Implications for Atmospheric State Specification from the AERI/LBLRTM Quality Measurement Experiment and the MWR/LBLRTM Quality Measurement Experiment

S.A. Clough and P.D. Brown
Atmospheric and Environmental Research, Inc.
Cambridge, Massachusetts

J.C. Liljegren, T.R. Shippert, and D.D. Turner
Pacific Northwest National Laboratory
Richland, Washington

R.O. Knuteson, H.E. Revercomb, and W.L. Smith
University of Wisconsin
Madison, Wisconsin

Introduction

The ongoing Atmospheric Emitted Radiance Interferometer (AERI)/Line By Line Radiative Transfer Model (LBLRTM) Quality Measurement Experiment (QME), in which the spectral residuals between the downwelling longwave radiance measured by the University of Wisconsin AERI at the Central Facility of the Southern Great Plains (SGP) site and the spectral radiance calculated by the LBLRTM are analyzed, continues to facilitate the assessment of the quality of AERI measurements, LBLRTM calculations, and the ability to define the radiating atmospheric column. The objective of this experiment is to evaluate and improve the treatment of radiative transfer modeling in general circulation models (GCMs) for climate change applications. Statistical analyses of the residuals between observed and calculated spectral radiance by physical process are used to evaluate the three components of the experiment. Validations have been performed on AERI spectral radiance data obtained from April 1994 through July 1995 over a wide range of atmospheric states. Analysis of these results suggests that the determination of the water vapor profile by the radiosondes, used as input to LBLRTM, is a principal source of the difference between the model and the measurements. In addition, validations between brightness temperature observed from the surface at the 23.8-GHz frequency by the Atmospheric Radiation Measurement Program (ARM) Microwave Radiometer (MWR) and calculated brightness temperature from LBLRTM have been analyzed, and these results are applied to improve the characterization of the H_2O profile in the atmospheric radiating column. Although the initial focus is concerned with clear sky cases, efforts are underway to include the effects of aerosols and clouds. An overview of the QME concept is discussed by Miller et al. (1994), and a detailed description of this study is given by Clough et al. (1994).

Radiance Observations and Calculations

Spectral measurements of downwelling radiance at the surface are obtained by the AERI instrument at the Central Facility of the SGP site in Lamont, OK. The AERI is zenith viewing with a spectral resolution of 0.5 cm^{-1} (wavenumber value to first zero of the unapodized spectrum) over the region 550-3020 cm^{-1}. Measurements were taken by the prototype AERI-00 from April 1994 through July 1995, and by the updated AERI-01 from late July 1995 through the present. Radiometric microwave brightness temperature measurements at 23.8 GHz and 31.4 GHz are obtained from the ARM MWR at the central facility with an accuracy of approximately 0.5 K. Radiance and brightness temperature calculations are performed using LBLRTM with the CKD water vapor continuum model (Clough et al. 1989) that has been updated to improve agreement with atmospheric observations (CKD_2.2). The atmospheric column is divided into 54 layers for optimal calculation of radiative transfer as well as for the calculation of layer cooling rates, which are important for other aspects of ARM. Quality controlled radiosonde data are ingested into the model for all reporting levels at which temperature and water vapor column amount are calculated.

Characterization of the Atmosphere

A spectral validation is currently performed for each radiosonde release, four times per day under standard conditions and eight times daily during Intensive Observation Periods (IOPs). Temperature and water vapor profiles are obtained from radiosonde observations, and a standard ozone profile has been derived from a retrieval based upon an April 23, 1994, AERI-00 spectral radiance measurement. The characterization of the atmospheric state in the radiating column using radiosondes is of major concern as a result of the difficulties in accurately measuring water vapor, as well as both spatial and temporal displacement of the sonde and AERI measurements.

Spectral Validations

A set of spectral residuals is obtained by subtracting the LBLRTM calculated results from the AERI measured spectra. The residuals are statistically analyzed by 1) spectral domain, similar in structure to the spectral bands used in the radiative transfer models for GCMs; and 2) physical process, determined by mapping each spectral element to a physical process (e.g., spectral elements corresponding to O_3 lines). A representative AERI-00 spectrum with an associated integrated water vapor column of 2.6 prec. cm., taken April 25, 1994, is shown in Figure 1. The spectral range of 550-1800 cm^{-1} is consistently emphasized due to its importance for climate studies. It is important to note that radiance in the saturated spectral regions of CO_2 over 630-705 cm^{-1} and of H_2O over 1350-1800 cm^{-1} is dominated by the characteristics of the Planck function associated with the atmosphere in close proximity to the instrument. H_2O lines dominate the spectral structure over the window region from 800-900 cm^{-1} and 1080-1200 cm^{-1}, and O_3 is dominant over the 980-1080 cm^{-1} range. The strong effects of the water vapor continuum is evident throughout the 800-1200 cm^{-1} window region.

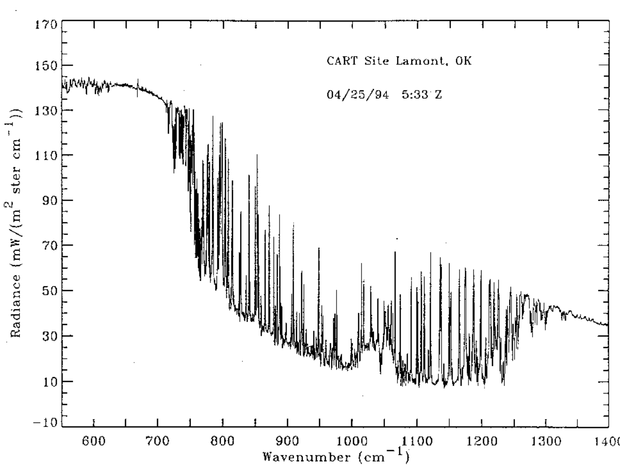

Figure 1. AERI-00 downwelling radiance spectrum measured April 25, 1994.

AERI measurements have been taken over a wide range of atmospheric states. Figure 2 shows the integrated radiance measured as a function of integrated water vapor in precipitable centimeters from the observed radiosonde column over the entire AERI-00 observational time period of April 1994 through July 1995 for three physical processes: O_3 lines, H_2O lines, and the transparent regions between the lines (which are associated with the radiative effects of cloud, aerosols, and the water vapor continuum). Figure 3 contains the integrated radiance residuals as a function of precipitable water for the same physical processes from Figure 2. An estimate of the error in the integrated flux may be obtained by multiplying the integrated radiance residual values by a factor of approximately 5 for an effective angular integration. It is apparent that while H_2O lines and the transparent regions contribute roughly the same amount of radiance to the integrated total, the radiance difference associated with the transparent regions provides the dominant contribution to the total overall residual. It is of interest to note that the ozone residuals are quite low, on the order of 0.5 W/m^2, over a

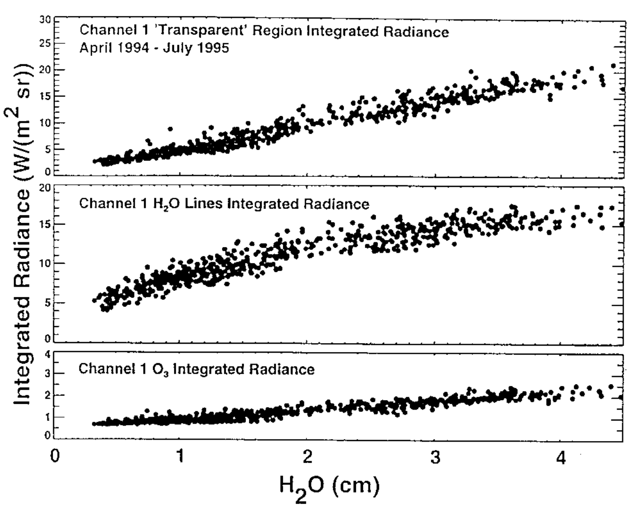

Figure 2. AERI-00 integrated measured radiance as a function of radiosonde column water vapor for the transparent regions (top), H_2O lines (middle), and O_3 lines (bottom).

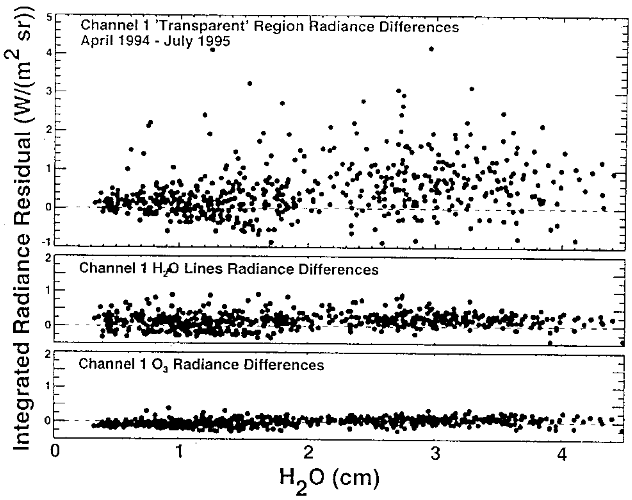

Figure 3. Integrated radiance residuals between the measured AERI-00 radiance and the LBLRTM calculated radiance as a function of radiosonde column water vapor for the transparent regions (top), H_2O lines (middle), and O_3 lines (bottom).

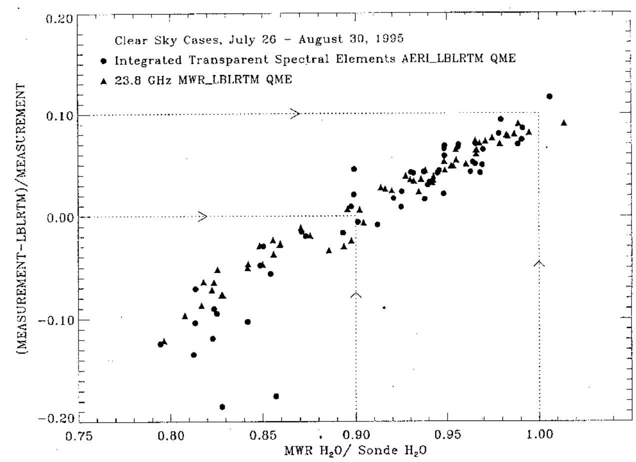

Figure 4. Fractional error for both the longwave transparent region radiances and the 23.8 Ghz brightness temperatures as a function of the ratio of the MWR water vapor product to the BBSS measured water vapor column for the time period July 26 - August 30, 1995.

wide dynamic range of water vapor, despite a constant standard profile being used as input to the model. The ozone region is strongly influenced by the radiative effects of water vapor, and the behavior of both the radiances and the residuals associated with O_3 lines are correlated closely with those of the transparent region.

Analysis

The large and highly variable transparent region residuals have been analyzed with respect to an extensive range of variables. Studies by Clough et al. (1996) have shown that these differences are not well correlated with the water vapor column and only slightly correlated with time of day. A strong correlation exists, however, between the transparent region residuals and the ratio of the total water vapor column MWR product and the water vapor column measured by the radiosonde. This strong correlation suggests significant problems with the sonde H_2O measurements.

In order to evaluate the above observations further, the results of the AERI/LBLRTM QME are compared to those of the newly developed MWR/LBLRTM QME, which is based upon an independent radiometric measurement but uses the same radiosonde profiles as model input. Figure 4, showing the fractional error of the residuals from both the 23.8-GHz microwave measurements and the infrared transparent region measurements as a function of the MWR/BBSS column H_2O ratio, indicates that the relationship between the MWR/LBLRTM QME results and those of the AERI/LBLRTM are strikingly consistent.

An approach has been developed to correct the error attributed to water vapor measurements. Integrated column water vapor amounts are retrieved from the measured brightness temperature at 23.8 GHz from the MWR, using the sonde input model calculated brightness temperature as a first guess. In general, the ratio of brightness temperature difference to water vapor difference is ~13 K/prec. cm. The sonde water vapor profile is uniformly scaled to obtain the identical integrated amount as the retrieved column, and the new profile is used as model input for updated calculations in both the microwave and the longwave. Two examples of spectral residuals before and after implementing this approach are shown in Figure 5 and Figure 6. Figure 5a shows the spectral radiance residuals associated with an AERI-01 measured downwelling radiance spectrum taken August 17, 1995, for which the total column water vapor measured by the radiosonde was 4.12 prec. cm. This set of spectral residuals between the LBLRTM calculation and the AERI measurement is among the lowest observed over this time period. The difference between the MWR 23.8-GHz brightness temperature measurement and the model calculation at 23.8 GHz for this case is small. The resulting water vapor column retrieval using the above method yields a column amount of 4.13 prec. cm., which does not appreciably change the agreement between model and measurement, as shown in

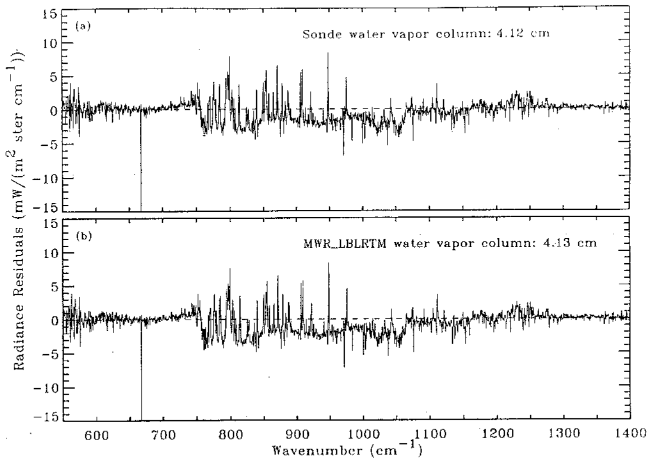

Figure 5. AERI-01 - LBLRTM residuals for 11:29Z August 17, 1995 using (a) sonde measured water vapor and (b) LBLRTM retrieved water vapor column as model input.

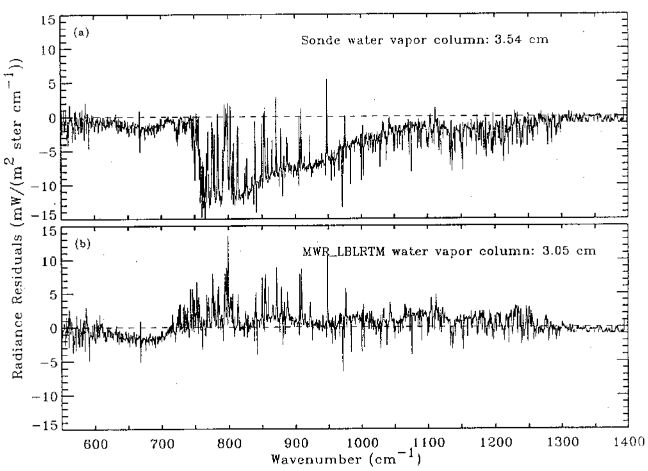

Figure 6. AERI-01 - LBLRTM residuals for 08:30Z July 28, 1995 using (a) sonde measured water vapor and (b) LBLRTM retrieved water vapor column as model input.

Figure 5b. Another case, from July 28, 1995, is shown in Figure 6a. The radiosonde measurement of 3.54 prec. cm. of H_2O input to LBLRTM yields spectral residuals that are predominantly negative through the window region with respect to the AERI measurement, approximately -20 W/m^2. This type of behavior indicates that the amount of water is overestimated by the radiosonde measurement. Upon retrieving a column amount of 3.05 prec. cm. H_2O, LBLRTM model agreement is improved to ~4 W/m^2 with the AERI-01 measurement, shown in Figure 6b.

Conclusions

The AERI/LBLRTM QME and the MWR/LBLRTM QME have been instrumental in identifying and assessing problems associated with the measurement of downwelling spectral radiation, the characterization of the atmosphere in the radiating column, and the modeling of spectral radiances. Major issues including the obscuration of the field of view in AERI-00 measurements and the radiosonde calibration irregularities have been identified through this experiment.

A critical correlation between integrated spectral residuals in the longwave and the ratio of radiosonde measured water vapor columns to MWR-derived water vapor amounts has been identified. An equally strong correlation has been found in the microwave. This behavior indicates serious problems with the sonde H_2O measurements. A retrieval method using the brightness temperature as measured by the ARM MWR at 23.8 GHz has been developed to improve the characterization of water vapor in the atmospheric radiating column. This approach provides significant improvement in the AERI/LBLRTM and the MWR/LBLRTM residuals for the 1995 period. Nevertheless, the current limiting factor in the QME is the ability to accurately measure the water vapor field in the atmospheric radiating column. A Data Quality Report, which will enumerate the major data quality issues over the lifetime of the AERI/LBLRTM QME, will be available.

The AERI/LBLRTM QME will be run over an extended time period using both the measured radiosonde and MWR/ LBLRTM retrieval scaled sonde H_2O columns. Further assessment of the characterization of the atmospheric radiating column will be ongoing. Increased emphasis will be placed on both the modeling of the microwave using LBLRTM and the MWR measurements.

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