Long-Term Analyses of Observed and Line-by-Line Calculations of Longwave Surface Spectral Radiance and the Effect of Scaling the Water Vapor Profile

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Abstract

A Quality Measurement Experiment (QME) comparing longwave radiance at the surface observed by the atmospheric emitted radiance interferometer (AERI) instrument with calculated radiance from the line-by-line radiative transfer model (LBLRTM) has generated almost 4 years of data and statistics. These statistics have been used to assess the quality of the AERI measurements, the capability of the model, and the ability to characterize the atmospheric state. By scaling the input moisture profiles measured by radiosondes to match the total precipitable water derived from an adjacent microwave radiometer, the bias and variability of the residuals are significantly reduced. Comparisons of the unscaled and scaled residuals by physical process (e.g., spectral elements associated with water vapor lines) as a function of total precipitable water vapor are shown and discussed.

Introduction

QMEs provide a mechanism to automatically compare multiple datastreams. The primary goal of QMEs is to identify data anomalies, and if one exists, to provide information needed to identify the root cause of the exceptional behavior (Miller et al. 1994). One of the first QMEs implemented in the Atmospheric Radiation Measurement (ARM) Program compares high spectral resolution longwave downwelling radiance at the surface measured by the AERI (Revercomb et al. 1991) at the ARM Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) with radiances calculated from the LBLRTM (Clough et al. 1991). This QME data is analyzed to assess the quality of the AERI measurements, the ability to define the atmospheric state, and to validate the LBLRTM calculations. The objective of this study is to evaluate and improve radiative transfer modeling capability, which can then be transferred into general circulation models (GCMs), thereby tying the radiation codes used in GCMs to direct observations. To date, almost 4 years of QME data (April 1994 through February 1998) have been collected, which encompass a wide range of atmospheric states.

This QME has been instrumental in identifying issues associated both with the AERI measurements as well as the ability to specify the atmospheric state (Revercomb et al. 1996; Clough et al. 1996). The data quality issues associated with the AERI have been identified and addressed, either via reprocessing or modifications to the instrument itself. The primary workhorse for specifying the atmospheric state, i.e., the water vapor and temperature profiles, during this time period is the radiosonde. However, the radiosondes have been shown to have considerable variations in calibration of their water vapor measurements (Lesht and Liljegren 1996), as well as a dry bias of 8% to 10% (Clough et al. 1996). This bias can lead to a bias of +5 W/m^2 to 10 W/m^2 in flux between the measurement and the model, while the variations in calibration add scatter in the integrated radiance residuals.

Analysis

The limiting element in the validation of clear-sky longwave radiative transfer is the measurement of water vapor in the radiating column (Brown et al. 1997). Radiosondes have been shown to have differences in calibration both by batch (Lesht and Liljegren 1996) and significant sonde-to-sonde variability within a given batch (Whitney et al. 1996). To reduce this variability, several different techniques were developed in an attempt to appropriately scale the radiosonde's moisture profile. Whitney et al. (1996) attempted to scale the sonde profile to agree with the in situ 25-meter and 60-meter tower measurements, but concluded that the finite response time of the radiosonde's moisture sensor was the limiting factor. The brightness temperature was computed twice at 23.8 GHz with the LBLRTM: once for the sonde's original moisture profile and once where the moisture profile was arbitrarily scaled up by 10%. Brown et al. (1997) then used the microwave radiometer's (MWR's) brightness temperature measurement at this frequency to calculate the scale factor. While this second technique proved useful for moist conditions, at the low precipitable water vapor amounts (approximately below 1 cm), the scale factors derived in this manner proved erroneous due to suspected errors in the oxygen continuum in this window. A third technique, and the one utilized in the rest of this paper, uses the total precipitable water vapor (PWV) calculated from the MWR's two brightness temperatures, using a model based upon Liebe's millimeter wave propagation model (Liljegren and Lesht 1996; Liebe and Layton 1987). The sonde's mixing ratio profile is then scaled such that the PWV measured by the sonde matches the MWR's PWV.

Analysis of this scale factor, computed as PWV_{MWR}/PWV_{sonde}, for almost 2000 cases from April 1994 through December 1997, shows no systematic differences as a function of the radiometer's PWV (Figure 1). The mean of this ratio is 1.043, with a standard deviation of 0.08, which indicates the sondes are on average less dry than initially reported by Clough et al. (1996). However, when these scale factors are separated as a function of time of day (Figure 2), a diurnal difference in the mean scale factors can be seen. During the nighttime (0-12 UTC), the mean scale factor is about 1.02 to 1.03, which increases to 1.04 to 1.06 during the day, indicating a 2% to 3% diurnal difference in water vapor calibration for one of the two measurements.

The mean observed minus calculated longwave radiance residuals for the clear-sky cases during the month of October 1997, which have been separated into night and day (Figures 3 and 4, respectively) clearly show the large change in the daytime residuals when the sondes are scaled,

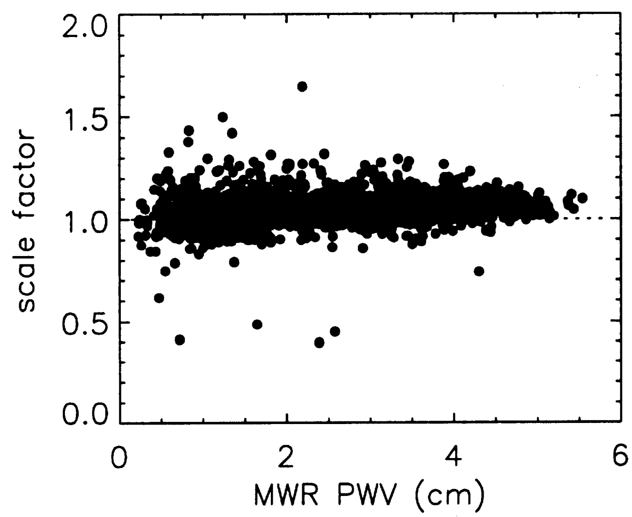

Figure 1. Sonde scale factors, computed as PWV_{MWR}/PWV_{sonde}, for 1960 points from 4/94 to 12/97 as a function of PWV from the MWR.

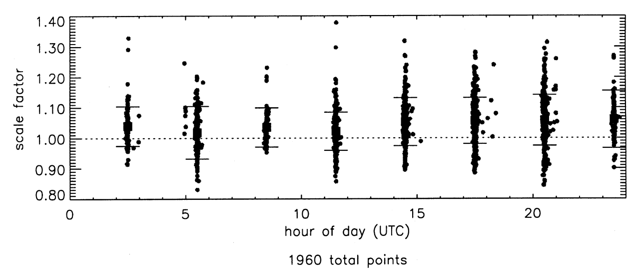

Figure 2. Sonde scale factors by hour of day. The black squares denote the mean factor for each time period, while the error bars denote one standard deviation about the mean. A diurnal trend in the mean scale factor is seen here.

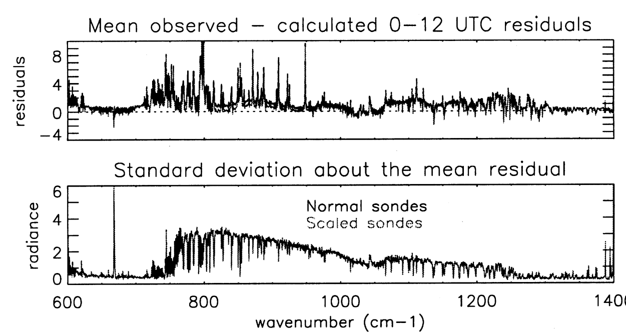

Figure 3. Mean residual (observed - calculated) radiance profile from October 1997 for 24 clear-sky nighttime (0-12 UTC) cases. The residual radiance unit is mW/(m^2 ster cm^{-1}).

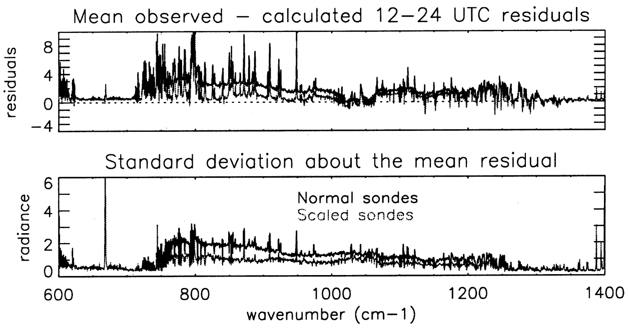

Figure 4. Mean residual (observed - calculated) radiance profile from October 1997 for 32 clear-sky daytime (12-24 UTC) cases. The residual radiance unit is mW/(m^2 ster cm^{-1}).

while at night the scaling has a very small effect. The scaling also significantly reduces the standard deviation about the mean error residual during the day, suggesting that scaling the sondes to the MWR is reducing the sonde-to-sonde variability.

The QME was designed to help identify the root cause of anomalies; therefore, it was anticipated that any inadequacies in the model would be best found by analyzing the spectral elements by physical process. To this end, the various physical processes that affect the longwave radiance, such as the H_2O lines, CO_2 lines, self-broadening water vapor continuum, etc., were all spectrally "mapped" (Clough et al. 1994). Using this mapping, the QME computes statistics associated with each of these physical processes that can then be analyzed with other variables to identify trends and abnormalities in the data.

Figure 5 shows the integrated radiance residuals from both the transparent region and H_2O lines in 520 cm^{-1} to 1800 cm^{-1} regime for both the normal and scaled radiosondes for over 800 cases from April 1994 to December 1997. The transparent region is the spectral elements between the absorption lines, which are sensitive to clouds, aerosols, and the self-broadening water vapor continuum. While measurements from other instruments (such as the micropulse lidar) are used to screen out the unclear conditions, a few such samples are not caught. However, comparing the scaled to the unscaled results, a reduction in the scatter by a factor of 2 between the two datasets is seen.

Breaking these integrated residuals down as a function of time of day, the diurnal difference between the MWR and the sonde can be investigated. If the diurnal difference was totally due to the MWR, then the scaled results would show

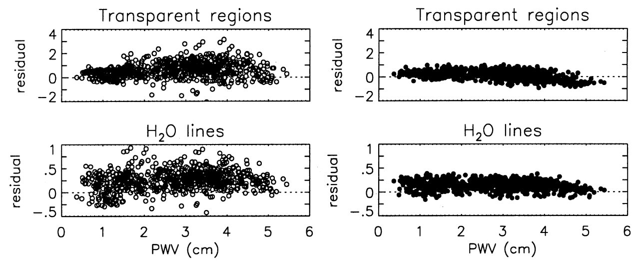

Figure 5. Integrated radiance residuals from 4/94 - 12/97 from both the transparent regions and the H_2O lines for both the normal (left) and scaled (right) radiosonde-driven model runs as a function of the MWR's PWV. The residual radiance unit is W/(m^2 ster cm^{-1}).

a diurnal signal, or vice versa. Figure 6, however, shows the scaled residuals to be very consistent for the entire day, while the normal radiosonde residuals have a strong diurnal difference in the residuals. These results suggest that the diurnal feature seen in the MWR/sonde scale factor is a characteristic of the radiosondes.

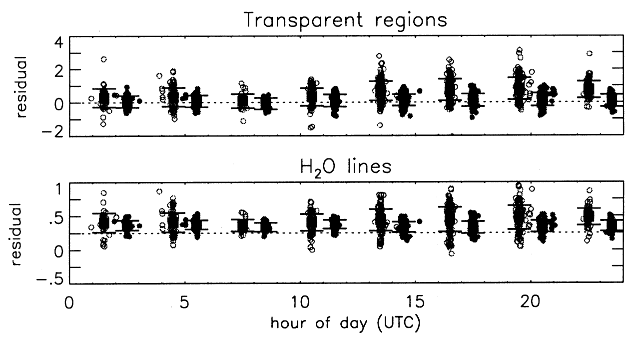

Figure 6. Integrated radiance residuals from 4/94 - 12/97 from both the transparent regions and the H_2O lines for both the normal (open) and scaled (closed) radiosonde-driven model runs as function of time of day. The residual radiance unit is W/(m^2 ster cm^{-1}).

Conclusion

Radiosondes have been shown to have large batch and sonde-to-sonde variations in water vapor calibration, and we have shown that a diurnal difference in calibration exists also. Scaling the sonde moisture profile, such that the total precipitable water amount integrated from the sonde matches that retrieved from the MWR, has been shown to significantly reduce the scatter and diurnal differences in the AERI/LBLRTM radiance residuals.

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