Analysis of the AERI/LBLRTM QME

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Introduction

A Quality Measurement Experiment (QME) comparing clear-sky downwelling longwave radiance at the surface from observations and model calculations has been performed by the Atmospheric Radiation Measurement (ARM) Program for many years (e.g., Brown et al. 1995; Clough et al. 1996). This QME has been used to (1) validate and improve absorption models and spectral line parameters used within the Line-by-Line Radiative Transfer Model (LBLRTM), (2) assess the ability to define the atmospheric state, and (3) assess the quality of the atmospheric emitted radiance interferometer (AERI) observations. Extensive analysis of a 1994 to 1997 dataset has highlighted many issues associated with the ability to specify the atmospheric state (primarily water vapor) in the model and to characterize the influence of thin clouds and aerosols. The QME also revealed some uncertainties in the AERI observations themselves. Many of these issues have been addressed via reprocessing or various correction techniques. However, the uncertainties that remain in this dataset prohibit the use of the QME for its original goal: the improvement of the radiative transfer model itself, particularly with respect to the longwave self-broadened water vapor continuum absorption. This work concentrates on the analysis of a new QME dataset, which addresses some of the uncertainties in the older dataset.

The new QME dataset consists of 241 nighttime only cases from 1998 to 2001 from the Southern Great Plains (SGP) Central Facility. Coincident and quality controlled AERI, Vaisala radiosonde, ARM Raman lidar, and microwave radiometer (MWR) observations exist for each case. The dataset is restricted to nighttime only because daytime water vapor profiles from the Vaisala radiosondes have higher variability and larger biases with respect to the MWR, as inferred from long-term comparisons of radiosonde and MWR precipitable water vapor (PWV) measurements. The Raman lidar water vapor profiles also extend to higher altitudes (~12 km) at night, but only to ~3.5 km during the day. The depolarization sensitivity of the Raman lidar is used to screen for thin clouds. The Raman lidar also provides aerosol optical depths for each case, allowing the effects of aerosols on the infrared residuals to be characterized. MWR tip curve data and variability of AERI data over the averaging period is used to screen for sky inhomogeneity. In contrast to the 1994 to 1997 dataset, this time period also includes MWR processing, including consistent tipping-curve operation and processing and application of beam width and other small corrections (Liljegren 1999).

MWR Processing

The MWR provides ground-based observations of downwelling microwave radiance at 23.8 GHz and 31.4 GHz. The absorption properties of the 22.22 GHz water vapor line, particularly its line strength, are well known. This, combined with the specification of the water vapor channel to be near the hinge-point of the line and the absolute accuracy of the MWR brightness temperature observations, make the observations well suited for determining PWV with high absolute accuracy. Variability in the QME infrared residuals is high when the atmospheric water vapor is specified with Vaisala radiosonde measurements. Dual radiosonde soundings (two sensors launched on the same balloon) have characterized Vaisala radiosonde calibration errors to be largely independent of altitude in the lower troposphere. We therefore use a "MWR-scaling" technique whereby an altitude-independent scale factor, computed as the ratio of MWR PWV to radiosonde PWV, is used to transfer the accuracy of the MWR to the radiosonde profile (Turner et al. 2002).

In this analysis, we have studied the impact of (1) "instantaneous" tip-cal MWR processing, and (2) the differences between various microwave forward model algorithms on the MWR PWV. The instantaneous tip-cal procedure is applied during homogeneous, clear-sky-only conditions. It uses nearly instantaneous determined tip-cal parameters to perform the calibration, as opposed to nominal processing, which uses a statistical regression of the previous ~3000 observations to determine the calibration parameters. Example results comparing MWR-derived PWV and liquid water content (LWC) using the two techniques are shown in Figure 1. The instantaneous method results in PWV and LWC with lower random noise and small-scale differences with respect to the routine processing. However, when averaged over many QME cases, the instantaneous technique has a negligible PWV bias, and therefore no appreciable effect on the QME.

The Liebe '87, Rosenkranz '98, and monoRTM microwave forward models were used to retrieve PWV from the MWR observations. Statistical and physical retrieval methods were used for each case. Here, "statistical" refers to the use of monthly averaged mean radiating temperatures determined from a historical database of radiosondes; regression coefficients of PWV versus computed MWR T_bs are also computed using these monthly ensembles. "Physical" refers to the use of the collocated radiosonde profiles in an iterative solution. The results are not described in detail here. Generally, the various forward models and retrieval techniques produce very similar results, with respect to both bias and variability. For this dataset, the radiosondes exhibit nearly identical sensitivity to increasing water vapor as the MWR (slope = 1) but with a small dry offset of ~0.4 mm. In further investigation, radiosonde profiles were used as input to the forward models to compute MWR T_bs, and MWR minus computed T_bs were used to a determine zero PWV bias of ~0.6 K for the 23.8 GHz channel. This is attributed to some combination of small *offset* calibration errors in the MWR T_bs and uncertainties in the "dry" component of the microwave forward models, such as the oxygen absorption. After subtracting the zero PWV offsets from the MWR T_bs, physical retrievals were performed using Rosenkranz '98, yielding results that are slightly dryer (~0.4 mm) for all PWV.

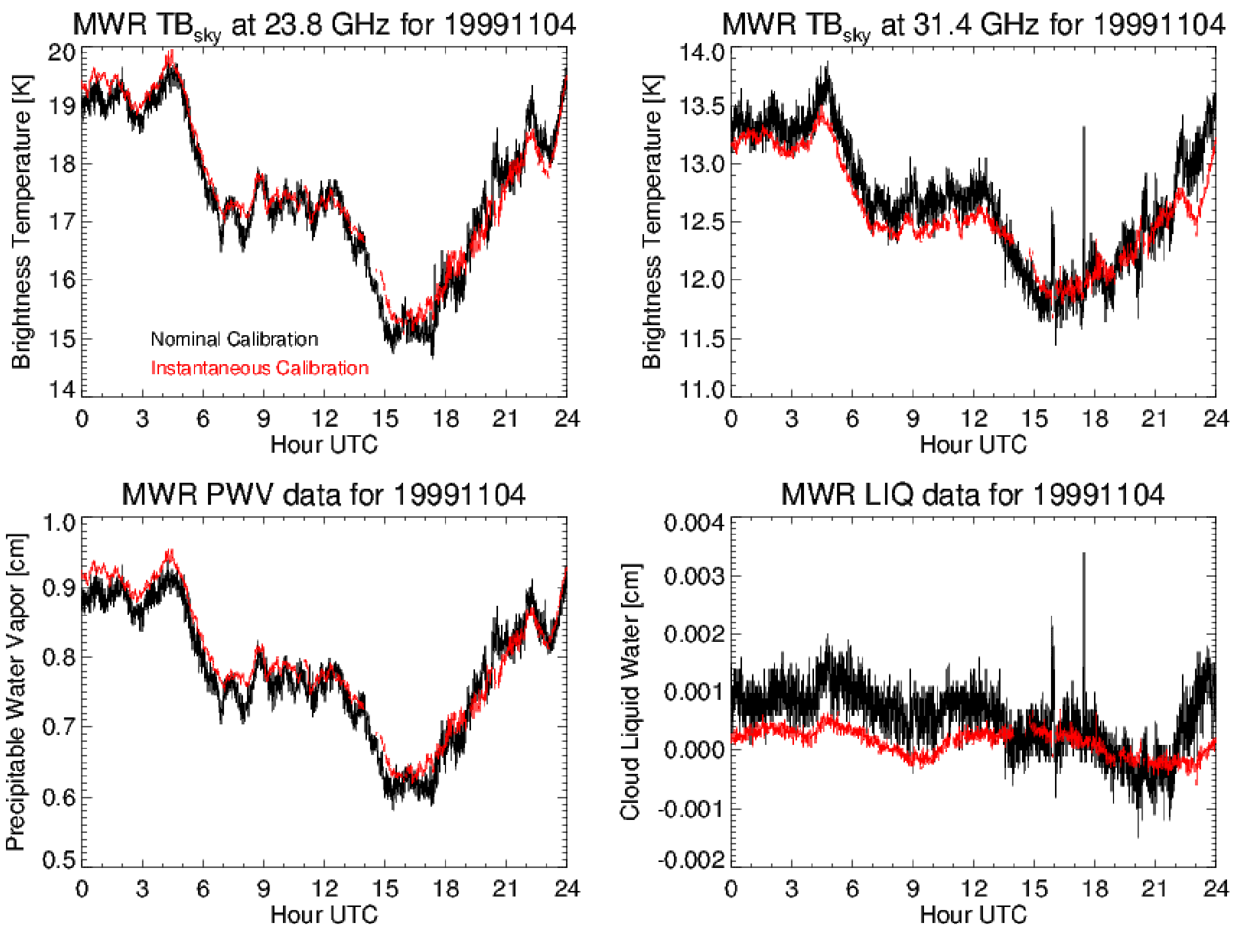

Figure 1. MWR brightness temperatures, PWV, and LWC determined using the nominal MWR calibration method (black curves) and using the instantaneous calibration method, as discussed in the text.

Improved Water Vapor Line Parameters

LBLRTM calculations were performed for the 1998 to 2001 QME dataset using MWR-scaled radiosondes using two spectral line databases: "High-Resolution Transmission (HITRAN) 1996/Jet Propulsion Laboratory (JPL)-extended," which is used for the operational QME calculations, and the HITRAN 2000 database that includes all HITRAN updates through April 2001. The HITRAN 2000 database includes updated water vapor line parameters provided by Toth et al. Results with the new HITRAN 2000 database show dramatic improvements in the residuals on water vapor lines. This is shown in Figure 2, and is evident in comparisons of upwelling observations and calculations. These improvements will have a large impact on the use of the weak water vapor lines in the high spectral resolution remote sensing of surface temperature and emissivity and of low-altitude water vapor and temperature inversions.

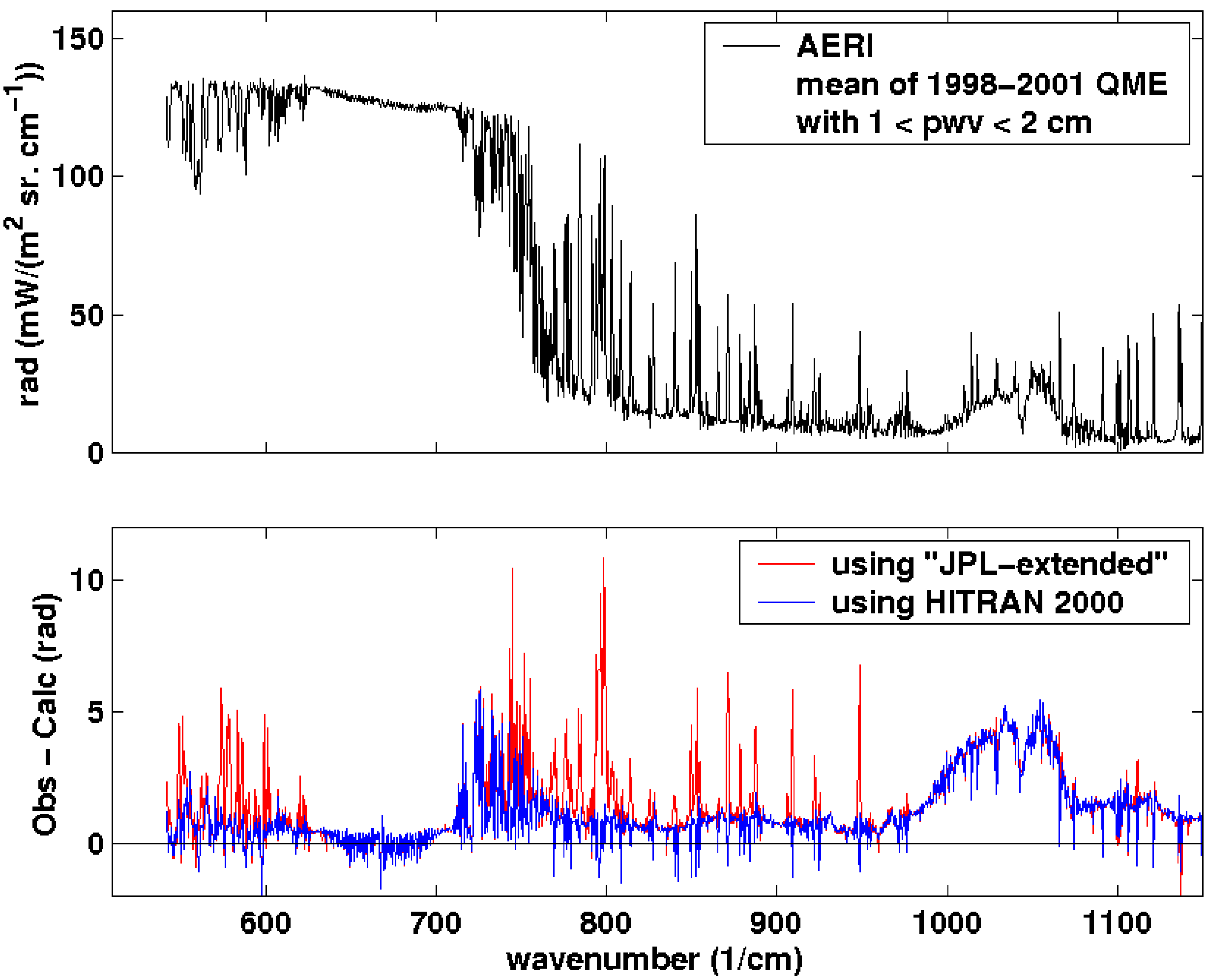

Figure 2. 1998 to 2001 AERI/LBLRTM QME residuals using MWR-scaled radiosondes using the HITRAN'96/JPL-extended and HITRAN 2000 spectral lines databases.

Microwindow Infrared Residuals

LBLRTM calculations performed with MWR-scaled radiosondes exhibit ~50% less variability (referenced to AERI) than calculations performed using unscaled radiosondes. Figure 3 shows 900 cm^{-1} to 904 cm^{-1} microwindow residuals versus PWV. At low PWV (< 1.5 cm), the infrared window region residuals (observed minus calculated) are slightly positive and do not correlate with Raman lidar aerosol optical depths. The cause of these residuals is uncertain; this is an area of active research. At higher PWV, the residuals are negative and show curvature with increasing PWV for all MWR-scaled results. This behavior is very similar to that which has been observed previously with the 1994 to 1997 QME dataset. Attributing the observed 1994 to 1997 dataset residuals to errors in the representation of the infrared self-broadened water vapor continuum absorption, we have derived preliminary continuum coefficients, which remove the high PWV residuals for ~20 microwindows in the 800 cm^{-1} to 1150 cm^{-1} region. Current work involves a similar derivation using the 1998-2001 QME dataset, along with a

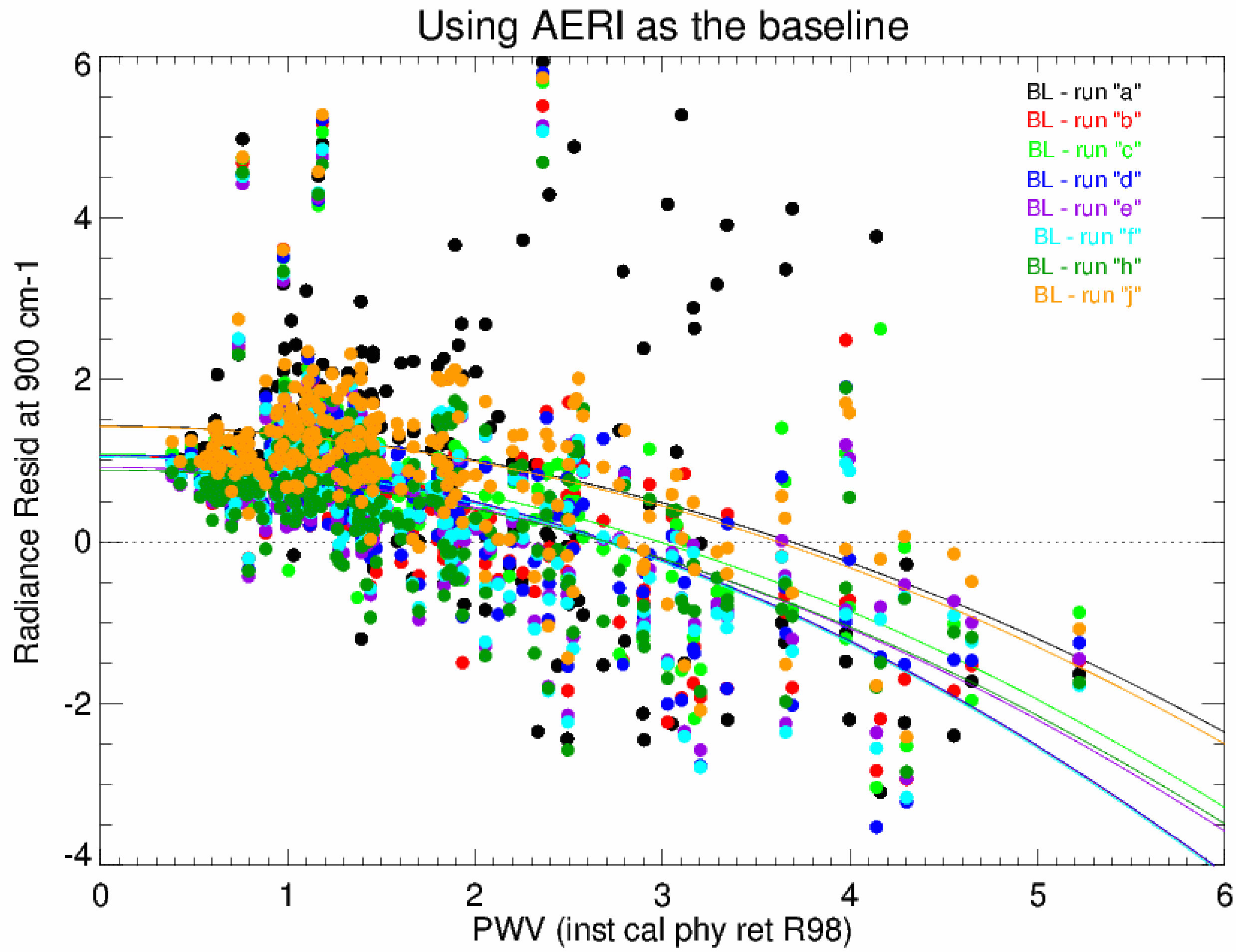

Figure 3. 900 cm^{-1} to 904 cm^{-1} microwindow AERI/LBLRTM QME residuals (AERI – LBLRTM) versus PWV for the 1998 to 2001 dataset using various water vapor inputs. The black dots are for unscaled radiosondes, and the rest are various MWR-scaled results.

rigorous account of the uncertainties. Previous changes to CKD models (Clough et al. 1989; Clough and Brown 1997) in this spectral region are due primarily to analysis of several case studies from the Combined Sensor Program in the tropical Pacific in 1996 (Han 1997). The preliminary coefficients suggested by this analysis of the SGP QME dataset are compared to the CKD continuum models and laboratory measurements of Burch in Figure 4.

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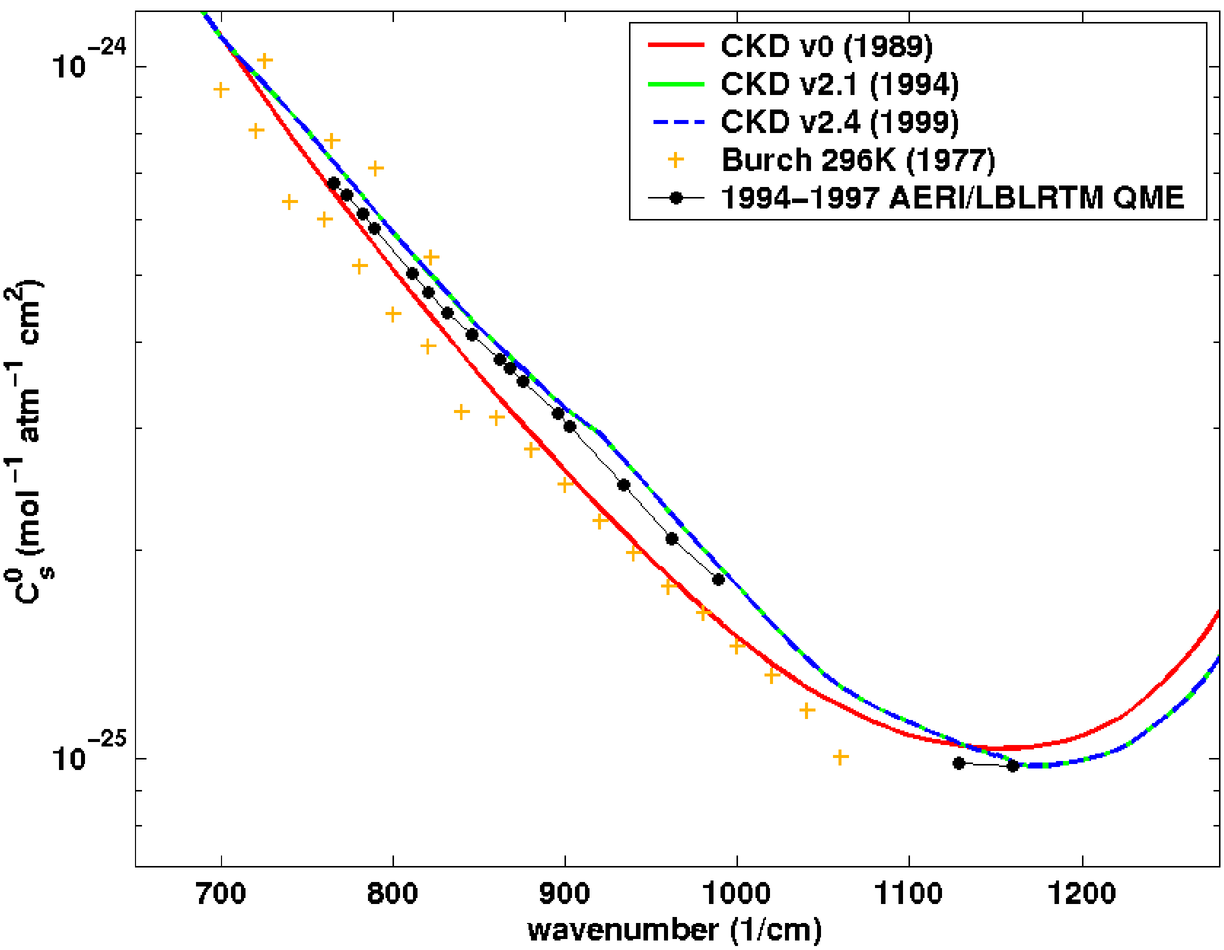

Figure 4. Self-broadened water vapor continuum coefficients, C_s^0, determined from the 1994 to 1997 QME dataset, along with CKD continuum models and laboratory results of Burch.

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