4.4 Analysis of Solar Absorption Derived from ARM Surface and Satellite Measurements

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1. INTRODUCTION

The second Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE II) was designed to provide insight on the debate of whether or not cloudy skies enhance solar absorption. The experiment brought together surface, aircraft, and satellite measurements. Because the Clouds and the Earth's Radiant Energy System (CERES) instrument provides the only directly measured top of atmosphere (TOA) broadband shortwave albedos for the ARM Southern Great Plains (SGP) site, but does not provide continuous diurnal sampling, other datasets must be employed. Visible radiances from the eighth Geostationary Operational Environmental Satellite (GOES-8) are converted to broadband shortwave fluxes using conversions derived from correlations of GOES-8 narrowband and coincident Earth Radiation Budget Experiment (ERBE) broadband measurements. These fluxes are validated against CERES and aircraft measured fluxes. ARESE-II only covered the cloud conditions for a single month over the SGP site. To provide a more comprehensive assessment of solar radiation absorption in clouds over this area, this paper uses the GOES-8 TOA broadband radiative fluxes and the ARM surface fluxes to derive monthly absorption parameters following the methods of Cess et al. (1995). Model calculations of absorption during ARESE II are also compared with the empirical estimates.

2. DATA

The GOES-8 visible (VIS, 0.65 µm) channel was calibrated against the Visible Infrared Scanner (VIRS) data from 1998 to 2000 (Minnis et al. 2002). Half-hourly GOES-8 VIS radiances taken from January through December 2000 were converted to VIS albedo as in Minnis et al. (1995). GOES-8 broadband shortwave (SW; 0.2 - 5 µm) albedos were then calculated from conversions derived from correlations of GOES-6 VIS and ERBE data over the SGP during October 1986. The resulting albedos are averaged on a 0.3° grid centered at the ARM SGP central facility.

CERES broadband TOA fluxes from the Terra satellite from March to December 2000 are used to validate the GOES-8 broadband flux calculations. Collocated and coincident fluxes taken over the ARM SGP central facility within 5 minutes of the GOES-8 image time are used for comparison. These data are averaged on a 1° grid centered at the ARM SGP central facility.

Half-hourly mean surface fluxes centered on the satellite image times were computed from 1-minute measurements by the upward and downward-looking radiometers on the Solar Infrared Radiation Station (SIRS) at the ARM SGP central facility.

Aircraft data used for validation in this study came from two radiometer platforms, the Kipp and Zonen CM-22 and the Total Solar Broadband Radiometer (TSBR; Valero et al. 1997), aboard the Twin Otter aircraft during ARESE II. Aircraft fluxes were averaged to 8-minute means centered on the GOES-8 image times. Only points where no clouds were above the aircraft were used for this study. The Fu-Liou (FL; Fu and Liou, 1992, 1993) radiative transfer model was used to adjust the mean aircraft fluxes to the TOA. For all clear-sky aircraft measurements, the surface albedo in the FL model was adjusted until the computed albedo matched the value measured at the aircraft level. The corresponding TOA albedo was calculated using the resulting surface albedo. For cloudy measurements, cloud microphysical properties derived from multi-spectral GOES-8 retrievals (Minnis et al. 2001) were used as input to the model. The liquid water path was held constant and the particle effective radius was adjusted until the measured albedo at the aircraft level was matched by the model and a corresponding TOA albedo was calculated. Only minor adjustments in the derived microphysical properties were required to match the albedos.

3. ANALYSIS

The coincident and collocated TOA satellite data are first validated to ensure that the broadband fluxes calculated from GOES-8 are an adequate surrogate for directly measured broadband fluxes. Figure 1 shows that there is a high correlation between the GOES-8 and CERES broadband fluxes. Comparisons with the CM-22 and TSBR aircraft measurements show similar results; the bias in albedo mostly appears in the clear measurements. The albedo bias ranges from -0.0089 to -0.0161. The mean difference of about 12 W/m^2 between GOES-8 and CERES and the albedo bias between GOES-8 and the aircraft measurements will be eliminated when new monthly narrowband-to-broadband conversions based on GOES-8 and CERES data become available.

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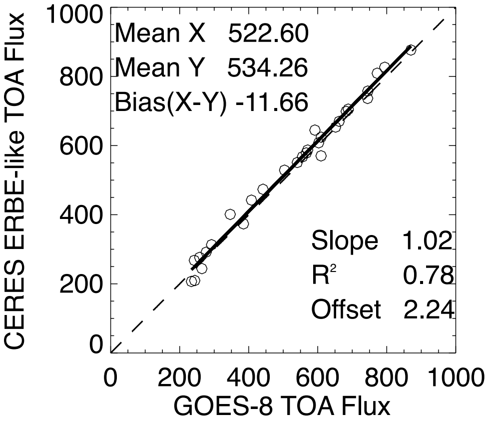

Fig. 1. Scatterplot of GOES-8 and CERES SW fluxes (Mar-Dec 2000).

The methods of Cess et. al (1995) were followed to calculate the monthly absorption parameters over the ARM SGP central facility. The method requires identification of the clear-sky fluxes and a linear regression fit of the fluxes as a function of solar zenith angle (SZA) at both the surface and TOA. The differences between the actual measurements and the clear-sky regressions are the instantaneous surface and TOA cloud radiative forcings, TCRF and SCRF, respectively. The ratio (R) between the mean SCRF and the mean TCRF is one of the absorption parameters that will be compared to the model calculations. An alternate technique to quantify cloud absorption is to determine the mean rate of change of TOA albedo with transmission at the surface. The albedo-transmission (AT) slope, β, will be determined using an average linear fit to the data by alternating the dependent variable. This method is justified because the uncertainties lie in both the surface and TOA data since spatially averaged satellite data are compared to temporally averaged surface data.

Total column atmospheric absorptance (A) was computed as

A= (net TOA SW flux - net sfc SW flux) / down SW flux

and compared with model results along with *R* and β.

For clear-sky validation, the nearest rawinsonde sounding from the central facility, aerosol optical depths from the Multi-Filter Rotating Shadowband Radiometer (MFRSR), and half-hourly averaged surface albedos from the SIRS were specified in the FL model calculations. Three stratus cloud cases from ARESE II were identified and modeled using the nearest sounding, SIRS surface albedos, and cloud microphysical data derived from GOES-8.

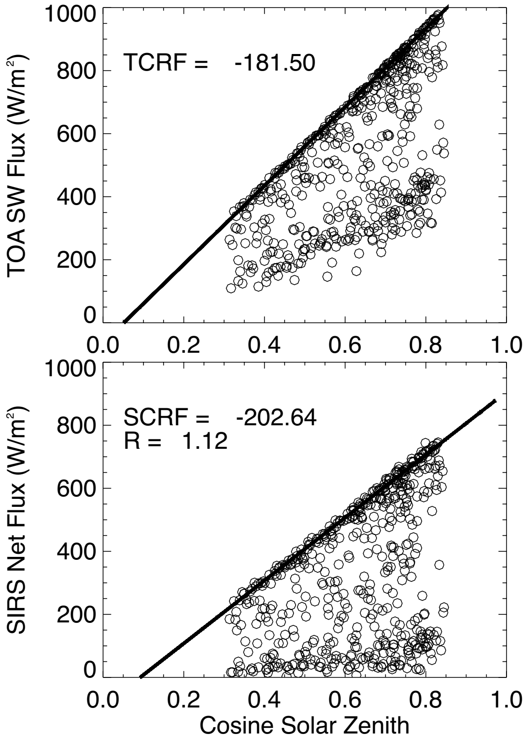

Fig. 2. ARESE-II measured TCRF and SCRF values.

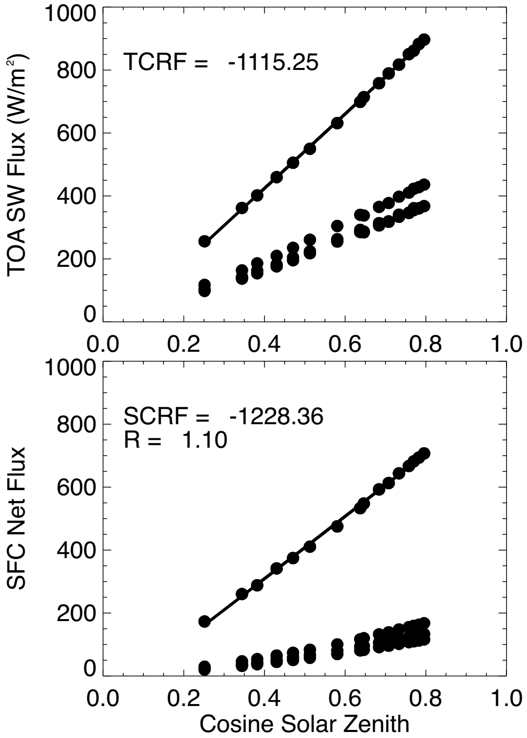

Fig. 3. ARESE-II modeled TCRF, SCRF, and net fluxes.

4. RESULTS

Clear-sky regression lines and cloud forcings were calculated from the data plotted in Fig. 2. The same quantities were derived from the theoretical results as shown in Fig. 3. The theoretical results are based on only 3 days of overcast stratus data compared to an entire month of fluxes observed in many different conditions. Nevertheless, the mean value of *R*, 1.12, in Fig. 2 is very close to that from the results in Fig. 3.

Figure 4 depicts the albedo-transmission (AT) slope computed from the measurements, while Fig. 5 shows the AT slope calculated with the FL model. Both the measurements and the model yield the same AT slope despite the lack of broken cloud conditions in the modeled absorption calculations. The broken cloud conditions are evident in Fig. 4 as the scatter of points between the upper-left cluster of points (overcast scenes) and the lower right cluster of points (clear scenes).

The measured total-column atmospheric absorptance during ARESE II is 0.238, which is slightly greater than the model-predicted absorptance of 0.217. Separating the results into clear and cloudy scenes shows that the difference is not a result of the model underestimating in cloudy skies only. For clear scenes, the model calculates an absorptance of 0.192, while the measurements calculate an absorptance of 0.216; a difference of 0.024. The FL model computes a cloudy-sky absorptance of 0.224, with the measurements showing an absorptance of 0.244; a difference of 0.020. These differences in *A* suggest that the model cannot account for all of the observed atmospheric absorptance. However, despite the differences, the model value is within the 0.05 standard deviation of the measured values. The results during ARESE-II are for only 1 month and may not be representative of other times of the year. To determine if the ARESE II period is typical, the computations of the monthly mean absorption parameters were repeated using the GOES-8 results fro the remainder of the year.

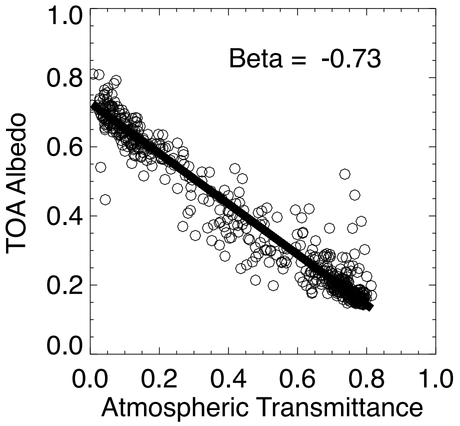

Fig. 4. ARESE-II measured albedo-transmission slope.

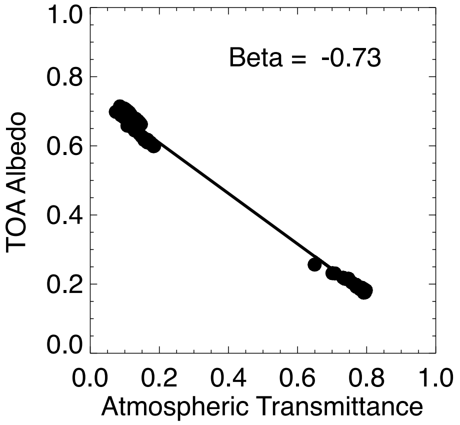

Fig. 5. ARESE-II theoretical albedo-transmission slope.

Summary plots of monthly means for *R*, *β*, and *A*, are shown in Figs. 6, 7, and 8, respectively. The monthly mean values of *R* range from 0.87 to 1.21. The extremely low values that appear in December are likely due to snow contaminating the cloudy cases. In those instances, the surface flux would have been closer to the clear-sky value while the TOA albedo would be bright like an overcast case. The low values in July may be due to broken clouds which do not shadow the radiometer, but provide diffuse radiation to it. In these cases the insolation at the surface would be greater than that for clear sky. This is a known drawback to this method for quantifying absorption.

Values of the AT slope range from -0.58 to -0.87 with the highest values appearing in December and July for the aforementioned reasons. The lowest values of *β* occur in August possibly due to the lack of extensive cloud cover. The mean cloud amount was only between 20 and 30% during August and September, but was at least 10% greater during all of the other months. Most of the observations fall on the clear-sky end of the slope with very few cloudy points, resulting in a skewed and highly uncertain slope. Since these two methods for calculating absorption seem to have biases, a better indicator of absorption should be monthly total column absorptance. Monthly absorptance ranges from 0.19 in December to 0.28 in August. The highest absorption appears to have occurred during August and September despite the minimal cloud cover. The calculations of

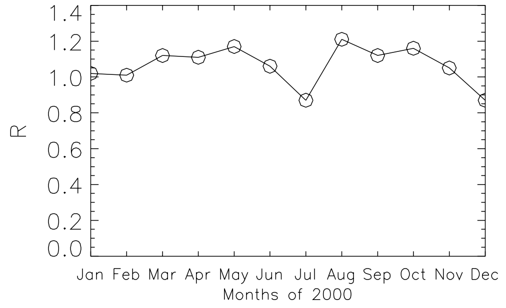

Fig. 6. Monthly mean cloud-forcing ratios.

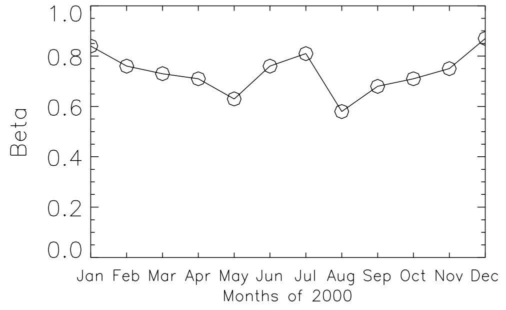

Fig. 7. Monthly albedo-transmission slope.

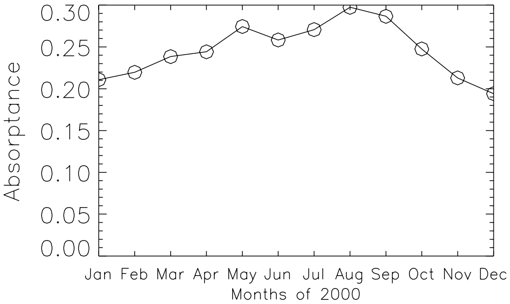

Fig. 8. Monthly albedo-transmission slope.

absorption for these months are most likely overestimated. This is possibly due to the very high albedos being observed at the surface, but not at the TOA. The single narrowband to broadband conversion applied to all months of the GOES-8 VIS data does not adequately capture the change in spectral albedo distributions observed at the surface during August and September. Again, this phenomena should be corrected when the monthly narrowband-to-broadband conversions based on GOES-8 and CERES data are applied.

Table 1 shows the maximum, minimum, mean, and standard deviations of the absorption parameters for the year 2000 along with the Fu-Liou model calculations for ARESE II.

5. CONCLUSIONS

Comparisons with CERES data, aircraft data, and FL model calculations have demonstrated that the GOES-8 SW broadband fluxes calculated from narrowband VIS radiances provide a reliable surrogate for directly measured TOA broadband fluxes. These comparisons show that GOES-8 slightly underestimates TOA albedos and that the bias is greatest under clear sky conditions. This bias will be corrected with improved narrowband to broadband relationships that will be derived from coincident GOES-8 and *Terra* CERES data as a function of month of the year.

Very good agreement was found between the absorption parameters calculated from the measurements and those from the Fu-Liou model. Slight differences are seen in the absorptance, but the modeled absorption parameters calculated for ARESE II all fall within the standard deviations of the calculations. Hence, relative to the Fu-Liou model, there is no evidence of enhanced shortwave absorption of solar radiation in cloudy skies during ARESE II.

The seasonal variation of solar absorption can be seen in Figures 6-8. The highest absorption occurs in the summer months with the lowest absorption occurring in the winter. The aforementioned bias in the GOES-8 data may contribute to the magnitude of seasonal difference, but the pattern will remain the same. The total column relative humidity, aerosol differences, and cloud type differences may also contribute to the seasonal difference seen here, but further investigation is required.

Table 1. Summary of monthly absorption parameters. FL model values from ARESE II in parentheses.

	Min	Max	Mean	Std Dev
R	0.87	1.21	1.06 (1.11)	0.22
β	-0.87	-0.58	-0.74 (-0.73)	0.08
A	0.19	0.29	0.24 (0.22)	0.02

Previous studies found discrepancies between measured and modeled atmospheric absorption that are not apparent in these results. Satellite and surface radiometer calibrations and radiative transfer model parameterizations were likely to be significant contributors to the absorption differences seen in the earlier studies. The small discrepancies between the observations and calculations seen in this study probably reflect the improvements in radiometer calibrations and radiative transfer models since ARESE-I in 1995. More detailed analysis of the aircraft data and the surface albedos as well as improved narrowband-to-broadband conversions might produce even smaller differences than those reported here.

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