Comparisons of Surface Longwave Radiance Between Line-by-Line Radiative Transfer Model and Atmospheric Emitted Radiance Interferometer Observations from the Atmospheric Radiation Measurement Program

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Abstract

Observed surface downward longwave radiances from the Atmospheric Emitted Radiance Interferometer (AERI) were compared with line-by-line radiative transfer model (LBLRTM) calculations from April 1994 to November 1996 for "clear-sky conditions" in the 800-1250 cm^{-1} atmospheric window region. Results show that the mean AERI-LBLRTM radiance differences are generally small and close to the instrument accuracy during the nighttime. However, during the daytime, the radiance differences are larger and increase as the H_2O amount increases when using radiosonde data as model input. Scaling the radiosonde H_2O profile by the ratio of the microwave to the radiosonde precipitable water (PW) reduces the mean and scatter of the radiance differences and makes the day and night differences consistent.

Introduction

Observations from AERI are being widely used by the Atmospheric Radiation Measurement (ARM) science team under a variety of conditions. Clear-sky conditions are the simplest ones for which the basic radiative transfer theory may be studied. Preliminary results of Shen and Ellingson (1996), using about four months' data from 1994, showed that spectra from recalibrated AERI-00 (Knuteson et al. 1995) have better agreement with LBLRTM calculations for clear-sky conditions compared with its previous calibration. However, the AERI-LBLRTM radiance differences increase as the precipitable water vapor amount increases, as does the scatter of the differences.

Now, more than two and half years of data are available. The purpose of this study is to determine if the above phenomenon is a general feature of the data, and, if so, to discover the causes for the differences. The long-term goal of the research is to improve the radiative model for applications to climate studies.

Data

The observed radiance data used herein were measured by the AERI at the ARM Southern Great Plains (SGP) site. We used recalibrated AERI prototype (AERI-00) data from April 1994 to July 25, 1995, and AERI-01 data from July 26, 1995, to November 1996.

The atmosphere was considered to be clear when the following four conditions were satisfied within a period from 10 minutes before through 25 minutes after a radiosonde launch:

- Micro-Pulsed Lidar (MPL) showed no clouds.
- The AERI brightness temperature difference between the surface (675 cm^{-1}) and the channel-2 window (2510 cm^{-1}) was larger than 35°K.
- The AERI standard deviation of radiance in the Channel-1 window (985 cm^{-1}) was less than 0.25 (radiance units).
- The liquid H_2O measured by the microwave radiometer was smaller than 0.01 cm.

Radiance calculations were performed with LBLRTM (continuum version CKD-2.2) using radiosonde temperature and water vapor profiles, line-by-line quality measurement experiment (LBLQME) retrieved ozone profiles, and LBLRTM climatological trace gases as model inputs. The surface temperatures used in the model were retrieved from the AERI observations in the 675-680 cm^{-1} interval. The model used 45 vertical levels up to 30 km with the HITRAN 92 line information.

Results

From April 1994 to November 1996, more than a thousand clear cases were selected. The AERI-LBLRTM radiance differences in the atmospheric window region (800-1250 cm^{-1}) are shown in Figure 1. Circles with cross inside are the cases Lesht (1996) identified as having radiosonde relative humidity (RH) calibration problems. These cases show systematic negative AERI-LBLRTM differences, indicating overestimated radiosonde water vapor, which is consistent with Lesht's report.

Three periods when the AERI-01 observations had problems were reported.

- September 1 to December 22, 1995 - problems were caused by increasing dust on the sensor mirror (Knuteson 1996a).
- January 18 to April 9, 1996 - snow from a winter storm and its melted residue were left on the sensor mirror.
- May 21 to June 13, 1996 - many bird droppings were found in the area around the AERI-01 sky hatch, and grass was found lying across part of the hatch opening (Knuteson 1996b).

Cases from the above three periods are marked as circles. Obviously, the material on the sensor mirror and the open hatch works similar to aerosol and increases the downward radiance at the surface, resulting in the positive AERI-LBLRTM radiance differences in the atmospheric window region. Neglecting the bad cases, the AERI observations are generally larger than the LBLRTM calculations, especially during warm seasons. The AERI instrument was updated from AERI-00 to AERI-01 in July 1995, and the general feature of the differences did not change.

Since the radiance in the window region is very sensitive to the water vapor in the atmosphere, we have plotted the radiance differences as a function of PW for day and night (Figure 2). The mean radiance difference is 0.83 ± 0.07 mW/(m^2 sr cm^{-1}) during the night and 1.93 ± 0.08 mW/(m^2 sr cm^{-1}) during the day. Notice that the mean differences at night are not significantly dependent on PW, while during the day, they increase significantly with increasing PW. Knowing that 1% of the Planck function radiance for the ambient temperature is approximately the instrument accuracy, we calculated the Planck radiances for the 800-1250 cm^{-1} interval using model input surface temperature and calculated the average for all cases. The dotted lines in Figure 2 are ±1% of the mean Planck radiance. The AERI-LBLRTM radiance differences are close to the instrument accuracy at the lower water amounts for both day and night. At higher water amounts, the differences are close to the instrument accuracy during the nighttime, but much larger during the daytime. For the clear–sky cases selected, the AERI-LBLRTM radiance differences in the window region are equivalent to a flux difference of about 2 W/m^2 at lower water (0.5-1 cm PW) to about 6 W/m^2 at higher water (4-5 cm PW). The water vapor dependence mainly comes from daytime cases.

The calibration of the microwave radiometer was changed in late February 1996 using a new technique (Liljegren 1996). We examined the relationship between the AERI-LBLRTM differences and the microwave-radiosonde PW and found a near linear relationship (not shown), particularly for the cases after Liljegren (1996) modified the calibration of the microwave radiometer. Compared with microwave PW, the sonde has too little water, and this is associated with lower calculated radiance. We also found that the microwave-radiosonde PW differences during the night were less than during the daytime.

To examine the effects of using the microwave PW, we reran the LBLRTM calculations using the radiosonde H_2O profile scaled by the ratio of the microwave to the radiosonde PW. This assumes the radiosonde gives the correct vertical distribution. Figure 3 shows the radiance differences before and after H_2O scaling. The mean and scatter of the radiance differences are reduced after scaling for both day and night. *Most importantly, the mean radiance differences are about the same for day and night after H_2O scaling*. We have also computed the line and continuum contributions separately for the window region. The results show that the radiance differences for both are consistent for day and night after H_2O scaling (not shown). Overall, the H_2O scaling made larger changes to the continuum portion than to the lines. Also the differences for the continuum are more scattered than for the lines.

The consistency of the day and night radiance differences using scaled H_2O suggests that the radiosonde profiles may have a daytime bias, perhaps resulting from solar effects. If the radiosonde temperatures have a 0.5° C bias, the H_2O mixing ratio will change by about 3% to 5%. We tested this effect on LBLRTM by increasing the daytime H_2O by 4%. Results show that these changes reduce the daytime radiance differences to values similar to those found during nighttime.

Another test of the sensitivity of the results to the water vapor input was made by using Raman Lidar H_2O profiles from the September 1996 Water Vapor Intensive Observation

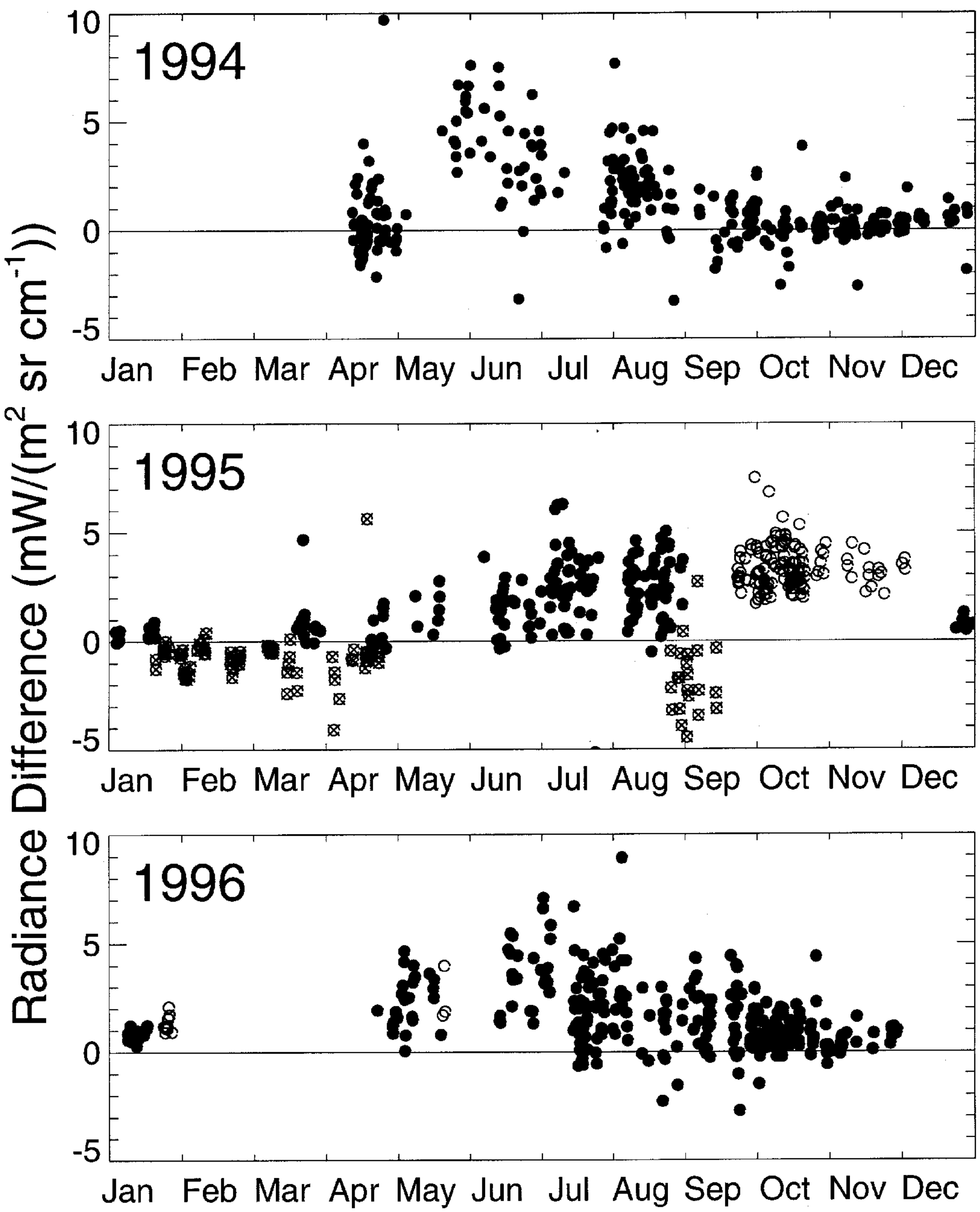

Figure 1. The AERI-LBLRTM radiance differences in the 800-970 + 1110-1250 cm^{-1} interval with clear-sky conditions. Circles denote cases with problem AERI measurement as reported by Knuteson (1996a, b), and the circles with crosses inside denote cases with problem radiosonde RH calibration as identified by Lesht (1996).

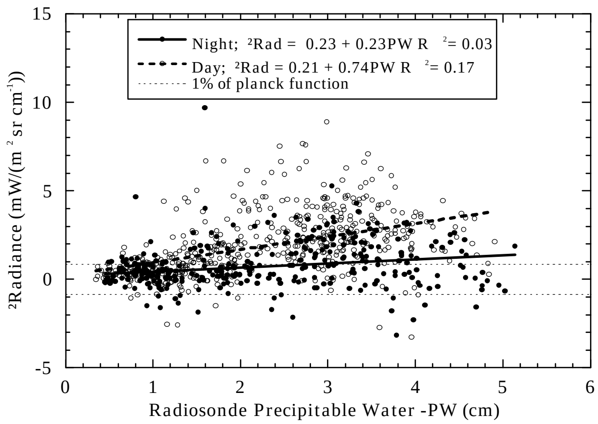

Figure 2. The AERI-LBLRTM radiance differences for the 800-970 + 1110-1250 cm^{-1} interval as a function of precipitable water under clear-sky conditions during the daytime (circles) and the nighttime (dots).

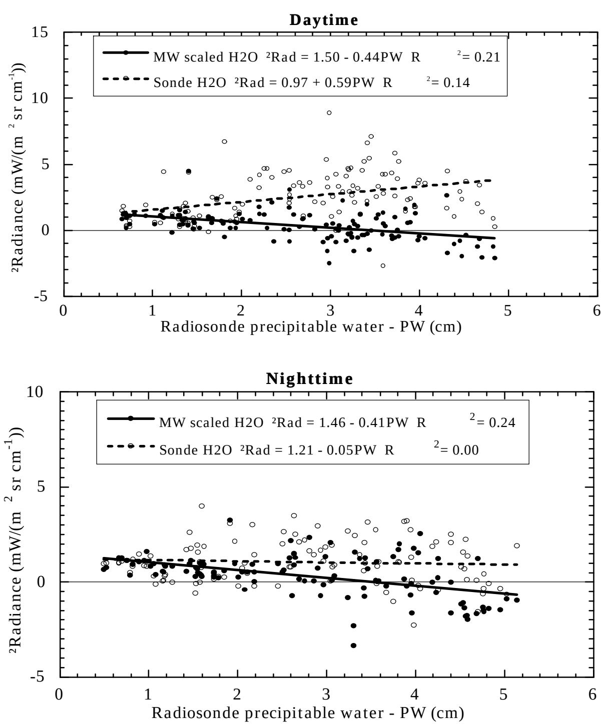

Figure 3. AERI-LBLRTM radiance differences for the 800-970 + 1110-1250 cm^{-1} interval resulting from use of radiosonde H_2O (open circles) and microwave-scaled H_2O (filled circles) profiles as model input. Upper and lower panels show daytime and nighttime results, respectively.

Period (IOP). The Raman water vapor profiles are available for both day and night, but with lower quality during the daytime. Figure 4 shows that the mean and scatter of the radiance differences are reduced when using Raman Lidar H_2O as input as compared with radiosonde data. It is believed that the Raman Lidar can give high quality water vapor profiles during nighttime. The above results suggest that the use of higher quality water vapor profiles as model input, such as one from the Raman Lidar, will result in smaller radiance differences between model calculations and observations.

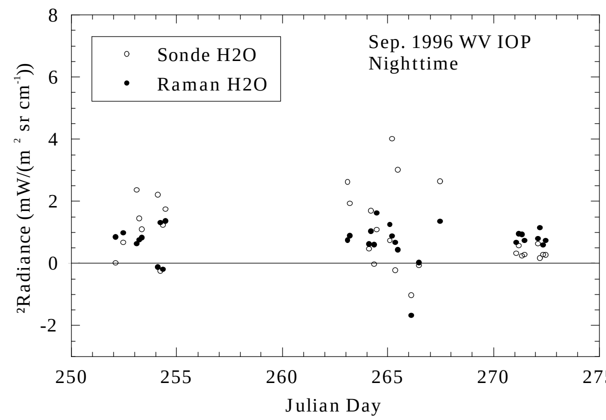

Figure 4. As in Figure 3, but for radiosonde (open circles) and Raman lidar (filled circles) H_2O profiles from nighttime observations during the September 1996 water vapor IOP.

Some of the large positive radiance differences that are not reduced by changing input H_2O may be the result of aerosol effects. For example, large radiance differences are noted between 2:30 and 5:00 UT, April 26, 1994, and the Raman Lidar observations show the presence of substantial aerosol loading (not shown). Such aerosol effects on longwave radiative transfer need more attention, but their study requires accurate H_2O data.

Summary

Under clear-sky conditions, the AERI-observed radiances are generally greater than LBLRTM calculations when using radiosonde data as input to the model. The mean radiance differences between AERI and LBLRTM are generally smaller during the nighttime, and they are close to the instrument accuracy. However, the differences are much larger during the daytime, particularly when water vapor amounts are large. Scaling the radiosonde H_2O profile by the ratio of the microwave to the radiosonde PW reduces the mean and scatter of the radiance differences and makes the day and night differences consistent. This suggests a systematic bias in the daytime radiosonde profiles. The water vapor dependency of the radiance differences may be solved by improving the calibration of the daytime radiosonde. The observation-model radiance differences are reduced when using Raman Lidar H_2O profiles as model input, suggesting the radiance differences are mainly caused by uncertainties in the input radiosonde profiles. The remaining cases with large differences might be due to aerosol effects, and these require further study.

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