Comparison of Model-Predicted Total Shortwave with Measurements Under Overcast Cloud Conditions

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Abstract

We use surface measurements at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site made with the multifilter rotating shadowband radiometer (MFRSR) and microwave radiometer (MWR) to obtain time-series of cloud optical depths and mean effective droplet radii using the method described by Min and Harrison (1996). We then use these data as inputs to three atmospheric shortwave models, and compare the result to surface pyranometric observations [Baseline Surface Radiation Network (BSRN) and Solar and Infrared Observing System (SIROS)]. We have extended this work to include analysis of the ARM Enhanced Shortwave Experiment (ARESE) events reported at the last ARM meeting, and data from the Fall '97 IOP. The results demonstrate closure of the observed vs. modeled surface fluxes to ~10 W/m^2. Furthermore, a detailed analysis of transmittances for several narrow bands and the total shortwave on October 30, 1995 (during ARESE), demonstrates the consistency of our understanding regarding the spectral dependency of shortwave irradiance through clouds, and provides an upper bound on potential anomalous cloud absorption. Our results contradict those reported from the aircraft measurements by Zender et al. (1997).

Introduction

The transmission, reflection, and absorption of radiation in a cloudy atmosphere is governed by the microphysical properties of the cloud medium through the optical thickness, single scattering albedo, and phase function, as well as the microphysics of cloud and the surface albedo. Currently, considerable contention is focused on the role of clouds in atmospheric absorption (Cess et al. 1995; Chou et al. 1995; Arking 1996; Zender et al. 1997; Valero et al. 1997). In order to provide a strict constraint on the cloud absorption, we focus our study on the spectral dependency of radiation transmittance in the cloud atmosphere and illustrate the consistency of radiation transfer models with respect to the surface measurements.

Measurement and Models

We have developed a family of inversion methods to infer the optical properties of warm clouds from surface measurements of spectral irradiance (Min and Harrison 1996). In conjunction with MWR, we can infer the cloud optical depth and the effective radius from MFRSR under overcast conditions. In this study, we use this approach to infer the cloud optical properties for the overcast days at the ARM SGP site, and then validate our inferred cloud optical properties by putting them into a shortwave model and comparing the predicted total shortwave against the pyranometer measurements. Further, we analyze the overcast case of October 30, 1995, in detail to demonstrate the consistency of our understanding regarding the spectral information of shortwave. We have chosen overcast days for the comparison. On those days, the direct irradiances of the MFRSR at the SGP site were fully blocked, and all relevant measurements were available.

Surface broadband shortwave irradiances were observed by the BSRN and the SIROS, and averaged over the time interval. The atmospheric profiles of temperature and pressure were measured by the Balloon-Borne Sounding System (BBSS). The water vapor profile was taken from the BBSS data, and scaled and interpolated with time based on total column water vapor measured by the MWR. We adopted climatologic profiles for ozone and the other minor gases and for extending the profiles beyond the measurements.

The cloud top and base heights were assumed 600 m to 2200 m for all the cases, except for the cases during ARESE, which were estimated based on supersaturation from the BBSS sonde. Possible aerosol effects under the cloud condition are expected to be small compared with cloud effects for those thick cloud optical depth cases. We use the closest clear-sky aerosol optical depth obtained from the MFRSR measurements as the aerosol optical depth under the cloud.

The surface albedo plays an important role in predicting the shortwave. Surface albedos for wavelengths less than 1000 nm were obtained from the tower measurements. From the SIROS, the downward-looking broadband pyranometer measurements at the tower provide the total shortwave surface albedo.

In this study, we exercised three atmospheric shortwave models: CCM3 (Briegleb 1992), SW93 (Smith and Shi 1994), and Fu-Liou (Fu and Liou 1993).

Results

We have processed the MFRSR and MWR data at the ARM SGP site for 1994 to 1997. The statistic summary of cloud retrievals done from March 1994 to May 1997 is shown in Figure 1. The mean optical depth is 37.5 and mean effective radius is 6.9 μm, which is the typical value for continental clouds.

On October 30, 1995, during ARESE both aircraft and surface measurements were available and many analyses have been done, so that we focus our attention on this day and analyze the spectral surface irradiances.

The top panel of Figure 2 shows the inferred cloud optical depths and effective radius for these two different schemes. The inferred optical depths based on Slingo's scheme (1989) are ~5% lower than those based on the Hu and Stamnes' (1993) scheme, due to differing assumptions of cloud droplet distributions.

The central panel of Figure 2 shows the measured and calculated surface shortwave irradiance. Measurements from unshaded and shaded pyranometers (BSRN and SIROS) illustrate the measurement uncertainties. Calculated surface shortwave from the CCM3 and Fu-Liou

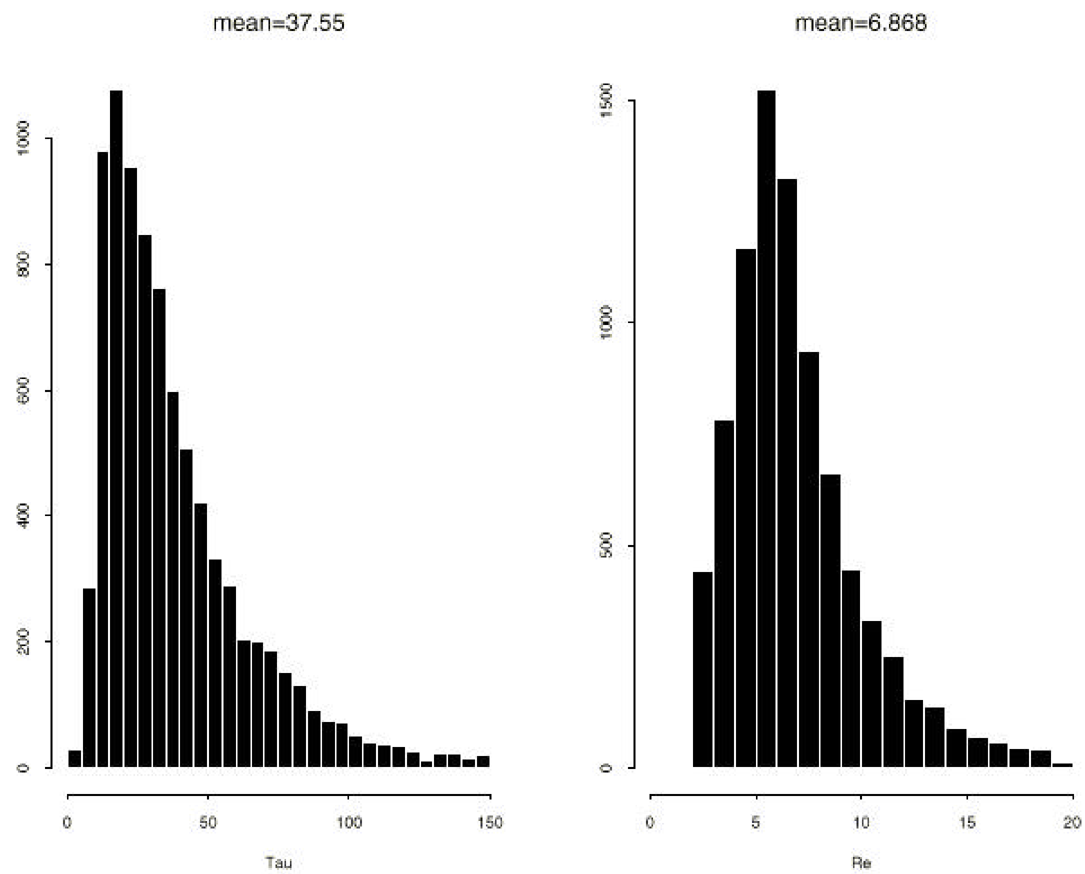

Figure 1. Three years of stratiform cloud statistics at the ARM SGP site.

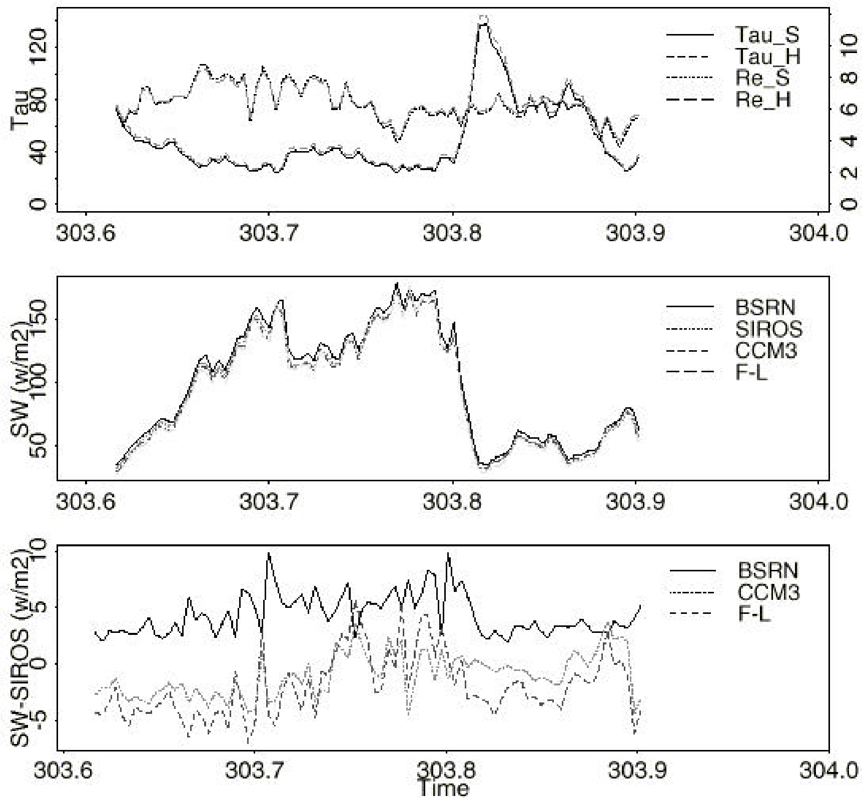

Figure 2. Inferred cloud optical properties from the MFRSR (XX_S for Slingo's scheme and XX_H for Hu and Stamnes' scheme), and measured and calculated surface shortwaves as well as the differences of BSRN - SIROS, CCM3 - SIROS, and Fu-Liou(F-L) - SIROS.

models, in which we use the inferred cloud optical depths based on Slingo's scheme, agree well with the SIROS measurements. The differences between the SIROS measurements and the model calculations as well as the BSRN measurements are shown in the bottom panel of Figure 2. The RMS errors between measurements of the SIROS and model predicted shortwave are less than 2.5 wm^{-2} and 3.5 wm^{-2} for CCM3 and Fu-Liou, respectively, on the same order as the differences between measurements from four instruments (4.7 wm^{-2}).

A relatively narrow band model, SW93, has been used to study the spectral information of shortwave by comparing the transmittances of the MFRSR with the transmittance predicted by the SW93 at the corresponding bands. The measured transmittance of the MFRSR are obtained as the ratio of the uncalibrated output to the extrapolated instrument's response to the top of the atmosphere (TOA).

Figure 3 shows the comparison of surface shortwave irradiances and of transmittances corresponding to five channels of the MFRSR for which standard Langley regression is possible. We exercised the SW93 model for both cloud parameterization schemes, and illustrated the differences in Figure 3. Despite relatively large cloud optical depth, the predicted transmittances of all channels based on Hu and Stamnes' scheme are larger than the results based on Slingo's scheme, resulting in a slight overestimate of the shortwave over the SIROS measurements of 3.8 wm^{-2}. If we use Slingo's parameterization alone, the predicted shortwave is slightly smaller than the SIROS measurements, and is consistent with the results of CCM3 and Fu-Liou models. Further, the first four channels show very good agreement with the measurements, except for the 862-nm channel for which the calculation underestimates the transmittance. Certainly, such a difference can be corrected by changing the surface albedo within the uncertainty range of measurements. Overall, the comparison demonstrates good agreement between shortwave models and measurements, and illustrates the spectral consistency of radiative transfer models under overcast conditions.

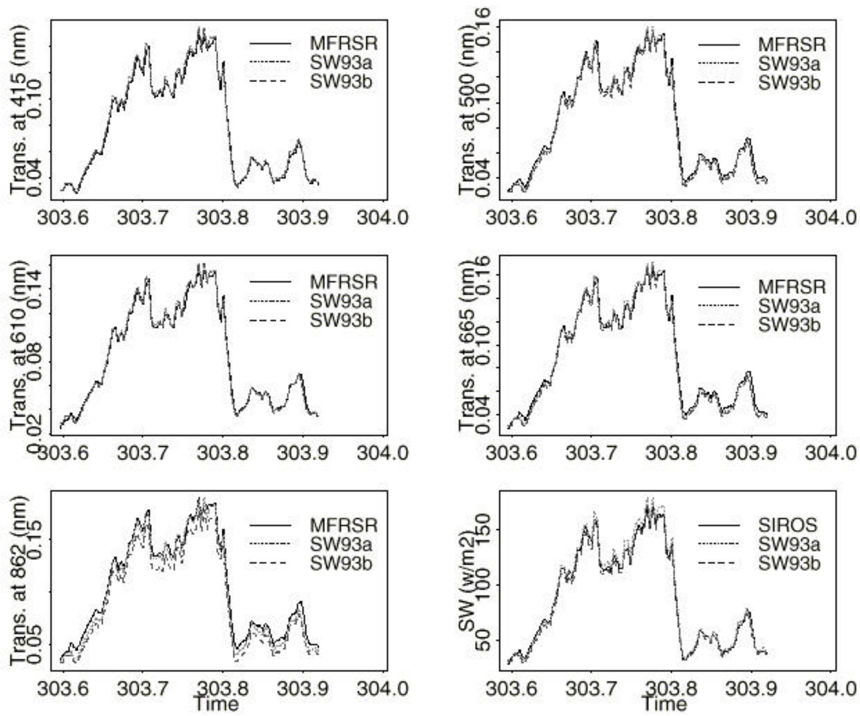

Figure 3. Comparison of measured and calculated transmittances and shortwave irradiance using SW93 SW93a for Hu and Stamnes' parameterization scheme and SW93b for Slingo's scheme.

Figure 4 shows the scattergram of the measured and calculated surface shortwave, which includes results of three overcast days during ARESE (September 27, October 30, and October 31, 1995). The surface shortwave predicted by the CCM3 reasonably agrees with the SIROS measurements. The statistics are displayed. For a mean shortwave of ~124 wm^{-2}, the RMS error is less than 5 wm^{-2}, within the uncertainty of the measurements.

Figure 5 shows the scattergram of the measured and calculated surface shortwave over 2 years, which includes 35 overcast days between 1996 and 1997. The surface shortwave predicted by the CCM3 reasonably agree with the averaged measurements of BSRN and SIROS. For a mean shortwave of ~130 wm^{-2}, the RMS error is about 10 wm^{-2}. A relatively larger RMS error than that during ARESE is due to the assumption of the same input parameters for all cases, such as the cloud base and top heights, and surface albedo. However, the differences have no trends regarding cloud optical depth, water vapor path, and cloud base temperature. It demonstrates that the consistency of our understanding regarding the spectral dependency of shortwave irradiance through clouds.

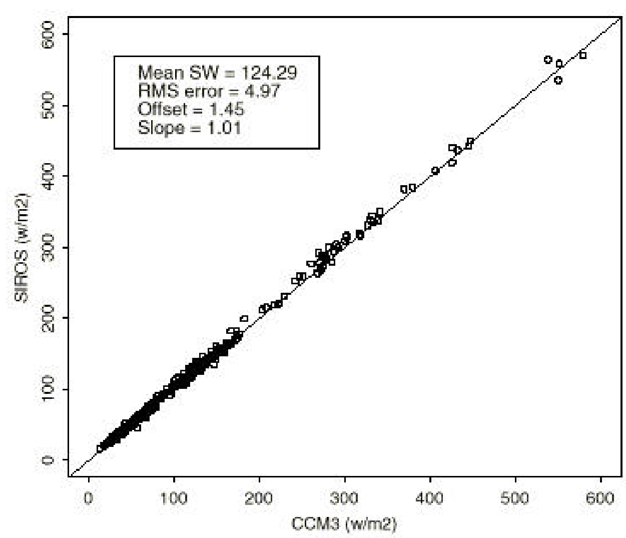

Figure 4. Correlation scattergram of measured and calculated surface shortwave during ARESE, 1995.

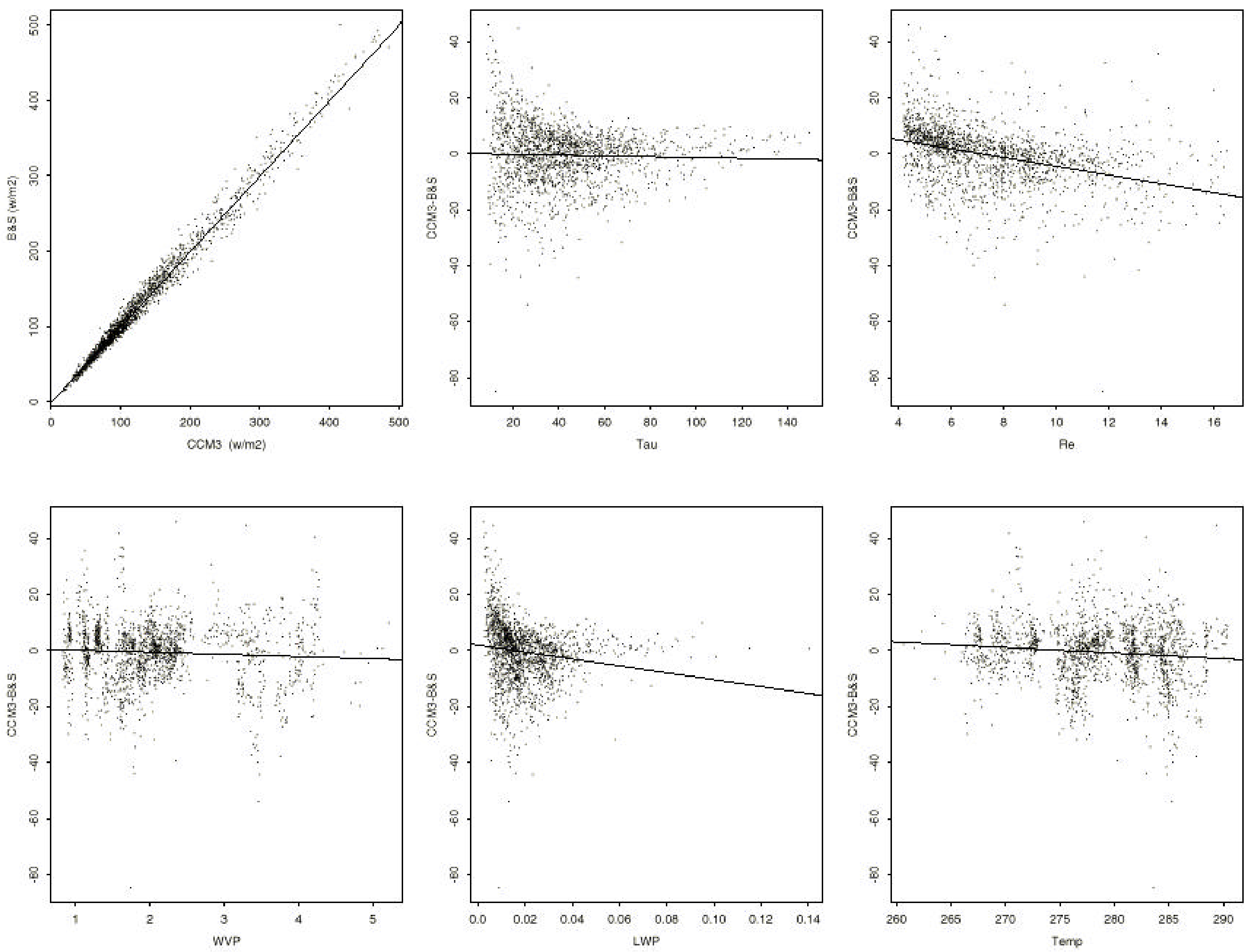

Figure 5. Scattergram of measured and calculated surface shortwave over 2 years. B&S represents averaged shortwave of BSRN and SIROS.

Conclusions

Extensive uncertainty studies indicate that at present the measurement uncertainties and errors are about ~5 wm^{-2} to 10 wm^{-2}, which is comparable with the uncertainty of the models associated with parameterizations. As shown previously, the model predicted shortwave under overcast cloud condition by using consistent cloud optical properties agree with the measurements, and the differences between models and instruments are within the current limitations of radiative transfer and experimental measurements. Based on our approach and spectral analysis, we may conclude that the spectral transmittances of shortwave are consistent with our understanding of radiative transfer. Spectral consistency of solar transmittance between model and measurement may not exclude the existence of any "anomalous absorption" of cloud at levels > 10 wm^{-2}, only if our inferred cloud optical properties such as effective radius are consistent with other in situ measurements. However, it at least provides a strict constraint: if any additional absorption of cloud exists, it should distribute over the whole solar region in such a way that the wavelength dependence of absorption should be consistent with current Mie theory, so that cloud optical properties inferred from a narrow band provide consistent parameters for the total shortwave model as well as for several narrow bands in the visible region.

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