Microwave Radiometers and Radiosondes During Nauru99

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Introduction

Previous experience, both in the tropical western Pacific (Westwater et al. 1999) and during Water Vapor Intensive Operational Periods (WVIOPs) at the Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site, has indicated the need for adjustments to Vaisala Humicap RS80 humidity soundings. The need for such corrections has been identified by measurements of water vapor by microwave radiometers (MWRs) and the subsequent adjustments by scaling of water vapor profiles. The scaled water vapor profiles, when inserted into the Line-By-Line Radiative Transfer Model (LBLRTM) have been in much better agreement with well-calibrated infrared radiance measurements by the atmospheric emitted radiance interferometer (AERI) operated at many ARM CART sites (Clough et al. 1996).

During Nauru99 (Post et al. 1999), a variety of ground- and ship-based instruments were available to test the quality of radiosonde (RAOB) soundings in the tropical environment around the island of Nauru. In particular, nearly simultaneous RAOB soundings from the Atmospheric Radiation and Cloud Station (ARCS-2) and from the research vessel Ronald H. Brown (RHB) were available. In contrast to the earlier Pilot Radiation Observation Experiment (PROBE), the lot numbers of the Vaisala RAOBs were available for subsequent analysis. A variety of remote sensing and in situ measurements were also available. These instruments at ARCS-2 include the Radiometrics MWR and a Vaisala ceilometer. Of special interest to our analysis was our independent calibration of the MWR that used a blackbody calibration target cooled by liquid nitrogen (LN2).

The RHB arrived at Nauru on July 5 and assumed a stationary position close to the ARCS-2 location, approximately 1 km away. The first indication that there were substantial differences between ARCS-2 and RHB radiosondes was observed on the very first day that the ship was in close proximity to the island. Figure 1 shows a time series of brightness temperatures (Tbs) observed by the MWR at 23.8 GHz and 31.4 GHz, and Tbs calculated from various radiosonde profiles. The Tb model used in these calculations was the latest Rosenkranz (1998) absorption model. Somewhat surprisingly, the RAOB data from the RHB agreed much better with the MWR than those from the collocated ARCS-2 soundings. The triangles show data that were calculated from corrected ARCS-2 soundings using a procedure described by Lesht (1999).

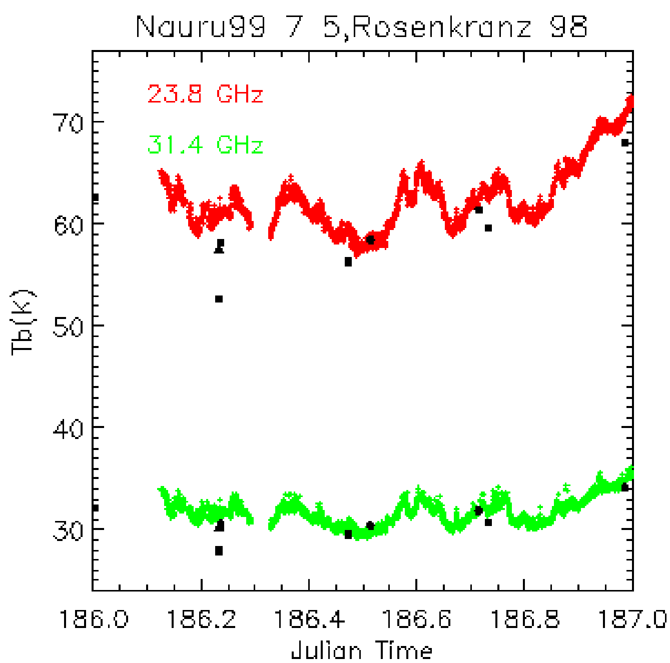

Figure 1. A 24-hr time series of Tb at 23.8 GHz and 31.4 GHz. Red 23.8. Green-31.4. Squares - calculated from original ARCS-2 RAOBs. Triangles - calculated from corrected ARCS-2 RAOBs. Circles - calculated from RHB RAOBs. RTE model - Rosenkranz 98.

The results of Figure 1 showed that, at the very least, there were significant differences between RAOBs that were launched at nearly the same time from the RHB and from the ARCS-2. A change in experimental plan was made and for five soundings, RAOB packages from the two sites were interchanged. This time, the original RHB radiosondes were in close agreement with the MWR, while the original ARCS-2 RAOBS, now launched from the RHB, were in substantial disagreement with the MWR. Thus, when the RAOBs were exchanged, the results were consistent with a RAOB problem, not a site problem. Again, using the procedure of Lesht (1999), the corrected RAOBs were in good agreement with the MWR Tbs. The reasons for the problem are now known to be associated with contamination of the RS80 humidity element as it ages. Later in this paper, we present results evaluating the accuracy of the RAOBs and their correction, as a function of RAOB age.

Many of our comparisons rely on the accuracy and consistency of the ARCS-2 MWR. During this experiment, the radiometer was run in a nearly continuous tip cal mode. When the sky conditions were favorable, as determined by symmetry of radiometry scans, the radiometer continued scanning at angles corresponding to the air masses 1, 1.5, 2.0, and 2.5 (elevation angles of 90°, 41.8°, 30°, and 23.6°). When clouds were present, angular symmetry was destroyed, and the radiometer went into a zenith-observing mode. Because we cannot calculate brightness temperatures from RAOBs during cloudy conditions, we will focus on clear conditions only; another reason for focusing on clear conditions is that during these conditions, calibration can be done on a nearly continuous basis. The original ARM calibration algorithm was used on the data and excellent data were obtained. We applied the Environmental Technology Laboratory (ETL) calibration method (Han and Westwater 2000) to the same tip cal data, and nearly identical results were obtained. Our results, requiring beam width and angular-dependent mean radiating temperatures, use equivalent zenith brightness temperatures as a measure of calibration quality. Root mean square (rms) departures of this measure were frequently better than 0.2 K, indicating a high degree of atmospheric stratification and antenna beam symmetry. We also performed a LN2 calibration experiment, in which a blackbody reference target (or load) was filled with LN2 and placed over the MWR. The measured Tbs during this experiment are shown in Figure 2. For the first two minutes after the load was inserted, the measured Tbs were about 79.6 K, which is close to the expected value of 79.4 ± 1.9 K (F. Solheim, private communication). After the first two minutes, moisture condensed on the underside of the Styrofoam container and increasingly spurious observations were obtained. However, the few minutes of good measurements indicated that the MWR was accurate to within ± 1 K. This single target calibration measurement, together with the continuous high quality of tip cals, indicated that the MWR could be used as a comparison standard for the experiment.

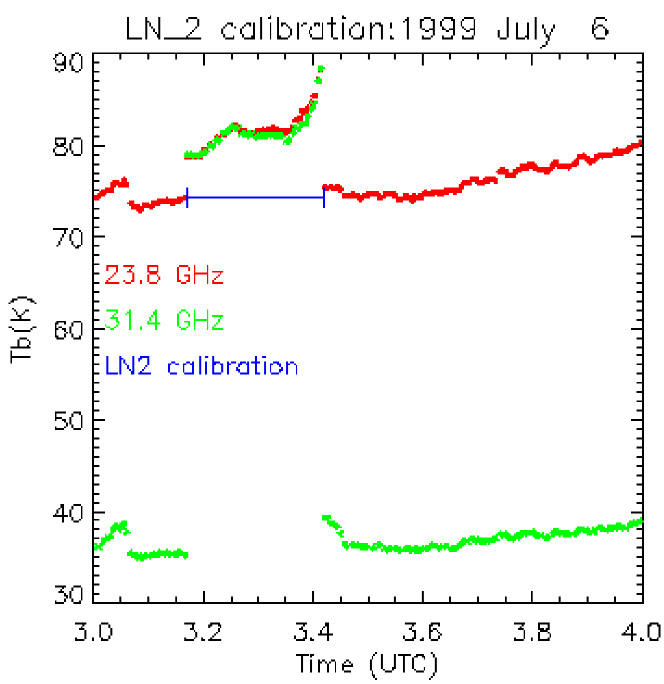

Figure 2. Results of the LN2 calibration.

The manufacturers of Vaisala radiosondes have developed a proprietary algorithm to correct for the dry bias problem (Miller et al. 1999). We have used a version of the algorithm that makes the correction based only on the age of the RAOB. Because we were also worried about diurnal effects, we divided our data samples into day and night subsets, and for these subsets compared Tbs measured by the ARM MWR with calculations, based on the Rosenkranz (1998) absorption model for both the original and corrected radiosondes. Our analysis showed that no statistically significant effects were present. Figure 3 shows a scatterplot showing the comparison of corrected and uncorrected Tb calculations versus the MWR Tbs for the period of June 15 to July 15, 1999.

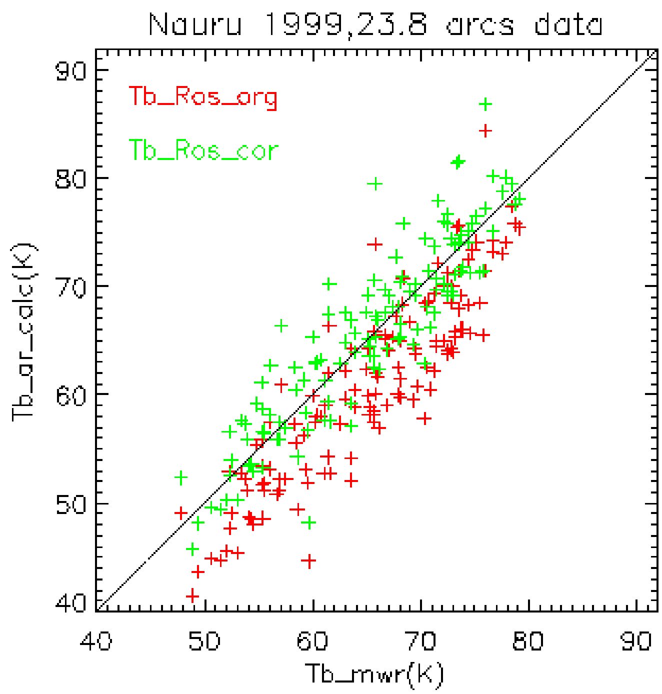

Figure 3. Comparison of Tb calculated from original (red) and corrected (green) RAOBs versus ARM MWR data. RTE model - Rosenkranz 98. Observations at ARCS-2.

Because the performance of the algorithm as a function of RAOB age was an important issue, we plotted the differences between measurements and calculations as a function of RAOB age. The results, shown for ARCS-2 in Figure 4, were surprising, and showed that although the algorithm, in general, improved the results, the improvement did not always occur for all RAOB lots. In fact, for the RAOB lots corresponding to the age around 360 days, the correction worsened the results.

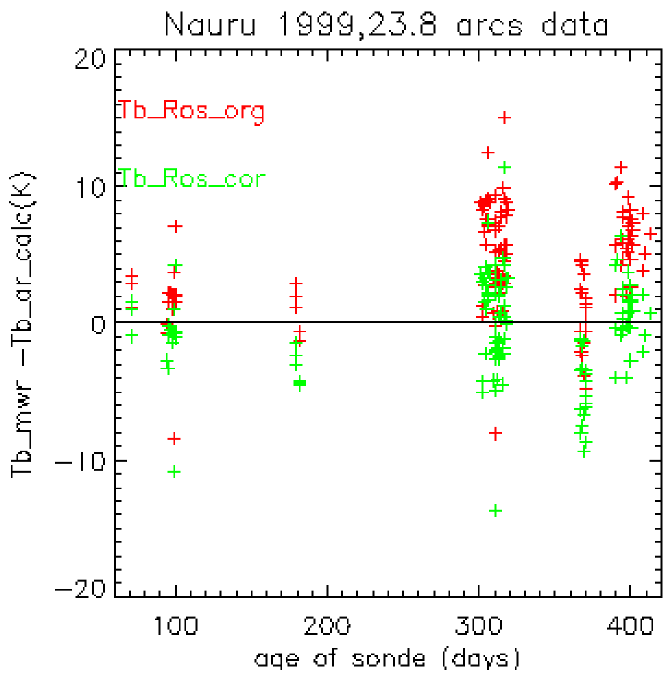

Figure 4. Comparison of Tb differences as a function of RAOB age. RTE model - Rosenkranz 98. Observations at ARCS-2.

Conclusions and Discussion

The ARM MWR operating at the ARCS-2 provided an excellent data set for the entire Nauru99 experiment. The calibration accuracy was verified by a LN2 blackbody target experiment and by consistent high-quality tip cals throughout the experiment. The data thus provide an excellent baseline for evaluation of the quality and consistency of Vaisala RAOBs that were launched from ARCS-2. Our preliminary results indicate that substantial errors, sometimes of the order of 20% in precipitable water vapor (PWV), occurred with the uncorrected RAOBs. When the Vaisala correction algorithm was applied to the RAOBs, better agreement with the MWR was obtained. However, the improvement was noticeably different for different RAOB lots and was not a monotonic function of RAOB age.

We have also performed our brightness temperature calculations with two other absorption algorithms—Liebe 87 and Liebe 93. The Liebe 87 model was in close agreement with Rosenkranz 98, but neither was in agreement with Liebe 93. Our final task in completing this study will be to use scaled RAOB data using all of the models to calculate infrared radiance and then to compare these calculations with AERI observations from the ARCS-2 site and Fourier transform infrared radiometric observations from the Ron H. Brown.

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