Improved Retrievals of Temperature and Water Vapor Profiles Using a Twelve-Channel Microwave Radiometer

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Introduction

Radiometrics Corporation has developed a twelve-channel microwave radiometer capable of providing continuous, real-time vertical profiles of temperature, water vapor, and limited-resolution cloud liquid water from the surface to 10 km in nearly all weather conditions (Solheim et al. 1998a). Since February 2000, a microwave radiometer profiler (MWRP) has been deployed for evaluation at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility (CF) near Lamont, Oklahoma except for a deployment at the North Slope of Alaska (NSA) CF at Barrow, Alaska from September 2000 to April 2001. In summarizing the results of the MWRP evaluation, Liljegren (2002) showed a significant bias between measured and modeled brightness temperatures in the 22-30 GHz channels, which caused significant biases in the retrieved profiles of water vapor and temperature and also adversely affected the vertical resolution.

In this paper, improvements in the accuracy and vertical resolution of the retrieved temperature and water vapor profiles derived from the MWRP are achieved by first, correcting the absorption model upon which the retrievals are based; and second, by combining the MWRP with data from the geostationary operational environmental satellite-8 (GOES-8) sounder.

Corrected Absorption Model

Brightness temperatures measured at the five K-band channels (22.235, 23.035, 23.835, 26.235, and 30.0 GHz) that span the water vapor resonance centered at 22.235 GHz were compared with calculations based on the Rosenkranz (1998) water vapor absorption model. To ensure that any dry bias in the radiosondes used in the model calculations did not affect the brightness temperature comparison, ARM’s scaled radiosonde product (sgplssondeC1.c1) was used. In this product, the relative humidity (RH) of the radiosonde is linearly scaled so that the integrated precipitable water vapor (PWV) matches the PWV reported by a collocated two-channel microwave radiometer operating at 23.8 and 31.4 GHz. The results, presented in Figure 1, show that the measured/modeled brightness temperature ratios are about 5% too large at 22.235 GHz but the ratios decline with increasing frequency separation from the line center. S. A. Clough (personal communication) pointed out that this trend is due to the line width in the Rosenkranz model being 5% too large; the air-broadened width parameter γ_{air} given by Rosenkranz (1998) is 0.00281 GHz/kPa whereas the value from the high-resolution transmission (HITRAN) database (Rothman et al. 1992) is 0.00268 GHz/kPa, which is about 5% less than the Rosenkranz value. When the line width in the calculations is reduced by 5%, the agreement with the measured brightness temperatures improves dramatically, as shown in Figure 1.

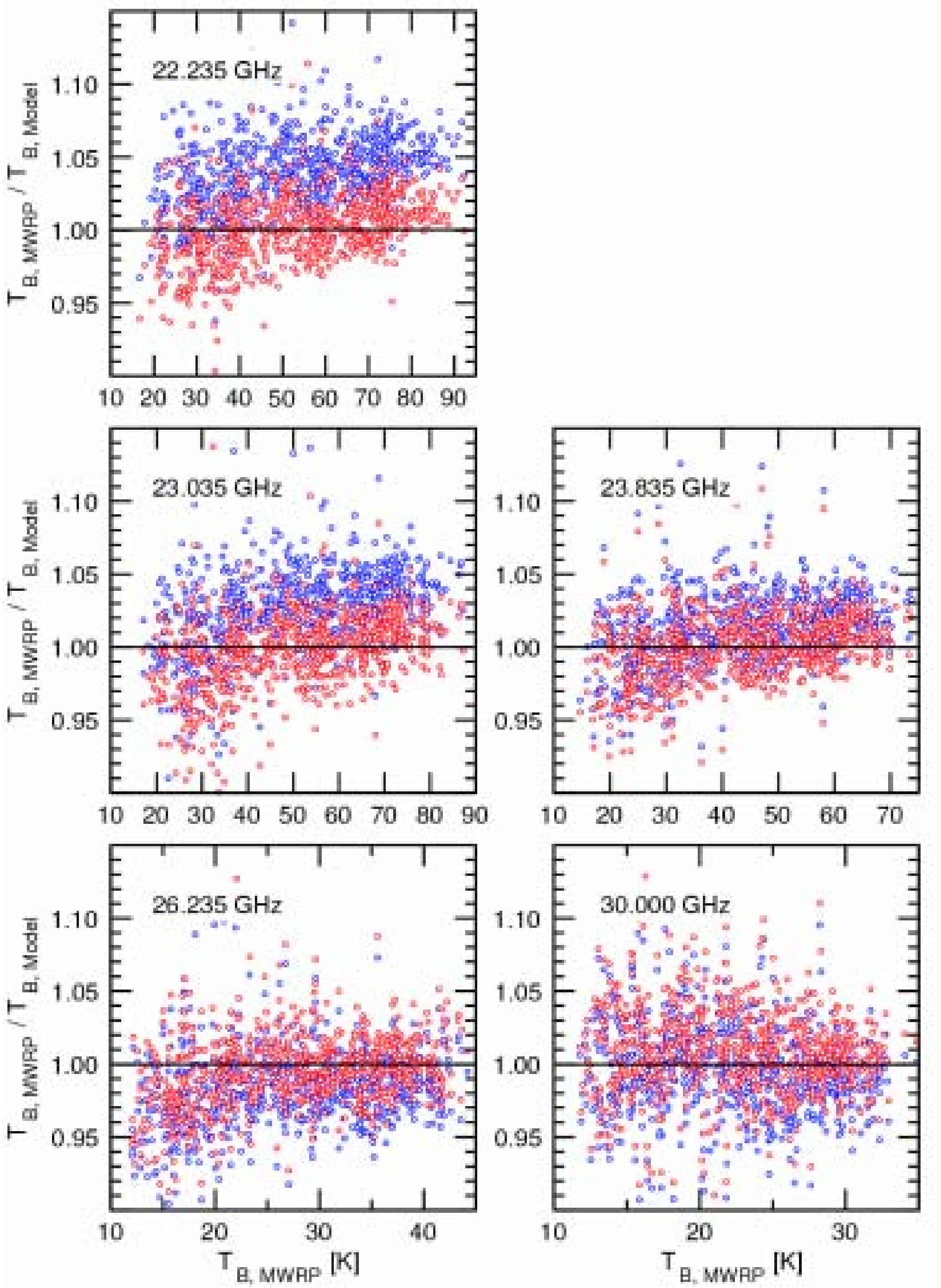

Figure 1. Ratios of the measured-to-modeled brightness temperatures are shown for the five K-band channels for both the original Rosenkranz (1998) absorption model (blue) and the modified Rosenkranz model with the 5% smaller 22 GHz water line width parameter (red).

Corrected Temperature and Water Vapor Retrievals

Statistical retrievals of temperature and water vapor profiles) based on the Rosenkranz absorption model with the reduced 22 GHz line width were developed for three-month periods (spring, summer, fall, and winter using 9041 radiosonde soundings from the SGP CF launched from 1994 through 2000. These were applied to brightness temperatures measured with the MWRP at the SGP from July 2001 through September 2002. The differences between the retrieved profiles of temperature and water vapor and those measured by 955 co-temporal (unscaled) RS-90 radiosonde soundings were calculated. The mean (bias) and standard deviation of these differences are presented in Figure 2 along with a comparison of the original neural network retrievals developed by Radiometrics (Solheim et al. 1998b) based on the unmodified Rosenkranz absorption model. The bias in the retrieved water vapor profiles in the lower and middle troposphere is substantially reduced using the new statistical retrieval based on the narrowed 22 GHz line width. The standard deviation is also slightly reduced. The large temperature bias in the upper troposphere is also substantially reduced using the new narrowed line width retrieval. The upper tropospheric temperature retrieval is dominated by the brightness temperatures at 51.25 and 52.28 GHz, which have a significant contribution from water vapor and therefore are sensitive to errors in the water vapor absorption model.

Figure 2 also presents calculations of the vertical resolution of the temperature and water vapor retrievals and the improvement in resolution, particularly for water vapor, due to the narrowed line width statistical retrieval. The resolution was calculated as the difference in the heights where the inter-level error covariance for each level of the retrieved profiles (relative to radiosondes) fell to 0.5. This is the method used by Smith et al (1999) to calculate the vertical resolution of temperature and water vapor profiles derived from the atmospherically emitted radiance interferometer (AERI) spectrometer and also by Gueldner and Spaenkuch (2001) in their analysis of the MWRP neural network retrievals.

Combined MWRP and GOES-8 Retrievals

Temperature and water vapor profiles retrieved independently from the MWRP and GOES-8 (ARM product sgpg8profC1.a1) were combined using the inverse covariance weighting technique:

$$Y(z) = [\ Y_1(z)/\sigma_1^2(z) + Y_2(z)/\sigma_2^2(z)\ ] \ / \ [\ 1/\sigma_1^2(z) + 1/\sigma_2^2(z)\ ].$$

Here Y is the temperature or water vapor density profile, z is the altitude, subscripts 1 and 2 indicate the two independent measurements of Y to be combined, and σ^2 is the error covariance, taken to be the square of the standard deviation of the difference between the retrieved profiles and collocated radiosonde soundings.

The results of the inverse covariance weighting are presented in Figure 3 along with results from the GOES+AERI retrieval (ARM product sgpgaeriprofC1.c1) for reference. For temperature, bias of the combined system is reduced relative to the separate retrievals below 1 km. Above 1 km, the GOES retrieval dominates due to its significantly lower standard deviation, so the combined bias tends toward the GOES only bias. The vertical temperature resolution of the combined system is also improved relative to the separate systems. For water vapor benefit of the combination is not as dramatic because

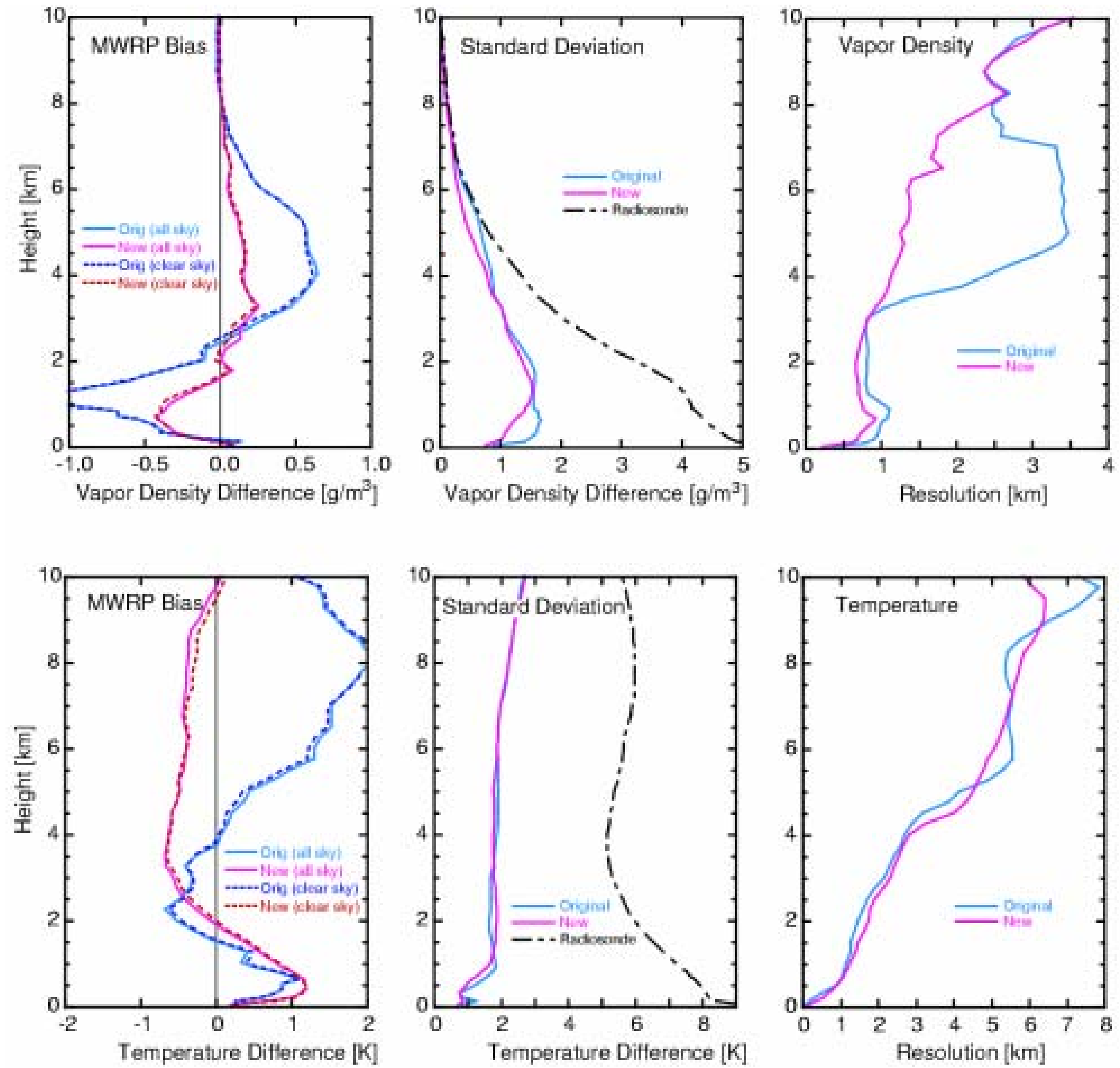

Figure 2. Mean (bias) and standard deviation of the MWRP-radiosonde differences in the water vapor and temperature profiles using the original retrievals (blue) based on the Rosenkranz (1998) absorption model and the new retrievals (red) based on the modified Rosenkranz model with the 5% smaller 22 GHz water line width parameter. The standard deviation of the radiosonde sounding ensemble about the mean of the soundings (black) is provided for reference. The vertical resolution of the water vapor and temperature retrievals for the original (blue) and revised (red) line width is also shown.

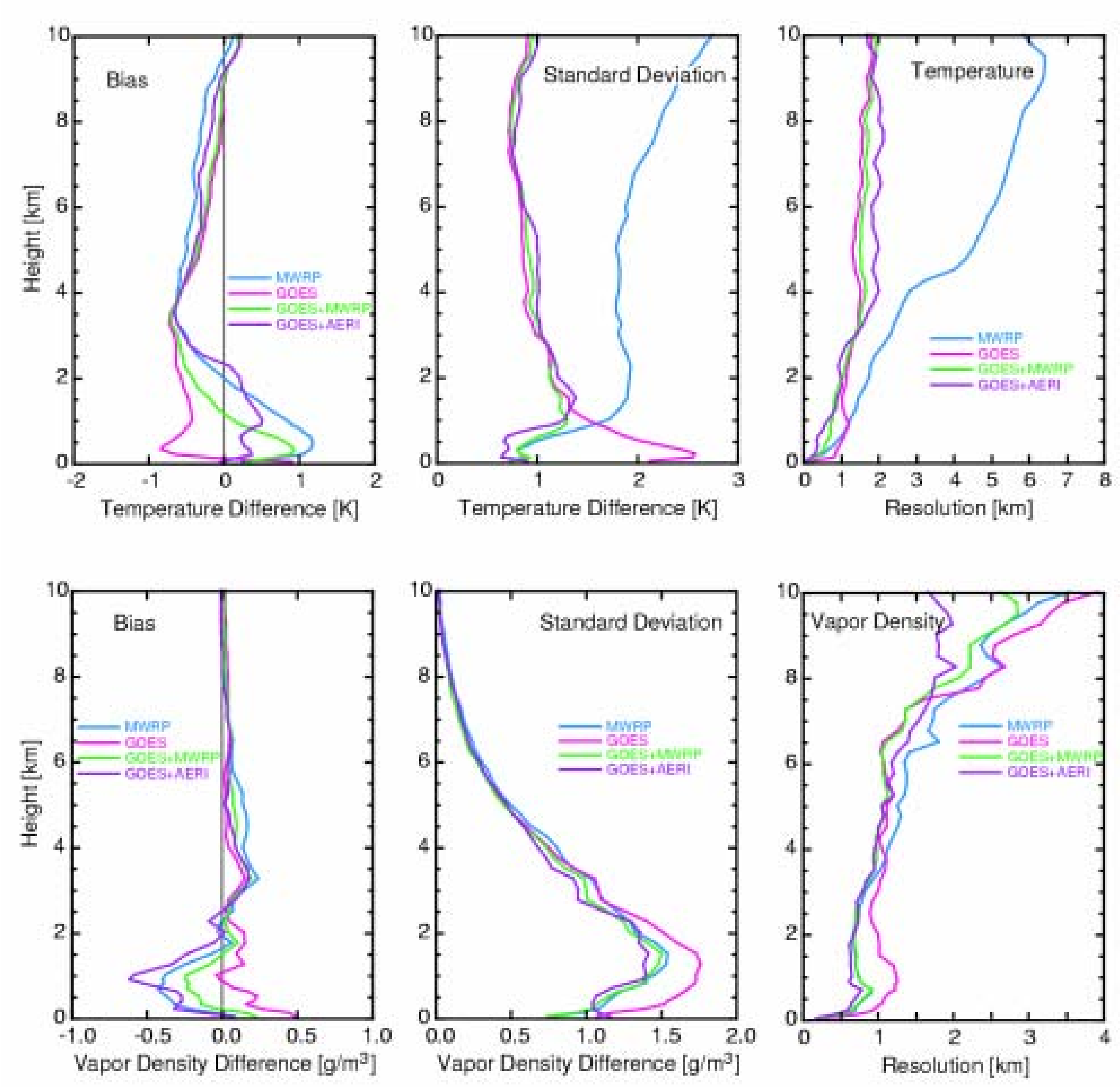

Figure 3. Mean (bias) and standard deviation of the retrieval-radiosonde differences for water vapor and temperature profiles derived from the MWRP alone (blue), GOES-8 sounder alone (magenta), GOES+MWRP (green) and GOES+AERI (maroon). Vertical resolution for water vapor and temperature profiles is also shown. Vertical resolution is determined based distance between the heights where the inter-level error covariance for each level falls to 0.5.

the standard deviation of the GOES retrieval errors are greater or equal to the MWRP retrieval error standard deviation below 4 km, above which the vertical resolution does benefit noticeably. One limitation of the combined MWRP+GOES profiles (which is also applicable to the AERI+GOES retrievals) is that the infrared systems (GOES and AERI) are restricted to clear sky conditions.

Conclusions

Biases in the temperature and water vapor profiles retrieved using the new twelve-channel profiling microwave radiometer have been attributed to the width of the 22 GHz water vapor line used in the Rosenkranz model being 5% too large. Retrievals based on a reduced line width that agrees with the value in the HITRAN database are shown to exhibit a temperature bias of less than 1 K and a water vapor bias of less than 0.5 g/m^3. The vertical resolution of the temperature and water vapor retrievals is also improved significantly by the reduced line width.

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