Preliminary Results with the Twelve-Channel Microwave Radiometer Profiler at the North Slope of Alaska Climate Research Facility

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Introduction

Coincident with the Arctic winter water vapor intensive operational period (IOP), the 12-channel microwave radiometer profiler (MWRP) was permanently deployed at the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) North Slope of Alaska (NSA) site at Barrow, Alaska, in February 2004. The purpose of the permanent deployment is to augment the routine once-per-weekday radiosonde launches at the Barrow site with continuous profiles of temperature, water vapor, and single-layer liquid water clouds. Figure 1 presents time-height contours of temperature (K), water vapor density (g/m^{-3}), and liquid water content (g/m^{-3}) for March 12-15, 2004, derived from the MWRP using statistical retrievals. The strong elevated temperature inversion is well represented, even during March 13-14 with low supercooled liquid water clouds, when infrared profiling techniques would not have performed well.

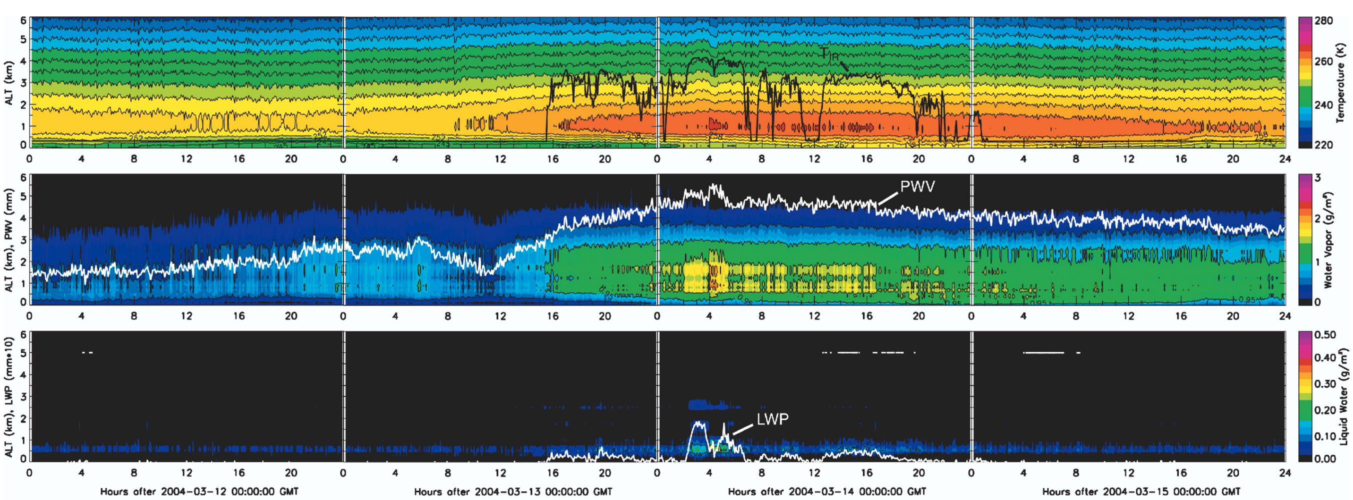

Figure 1. Time-height contours of temperature (top), water vapor density (middle), and liquid water content (bottom) for March 12-15, 2004, at the ARM ACRF NSA site at Barrow, Alaska. The black line in the top panel indicates the temperature reported by the infrared thermometer. The white lines in the middle and bottom panels indicate the precipitable water vapor and liquid water path, respectively

In this paper, we present preliminary results from the NSA deployment, including model-calculated brightness temperatures compared with brightness temperatures measured with the MWRP and the two-channel microwave radiometer (MWR) at Barrow. We also compare integrated precipitable water vapor (PWV) derived from the MWRP and MWR brightness temperatures. The PWV was measured with Vaisala RS90 radiosondes and the SuomiNet Global Positioning System (GPS) receiver. During this period, the PWV was very low, ranging from 1 to 5 mm.

Comparison with Model Calculations

Brightness temperatures measured at the five K-band channels (22.235, 23.035, 23.835, 26.235, and 30.0 GHz) and seven V-band channels (51.25, 52.28, 53.85, 54.94, 56.66, 57.29, and 58.8 GHz) were compared with calculations using the Rosenkranz (1998) water vapor absorption model and recent modifications by Rosenkranz with collocated RS90 radiosonde soundings. Based on previous findings by Liljegren (2003), comparisons were also made with a Rosenkranz model that had been modified to use the air-broadened half-width for the 22-GHz water vapor resonance from the high-resolution transmission (HITRAN) database (Rothman et al. 1992). The water vapor continuum was also modified to be consistent with the CKD 2.4 formulation described by Mlawer et al. (2003).

In Figure 2, the results for this period show generally good agreement between measurements and both the original and modified Rosenkranz models. The superior agreement with the model using the HITRAN half-width is particularly evident in the 22.235 GHz channel when the water vapor density reached its maximum value during March 14-15. The disagreement during cloudy conditions on March 14 arises because the radiosondes do not measure cloud liquid water.

The increased variability in the measured brightness temperatures before March 3, indicated in Figure 2, was due to an auxiliary internal heater added by the manufacturer before the NSA deployment. The heater was disconnected on March 2, and the variability decreased immediately. Disabling the internal heater did not adversely affect the thermal stabilization of the radiometer.

At 52.28 GHz (Figure 2), both models give values approximately 2-3 K greater than the measured brightness temperatures. This bias is consistent with similar results obtained at the ACRF Southern Great Plains (SGP) site near Lamont, Oklahoma. This observation suggests a problem with the spectroscopy of the oxygen resonances in this portion of the spectrum.

Comparisons with MWR Brightness Temperatures

In Figure 3, we compare the brightness temperatures measured with the two-channel MWR at 23.8 and 31.4 GHz to the MWRP measurements at 23.835 and 30.0 GHz. The MWR zenith brightness temperatures calculated from tip curves for ten elevation angles (from the nsamwrtipC1.a1 files) are presented, along with brightness temperatures for the zenith line of sight (LOS) alone, calculated from the calibrated noise diode (from the nsamwrlosC1.a1 files). The tip-derived and zenith LOS brightness

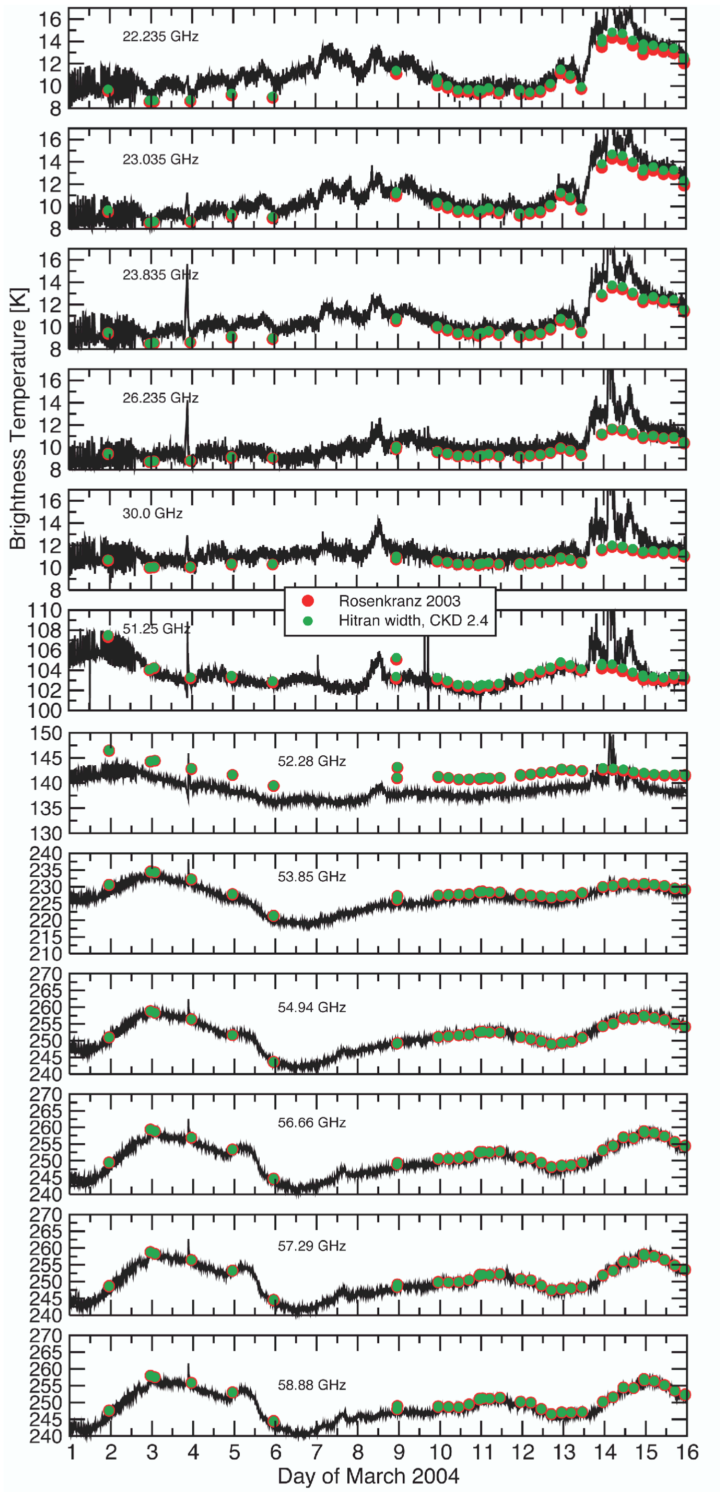

Figure 2. Brightness temperatures measured with the MWRP (black lines) compared with calculations using input from collocated radiosonde soundings in the unmodified (red circles) and modified Rosenkranz absorption model. The modification allows use of the HITRAN half-width for the 22-GHz water vapor resonance and consistency with the CKD 2.4 water vapor continuum (green circles).

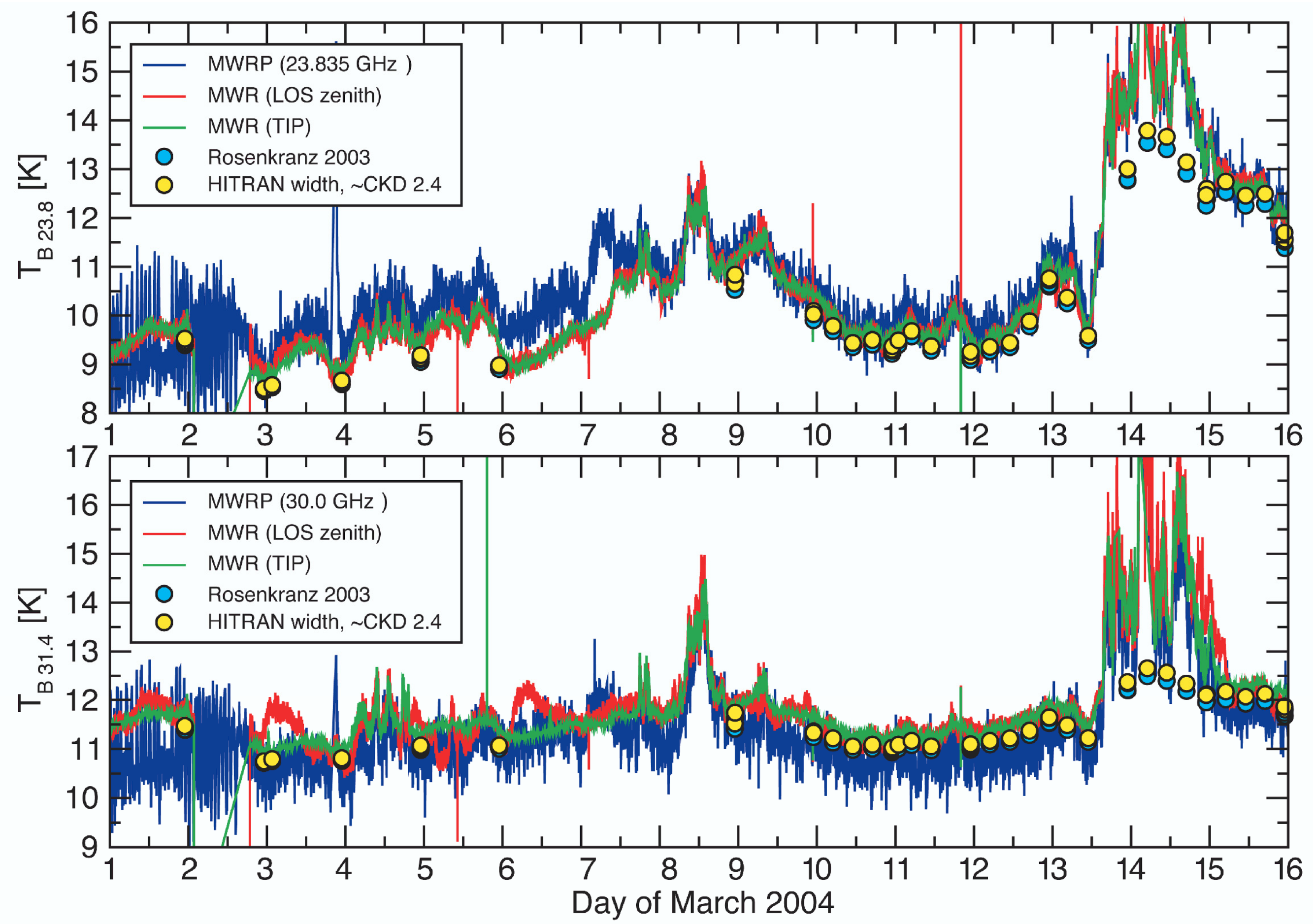

Figure 3. Brightness temperatures (T_B) from the MWR at 23.8 and 31.4 GHz are compared with values from the MWRP at 23.835 and 30.0 GHz, as well as with calculations based on the original Rosenkranz absorption model and the model modified to use the HITRAN half-width at 22 GHz and water vapor continuum adjustments to be consistent with CKD 2.4.

temperatures from the MWR are generally in good agreement, demonstrating the quality of the noise diode calibration. The tip-derived values are smoother because they are based on ten sky measurements, whereas the zenith LOS values are the result of a single sky measurement.

The brightness temperatures from the MWRP generally agree well with the MWR values. The MWRP brightness temperatures at 30.0 GHz should be (and are) slightly lower than the MWR values at 31.4 GHz. The brightness temperatures from the MWRP contain more noise than those from the MWR. This is due to the reduced sky sampling time of 0.5 s at each frequency for the MWRP compared with 1.0 s at each frequency for the MWR.

Comparisons of PWV with MWR, GPS, and Radiosonde

A priori statistical retrievals of PWV and liquid water path (LWP), based on the Rosenkranz absorption model with the HITRAN half-width, were developed using (a) only the 23.835 and 30.0 GHz brightness temperatures for comparison with the MWR retrievals and (b) all 12 MWRP measurement frequencies for comparison with the artificial neural network retrievals supplied the MWRP manufacturer. These retrievals were developed for 3-month periods (spring, summer, fall, and winter) by using 1381 radiosonde soundings from the NSA Barrow site launched for 1998-2003. Root-mean-square (RMS) brightness temperature errors of 0.5 K were assumed in the retrievals.

Initially, the statistical and neural network retrievals using all 12 measurement channels exhibited a positive bias in PWV and a negative bias in LWP relative to the two-channel statistical retrievals for the MWRP and MWR. This bias is attributed to the 3 K bias between measured and modeled brightness temperature in the 52.28-GHz channel described earlier. After the 3 K bias was removed, the 12-channel PWV and LWP retrievals were in good agreement with the two-channel retrievals for MWR and MWRP; the 12-channel PWV and LWP retrievals also exhibited less noise. These results are presented in Figure 4, where they are also compared with PWV derived from the collocated RS90 radiosonde soundings and from the SuomiNet GPS measurements (Ware et al. 2000).

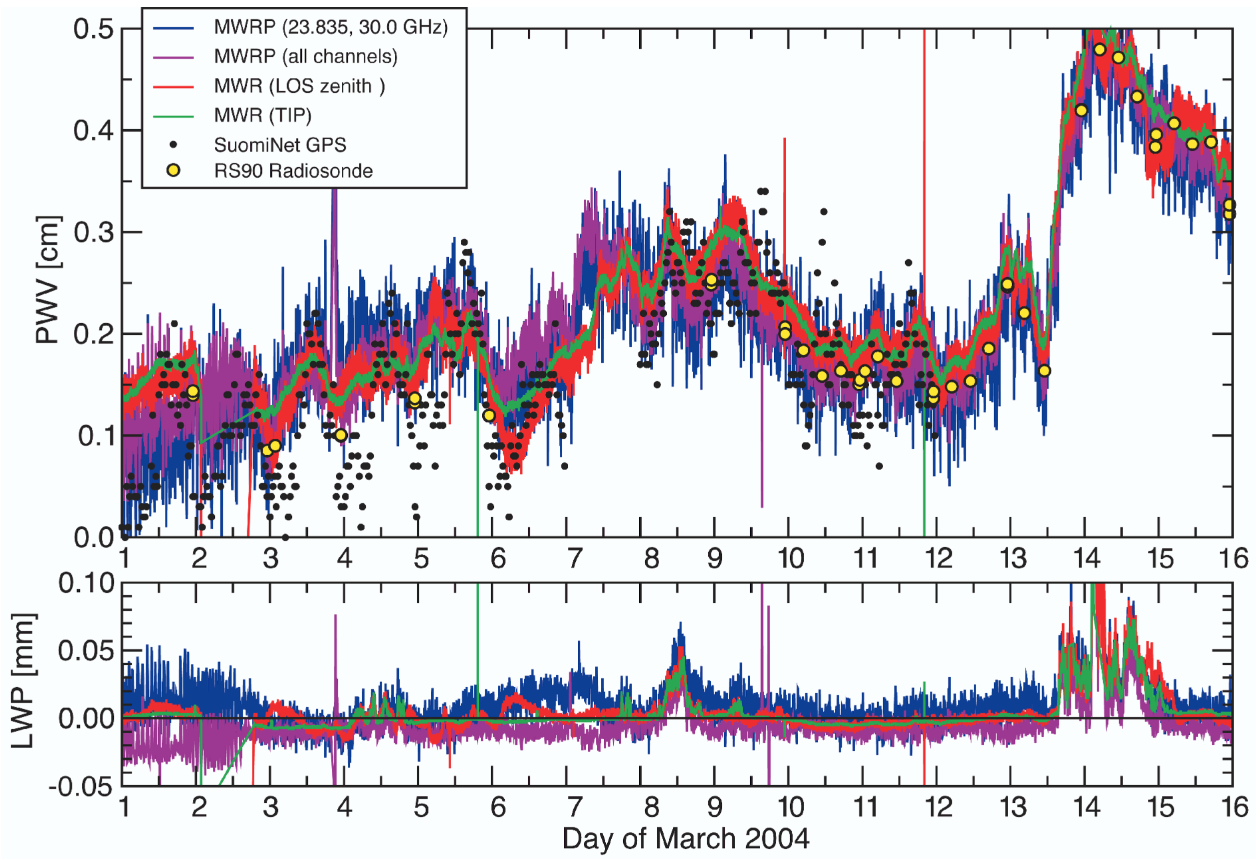

Figure 4. Estimates of PWV and LWP from *a priori* statistical retrievals using only the 23.835 and 30.0 GHz brightness temperatures from the MWRP (blue) and all 12 MWRP measurement frequencies (purple) are compared with retrievals from the two-channel MWR by using the zenith LOS brightness temperatures (red) and the tip-derived brightness temperatures (green), the SuomiNet GPS station (black circles), and RS90 radiosondes (yellow circles). The 3 K bias in the 52.28 GHz brightness temperatures shown in Figure 2 was removed before the 12-channel retrieval (purple) shown was applied.

The retrieved PWV from the MWR and MWRP agree well with the radiosonde data. The SuomiNet PWV estimates (gecsoumigpsX1.c1) are in general agreement with the others but exhibit significantly more variability than at the SGP site. This could be due to snow on the antenna at Barrow.

Comparison of Temperature and Water Vapor Profiles with Radiosondes

In Figure 5, temperature and water vapor density profiles derived from MWRP brightness temperatures using statistical and neural network retrievals are compared with radiosonde data for both a very dry, clear-sky day (March 12) and a day when supercooled liquid water clouds were present (March 14). The statistical and neural network temperature retrievals agree fairly closely; however, the water vapor density retrievals and the derived relative humidity and dew point temperature profiles exhibit some differences, First, the neural network retrievals appear to be smoother and to agree slightly better with the radiosonde data in the lower troposphere, but they exhibit a positive bias above 7 km. Second, both retrievals have difficulty resolving the sharp temperature and water vapor gradients at 200 m above ground level on March 14. Incorporating measurements at off-zenith angles into the retrievals may improve the vertical resolution.

Conclusions

Preliminary results from the 12-channel MWRP at the NSA Barrow site demonstrate good agreement with model-calculated brightness temperatures, except at 52.28 GHz, where a 3 K bias is observed. This bias was also observed in similar comparisons at the SGP site near Lamont, Oklahoma. This bias is likely due to shortcomings in the spectroscopy of the oxygen absorption resonances at 50-60 GHz.

The MWRP brightness temperatures at 23.835 and 30.0 GHz agree well with values from the MWR measured at 23.8 and 31.4 GHz. The former contain more noise because of a shorter sky-sampling time for the MWRP. The MWRP sky-sampling period should be increased to reduce this noise.

After accounting for the bias at 52.28 GHz, the PWV and LWP values retrieved by using all 12 MWRP measurement frequencies agree with the values retrieved by using only the 23.835 and 30.0 GHz frequencies, the MWR retrievals, and PWV from radiosonde soundings. The SuomiNet GPS PWV estimates exhibit considerable variation but are in general agreement with the other PWV estimates.

Profiles of temperature and water vapor derived from the MWRP brightness temperatures by using statistical and neural network retrievals are in general agreement. The neural network retrievals for water vapor are smoother but exhibit a bias above 7 km.

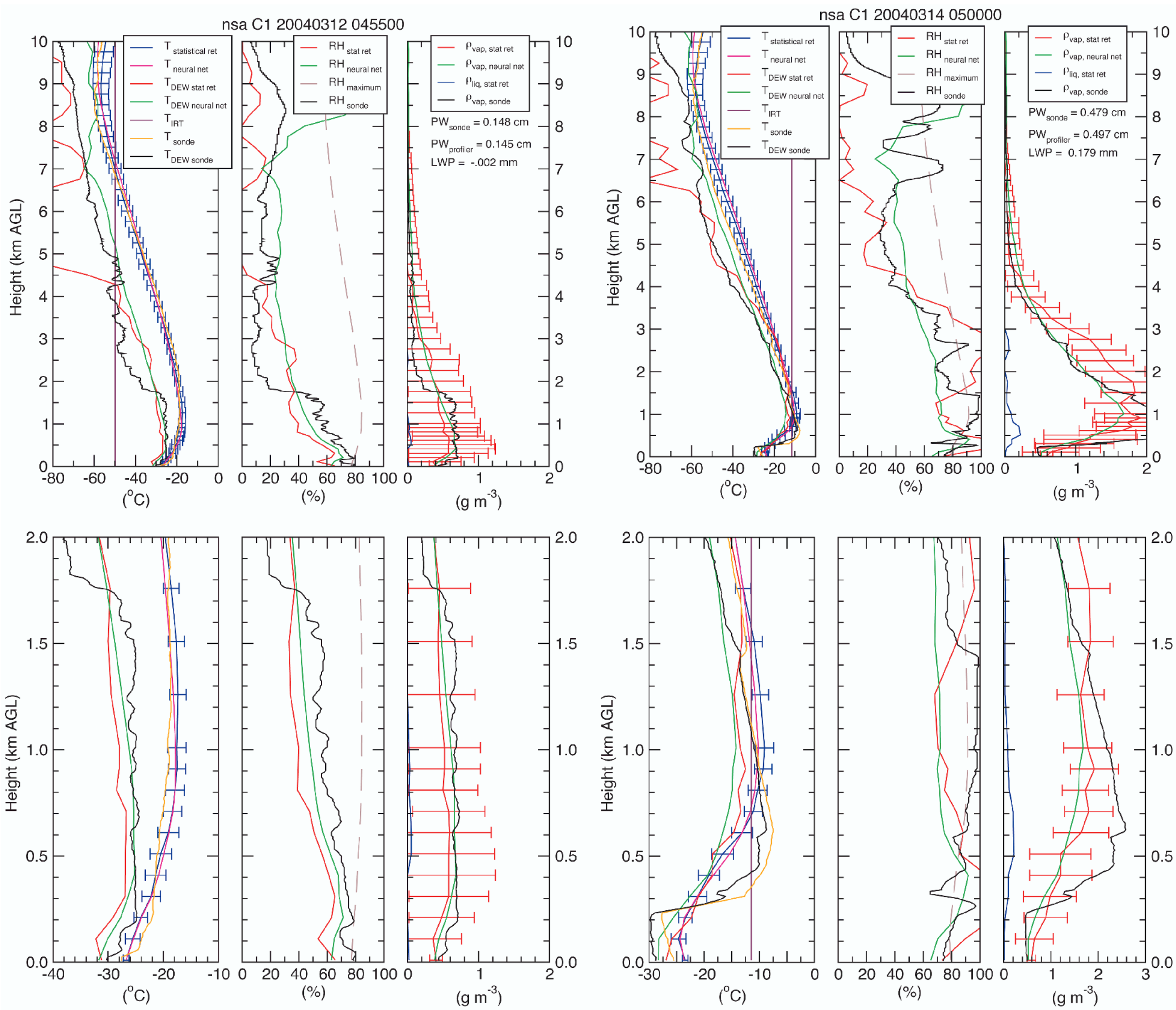

Figure 5. Profiles of temperature and water vapor density derived from the MWRP T_B by using *a priori* statistical and neural network retrievals for a very dry, clear-sky day (March 12) and a day with supercooled liquid water clouds (March 14). The 3 K bias at 52.28 GHz was removed before the retrievals were applied. Relative humidity (RH) and dew point profiles were computed from the retrieved profiles. Error bars represent the theoretical RMS error for a 0.5 K RMS error in T_B. RH maximum is the ratio of the saturation mixing ratio over ice to that over liquid water.

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