A Comparison of Clear-Sky Emission Models with Data Taken During the 1999 Millimeter-Wave Radiometric Arctic Winter Water Vapor Experiment

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Introduction

During March 1999, scientists from the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) and the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory (ETL) participated in the Millimeter-Wave Radiometric Arctic Winter Water Vapor Experiment at the Atmospheric Radiation Measurement (ARM) Program’s North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) field site near Barrow, Alaska. A description of the experiment is given by Racette et al. (2000) and calibration of the NASA, ETL, and ARM instruments is discussed by Han et al. (2000). Although the principal goal of the experiment was to measure precipitable water vapor (PWV) at low amounts, a secondary goal was to compare contemporary absorption models with radiometric data taken during known clear conditions. Use of a correct absorption model is important for retrieval of water vapor, both from the surface and from space, and thus, has general applications.

Description of Experiment

The salient details of the experiment are described by Racette et al. (2000) and by Racette et al. (1999). The radiometer channels used are given in Table 1 of Racette et al. (2000). As shown in the companion paper by Han et al. (2000), several of the ETL circularly scanning radiometer (CSR) and NASA millimeter-wave imaging radiometer (MIR) channels were in excellent agreement, although completely different calibration methods were used. In addition, after the original ARM microwave radiometer (MWR) data were corrected, the brightness temperatures (Tbs) from the 23.8-GHz and 31.4-GHz channels appeared to be of excellent quality. Because our measurements are most sensitive to absorption models at window frequencies, and because of our confidence in calibration at some channels, we decided to compare absorption models at the following frequencies only: 23.8 GHz, 31.8 GHz, 183±7 GHz, 220 GHz, and 340 GHz. Our confidence in calibration at these channels is justified by the applicability of the tipping calibration method to these data.

Absorption Models

Westwater et al. (1990) performed a study in which microwave Tbs were calculated from contemporary absorption models and then compared with well-calibrated radiometer measurements. Since then, several new models have been developed. However, the original model of Liebe and Layton (1987) has still shown to be an excellent one and we use it as one of our candidate models. For simplicity, we refer to the model as L87. This model is very close, but not identical, to the model published by Liebe in 1989. Based on measurements not available in 1987, Liebe et al. (1993) updated the L87 model, and made several modifications to the water vapor continuum, 22.235-GHz line parameters, and O2 band parameters. We refer to this model as L93. Finally, Rosenkranz (1998) made additional modifications to L87 and L93, and this model (ROS) is leading edge.

Model Calculations

To examine the behavior of the three models as a function of frequency, we selected a cold, dry profile measured during the experiment (PWV = 0.8 cm), and then extrapolated the profile above its last sounding level (~ 20 mb) to a level of 0.1 mb. The entire profile had a total of 413 levels from the surface at 1028.2 mb to the upper level of 0.1 mb. The calculated Tbs from 1 GHz to 350 GHz are shown in Figure 1. It is apparent that there are substantial differences between the models in some parts of the spectrum, especially above 200 GHz, where the L93 departs significantly from the other two. Changes in line parameters and different continuum formulations account for these differences. For this profile, we also computed the model differences from L87 and show the results in Figure 2a. It shows that differences exist, not only in the window regions, but also around the water vapor lines at 183.31 GHz and 325 GHz. These differences can be as large as 10 K. To illustrate the apparent differences around the 60-GHz O2 band and the 118 O2 line, we computed the differences for the same profile, but with the humidity set to zero. As shown in Figure 2b, significant changes in the O2 line parameters and interference coefficients exist in these models.

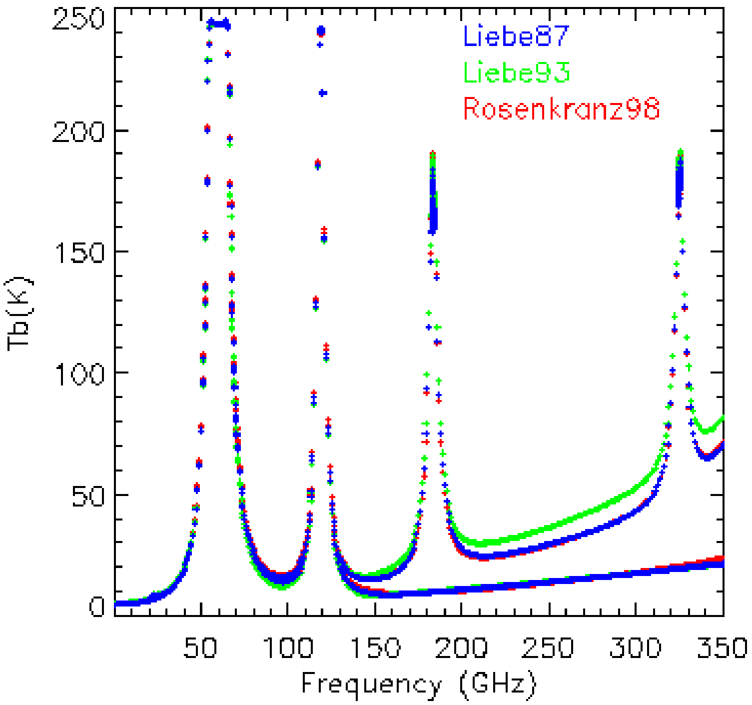
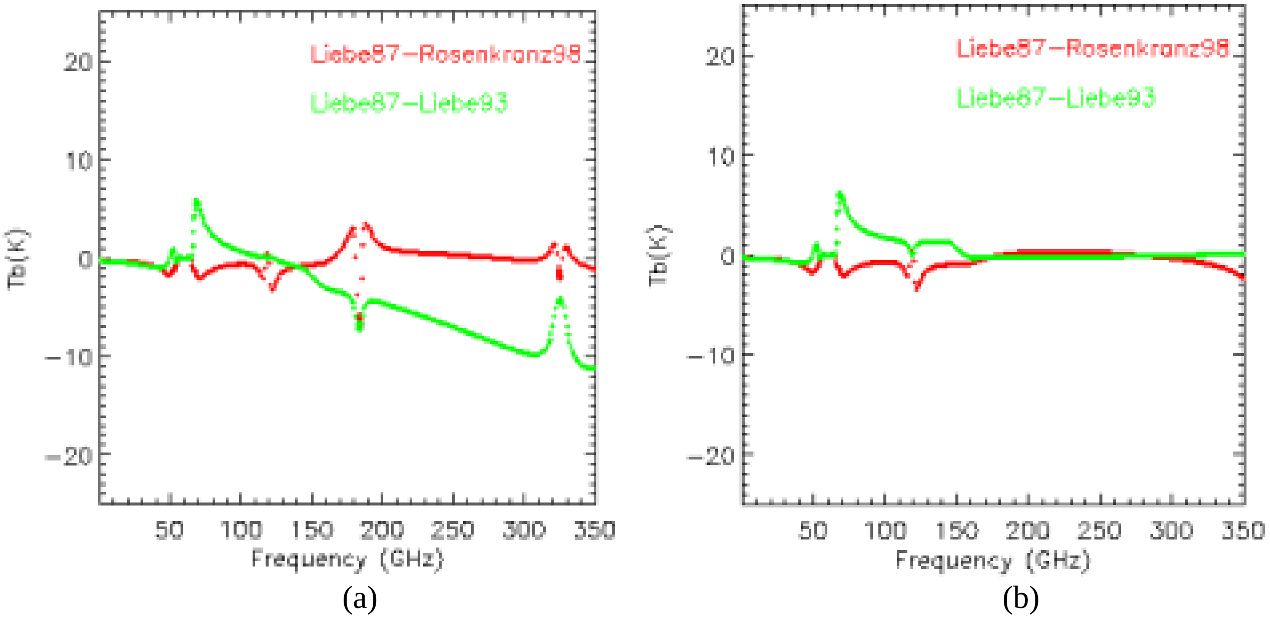


Figure 1. Comparison of three absorption models for calculations of clear air Tb for a Vaisala radiosonde [03/28/99: 11:13:58 Universal Time Coordinates (UTC)]. Blue-L87; Green-L93; Red-ROS98.



(a) (b)

Figure 2. (a) Differences of calculated Tbs from the L87 models for the profile of Figure 1.
(b) Differences of calculated Tbs from the L87 models for the profile of Figure 1, but with zero humidity.
Red: L87-ROS98; Green: L87-L93.

Radiosonde Observations at NSA/AAO

Only one radiosonde per day was launched at the NSA/AAO Cloud and Radiation Testbed (CART) site and the humidity elements on these radiosondes were of the Vaisala HUMICAP RS-80 type. Because of well-known problems associated with aging of these humidity elements, we applied the Vaisala correction algorithm and compared our Tb measurements with Tbs calculated from both original and corrected humidity profiles. Because of the close proximity (5 km) of the CART site to the Barrow National Weather Service (NWS) launch site, we were able to compare our Vaisala soundings with the NWS synoptic soundings at 00 UTC and 12 UTC. The NWS soundings used the VIZ resistive humidity elements. A time series of computed PWV for March 1999 is shown in Figure 3 and simple statistics are shown in Table 1. Note that the average PWVs of the NWS and corrected CART RAOBs are close, but that the original CART radiosonde observations (RAOBs) are somewhat drier. The maximum difference of the original and corrected CART RAOBs was 0.0.06, about 9%. Because the RAOB launches were not simultaneous, root mean square (rms) statistics were not computed.

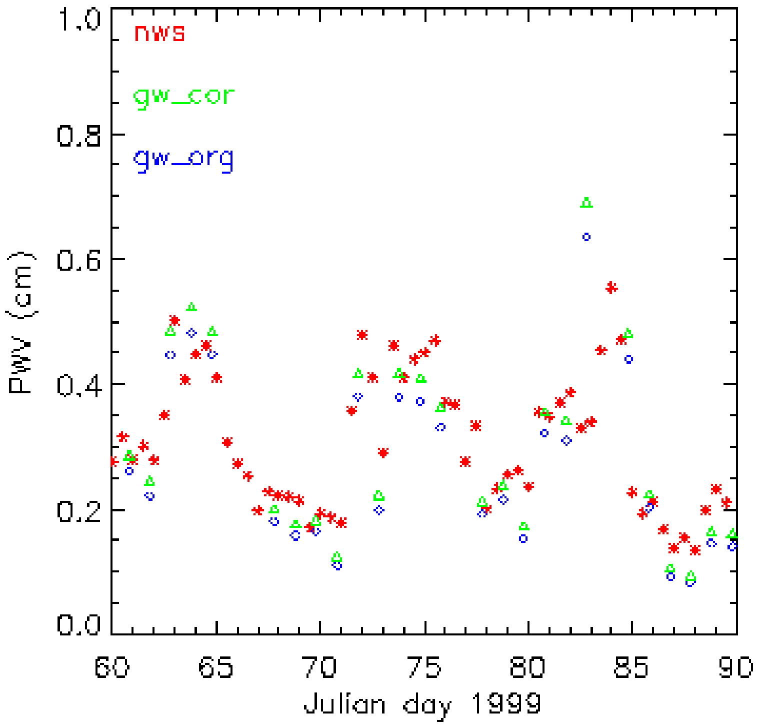


Figure 3. Time series of PWV calculated from NWS RAOBs (red asterisks), original (blue triangles), and corrected (green diamonds) Vaisala RAOBs, at Barrow, Alaska, during March 1999.

Table 1. Simple statistics of PWV measured by NWS, ARM original, and ARM corrected RAOBs at the NSA/AAO during March 1999.

	Average (cm)	**Standard Deviation (cm)**	**N**
NWS	0.31	0.11	61
ARM Original	0.27	0.14	27
ARM Corrected	0.30	0.15	27

Radiometric Observations Versus Calculations

To calculate the differences between the models, it was necessary to know that the conditions were cloud free, and we used the CART ceilometer for this determination. Two periods, one during the early portion of the experiment (Julian days 67 to 71) and one during the latter portion (Julian days 85 to 89), had a substantial number of cloud-free periods. Time series of measurements and calculations are given in Racette et al. (2000). In Table 2, we show statistical comparisons between measurements and calculations. It is apparent that if the corrected ARM RAOBS and the NWS RAOBS are more representative of atmospheric truth, then the L93 model is considerably higher than the MIR observations at 183 ± 7 GHz, 220 GHz, and 340 GHz, but that all models differ by at most 0.5 K at 23.8 GHz and 31.4 GHz.

Table 2. Measured – Calculated Tb(K) for Three Tb Models. NSA/AAO CART site, March 1999. N = 25 clear NWS RAOB soundings.

		Average (K)	**Standard Deviation (K)**
MWR (23.8 GHz)	L87	0.54	0.28
	ROS	0.20	0.25
	L93	-0.07	0.21
MWR (31.4 GHz)	L87	0.77	0.25
	ROS	0.26	0.12
	L93	-0.01	0.07
MIR (183 ± 7 GHz)	L87	3.57	4.88
	ROS	4.54	5.18
	L93	-5.93	3.99
MIR (220 GHz)	L87	-2.68	5.46
	ROS	1.97	6.01
	L93	-8.79	5.76
MIR (340 GHz)	L87	1.78	7.54
	ROS	2.11	7.84
	L93	-13.35	8.27

Conclusions and Recommendations

NWS radiosondes launched at Barrow, when compared with those of ARM, launched at the CART site showed agreement in PWV usually in the range of about 0.05 cm, although simultaneous radiosondes were not available. Because of the long data base of NWS RAOBs, and because currently, only one RAOB per day is launched at the NSA/AAO CART site, a more definitive radiosonde comparison is recommended. Because of the excellent data that are produced by the ARM MWR, perhaps the simultaneous operation of MWRs at the CART and NWS sites could aid in such a study.

We compared three frequently used absorption models with Tb measurements provided by three MIR window channels whose calibration was excellent: 183 ±7 GHz, 220 GHz, and 340 GHz. In addition, we also used re-calibrated data from the ARM MWR at 23.8 GHz and 31.4 GHz. Our radiosonde data consisted of 25 NWS RAOBs during known clear conditions. Our calculations showed that substantial (~10 K to 15 K) differences existed between the various models at some of the sub-millimeter frequencies. Our estimated radiometric calibration accuracy allowed us to resolve some, but not all, of the problems. For the MWR channels, the L93 model agreed with measured Tbs to better than a 0.1 K bias and a standard deviation of better than 0.2 K rms. However, for the millimeter wave channels, the L93 model significantly overpredicted Tb by 5.9 K, 8.8 K, and 13.3 K. However, the uncertainties in RAOB measurements of water vapor, coupled with MIR and CSR calibration uncertainties of perhaps 3 K, did not allow us to make a clear choice between the L87 and the ROS98 absorption models.

Because of the anticipated use of sub-millimeter radiometers in both ground- and satellite-based remote sensing, it would be of benefit to repeat the Arctic Winter experiment, but with a much more frequent set of radiosonde launches. Four launches per day, with two coinciding with NWS synoptic soundings, would be ideal.

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