Evaluation of Profiles of Temperature, Water Vapor, and Cloud Liquid Water from a New Microwave Radiometer

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Introduction

The Atmospheric Radiation Measurement (ARM) Program launches approximately 2600 radiosondes each year from its Southern Great Plains (SGP) facilities in Oklahoma and Kansas, USA, to acquire vertical profiles of temperature and moisture. The annual cost of this effort exceeds $500,000 in materials and labor. Despite this expense, the measured profiles are not as well suited to modeling as might be desired. Cost and slow ascent rate limit their temporal sampling interval (i.e., launch frequency) to 3 hours during intensive operational periods (IOPs) and 6 to 8 hours during routine operations. In contrast, the radiation measurements used for comparison with model calculations have temporal resolutions and reporting intervals of a few minutes at most. Conversely, radiosondes have a much higher vertical spatial resolution, about 10 meters, than most models can use. Modelers generally reduce the vertical resolution of the soundings by averaging over the vertical layers of the model.

In an attempt to acquire profile measurements with temporal and spatial characteristics similar to the radiation measurements and more appropriate to models, ARM deployed a variety of ground-based remote sensors. However, none of these remote sensors can provide a complete profile of tropospheric temperature or water vapor (WV) over the wide range of sky conditions and with the high reliability of the Balloon-Borne Sounding System (BBSS). Consequently, the BBSS remains the primary profiling instrument.

Recently, Radiometrics Corporation developed a ground-based microwave radiometer capable of providing continuous, real-time vertical profiles of temperature, WV, and limited-resolution cloud liquid water from the surface to 10 km in nearly all weather conditions. The Microwave Radiometer Profiler (MWRP), shown in Figure 1, offers a much finer temporal resolution and reporting interval (about 10 minutes) than the BBSS but a coarser vertical resolution that may be more appropriate for models.

To evaluate the performance of the new MWRP and the suitability of its profile measurements for driving typical radiation models, the radiometer was deployed at the SGP Central Facility (CF) from February 15 to August 8, 2000. Since September 15, 2000, it has been deployed at the ARM North Slope of Alaska (NSA) CF at Barrow, Alaska. Results of the evaluation to date are presented here.

The Microwave Radiometer Profiler

The MWRP is composed of two separate receivers in a single cabinet that share the same antenna and antenna-pointing system. A highly stable synthesizer permits tuning to a large number of frequencies within the receiver bandwidth. The temperature-profiling receiver measures the radiometric brightness temperature of the sky at seven frequencies corresponding to a complex of oxygen absorption lines between 51 and 59 GHz. The water-vapor-profiling receiver uses five frequencies extending from the center of the WV line at 22 GHz out to 30 GHz. Surface meteorological sensors measure air temperature, barometric pressure, and relative humidity (RH). To improve the measurement of WV and cloud liquid water profiles, cloud base altitude information is obtained with an infrared (IR) thermometer. The calibration of the water-vapor-profiling receiver is maintained by continuous tipping curves. A liquid-nitrogen-cooled blackbody target is used to calibrate the temperature-profiling receiver. Detailed descriptions of the instrument and calibration procedures were given by Solheim et al. (1998a).

Figure 1. The MWRP deployed at the ARM NSA CF in Barrow, Alaska. The IR (10-micrometer wavelength) thermometer mounted on the MWRP provides an estimate of cloud base temperature, which is used to infer cloud base height and constrain the liquid water content (LWC) retrieval.

Profiles of temperature, WV, and cloud liquid water are obtained at 47 levels: from 0 to 1 km above ground level at 100-m intervals, and from 1 to 10 km at 250-m intervals. The profiles are derived from the measured brightness temperatures with neural network retrieval algorithms. For the SGP deployment, the neural network was trained with brightness temperatures calculated by using a microwave radiation transfer model for ten years of radiosonde profiles from Oklahoma City for February through August. For the NSA deployment, monthly retrievals were developed using ten years of radiosonde data for 3-month periods centered on the target month. The neural network retrieval and alternative retrieval methods were discussed by Solheim et al. (1998b).

Time-height color contours of temperature, WV density, and LWC are presented in Figure 2 for January 13 - 17, 2001, at Barrow, Alaska. Except for the power outage, the data provides a continuous record of an interesting period of warming and moistening. Because this took place over a holiday weekend, no soundings are available for comparison. Typical profiles from the MWRP are compared with profiles from the BBSS in Figure 3 for inversion and lapse conditions at the SGP and NSA.

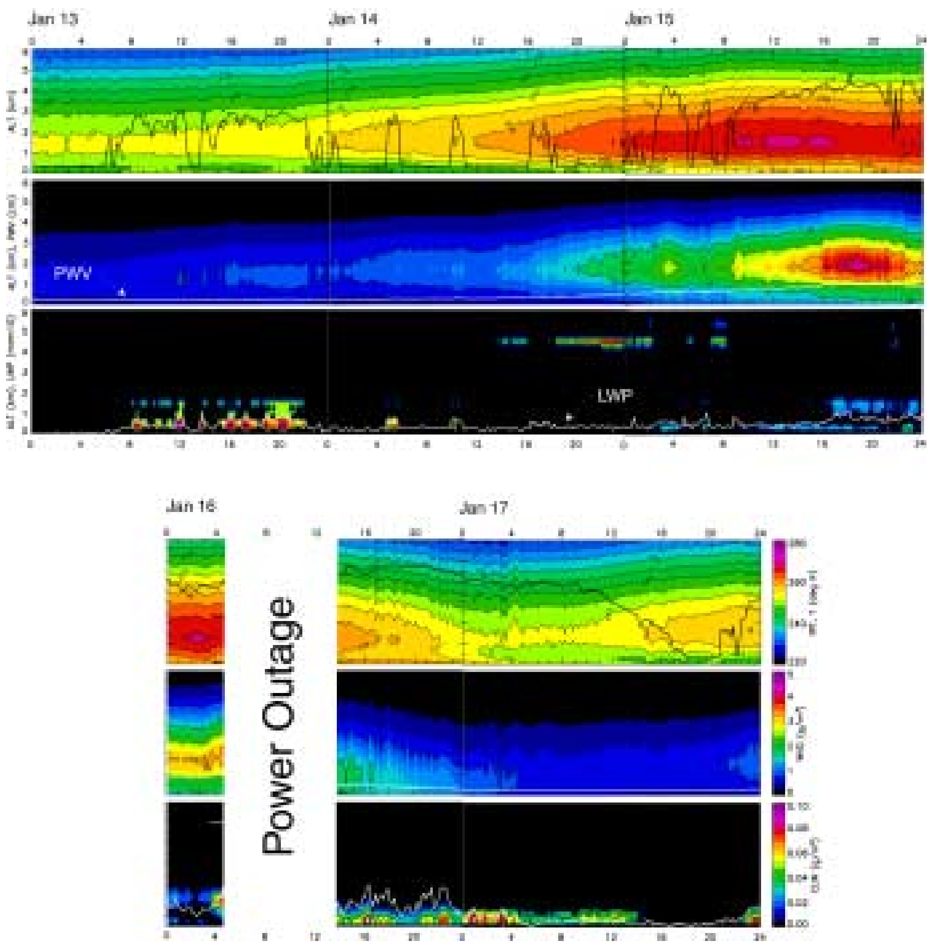

Figure 2. MWRP profiles of temperature, WV, and cloud liquid from Barrow, Alaska, for January 13 - 17, 2001, shows a substantial warming and moistening above the surface temperature inversion.

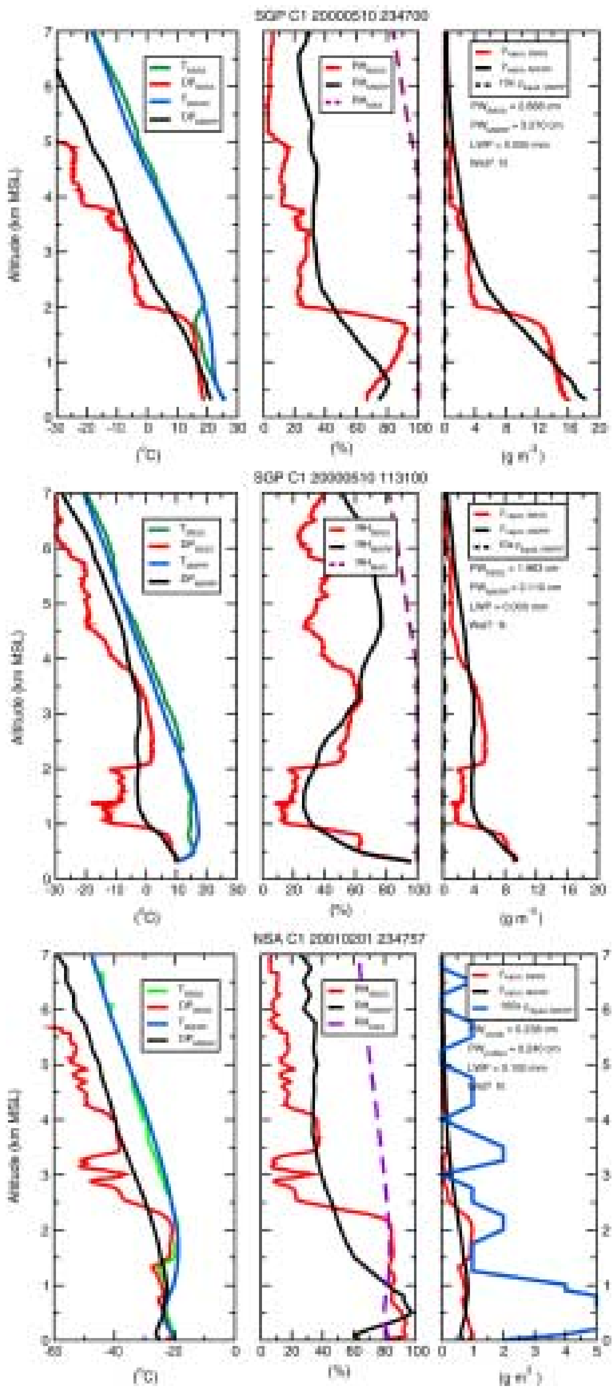

Figure 3. The MWRP profiles coincident with SGP soundings for May 10, 2000, 11:31 Universal Time Coordinates (UTC) (05:31 local) and 23:47 UTC (17:47 local), and the NSA sounding for February 1, 2001, 23:48 UTC. For the MWRP, RH, and dew point are calculated using the retrieved temperature and WV density profiles. The profiles labeled “RH max” indicate the ratio of the saturation mixing ratio over ice to the saturation mixing ratio over liquid water at the prevailing temperature; this is used as a quality check on the retrievals. These results illustrate typical performance for temperature inversion and lapse conditions.

Statistical Comparisons

In Figure 4 we present statistical summaries of the comparison of MWRP profiles with soundings. We also compared the MWRP profiles from the SGP with profiles retrieved from the atmospherically Emitted Radiance Interferometer (AERI) Spectrometer, both alone (Smith 1999) and when combined with profiles from the rapid update cycle (RUC) model. The latter are designated "AERI+." The AERI and AERI+ results are limited to clear-sky conditions. The SGP data were divided into two parts: the cooler, dryer period from mid-February to mid-May, and the warmer, moister period from mid-May to early August. The standard deviation about the ensemble mean of the BBSS profiles for each of these periods, often referred to as "climatology," is also plotted as a reference as are the mean BBSS profiles. The nearly all-weather capability of the MWRP allowed for about 35 percent more valid profiles coincident with BBSS soundings than were obtained with the AERI during the spring (193 vs. 145) and 20 percent more during the summer (150 vs. 124). Gueldner and Spaenkuch (2000) obtained similar results with an identical MWRP when they used a neural net retrieval; they also reported improved results with a regression-based retrieval.

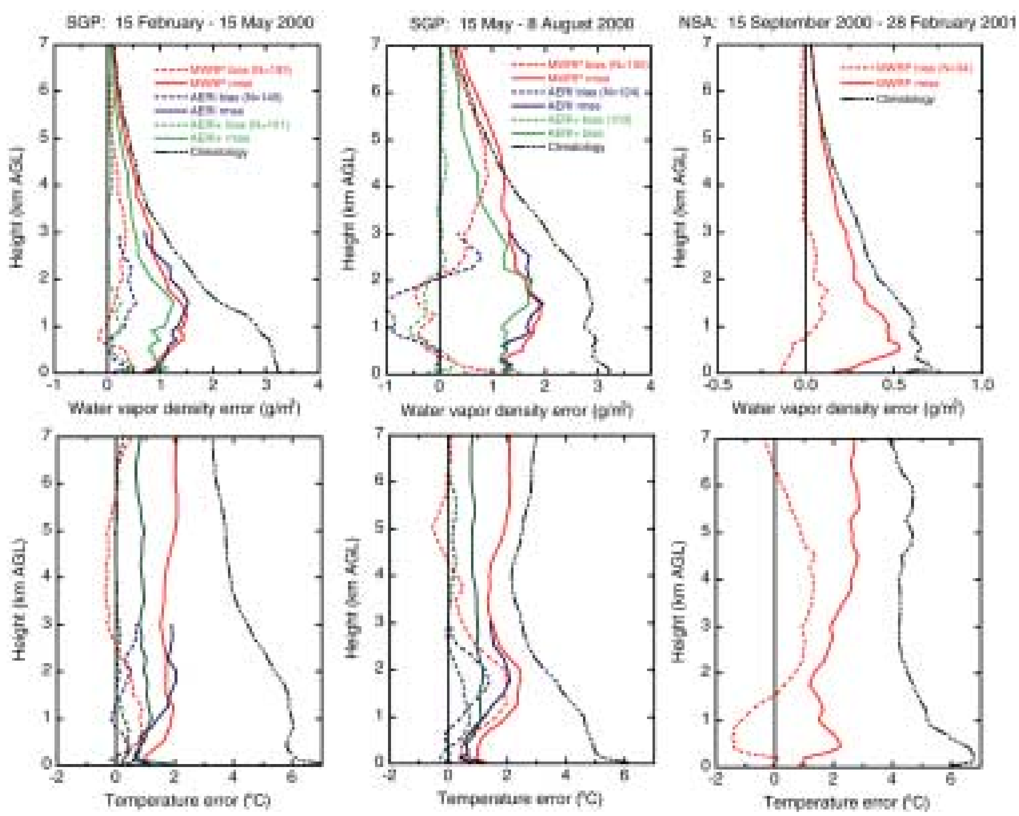

Figure 4. The profiles of temperature and WV density derived from the MWRP brightness temperatures were compared with routine soundings and with profiles derived from the AERI spectrometer, both alone and in combination with the RUC model ("AERI+"). The mean difference ("bias") and the root mean square difference ("rms error") between the MWRP, AERI, or AERI+ profiles and the BBSS at the SGP are presented. Results of the comparison with soundings at Barrow, Alaska are also presented.

Comparisons of precipitable water vapor (PWV) and liquid water path (LWP) from the MWRP with the 2-channel Microwave Radiometer (MWR) at the SGP are presented in Figure 5. The results show generally good agreement, but an increasing bias at high PWV, probably due to use of a single set of retrieval coefficients for the entire period rather than monthly retrievals as was done for the NSA. Comparison of LWP also shows good agreement, but reveals the need for higher resolution of the output format.

Conclusions

A new microwave radiometer profiler has been deployed at the ARM SGP and NSA facilities for extended periods for evaluation. The instrument has proved to be highly reliable and to perform well over a wide range of conditions. Comparisons with radiosondes demonstrate rms accuracy of 1° to 2°C for temperature at the SGP and NSA. For WV, an rms accuracy of 1 to 2 g/m^3 or better was achieved at the SGP. Better than 0.5-g/m^3 rms WV accuracy was achieved at the NSA, but the absolute amount of WV was quite small—only about 1 g/m^3 near the ground on average—during the deployment period.

Future Work

Based on these results, Radiometrics is developing improved retrieval algorithms. In addition, Radiometrics is modifying its software to reduce the observing cycle time from 10 to 2 minutes to reduce the variation in sky conditions during the measurement cycle, which can adversely affect the retrievals.

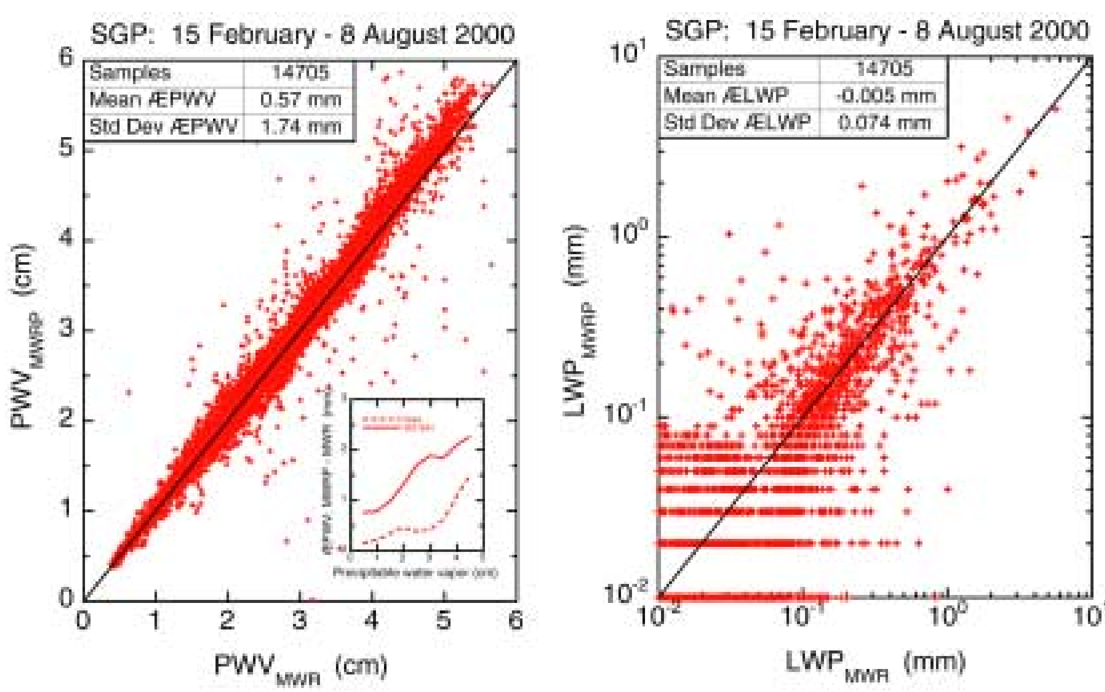

Figure 5. Comparisons of PWV and LWP from the MWRP with the 2-channel MWR at the SGP.

Acknowledgements

This work was supported by the Environmental Sciences Division, U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research, under Contract W-31-109-Eng-38, as part of the ARM Program.

Wayne Feltz, University of Wisconsin, Space Science and Engineering Center provided the AERI+ retrievals.

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