Radiometric Observations of Water Vapor During the 1999 Arctic Winter Experiment

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Introduction

The Millimeter-Wave Radiometric (MMWR)-Arctic experiment was conducted in March 1999 at the North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART) site. During the experiment, the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) deployed four microwave radiometer (MWR) systems with a total of 24 radiometric channels ranging in frequency from 20.6 GHz to 340 GHz. One of the objectives of this experiment was to evaluate, during extreme cold conditions, the performance of the Atmospheric Radiation Measurement (ARM) Program's dual-channel (23.8 GHz and 31.4 GHz) MWR that is routinely operated at the CART site to derive precipitable water vapor (PWV) and cloud liquid water. The MWR measurements are compared with water vapor measurements using frequency channels around the much stronger 183-GHz water vapor absorption line. NASA's millimeter-wave imaging radiometer (MIR) has three channels near the 183-GHz absorption line and ETL's circularly scanning radiometer (CSR) has seven channels around 183 GHz. In this paper, we focus on the evaluation of the performance of the ARM MWR by comparing its PWV retrievals with those derived from the 183-GHz channels and radiosondes, which were released at the NSA/AAO CART site.

Calibration Methods

External Blackbody Reference Targets

The MIR and CSR systems both have two external blackbody reference targets, one at the ambient temperature of about -30°C and the other at 26°C. During each scan, the radiometers observed each of the reference targets once and the voltage measurements of the atmospheric portion of the scan were linearly interpolated or extrapolated using these two reference points.

Tipping-Curve Calibration

For channels with low atmospheric opacity, the measurements can be calibrated by the so-called tipping-curve calibration procedure (Han and Westwater 2000) in which a calibration factor in the radiometer equation is adjusted to yield a straight line of opacity τ versus air mass a that passes through the origin.

Intercomparisons of Brightness Temperature Measurements

The CSR 183 channels were calibrated first using blackbody reference targets and then recalibrated using the tipcal method because of a problem in the hot reference load. The MIR 183 channels were calibrated with blackbody references whose characteristics had been carefully evaluated in laboratory tests. The recently constructed CSR did not have the advantage of such testing. Both of the radiometers performed continuous elevation scans, but due to instrument differences, the scan patterns were different, the principal difference being that the CSR performed a symmetrical scan that yielded good data over roughly three air masses. The two MWR channels were initially calibrated and then re-calibrated, using different tipcal averaging methods.

As shown in Figures 1 and 2, the two 183-GHz radiometer systems agreed very well, especially the 183.31 ± 7 channels, which are used to derive PWV in this study. However, initial comparisons of the 183 GHz with the original archived ARM MWR brightness temperature T_b measurements showed substantial differences. These differences were the result of a software attempt to compensate for improper temperature regulation at low temperatures. Figure 3 shows these discrepancies between the archived ARM MWR T_b measurements that were calibrated using averaged calibration factors and those re-calibrated by ETL using an instantaneous calibration factor. Figure 4 indicates that there is a strong correlation between the calibration factor Tnd and the radiometer mixer temperature and that the temporal variations of Tnd were not properly taken into account in the original calibration process but were correctly restored by the instantaneous calibration.

PWV Retrievals

As shown in Figure 5, the discrepancies shown in Figure 3 resulted in significant differences in retrieved PWV. The ETL-derived MWR PWV agrees very well with that from MIR, as shown in Figure 6. Figures 7 and 8 show comparisons of PWV between radiometer-derived PWV and that measured by radiosondes. The NWS radiosondes are about two-tenths of a millimeter wetter than both of the radiometric measurements.

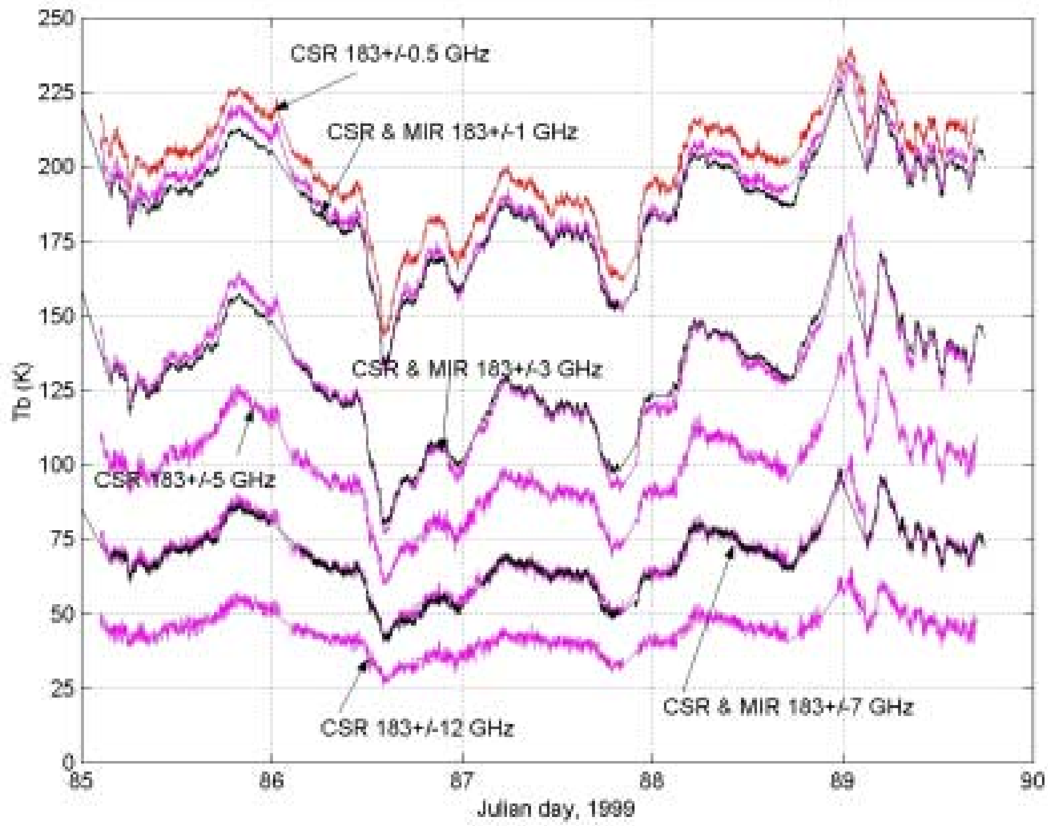

Figure 1. Time series of T_b around 183 GHz. Red line - CSR; black line - MIR. The CSR channels were calibrated using the tipcal procedure and the MIR channels were calibrated with two external blackbody references.

Conclusions and Suggestions

There was remarkable agreement between CSR and MIR 183 ± 7 channels [root mean square (rms) difference = 1.35 K], although the two systems are calibrated using different methods. Original ARM MWR data suffered from an incorrect averaging of their calibration factor Tnd. The use of instantaneous tipcal largely eliminated the errors. The ETL-derived MWR retrievals agreed much better with MIR-derived PWV. Tipcal data analysis reveals that the ARM MWR calibration factor Tnd is strongly correlated with the mixer physical temperature, but is poorly correlated with ambient or blackbody reference temperatures. Further studies are needed to explain the correlation between the Tnd and mixer temperature, to obtain a reasonable time scale for Tnd time averaging, and to develop methods to estimate Tnd during conditions in which tipcal data are not available.

References

Han, Y., and E. R. Westwater, 2000: Analysis and improvement of tipping calibration for ground-based microwave radiometers. *IEEE Trans. Geosci. and Remote Sensing*. In press.

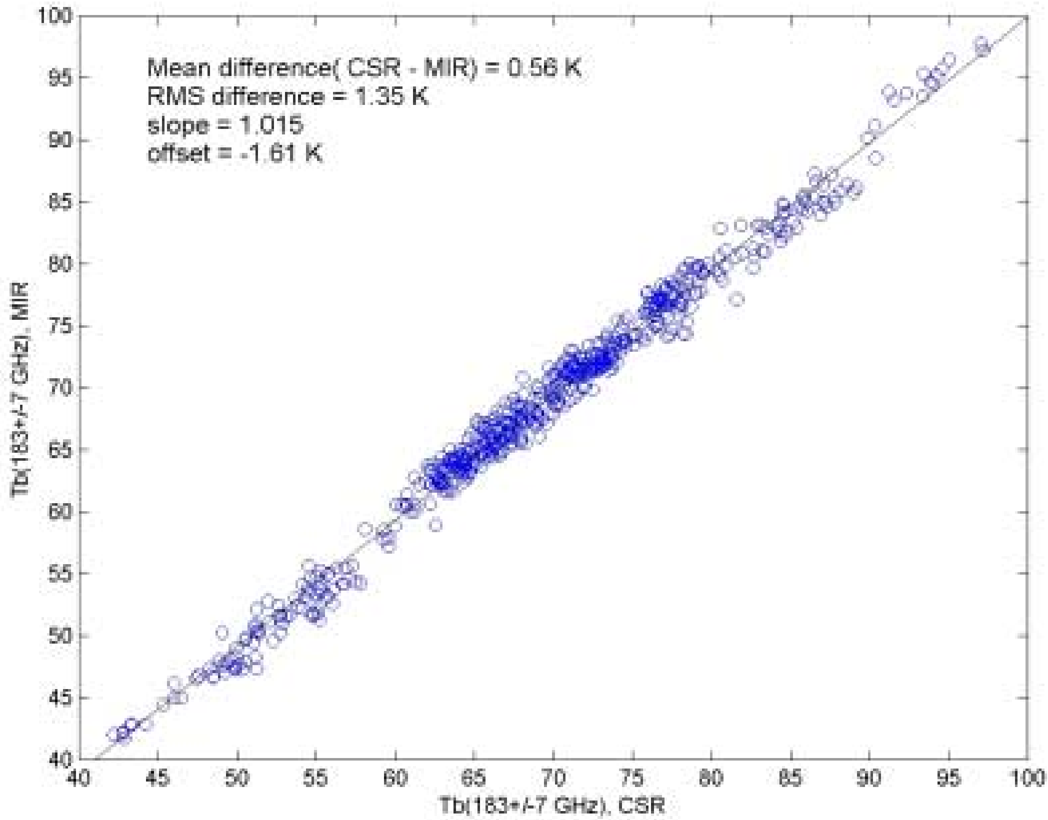

Figure 2. Statistics of comparisons between CSR and MIR 183.31 ± 7 channels. Data were collected during the experiment from March 7 to March 30, 1999. Each data point is a 10-min average.

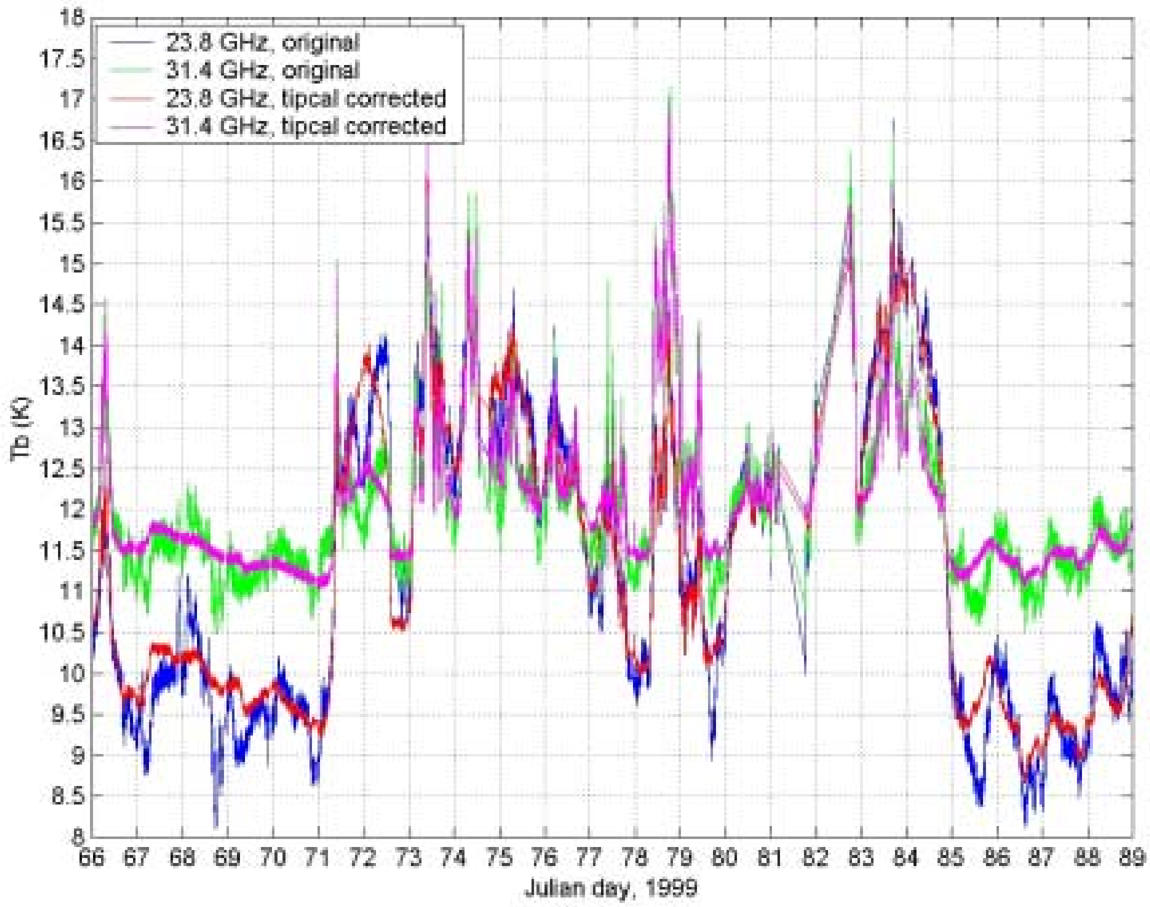

Figure 3. Comparisons of MWR T_b measurements. The green and blue lines are measurements obtained from ARM-archived MWR data files. These measurements were calibrated with a tipcal method in which the calibration factors are averaged over a specified period. The magenta and red lines are measurements that were recalibrated by ETL using instantaneous calibration factors.

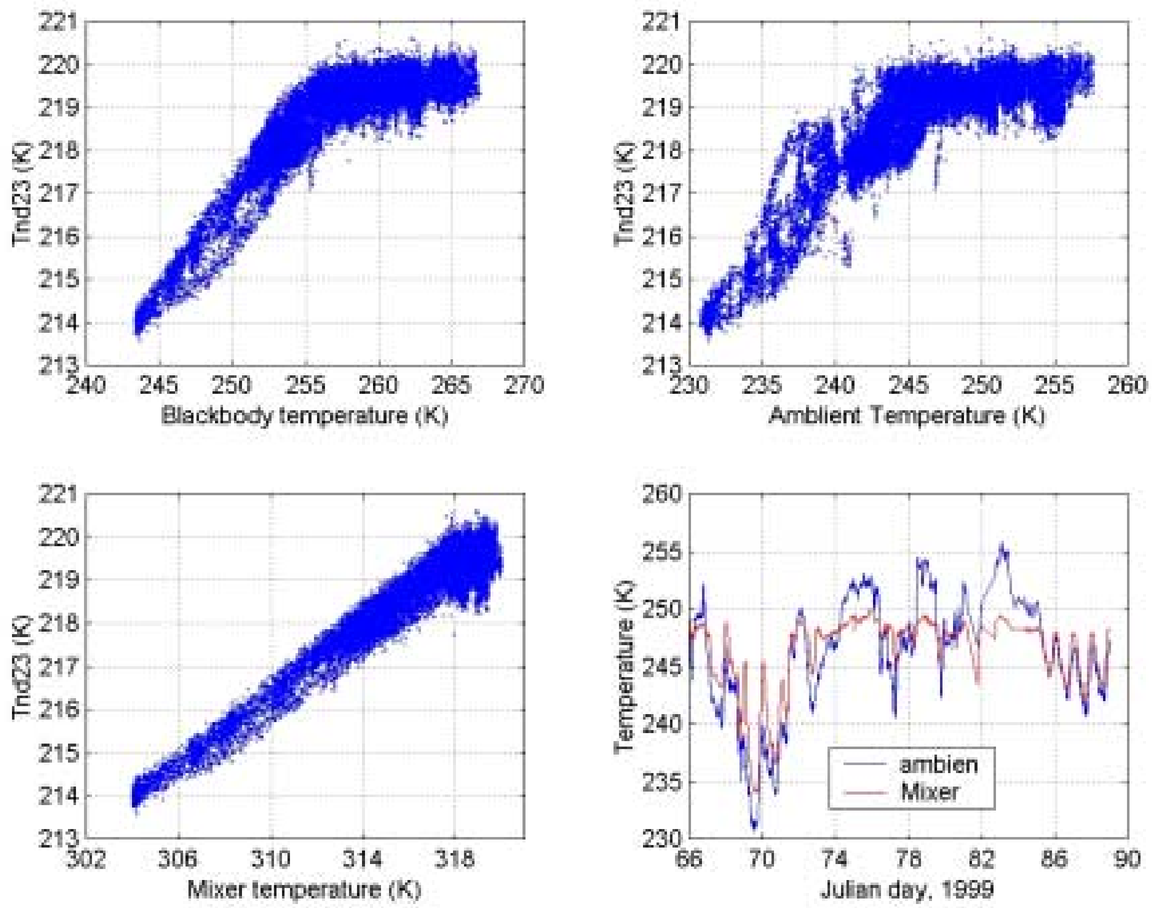

Figure 4. A: Tnd versus blackbody reference temperature. B: Tnd versus ambient temperature. C: Tnd versus mixer temperature. D: Time series of ambient and mixer temperatures.

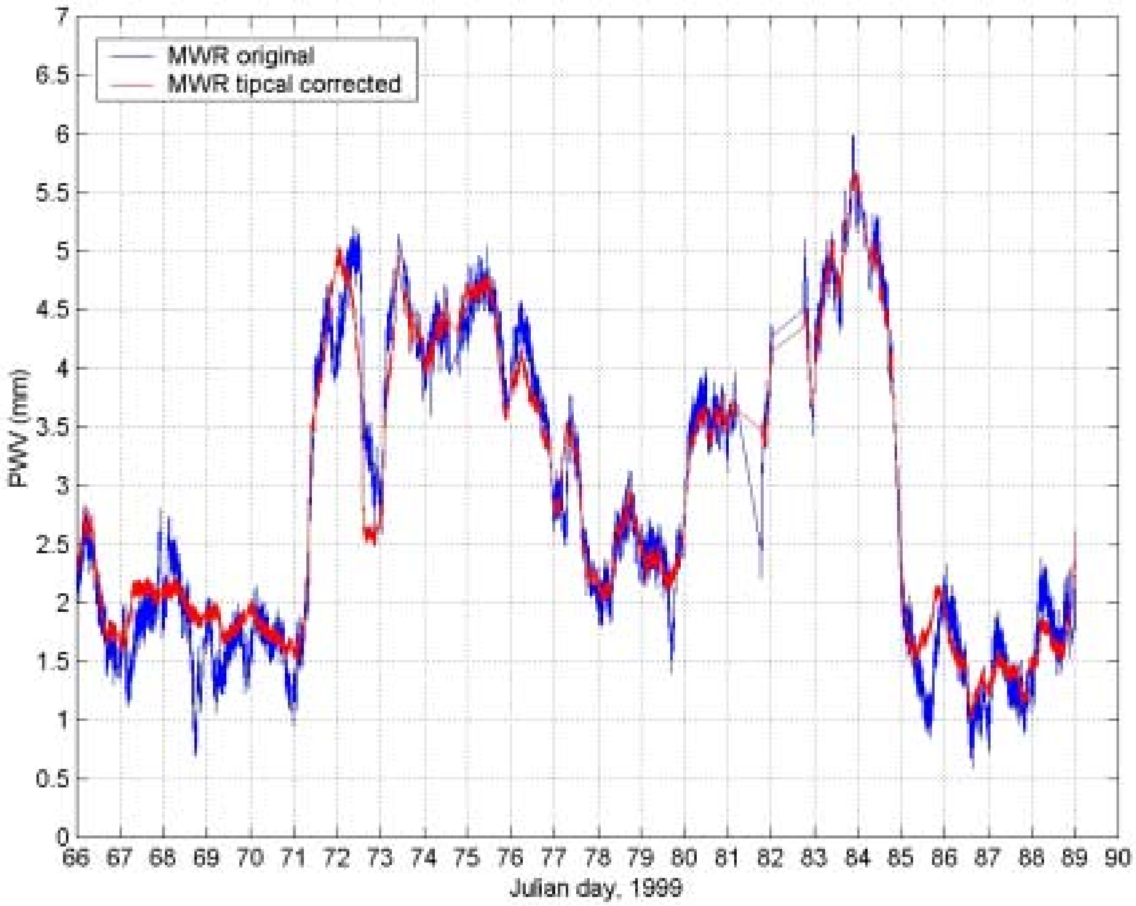

Figure 5. Time series of PWV obtained from the ARM-archived MWR data file and derived from the MWR measurements that are recalibrated at ETL using instantaneous calibration factors.

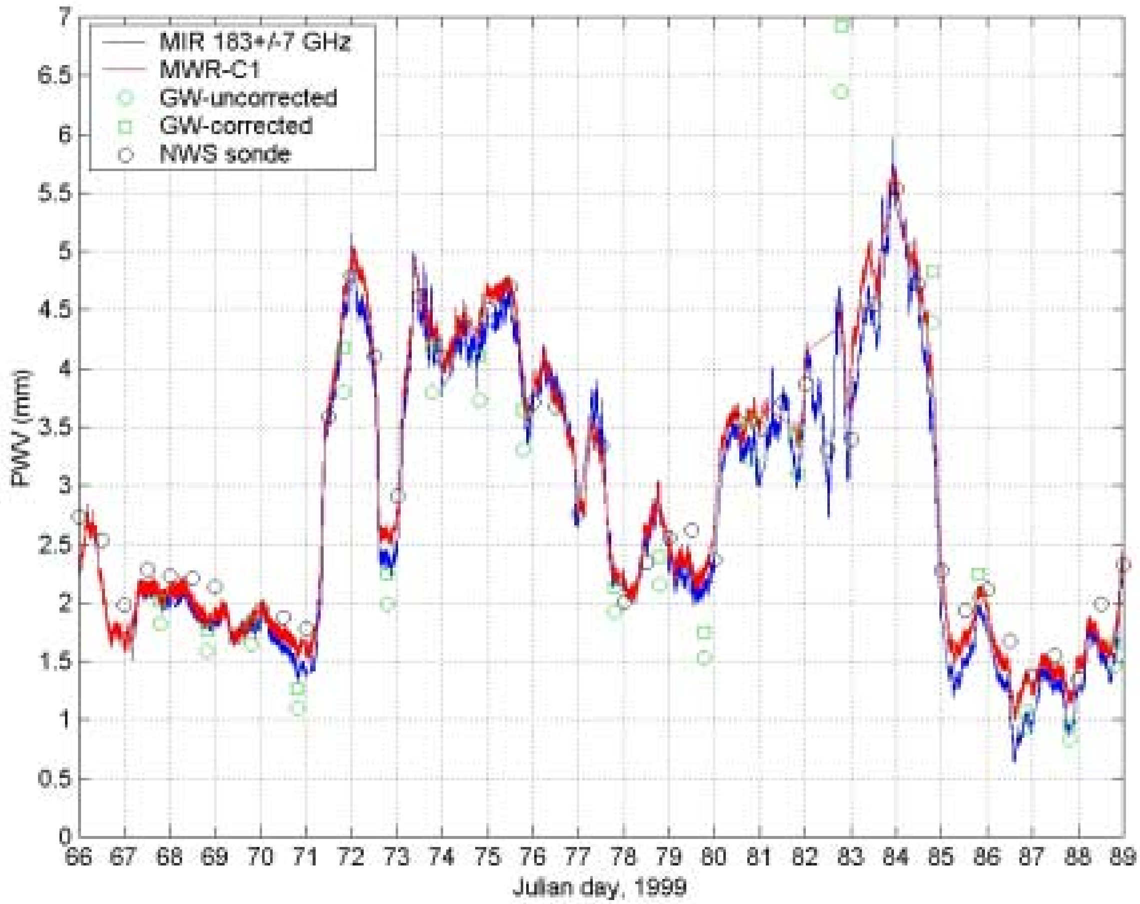

Figure 6. Time series of MIR (blue) and ETL-derived (red) MWR PWV, and radiosonde measured PWV (black circles - NWS radiosonde, green circles - original Vaisala radiosondes, and squares - corrected Vaisala radiosondes.

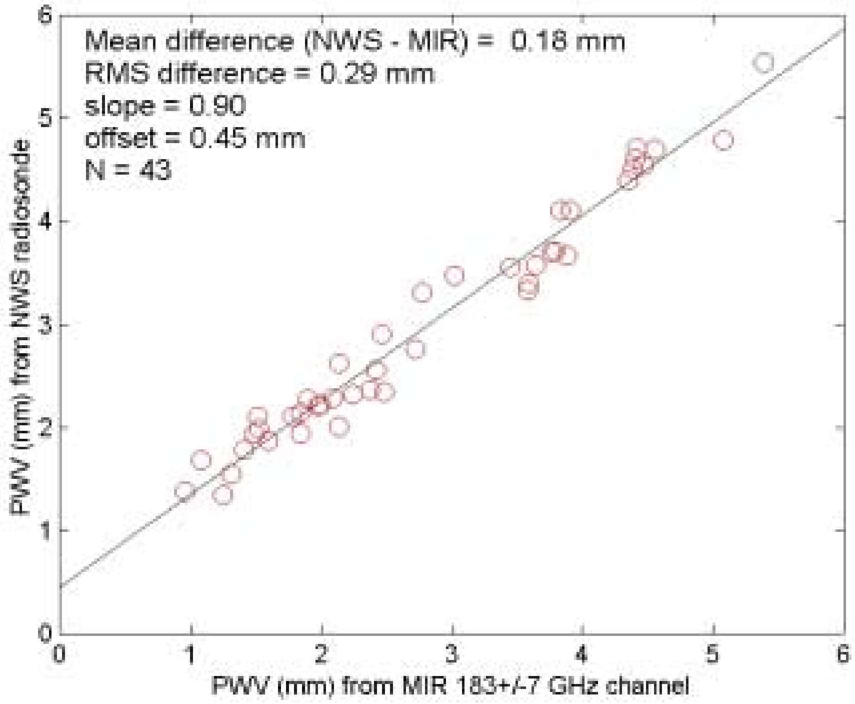

Figure 7. Comparison of PWV retrieved from MIR and measured by NWS radiosondes.

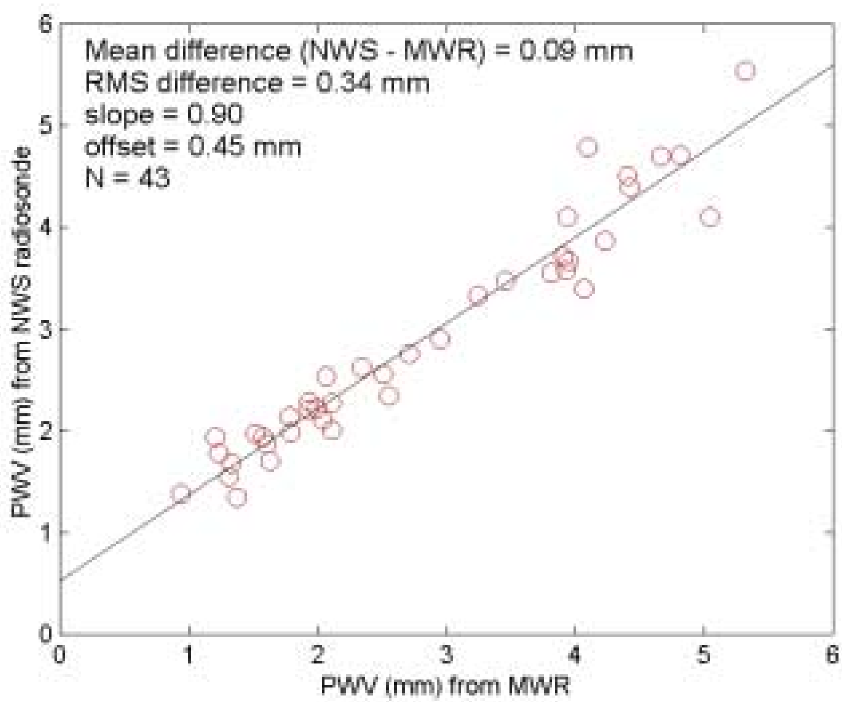

Figure 8. Comparison of PWV retrieved from MWR and measured by NWS radiosondes.