Validation of the Archived CERES Surface and Atmosphere Radiation Budget at SGP

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Introduction

The Clouds and Earth's Radiant Energy System (CERES) Surface and Atmosphere Radiation Budget (SARB) product (Charlock et al. 2002) includes the vertical profile of broadband shortwave (SW), broadband longwave (LW), and 8-12 micron window (WN) fluxes; upwelling and downwelling at top of the atmosphere (TOA), 70 hPa, 200 hPa, 500 hPa, and the surface; and for all-sky and clear-sky conditions. We test the archived CERES Tropical Rainfall Measuring Mission (TRMM) record of SARB for January-August 1998 and focus on discrepancies with ground-based measurements at Southern Great Plains (SGP).

The CERES SARB is generated by a highly modified Fu-Liou radiative transfer code (Fu and Liou 1993). The most critical inputs for this application are cloud optical properties (fractional area, optical depth, particle size and phase, height of top, and estimate of geometrical thickness; Minnis et al. 2002) from the narrowband visible infrared scanning radiometer (VIRS) imager. Numerous VIRS pixels (approx. 2 km resolution at nadir) are matched to each of the large (approx. 20 km) CERES broadband footprints (Wielicki et al. 1996). Other inputs include temperature and humidity from the European Centre for Medium-Range Weather Forecasts (ECMWF; Rabier et al. 1998), National Centers for Environmental Prediction (NCEP) ozone profiles from SBUV and TOVS (Yang et al. 2001), aerosol optical thickness (AOT) from the Model for Atmospheric Transport and Chemistry (MATCH) aerosol assimilation (Collins et al. 2001) or alternately from the VIRS imager (Ignatov and Stowe 2000). VIRS AOT is available for clear and partly cloudy ocean footprints during daylight; and only when viewing geometry renders a contribution from sun glint as unlikely. For other footprints, AOT is taken from MATCH. AOT is apportioned into fractions of dust (Tegan and Lacis 1996), sea salt, sulfate, dust, soluble organic, insoluble organic, and soot (Hess et al. 1996) using the 6-hourly MATCH output.

Tuned fluxes are retrieved by adjusting inputs to nudge computed TOA fluxes toward CERES observations (Rose et al. 1997). In clear conditions, the fields of humidity, surface skin temperature, surface albedo, and AOT are adjusted to produce a closer match of computed and observed fluxes at TOA. When CERES footprints have clouds, the cloud optical thickness, fractional area within the footprint, and temperature of cloud top are adjusted by the tuning algorithm. Both tuned and untuned fluxes are archived, as are the respective adjustments to any parameters at the surface or within the atmosphere.

Resources for Validation

Starting with the development of pre-launch algorithms, the SGP Central Facility (CF) has been a core validation site for the CERES SARB. The pre-launch, temporally intensive CERES ARM GEWEX Experiment (CAGEX; Charlock and Alberta 1996) has been modified and extended to the CERES ARM Validation Experiment (CAVE; Rutan et al. 2001). CAVE has 40 sites with long term, continuous measurements of broadband surface radiation; one half are the boundary and extended facilities at SGP. The other CAVE sites, which include Surface Radiation Budget Network (SURFRAD) and the Baseline Surface Radiation Network (BSRN; Ohmura et al. 1998), subscribe to the strict BSRN protocol for observation and calibration. CAVE provides on line access to files and plots of half-hour means of observed surface radiation and meteorological parameters; co-located CERES TOA observations and subsets of the retrieved SARB; probability distribution function (PDF) tables for each ground site comparing the retrieved TOA and surface fluxes with observations; and “point and click” versions of the Fu-Liou and Coupled Ocean Atmosphere Radiative Transfer (COART) code (Jin et al. 2002). A google search for “CERES CAVE” will lead to the CAVE URL.

Test at SGP CF

Table 1 is an abbreviated assessment of SARB retrievals from the TRMM record for January to August 1998 at the ARM SGP E-13 at the CF. The formal product is called TRMM CRS Edition 2b. An earth observing system (EOS) product labeled “Edition” is available thru a Distributed Active Archive Center (DAAC) in hdf format; and is validated and useable in scientific, peer review publications. Surface (Sfc) observations in Table 1 are each 30 minute mean values (i.e., 0000-0030, 0030-01000, 0100-0130…). The half-hourly mean observed fluxes for surface SW were scaled upward or downward to correspond with the exact cosine of the solar zenith angle (SZA) of the instantaneous CERES satellite observation. No such scaling was done for LW at the surface. The SARB algorithm uses absolutely no surface radiometric data for input or tuning. The bias for TOA flux is small because we tune to the calculations to the broadband observations from CERES. The small bias for surface LW attests to the high quality of cloud property retrievals with VIRS (Minnis et al. 2002).

What accounts for the much larger bias in surface SW insolation (SW Dn Sfc)? In a study (Charlock et al. 2001) of clear insolation with the same version of the Fu-Liou code employing surface photometer measured AOT (Holben et al. 1998), the mean bias (for 500 cloud-screened intervals of 30 minutes) was well within the errors specified for the measurements. This earlier test suggests that under cloud free conditions, insolation can be reliably computed (retrieved), provided that AOT from a ground based photometer is available. Note that in Table 1, the global MATCH provided the AOT input for all CRS Edition 2b calculations, clear or cloudy. While MATCH is arguably the best model of the space-time distribution of AOT, it surely is not as reliable as a ground-based measurement. Table 1 shows the retrieved aerosol forcing (Aer Forc) for cases identified as clear according to the satellite data only (CLEAR VIRS row); and as according to both the satellite AND the minute-by-minute time series (Long and Ackerman 2000) of surface radiometric data (CLEAR VIRS + pyranometer row).

Retrospective study (not shown) of the MATCH AOT for January-August 1998 at E-13 indicates values only 60% of those reported by the ground-based AERONET Cimel. The retrieved aerosol forcing is thus small by roughly a factor of two. If the aerosol forcing were doubled, the biases for clear-sky SW insolation would then approach zero.

Table 1. Comparison of Observations (Obs) and CERES SARB retrievals at SGP E-13 site for January-August 1998.

	Obs Mean	N	Bias Obs-SARB	RMS	Cloud forcing
ALL SKY					
LW Dn Sfc	349	455	-3	18	17
LW Up Sfc	416	430	-3	16	
SW Dn Sfc	428	260	-21	60	-128
SW Up Sfc	87	260	11	20	
LW Up TOA	247	457	0	4	-27
SW Up TOA	224	258	2	10	87
OVERCAST					
SW Dn Sfc	243	68	-27	87	
CLEAR VIRS					Aer Forc
SW Dn Sfc	512	94	-23	29	-16/0.6
					SW/LW
CLEAR VIRS + pyranometer					
SW Dn Sfc	324	17	-14	17	-12/0.5
SW direct			-5		
SW diffuse			-9		

Table 1 also shows a substantial bias (-21 Wm^{-2}) for the surface insolation retrieved under all-sky (total-sky) conditions. All sky includes the natural combination of clear and cloudy. If we ascribe the large bias in retrieved surface insolation under clear conditions (-23 Wm^{-2}) to the small magnitude of the inputs for AOT, should not we expect the all-sky bias, which includes cloudy conditions, to display a smaller bias (than -21 Wm^{-2})? If the sole consideration is the scattering by aerosols, the answer is yes. But cloudy-sky insolation is more strongly affected by the input value for surface albedo, which is yet another uncertainty.

The impact of surface albedo on surface insolation is illustrated in Figure 1. The impact of secondary surface-to-atmosphere-to-surface reflection is fairly small when both reflectors (surface and atmosphere) are weak. But if the albedo of either the surface or the atmosphere (i.e., cloud) is high, this secondary reflection can have a considerable impact on the insolation: For high sun with an optically thick cloud, an increase of 0.10 in surface albedo can push the insolation up by 30 Wm^{-2}. When a cloud is present, the relevant spatial scale of the surface albedo is equally significant for the bias in computed insolation. Figure 1 shows that if cloud base is very low (~1 km); the surface albedo within only 1 km to 2 km has the most impact on insolation at a point.

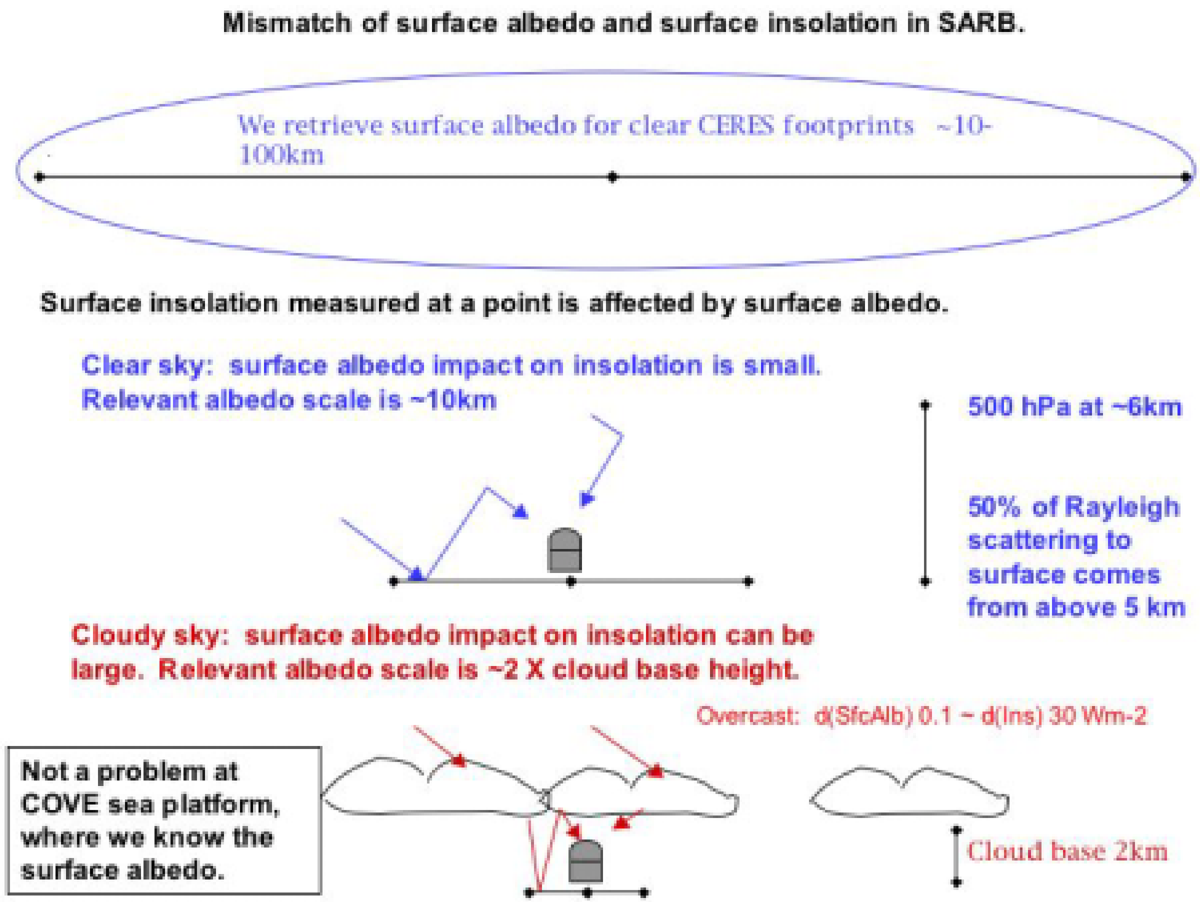

Figure 1. Spatial scale of surface albedo and its impact on downwelling SW at a point.

It should be noted that SARB CRS Edition 2b algorithm retrieves the surface albedo on the much larger ~20 km scale of the CERES footprint (Rutan and Charlock 1999). The surface albedo for a cloudy footprint is estimated from previous (or subsequent) observations, with appropriate adjustments for SZA, in the same area. A surface albedo input on the small spatial scale of the base heights of typical clouds was not available for CRS Edition 2b. Hence discrepancies between retrieved and observed insolation should indeed be expected for cloudy conditions, until (1) a higher resolution surface albedo product is available (i.e., from MODIS) or unless (2) the comparison is made over a low albedo surface such as the ocean. A companion paper (Rutan et al. 2003) uses high resolution helicopter data to test the coarse resolution CERES SARB retrievals of surface albedo (Zhou et al. 2001).

Conclusion

Tests at SGP suggest that the CERES SARB product (TRMM CRS Edition 2b) performs well for LW fluxes at the surface. Errors in surface insolation (SW down at the surface) are much larger for both clear- and all-sky conditions. The input values for AOT are too small; this explains the discrepancy for insolation in clear conditions. The insolation discrepancy in cloudy conditions may be associated with an error in the retrieval of surface albedo or the spatial representativeness of surface albedo. Tests over the ocean itself (i.e., radiometers on a stable ocean platform, rather than on an island), which has a low albedo that is known, are planned to resolve this issue.

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