The Status of Quality Measurement Experiments in the Microwave, Longwave, and Shortwave

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Introduction

Spectral analyses from the Atmospheric Emitted Radiance Interferometer/Line-by-Line Radiative Transfer Model (AERI/LBLRTM) Quality Measurement Experiment (QME) have proven critical in the assessment of clear sky radiative transfer modeling capability for general circulation models (GCMs). The QME provides a mechanism for the assessment of the three critical components of the longwave spectral validation: 1) the high resolution spectral radiance measurements from the University of Wisconsin AERI instrument, 2) the line-by-line calculation from the LBLRTM algorithm, and 3) the characterization of the atmospheric state in the radiating column as derived from various instruments at the Central Facility of the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site.

Validations have been performed on spectral radiance data obtained from April 1994 to the present over a wide range of atmospheric states through the analysis of the spectral residual differences between the measured and calculated radiances. These residuals have been analyzed by both spectral interval and physical process. The analyses have shown that there is a large variability with a dry bias on the part of the radiosondes, and that this bias is in general 8-10% for clear sky cases (Clough et al. 1996).

The scope of the QME has been extended to include analysis of cloud effects. New QME cloud products, including effective cloud emissivities, are being produced as a standard deliverable to Atmospheric Radiation Measurement (ARM) Science Team members. Detailed analyses using the Code for High resolution Accelerated Radiative Transfer with Scattering (CHARTS) (Moncet and Clough 1997) have begun, and initial results have demonstrated the ability to accurately model low stratus clouds based upon retrievals of cloud liquid water content, effective particle radius, and effective cloud fraction. Finally, initial work has been done to establish a shortwave QME using the University of Denver Absolute Solar Transmission Interferometer (ASTI) and LBLRTM over the spectral range 2000-10000 cm^{-1}.

Data Quality Assessment

The longwave AERI/LBLRTM QME has made important contributions to the detection and evaluation of data quality problems related to the continuous long-term measurements at the ARM SGP site. Radiosonde data issues such as the departure from nominal processing mode to research mode over the period April 8-May 21, 1994; the unreliability of groundcheck data; the recorded negative relative humidity; and the calibration irregularities of radiosondes launched in the January-September 1995 timeframe have all been identified by the QME. Figure 1 shows a timeline of important issues and milestones related to the QME from April 1994 to the present.

Water Vapor Issues

The limiting element in the validation of clear sky longwave radiative transfer modeling is the measurement of water vapor in the radiating column. It has been demonstrated that the radiosonde profiles have a tendency to be dry 8-10% in the total column (Clough et al. 1996). This tendency in the radiosondes causes insufficient calculated absorption which amounts to a bias of +5-10 W/m^2 in flux between measurement and model.

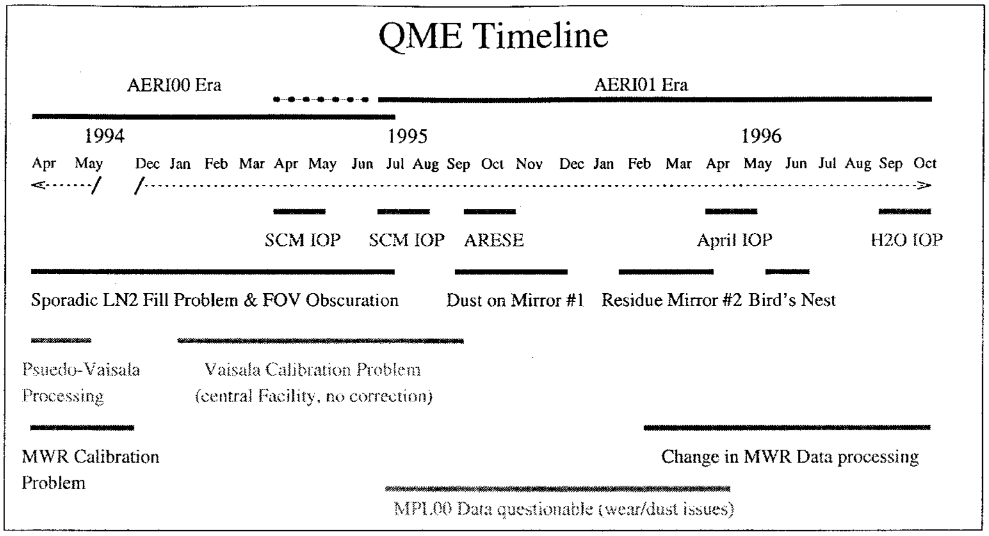

Figure 1. Major events in the AERI/LBLRTM QME era. The shaded lines indicate different platforms and events.

Using the microwave radiometer (MWR) brightness temperature measurement to determine total column water vapor and applying a scale factor to the sonde water vapor profile to provide agreement in the column H_2O amount from both instruments improves AERI/LBLRTM validations substantially, to 2-3 W/m^2. This is a result of the establishment of an MWR/LBLRTM QME in the microwave.

Radiometric measurements of brightness temperature at 23.8 GHz and 31.4 GHz, which are temporally and spatially near the AERI measurements and platform, are compared with model results using the nearest sonde launch time. LBLRTM is used to calculate the equivalent brightness temperature at the MWR frequencies using input profiles similar to the longwave AERI/LBLRTM validations. The 23.8-GHz MWR frequency T_b measurement is used to retrieve column water vapor. The water vapor profiles from the radiosonde are scaled to agree with the MWR retrieved column, and the scaled profiles are used as a new input to LBLRTM. The longwave AERI/LBLRTM QME analyses are redone to compare the spectral residuals before scaling with those after scaling.

Figure 2 shows the average spectral residuals before and after scaling for clear sky daytime cases in September 1996. It is important to note that the MWR and AERI data reflect independent radiometric observations and that the microwave and longwave QME results are consistent. There is an apparent diurnal variation in the residuals, whereby the residuals associated with nighttime clear sky measurements using unscaled sonde profiles are smaller than the daytime counterparts. Nevertheless, the use of MWR scaling reduces both daytime and nighttime residuals to approximately the same level. The cause of this variation is under investigation.

The use of the raman lidar in the September 1996 Water Vapor Intensive Observation Period (IOP) enabled the use of an additional water vapor profile measurement in the LBLRTM validations. The lidar only provided water vapor measurements from the surface to approximately 7 km, so radiosonde profile data were used above the lidar vertical threshold. Since most of the atmospheric water vapor is contained in this region of the atmosphere, the longwave residuals, particularly through the 800 - 1200 cm^{-1} window region, showed marked improvement over the use of radiosonde profiles alone in the model. Recent studies by Lesht (1997) have shown that there exists a variation between radiosonde calibration batches.

Figure 3a shows a comparison of channel 1 ensemble spectral residuals during the September 1996 IOP between the AERI and LBLRTM radiances using the measured radiosonde water vapor profiles from one calibration batch (“62 series”) and using the raman lidar water vapor profiles. Figure 3b shows a similar comparison, except that it reflects a different radiosonde calibration batch (“63 series”). These plots demonstrate the effectiveness of identifying calibration batches when studies include the use of water vapor measured by radiosondes.

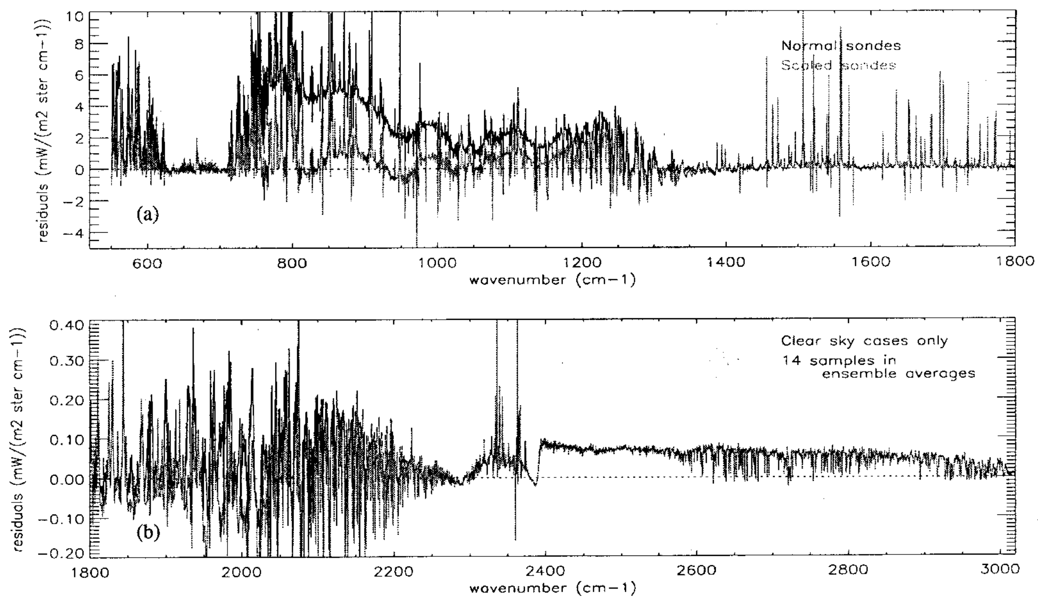

Figure 2. Average AERI-LBLRTM radiance residuals for clear sky daytime cases during September 1996 water vapor IOP for channel 1 (a) and channel 2 (b).

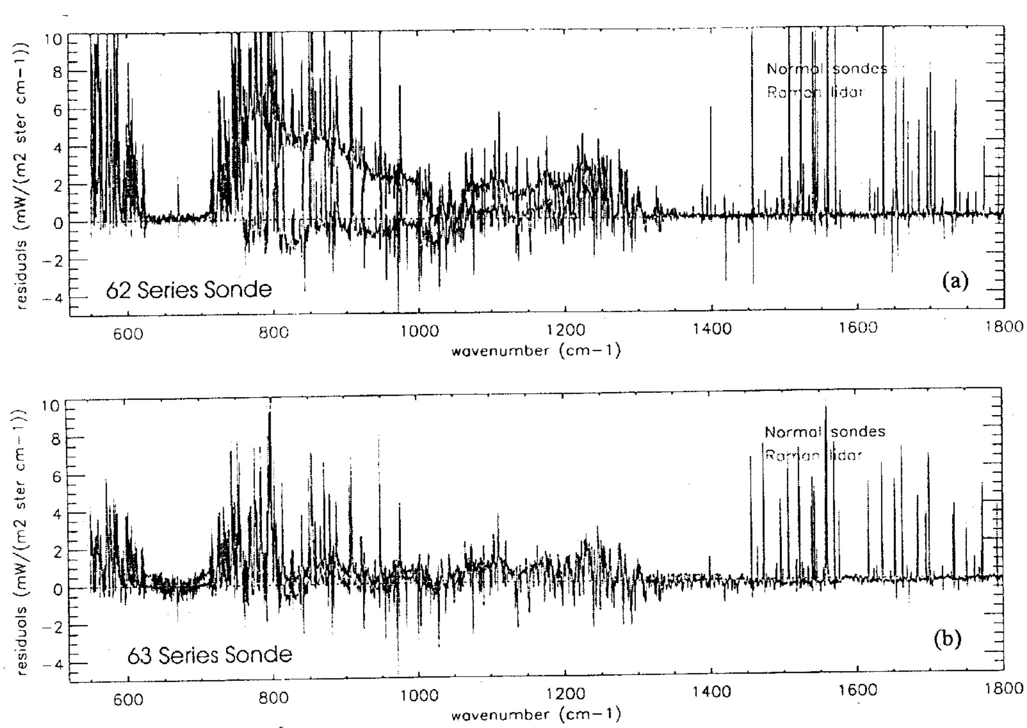

Figure 3. Average of clear sky AERI-LBLRTM differences for September 1996 using sonde calibration series 62 (a) and 63 (b) for atmospheric temperature and water vapor input to LBLRTM. The lower, gray curves in each plot reflect the residuals associated with raman lidar water vapor profiles as input to LBLRTM.

AERI Cloud Products

Measured longwave spectral radiances from the AERI have also proven useful for developing spectrally dependent effective cloud emissivities. These functions are directly applicable for use in GCMs. Two approaches are used to provide emissivity spectra, with LBLRTM- calculated radiances used for non-scattering layers. The first approach assumes a transmitting cloud, with emissivity that can be expressed as

$$\epsilon_{cld} = [I_{meas} - I_{cld}]/[B_{cld}*T_{low} + I_{low} - I_{clr}]$$

where $T_{cld} = 1 - \epsilon_{cld}$. The AERI-measured downwelling radiance is given as I_{meas}. The downwelling radiance and transmittance from the cloud are given as I_{low} and T_{low}, respectively. The term I_{clr} is the clear sky radiance as calculated from LBLRTM and B_{low} is the Planck source function at the temperature of the cloud base.

The second approach assumes an opaque cloud, such that

$$\epsilon_{cld} = [I_{meas} - I_{low}]/[B_{cld}*T_{low} + I_{up} - I_{clr}]$$

where the reflectance $r_{cld} = 1 - \epsilon_{cld}$.

In this case, I_{up} is the upwelling radiance from the ground to the cloud base. These spectra may be used directly in GCMs, where a typical longwave implementation would be given as

$$T_{cld} = e^{(-K*H_2O_{cld})}$$

where K is the absorption coefficient and H_2O_{cld} is the total cloud liquid water path.

Clouds and Aerosols

The extension of the analysis from clear sky radiance using LBLRTM to the treatment of clouds and aerosol has been achieved using the CHARTS model. CHARTS is a new rapid and numerically accurate adding-doubling algorithm developed by Moncet and Clough (1997) which makes use of optical depths generated by LBLRTM and performs calculations in plane-parallel atmospheres. The code is applicable to both thermal and solar radiance calculations done at the monochromatic level, with the number of computational streams limited only by the computer resources. Its computational efficiency, with a gain as high as 3000 over existing multiple scattering algorithms, makes its use in retrieval applications and atmospheric validation studies feasible. To demonstrate the utility of high spectral resolution multiple-scattering calculations, CHARTS has been applied to the modeling of observations from the AERI taken under cloudy sky conditions. Due to the absence of independent measurements of the relevant physical parameters of the clouds, this study has been undertaken in the limited context of the parameterization of the effects of water clouds on observed downwelling radiances in the infrared and near-infrared regions.

The results of this study indicate that CHARTS is adequate for fitting observed high spectral resolution radiances in the 500-3000 cm^{-1} region. Given the cases studied, more sophisticated three-dimensional models are not required for applications in which spectral fitting in the infrared is the objective. In the case of non-opaque clouds, it has been established that high spectral resolution measurements in the 10-µm window contain information about the particle size distribution. Given the altitude of the cloud base, however, no more than two independent parameters can be unambiguously determined from the 10-µm window measurements alone (e.g., cloud liquid water and effective radius, or cloud fraction). The cloud fraction parameter has been introduced primarily to account for the impact of spatial inhomogeneities on the scattered solar energy in the 3.7-µm window. With solar illumination, the use of three cloud parameters has been found to provide acceptable fit to the AERI observation on both the 10-µm and 3.7-µm windows, as shown in Figure 4.

The Shortwave

The extension of the QME concept from the longwave to the shortwave is uncomplicated, though certain aspects of radiative transfer at shorter wavelengths differ from those in the far infrared: 1) the solar source function input into the model replaces the atmospheric thermal contribution and requires validation; 2) the spectroscopy is not as well known; and 3) a multiple scattering algorithm must be employed for diffuse radiation calculations.

A preliminary set of validations in the shortwave was done with LBLRTM using ASTI data taken at the SGP CART site in April 1996. The ASTI instrument measures the total direct radiance from the center 16% of the solar disk over the spectral region 2000-10000 cm^{-1} with a resolution of 0.6 cm^{-1} (HWHM), sufficient to resolve vibration-rotation lines.

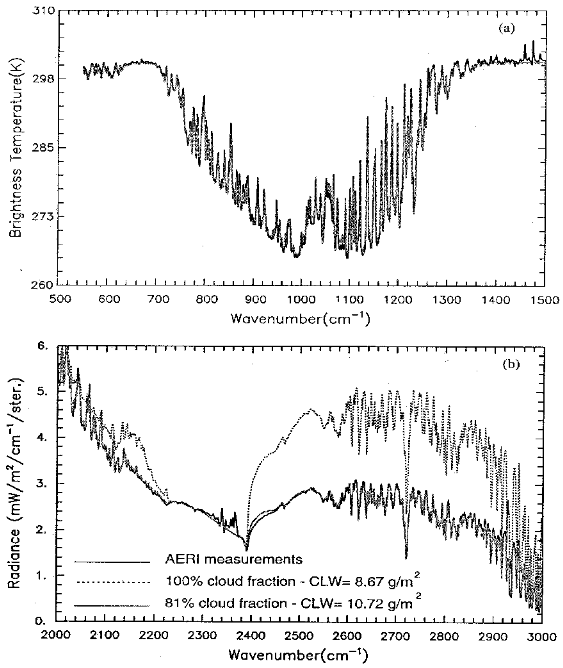

Figure 4. Comparison of AERI measurement (solid black line) with model calculations for channel 1 (a) and channel 2 (b). For the calculated spectra, the dotted line assumes 100% cloud fraction, while the solid grey line assumes 81% cloud fraction.

Figure 5a shows part of an ASTI measurement taken at 1730 local time (corresponding to a zenith angle of 71.5°), which is temporally coincident with a radiosonde launch. The LBLRTM calculation employs the same atmospheric input profile as the longwave AERI/LBLRTM QME, and also uses the high resolution Kurucz (1992) solar source function.

As shown in Figure 5b, the residuals between measurement and model are quite low, and the differences evident in the wings of the band are likely attributable to foreign water vapor continuum adjustments made at 1600 cm^{-1} which were not recalculated for this region.

Other spectral regions show larger errors, particularly over the region 7300-10000 cm^{-1}. Scaling of the background solar irradiance on the order of +10% is required to bring measurement and model results into better agreement. These differences may be attributable to calibration issues or to errors in the solar source function or may be the result of the ASTI observing only the brightest center portion of the disk, while the model calculation includes the whole disk. Also, differences in the O_2 bands centered at 7882 cm^{-1} and 9366 cm^{-1} are observed, which are likely attributable to modeling issues. The residuals in these bands are currently being addressed.

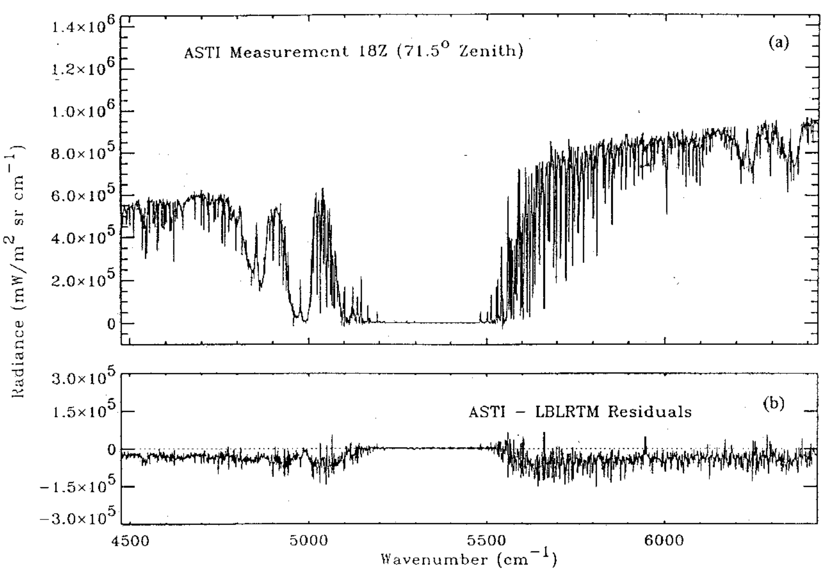

Figure 5. Spectral plot of ASTI measurement (a) and observed — LBLRTM calculated residuals (b) over the range 4500-6500 cm^{-1} for observation taken at ~18Z on April 18, 1996.

Conclusions

The AERI/LBLRTM and MWR/LBLRTM have established that the characterization of water vapor using radiosonde profiles is the principal contributor to the residuals in the longwave. Use of the MWR/LBLRTM QME to retrieve and apply column water vapor amounts reduces the residuals from ~5 W/m^2 to ~1-2 W/m^2. Reprocessing of the longwave QME from April 1994 to the present is under way.

Understanding and accurately modeling the radiative impact of clouds and aerosols is of vital importance for the improvement of climate studies using GCMs. Studies of the effects of clouds and aerosols are ongoing, including the calculation of effective cloud emissivities using AERI data and the use of CHARTS to model multiple scattering.

The extension of the QME concept to the shortwave should continue the success of the longwave QME in identifying and assessing modeling, spectroscopic, and atmospheric state issues. The use of the ASTI and other high resolution instruments in validations with LBLRTM over the spectral range of 2000-30000 cm^{-1} will enable ARM to address these issues of relevance.

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