frequencies that can bring independent informations. Therefore, ground-based passive retrievals usually tend to smooth elevated sharp humidity gradients, although provide good estimates of the main water vapor content. On the other hand, active instruments, such radar wind profiler (RWP), are able to detect changes in atmospheric refractivity related to humidity gradients. Thus, we present an algorithm to compute high-resolution atmospheric humidity profiling by synergetic use of microwave radiometer and RWP. Radar data are input for the computation of the potential refractivity gradient profiles, and combined with radiometer estimates of potential temperature profiles, in order to fully retrieve humidity gradient profiles. The algorithm makes use of recent developments in radar and radiometer signal processing applied to simultaneous observations collected in June 2002 at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) site, Lamont, Oklahoma. The combined algorithm performances in retrieving humidity profiles are tested with simultaneous radiosonde measurements. The synergy of microwave radiometer and wind profiler measurements shows potential for significantly improving the spatial vertical resolution of atmospheric humidity profiles. We show preliminary results and discuss advantages and limitations related to this technique.

Basic Principles

The role of ground-based remote sensors in boundary layer research is now days well established due to the ability of remote sensors to monitor important meteorological parameters continuously in height and time. One main focus in this area is to evaluate derived meteorological quantities when a multi-sensor synergy is used. The aim of this work is to compute high-resolution atmospheric humidity profiles by synergetic use of ground-based remote sensors, such as a microwave radiometer and a RWP. Moreover, new algorithms have been developed and tested in previous work (Bianco and Wilczak 2002), which obtain parameters from RWPs other than wind. Most atmospheric boundary layer parameters currently obtained by remote sensing systems are derived from the first three moments of the measured Doppler spectra. The mean velocity profile, obtained by the first moment of the Doppler spectrum, was one of the earliest quantities extracted from remote sensing observations. Radar signals often show contamination from other sources, which includes, but not limited to, ground clutter, intermittent clutter, radio frequency interference, and sea clutter. For this reason, signal-processing techniques have been developed to identify the true atmospheric signal from the spectra (Wilczak et al. 1995, Cornman et al. 1998, Jordan et al. 1997). Proper identification of the first moment in the spectrum is very important for further applications, since it allows for more accurate computation of the area under the signal peak, or zeroth moment, which can be related to the signal-to-noise ratio of the backscattered power and to other parameters. On the other hand, the second moment of the Doppler spectrum (when the radars are pointing vertically) has not been widely exploited, and its use is still in the research and evaluation stage. It is a measure of the broadening of the Doppler spectrum due to a variety of factors, including velocity variance resulting from atmospheric turbulence on scales smaller than the pulse volume. It has the potential to provide profiles of turbulence quantities, such as eddy dissipation rate and structure parameters, continuously in time. Over the last two decades several attempts have been made to use spectral width from profilers to measure the turbulence intensity without much success (Gossard et al. 1990, Cohn 1995). The principal problem is related to the fact that contamination by unwanted targets is especially detrimental to second-moment calculations. Other non-turbulent processes also contribute to the broadening. In order to be able to use the spectral width to measure turbulence intensities, it is necessary to be certain that the entire broadening is due to turbulence. To obtain accurate moments, an algorithm that makes use of recent developments in RWP signal processing for computing the zeroth, first, and second moments of RWP Doppler spectra using a fuzzy logic method (Bianco and Wilczak 2002) was incorporated to provide quality control of radar data in the spectral domain. Once the RWP data have been re-processed, the zeroth, first, and second moments, computed by the fuzzy logic algorithm can be employed to compute the structure parameter of potential refractivity (C_ϕ^2), the horizontal wind (V_h), and the structure parameter of vertical velocity (C_w^2), respectively (Stankov et al. 2003). C_ϕ^2, V_h, and C_w^2 can then be combined together to retrieve the potential refractivity gradient profiles ($d\phi/dz$). Measurements from a multi-channel microwave radiometer profiler (MWRP), operating in the 20-60 GHz range, can provide tropospheric temperature profiles and thus estimates of potential temperature gradient profiles ($d\theta/dz$). Profiles of $d\phi/dz$ and $d\theta/dz$ are needed to fully retrieve humidity gradient profiles (dQ/dz) as suggested by (Stankov et al. 1996). The advantage of such a technique is to retrieve humidity profiles from RWP and MWRP measurements, independently from radiosonde observations. Humidity profiles from the combined algorithm have been compared with simultaneous radiosonde observations to test their validity.

Instruments and Data Processing

The empirical sets of RWP and MWRP data were provided by the ARM Program and collected at the ARM SGP site. The RWP is a 915 MHz five-beam phased-array system manufactured by Radian Corp. (now Vaisala). The antenna is approximately 4 m square and is oriented in a horizontal plane so the "in-phase" beam travels vertically. Only the 60m mode, sampling the boundary layer from 90 m to 2500 m above ground level (AGL) in the vertical, is used for this study. Figure 1 is the time-height cross section of range corrected signal-to-noise ratio (SNR) obtained by the RWP on June 7, 2002. The MWRP, manufactured by Radiometrics, observes radiation intensity at 12 frequencies in the 20-60 GHz spectrum. The system includes a vertical infrared sensor and surface temperature, humidity and pressure sensors. Observation frequencies (22.035, 22.235, 23.835, 26.235, 30.00, 51.250, 52.280, 53.850, 54.940, 56.660, 57.290, and 58.800 GHz) were chosen by eigenvalue analysis to optimize profile

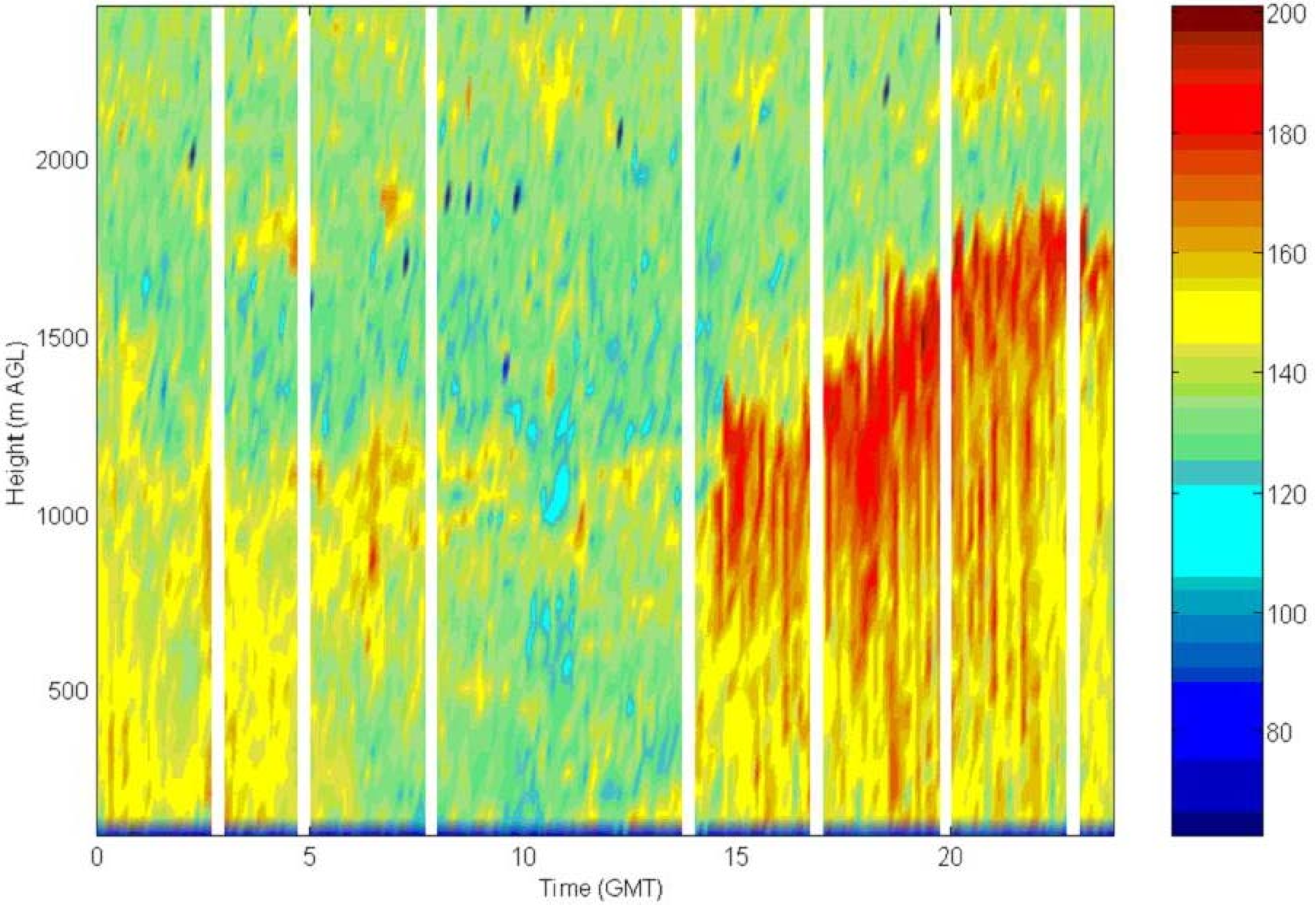

Figure 1. Time-height cross section of range-corrected SNR obtained by the RWP located at SGP on June 7, 2002.

retrieval accuracy (Solheim et al. 1998). The retrieval algorithm is based on a neural network trained with a synthetic data set produced from historical radiosondes launched at the same site. The radiometer 22-30 GHz channels are calibrated by tipping (Han and Westwater 2000). The 51-59 GHz channels calibration uses a cryogenic blackbody target. Figure 2 is the time-height cross section of temperature T (K) and humidity Q (g Kg-1) obtained by the MWRP on June 7, 2002.

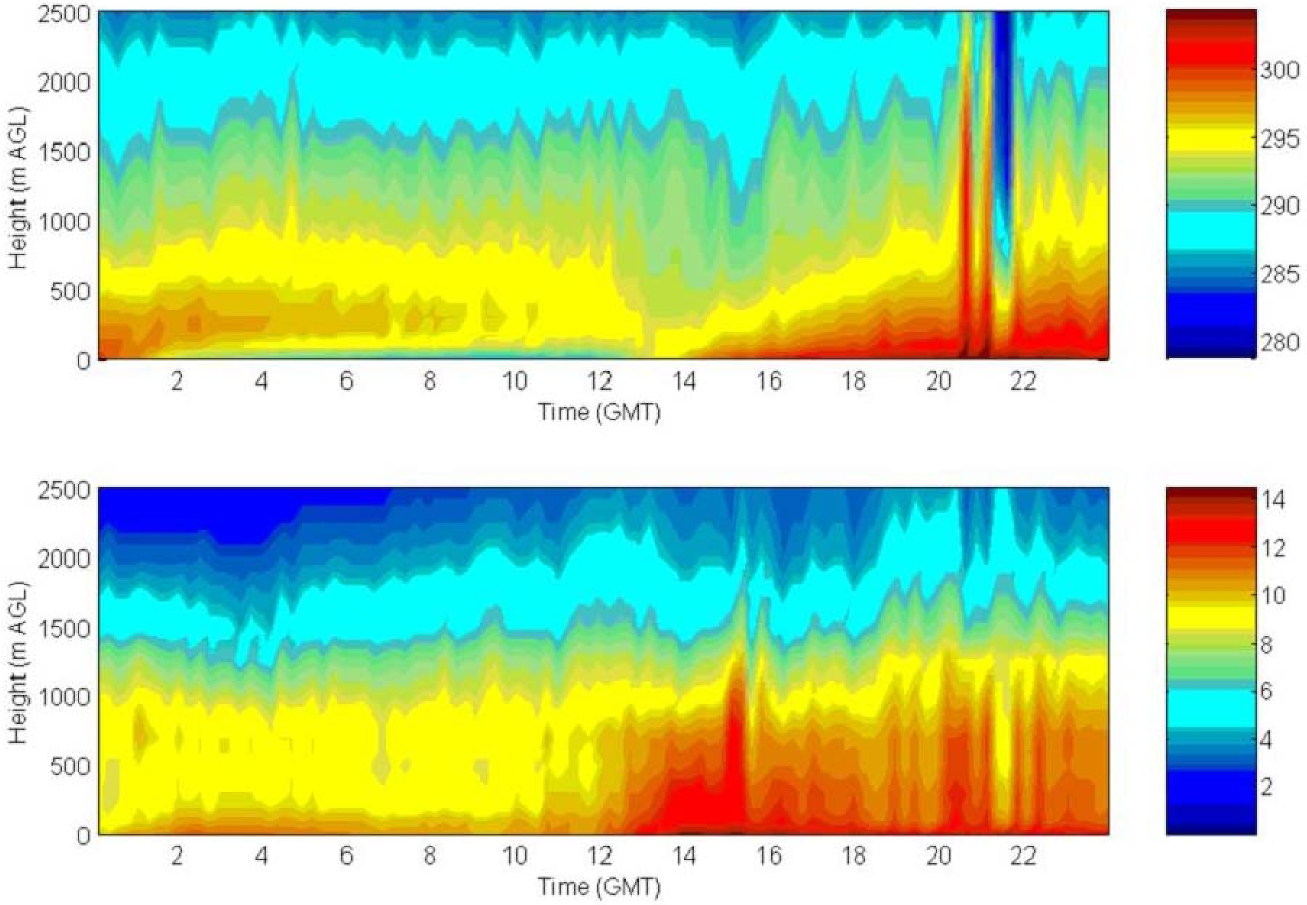

Figure 2. Upper panel: Time-height cross section of temperature T (K). Lower panel: Time-height cross section of humidity Q (g Kg-1). Estimates were obtained by the MWRP located at SGP on June 7, 2002.

Case Study

To test the potential of this technique, simultaneous measurements from a radiosonde and ground based instruments on 23:30 Universal Time Coordinates (UTC) June 7, 2002, were processed. C_ϕ^2, C_w^2, and dV_h/dz profiles, are computed from RWP measurements using the vertical beam only. For the computation of C_w^2 the algorithm uses a recently developed approximate formula (White et al. 1999) for correcting Doppler spectral width for the spatial and temporal filtering effects. For the same hour the profile of $d\theta/dz$ is obtained from temperature and pressure profiles estimated by MWRP. Introducing the constants $a_0 \approx 1$ and $b_0 \approx 6$ and the outer length scales for potential refractive index (L_ϕ) and shear (L_w) as defined in Gossard et al. (1982), the following equations are valid (Stankov et al. 2003; Gossard et al. 1982, White 1997):

$$\left(\frac{d\phi}{dz}\right)^2 \approx \left(\frac{L_w}{L_\phi}\right)^{4/3} \left(\frac{dV_h}{dz}\right)^2 \frac{C_\phi^2}{C_w^2} \tag{1}$$

$$\frac{dQ}{dz} = (b_0)^{-1}\left[\frac{d\phi}{dz} + a_0 \frac{d\theta}{dz}\right] \tag{2}$$

Ground-based estimates of C_ϕ^2, C_w^2, dV_h/dz and $d\theta/dz$ profiles are input in Eqs. (1) and (2) to retrieve humidity gradient profiles, which are finally compared with in-situ measurements made by the radiosonde. Results are presented in Figure 3. In the upper left panel we show of $d\phi/dz$ measurements from radiosonde (red line), estimates from RWP (black line) and MWRP (blue line). In the upper right panel is the vertical gradient profile of potential temperature as obtained by the MWRP (blue) and by the radiosonde (red). In the lower left panel, red line is dQ/dz profile from the radiosonde; blue line is from the MWRP, while black line is obtained with the proposed technique (MWRP-RWP), in which the sign ambiguousity of $d\phi/dz$ has been resolved looking at the profile of the same quantity estimated by MWRP. Finally, in the lower right panel, vertical profiles of Q as obtained by MWRP (blue), the combined technique (black), and the radiosonde (red) are compared. The case study shows that the combined technique improves substantially the vertical resolution of dQ/dz profiles with respect to the MWRP only. The height of the peak in the MWRP-RWP dQ/dz profile is consistent with the fact that the refractive index structure parameter C_w^2 has a local maximum at the inversion, as visible in Figure 1 at approximately 1650 m AGL.

Summary and Future Developments

We explored the possibility to improve vertical resolution of tropospheric humidity profiles using only ground-based remote sensors. The proposed technique is advantageous with respect to previous work (Stankov et al. 2003) because is completely independent on radiosonde measurements, which are used only as a comparison. Case study shows the potential of the proposed technique in retrieving continuous humidity profiles and in detecting sharp humidity gradients. Future research is planned to look at a statistical analysis from a large dataset comparing MWRP-RWP technique results and radiosonde observations.

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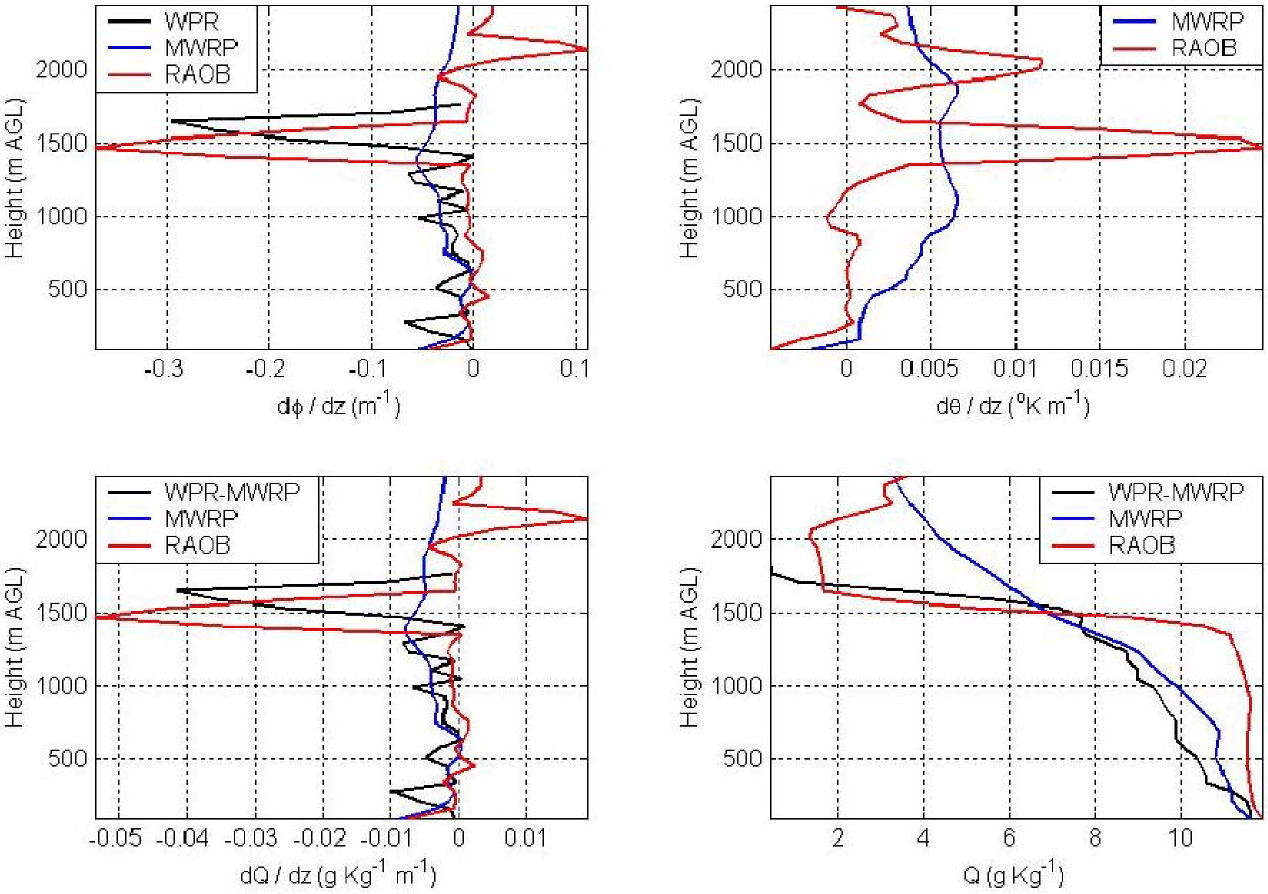

Figure 3. Comparison of the RWP-MWRP, MWRP, and radiosonde observed profiles on June 7, 2002, 23:30 Greenwich Mean Time (GMT). Upper left panel: dϕ/dz measurements. Upper right panel: Vertical gradient profiles of potential temperature. Lower left panel: dQ/dz profiles. Lower right panel: Vertical profiles of Q.

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