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Analyses of Atmospheric Radiation Measurement (ARM) program's Enhanced Shortwave Experiment (ARESE) multiple data sets for studying cloud absorption

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Abstract. Following the Atmospheric Radiation Measurement (ARM) Enhanced Shortwave Experiment (ARESE), some studies reported a cloud absorption anomaly (CAA) of unprecedented magnitude. The largest discrepancy was found on a heavy overcast day (October 30, 1995) when cloud absorptance inferred from aircraft observations was 37% of the incoming solar irradiance, almost twice that of model calculations. The essential measurements supporting the finding were made with an airborne total solar broadband radiometer (TSBR). A thorough analysis is performed here, employing a variety of observations from more sources including aircraft, spacecraft, and ground-based instruments. It is found that albedos measured with the TSBR are systematically less than those inferred from other instruments. The difference in mean albedo between TSBR and that inferred from the scanning spectral polarimeter (SSP) on board the same aircraft amounts to 0.15, which is comparable to the reported CAA. SSP data were validated by (1) comparing them to data from the total direct diffuse radiometer (TDDR) spectral radiometer, (2) comparing the SSP's albedo-transmittance slope with that derived from ScaRaB satellite data, and (3) comparing SSP-derived albedos with those inferred from cloud optical parameters estimated from ground-based passive and active observations. All these comparisons show that SSP data are consistent with other measurements within the data uncertainties whose accumulated upper limit is <0.06. A reasonable doubt is thus cast on the claim of a very strong cloud absorption anomaly found using TSBR data on October 30.

1. Introduction

Through their role in determining Earth's radiation budget (ERB), clouds are thought to be primary regulators of global and regional climate. Clouds and their effect on ERB have been observed from space for many years [*Stephens et al*., 1981; *Ramanathan*, 1987; *Wielicki et al*., 1995]. These observations have revealed that general circulation model (GCM) simulations of clouds and cloud-radiation interactions are fraught with difficulties and uncertainties. At present, an alarming lack of consensus regarding absorption of solar radiation by cloudy atmospheres still exists. Conventional wisdom, as dictated by both theory and some observations, states that clouds, on average, have a small influence on total atmospheric absorption but have a marked influence on the vertical distribution of absorption [*Stephens and Tsay*, 1990; *Li et al*., 1997].

By analyzing recent observational data this conventional view has been both challenged [e.g., *Cess et al*., 1995; *Ramanathan et al*., 1995; *Pilewskie and Valero*, 1995] and supported [*Li et al*., 1995; *Imre et al*., 1996; *Francis et al*., 1997; *Chou et al*., 1998]. Several attempts were made to explain the inconsistencies between observed and modeled cloud absorption as found by some studies by exploring a range of potential mechanisms. However, all potential mechanisms fall far short of explaining the estimated globally averaged cloud absorption anomaly (CAA) of ~25 Wm^{-2} [*Cess et al*., 1995]. These include effects of inhomogeneous clouds [*Marshak et al*., 1997; *Barker et al*., 1998a], large cloud droplets [*Wiscombe et al*., 1984; *Lubin et al*., 1996], aerosols [*Kondratyev et al*., 1996; *Li*, 1998], water vapor dimers [*Chylek et al*., 1999], continuum absorption [*Arking*, 1996], and use of inaccurate parameterization schemes [*Li et al*., 1997]. Meanwhile, a number of studies [*Stephens*, 1996; *Arking et al*., 1996; *Barker and Li*, 1997] addressed potential shortcomings in the methodologies that have been employed in studies that claim a strong CAA.

To expedite a solution to this critical debate, the U.S. Department of Energy sponsored a field experiment in the fall of 1995 (September 22 to November 1) under the auspices of its Atmospheric Radiation Measurement (ARM) program. The experiment, dubbed the ARM Enhanced Shortwave Experiment (ARESE), took place around the ARM southern Great Plains (SGP) central facility (CF) in Oklahoma [*Valero et al*., 1997b]. Analyses of a subset of the ARESE data revealed an even larger CAA [*Valero et al*., 1997a; *Zender et al*., 1997].

Valero et al. [1997a] employed collocated measurements of

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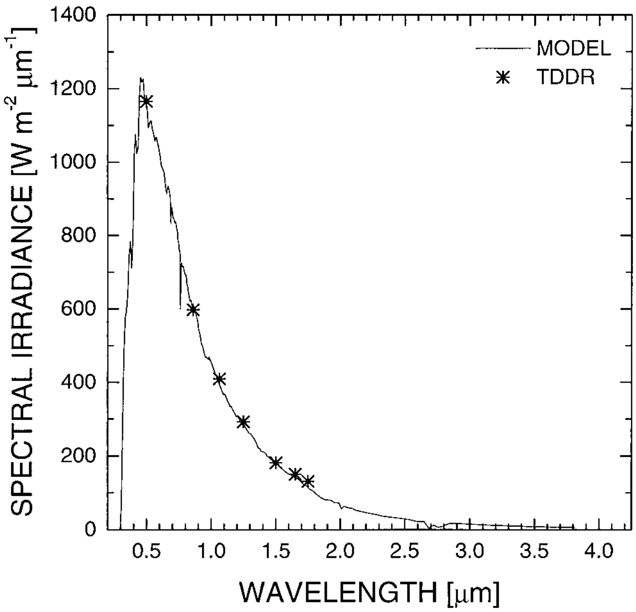

Figure 1. A comparison of downwelling spectral irradiances observed by total direct diffuse radiometer (TDDR) and computed by a radiative transfer model at 1730 UTC on October 30, 1995.

upwelling and downwelling radiative fluxes made on two stacked aircraft (above and below cloud). They reported that cloud absorption increases dramatically with cloud amount. The largest discrepancy between model and observation was found for the heavy overcast conditions on October 30, 1995. They reported that the cloud layer between the aircrafts absorbed 37% of the incoming solar irradiance. In comparison, model estimates of total atmospheric absorptance are usually ~24% [*Li et al.*, 1997]. In a companion study, *Zender et al.* [1997] reported a mean discrepancy of ~100 W m^{-2} in cloud absorption on the same day. Although Zender et al.'s study employed ground-based surface measurements, their finding of CAA actually originated from the Valero et al.'s total solar broadband radiometer (TSBR) data. They attempted to match modeled and TSBR albedos by assuming a seemingly too large cloud droplet effective radius r_e of 10 μm, which led to an underestimation of cloud optical depth by ~30% (see section 3). As noted in their study, if a more sound value of 7 μm was used for r_e, they would eliminate their discrepancy between modeled and measured surface irradiance but would create a large discrepancy between modeled and TSBR-measured albedos at the Egrett level.

Given the climatic significance of the reported CAA, a comprehensive and independent evaluation of cloud absorption is conducted here using data from a group of sensors, including TSBR. The data sets and radiation model employed are discussed in section 2. Section 3 presents the results of (1) a direct comparison between scanning spectral polarimeter (SSP) and total direct diffuse radiometer (TDDR) spectral fluxes, (2) comparisons of broadband visible and (3) shortwave (SW) albedo obtained from SSP and differences between TSBR and fractional solar broadband radiometer (FSBR) measurements, (4) a comparison of slopes of albedo-transmittance linear regressions, and (5) an analysis of cloud properties retrieved from a set of ground instruments with TSBR and SSP observations around ARM's CF. Concluding remarks are given in section 4.

2. Data

Measurements made from a variety of platforms were employed in this study. The majority of data analyzed here were collected on October 30, 1995, at the SGP central facility site in Oklahoma (36.605°N, 97.485°W). The primary data set was obtained by the Egrett aircraft flying at 14 km with different up- and down-facing radiometers [*Valero et al.*, 1997b]. The TSBR measured total solar irradiance between 0.224 and 3.91 μm. The TDDRs measured irradiance at 10-nm-wide spectral intervals centered on seven wavelengths: 0.500, 0.862, 1.064, 1.249, 1.501, 1.651, and 1.75 μm. The FSBR measured solar irradiance between 0.678 and 3.3 μm [*Valero et al.*, 1997a]. Calibration and operation of these instruments were discussed by *Valero et al.* [1997b].

The Egrett was also equipped with a downward SSP designed by *Stephens et al.* [1999]. It measures reflected solar radiances and irradiances (fluxes) from ~0.4 to 1.1 μm, with a spectral resolution varying from ~0.015 to 0.03 μm. SSP data are compared with measurements from other radiometric instruments. Hemispherical integration of SSP radiances leads to irradiances that are consistent with direct SSP irradiance measurements. SSP calibration employed an integrating sphere with standard lamps and spectral, angular, and temperature responses were accounted for. Relative to an isotropic calibration source, the calibration uncertainty for SSP fluxes was determined to be 3–5% for most of the spectrum [*Stephens et al.*, 1999]. The SSP's cosine response deteriorates beyond zenith angles of 65°–70°. The precision of calibration is generally slightly higher (~1–2%) in the visible spectrum than in the near-IR spectrum.

Note that SSP only measured upwelling radiance and irradiance. In order to obtain albedos, downward irradiances are needed. Without the presence of cloud above the high-flying Egrett aircraft, downward fluxes can be modeled rather accurately, since only Rayleigh scattering and ozone absorption are dealt with essentially. A two-stream radiative transfer model was used here. Transmittance was computed by a 287-band k-distribution model [*Chou and Arking*, 1981; *Chou*, 1990] with an ozone cross-section parameterization from *Stamnes and Tsay* [1990]. Ozone amounts were obtained from the ozonesonde launched at ~1500 UTC. Figure 1 is a comparison of downwelling spectral irradiances computed by the model and observed by TDDR. The good agreement bolsters confidence on the use of the model in determining albedos from SSP.

Surface irradiance measurements were made with two different systems consisting of shaded and unshaded broadband Eppley PSP pyranometers and pyrheliometers. One is named Baseline Surface Radiation Network (BSRN); the other is called Solar and Infrared Radiation Observation System (SIROS). The quality of surface radiation data was assessed in the framework of the ARM program by intercomparing the two independent systems and comparing them to the much more reliable cavity radiometer. After corrections, BSRN and SIROS irradiances agree to within 10 W m^{-2} [*Michalsky et al.*, 1999].

In addition, ground-based remote sensing instruments were available thus enabling retrieval of cloud properties. Employed here are the multichannel microwave radiometer, the 94-GHz cloud radar, and the laser ceilometer. These instruments pro-

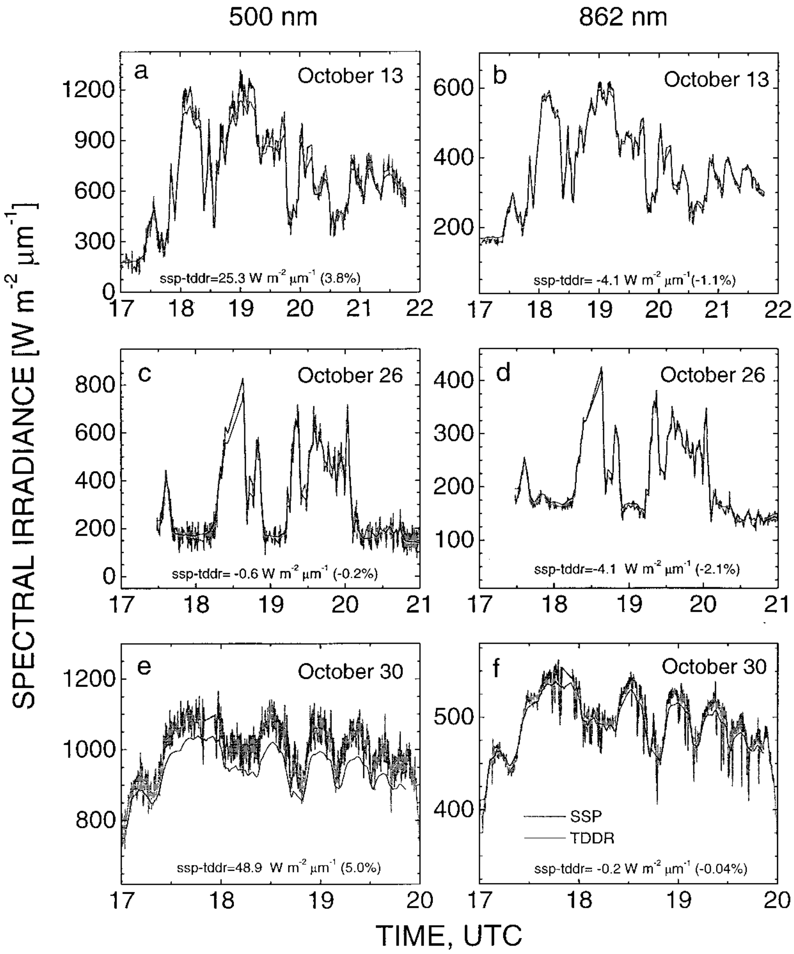

Figure 2. Comparison of scanning spectral polarimeter (SSP) (thick line) and TDDR (thin line) spectral irradiances at 500 and 862 nm on October 13, 26, and 30, 1995. Mean differences are listed on the plots.

vide information pertaining to cloud liquid water paths (LWP), cloud top, and cloud base height, respectively. Conventional radiosondes were also launched, providing vertical profiles of temperature, pressure, and relative humidity.

Satellite data from the Scanner for Radiation Budget (ScaRaB) on board Meteor 3 were also employed. ScaRaB provided onboard calibrated SW (0.2–4 μm) and visible (0.55–0.65 μm) reflected radiance measurements at a spatial resolution of ~60 × 60 km at nadir with varying equator-crossing time. The calibration accuracy is estimated to be 1–2% [*Kandel et al.*, 1998; *Trishchenko and Li*, 1998] and is consistent with the Earth Radiation Budget Satellite (ERBS) [*Bess et al.*, 1997]. Although ScaRaB functioned from February 1994 to March 1995, it is useful in several ways for the current investigation. First, ScaRaB provided simultaneous and collocated visible and SW albedos. This enables derivation of a relationship between them [*Li and Trishchenko*, 1999] in order to transfer visible measurements into broadband ones. Second, ScaRaB data were employed to determine the slope of albedo at the top of the atmosphere (TOA) versus atmospheric transmittance at the surface for comparisons with those derived from other data sets.

3. Analyses

Data from all three instruments employed by *Valero et al.* [1997a] were analyzed by comparing them with other data. The most direct comparison is between SSP and TDDR measurements at individual wavelengths. These comparisons generally show good agreements, as is seen in Figure 2 for October 13, 26, and 30 at 500 and 862 nm. The largest time-averaged relative difference is 5% observed on October 30, which is comparable to uncertainties in calibration and angular correction. Note, however, that for the smallest values on that plot, differences are much less than 5%.

The second comparison is for broadband visible albedos. On October 30, *Valero et al.* [1997a] observed strong cloud absorption in the visible band but not at 500 nm, whereas a radiative transfer model usually produces negligible cloud absorption across the entire visible band, barring absorption due to absorbing aerosols. Note that the visible albedo was not directly measured by Valero et al. but simply taken as the difference between their TSBR and FSBR measurements, which gives an equivalent visible albedo over a wide band spanning from 224 to 678 nm. Similar albedos can also be derived by integration of the spectral irradiance measurements of SSP from 428 to ~680 nm. Model calculations indicate that the difference in the spectral coverage from 224 to 428 nm has almost no effect on the comparison (<0.1%). Figure 3 shows a comparison of visible albedos from SSP and from TSBR and FSBR on October 30. The difference is very large, with a mean value close to 0.2 (~25%), in contrast to the much closer comparison between SSP and TDDR at 500 nm. On the basis of this

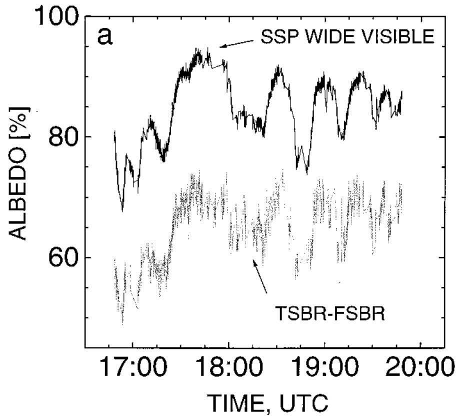

Figure 3. Comparison of visible albedos derived from SSP and from total solar broadband radiometer (TSBR) and fractional solar broadband radiometer (FSBR) on October 30, 1995.

difference, *Valero et al*. [1997a] argued that there is a strong CAA existing in the visible band though not near 500 nm. If this were true, one would expect to see a local maximum in SSP spectral albedo near 500 nm. As Figure 4 shows, this is not the case. The smooth behavior of cloud albedo around 500 nm is supported also by experimental results available from many previous experiments such as those compiled by *Bowker et al*. [1985]. These results show spectrally smooth albedo in the visible range for all cloud types. Figure 4 also shows the ratio of 500 nm albedo to wideband visible albedos from SSP, TSBR/FSBR, and the model. The model calculations were based on an adding-doubling algorithm described in detail in Section 3. Altogether, 21 spectral measurements made by SSP between 428 and 680 nm were considered. It is seen that SSP values are very close to the model results, whereas values for Valero et al.'s instruments are ~25% larger.

The third comparison is concerned with broadband shortwave albedos measured by TSBR and inferred from SSP. Since SSP has a limited coverage in wavelength, a narrowband to broadband conversion is needed. To reduce the uncertainty of the conversion, an observed relationship between TOA visible albedo and shortwave albedo obtained from ScaRaB data is used. *Li and Trishchenko* [1999] used ScaRaB data to show that the two types of albedos are highly correlated in a linear manner. To take advantage of the narrowband-broadband relation, the SSP spectral data were integrated over the ScaRaB visible band using ScaRaB's response function as a weighting function. A minor correction factor determined by modeling is introduced for the relation to be used at the aircraft level, instead of at the TOA. The uncertainty of this model correction is estimated to be <1% (relative).

Figure 5 presents the conversion relation derived from ScaRaB measurements made over the SGP region. It is seen that the data points are tightly distributed along linear regression lines that vary slightly with solar zenith angle (SZA). During the experiment on October 30, SZA was <60°, and the conversion uncertainty in SW albedo is <0.02.

Figure 6 shows the comparison of the resulting broadband albedos from SSP and TSBR. The difference is less than that for visible albedo but still very large, with a mean of 0.15. Note that the disparity in albedo is approximately equivalent to the magnitude of the CAA reported by *Valero et al*. [1997a], and it significantly exceeds the uncertainties in all the steps of deriving TOA albedo from SSP. These steps include the following: calibration (<5%, relative), narrowband to broadband conversion (0.02, absolute), conversion between values at the aircraft and TOA levels (<1%, relative), and spectral integration over visible band (0.1%, relative). The upper limit of accumulated uncertainty for SSP-derived cloud albedo is expected to be <9% (relative) or 0.06 (absolute).

To further assess the quality of SSP and TSBR data, two indirect comparisons were made using satellite and surface measurements. During the ARESE, there was no calibrated broadband spaceborne sensor in operation. However, data from different periods are still useful if a comparison is made in terms of the relationship between TOA albedo and surface transmittance. The slope of this relation has served as a proxy of inherent cloud absorption [*Cess et al*., 1995]. Although it has some limitations in indicating cloud absorptance [*Li and Moreau*, 1996; *Barker et al*., 1998a], it is much less variable than TOA albedo and atmospheric transmittance, especially for overcast scenes. For broken clouds the approach suffers from considerable uncertainties because of both large errors in matching TOA and surface measurements [*Arking et al*., 1996] and the horizontal exchange of photons [*Barker and Li*, 1997].

Using data obtained during ScaRaB's 1 year of operation, TOA albedo data were matched with atmospheric transmittance as measured by BSRN at the ARM SGP site. The centers

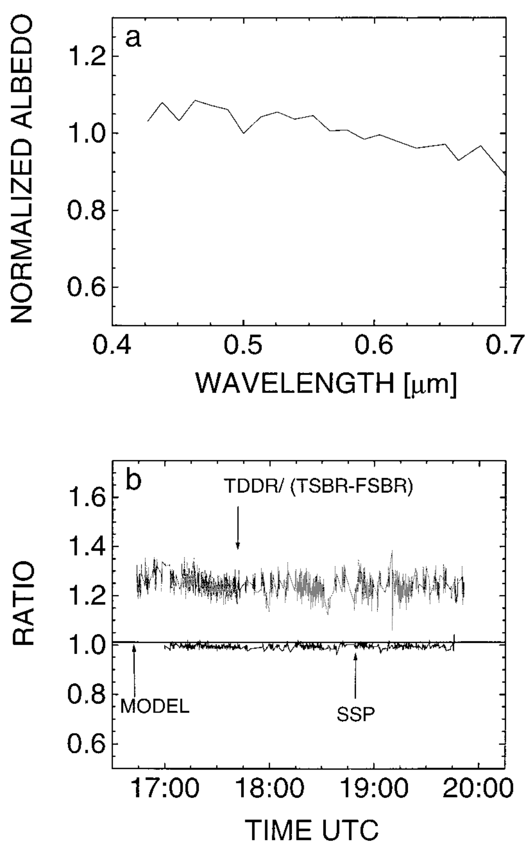

Figure 4. (a) An averaged sample of spectral variation of monochromatic albedo observed by SSP on October 30, 1995, normalized to albedo value at 500 nm. (b) The ratio of albedos at 500 nm and in the visible region obtained from SSP, a combination of TDDR, FSBR, and TSBR, as well from model calculation.

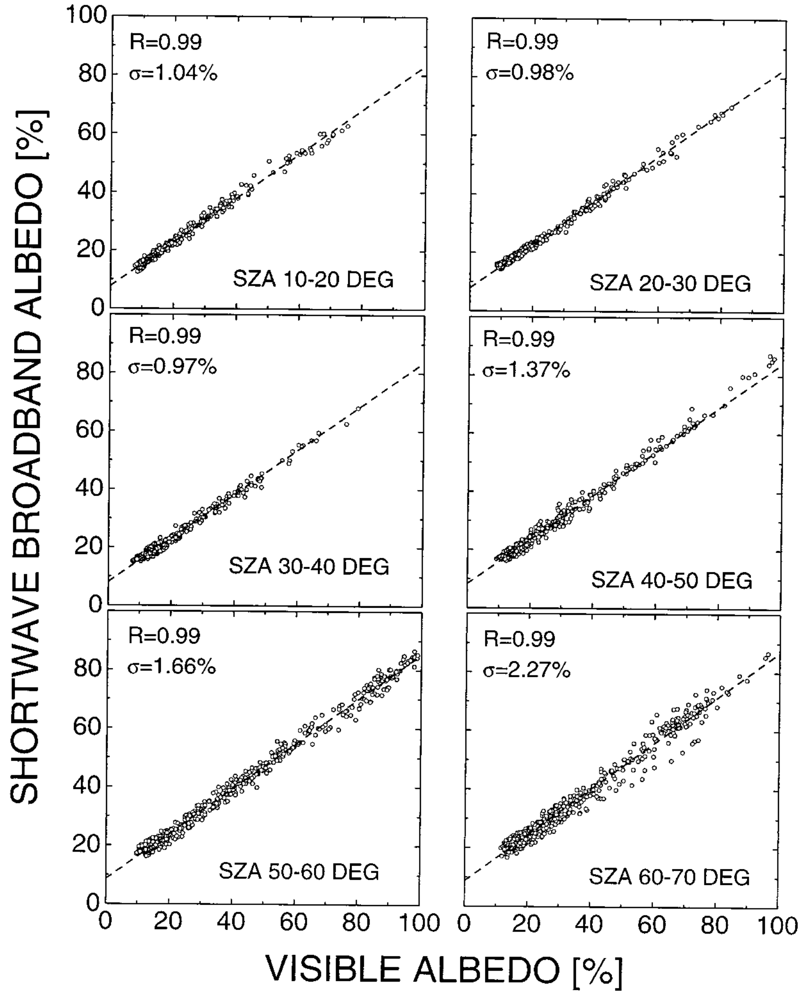

Figure 5. Relationship between visible and shortwave (SW) albedos observed by ScaRaB over the southern Great Plains (SGP) Atmospheric Radiation Measurement program (ARM) locale in 1994 for different ranges of solar zenith angles (SZA). Correlation coefficients R and standard deviations (SD) σ of the linear regressions are listed on the plots.

of the ScaRaB pixels were restricted to within 30 km of the CF. Bearing in mind the limitations of this method, matched pairs were screened on the basis of scene types and the standard deviation (SD) of 1-min surface irradiance data for 30-min stretches. Since partly cloudy scenes are highly variable and usually evolve rapidly, only clear and overcast satellite data with corresponding value of SD <20 W m^{-2} for snow-free surface observations were analyzed. SSP data were taken within 0.5 km of the CF for the cloud scenes observed on October 30. They are marked as squares in Figure 6. In order to obtain a regression line, clear-sky SSP data that were taken from October 11 and 19, 1995, following similar screening are also required. Moreover, comparing Figures 2 and 6, it can be seen that the screened SSP values are relatively small, where agreement with TDDR values is better than average.

Figure 7 is the albedo-transmittance plot for the matched data from ScaRaB, SSP, and TSBR. Note that albedos measured at the aircraft level (14 km) were converted to the TOA values by virtue of radiative transfer modeling as described by *Doelling et al*. [1998]. It is seen that there is a tight cluster of clear-sky points on the right but very large discrepancies for thick overcast clouds on the left. Slopes of least square linear regression lines are −0.78 for SSP and −0.82 for ScaRaB data; both are indistinguishable from model values, which are typically ~0.8 [*Cess et al*., 1995; *Li and Moreau*, 1996]. For TSBR, however, the slope is just −0.571. It is worth mentioning that the slightly larger values from ScaRaB are probably associated with uncertainties due to the bidirectional correction based on the Earth Radiation Budget Experiment (ERBE) angular dependence model (ADM) [*Suttles et al*., 1988]. Three-dimensional effects and the lack of dependence on cloud optical depth in the ERBE ADM may lead to overestimation of albedos for clouds with uneven top and thick clouds (B. A. Wielicki, private communication, 1998). On the basis of our preliminary investigation the overestimation is usually <10% (relative value).

Finally, the measurements from a suite of ground-based instruments were also compared indirectly with SSP data. Ground data were first used to retrieve cloud optical depth τ and droplet effective radius r_e. These were then used to compute cloud albedos that were compared with SSP values. Retrieval of τ from ground-based irradiance observations is a straightforward and widely used technique [*Leontyeva and Stamnes*, 1994; *Min and Harrison*, 1996; *Dong et al*., 1997;

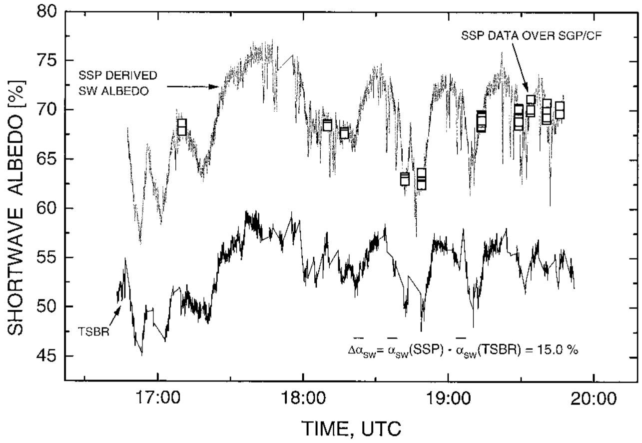

Figure 6. Comparison between broadband solar albedos from TSBR and SSP at the aircraft level. Squares represent SSP measurements made near SGP central facility (CF).

Barker et al., 1998b]. Basically, for overcast conditions, transmittance (or insolation) measured at the surface is governed primarily by τ and SZA. Other cloud and environmental parameters (e.g., droplet effective radius and surface albedo) are of secondary importance [*Leontyeva and Stamnes*, 1994]. For the ARESE experiment few assumptions are needed thanks to plenty of ancillary observations. For example, surface albedo is measured, cloud bases and tops are known from cloud-profiling radar and laser ceilometer, while microwave radiometer (23.8 and 31.4 GHz) provides cloud LWP. From these measurements one can retrieve both τ and r_e.

Our retrieving method utilizes lookup tables obtained by running an adding-doubling radiative transfer code with 105 spectral bands from 0.2 to 5.0 μm. The tables were generated for different input variables with some parameters fixed according to observations such as cloud top and bottom. Sixteen discrete values were selected for τ: 0, 1, 2, 4, 8, 12, 16, 20, 24, 32, 48, 64, 96, 128, 196, and 256. SZA was set to be 8.46°, 19.35°, 30.11°, 40.58°, 50.60°, 60.00°, 68.58°, 76.09°, 82.25°, 86.76°, and 89.38°. Multidimensional interpolation was carried out to determine τ, as well as TOA broadband flux and albedo based on surface transmittance, solar zenith angle, precipitable water, cloud layer location, and surface albedo. After solving for τ using a measured transmittance, r_e is approximated as

$$r_e = 3\ \mathrm{LWP}/2\tau. \tag{1}$$

Note that LWP was retrieved from 5-min averages of microwave radiometer measurements. Surface irradiance measurements were taken from both BSRN and SIROS for the sake of comparison.

Note that an initial value of effective radius r_e^* had to be selected to construct the lookup tables. However, the dependence of r_e on the selection of r_e^* is very weak. For several reasonable values of r_e^*, retrieved r_e differ by just ~0.3 μm. This is because τ retrieved from surface insolation measurements depends only weakly on r_e. However, if one uses (1) to estimate τ with a measured value of LWP and an assumed r_e, both τ and surface insolation are much more sensitive to r_e. For example, if $r_e = 10\ \mu$m is used instead of 7 μm, as in the study by *Zender et al.* [1997], the resulting τ decreases by a factor of 30%, leading to a large discrepancy between modeled and observed values of surface downward flux.

Figure 8 presents the major input and output parameters for the retrieval and a comparison of albedos. It is seen that the BSRN and SIROS measurements differ slightly (<5 W m^{-2} on average), and their variations are anticorrelated with changes in LWP. Plotted in Figures 8c and 8d are τ and r_e retrieved from the two radiometers. Our retrievals are in excellent agreement with those retrieved independently by X. Dong et al. (Comparison of stratus cloud optical depths retrieved from surface and GOES measurements over the ARM SGP central facility, submitted to *Geophysical Research Letters*, 1998, hereafter X. Dong et al., submitted, 1998), whose mean τ is 33 and r_e is 7.4 μm. Although the input parameters employed in both studies are the same, the retrieval methods are quite different. The iterative method of X. Dong et al. (submitted, 1998) is more complex and relies on a two-stream model. Dong et al.'s method has been validated with in situ cloud microphysical observations and very good agreement was found. Furthermore, *Min and Harrison* [1998] also obtained similar cloud optical properties using independent data sets and a different retrieval model [*Min and Harrison*, 1996]. Their major inputs are measurements from their multi-filter rotating shadowband radiometer (MFRSR). All these studies suggest that mean r_e should have been in the neighborhood of 7 μm on October 30.

Figure 8e compares albedos computed using the retrieved cloud optical properties with those from SSP and TSBR, which were made within 0.5 km of the CF. Albedos retrieved from ground irradiance observations are slightly smaller than the SSP-based albedos but much larger than TSBR measurements. This attests further to the quality of SSP data.

4. Concluding Remarks

Following the ARM Enhanced Shortwave Experiment (ARESE) held in October 1995 at the ARM SGP site in Oklahoma,

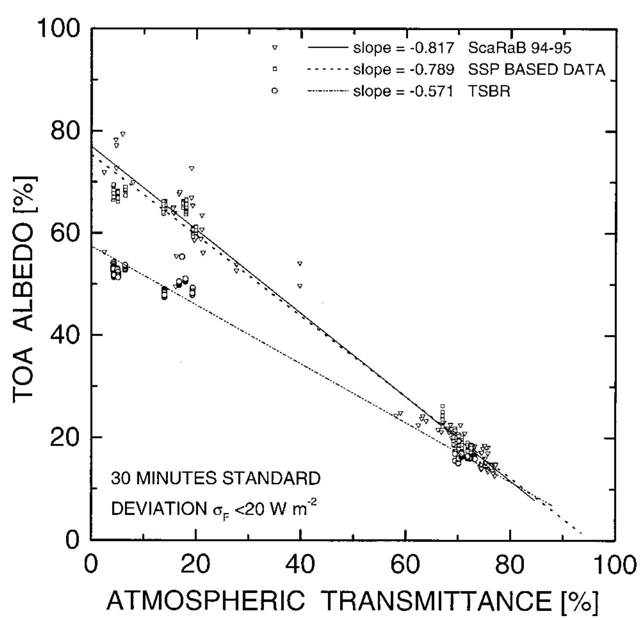

Figure 7. The relationship between top of the atmosphere (TOA) albedo and atmospheric transmittance. TOA albedos were derived from ScaRaB, SSP, and TSBR. Atmospheric transmittances were computed from Baseline Surface Radiation Network (BSRN) surface irradiance measurements. Slopes of the linear egressions are listed on the plot.

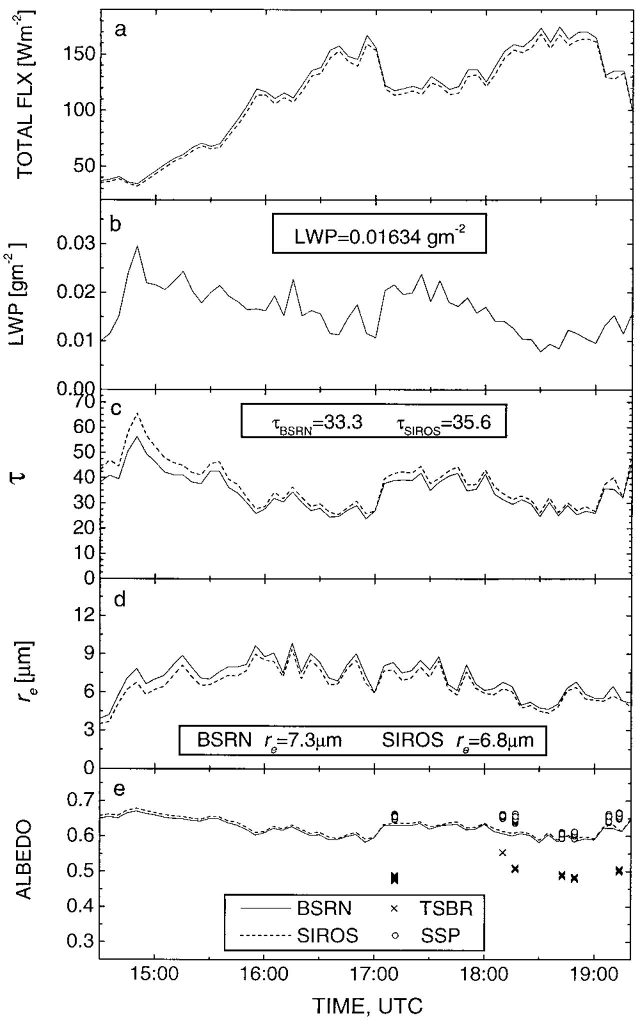

Figure 8. Input and output for the retrieval of cloud properties and a comparison in TOA albedo computed from ground-based measurements and from SSP. Two major input parameters are surface downwelling flux from (a) BSRN and Solar and Infrared Radiation Observation System (SIROS) and (b) cloud liquid water paths (LWP). Retrieved cloud variables are (c) cloud optical depth and (d) cloud droplet effective radius r_e from which (e) albedo were computed.

very large discrepancies between observations and models were reported [*Valero et al*., 1997a; *Zender et al*., 1997] regarding cloud absorption. The largest discrepancy was found for a thick overcast cloud layer on October 30, 1995, when the observed cloud absorptance was almost twice the modeled value. The key piece of supporting information in both studies came from measurements made by airborne total solar broadband radiometers (TSBRs).

An investigation was presented here employing a variety of observations from all instruments available that can be brought to bear on the quality of TSBR measurements. They include airborne measurements of broadband fluxes from TSBR and FSBR; spectral fluxes from TDDR, as designed and operated by *Valero et al*. [1997b]; *Stephens et al*.'s [1999] SSP; ground-based observations of solar irradiance from BSRN and SIROS; cloud LWP from a microwave radiometer; cloud base from a laser ceilometer; and cloud top from a cloud-profiling radar, as well as spaceborne measurements of solar reflection from ScaRaB. The analysis was limited largely, but not exclusively, to data from October 30, 1995.

Two spectral radiometers, namely, SSP and TDDR, were first compared and good agreements were obtained. However, broadband visible and shortwave albedos derived from SSP, TSBR, and FSBR showed very large discrepancies. The mean differences in visible and SW albedos from SSP and TSBR/FSBR are 0.20 and 0.15. The value for SW albedo is approximately equivalent to the reported cloud absorption anomaly itself. Observations of spectral albedo by SSP exhibit a smooth dependence on wavelength, which does not support the finding of "strong absorption in the visible but not at 500 nm" [*Valero et al*., 1997a]. A major discrepancy also emerged in the comparison of slopes of linear regression lines between TOA albedos as measured by satellite and aircraft and atmospheric transmittances observed at the surface. The slopes derived from ScaRaB and SSP are close to −0.8, in conformity with radiative transfer models. However, the slope from TSBR data is −0.57. SSP-based albedos were also compared with those based on cloud optical properties inferred from ground-based instrumentation. Once again, SSP showed much better agreement than the TSBR.

Although some comparisons presented here involve modeling and corrections, the resulting uncertainties are significantly smaller than the discrepancy found here. The major sources of uncertainty in the SSP-derived broadband albedos are calibration (<5%, relative), narrowband to broadband conversion (0.02, absolute), conversion between values at the aircraft and TOA levels (<1%, relative), and spectral integration over visible band (0.1%, relative). Therefore the upper limit of accumulated uncertainty for cloud albedo is estimated to be <9% (relative) or 0.06 (absolute). This falls well below that needed to bridge the gap between SSP and TSBR albedos (i.e., 0.15). The "signal-to-noise ratio" of our study is thus sufficient enough to cast reasonable doubt on the quality of TSBR data collected on October 30, 1995, and so is the strong cloud absorption anomaly drawn from the data.

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