CERES Aqua Edition2A CRS Data Quality Summary

Investigation:	**CERES**
Data Product:	**Clouds and Radiative Swath (CRS)**
Data Set:	**Aqua (Instruments: CERES-FM3 or CERES-FM4, MODIS)**
Data Set Version:	**Edition2A**

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES (Wielicki et al., 1996) Science Team. This document briefly summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data product, algorithms, and accuracy, and gives information about planned data improvements. This document also automates registration in order to keep users informed of new validation results, cautions, or improved data sets as they become available.

This document is a high-level summary and represents the minimum necessary information for scientific users of this data product.

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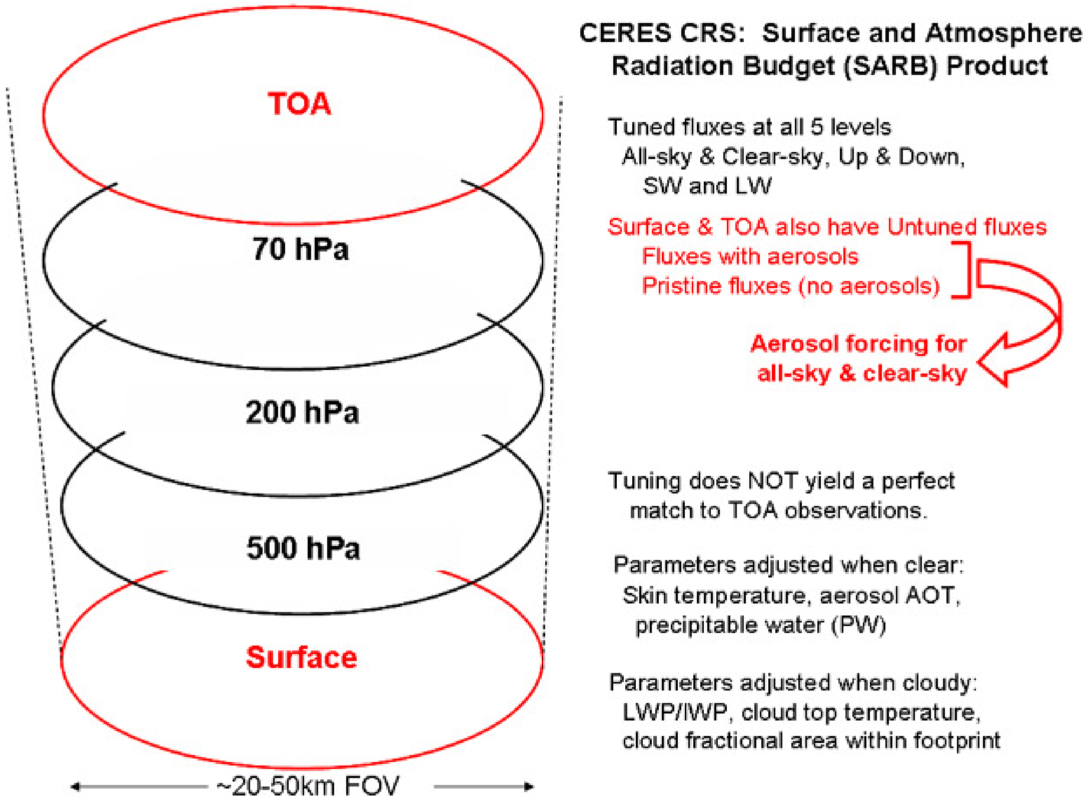

Figure 1 CRS: CERES Surface and Atmosphere Radiation Budget (SARB) product

Nature of the CRS Product

Introduction

The CRS product (Figure 1) is designed for studies which require fields of clouds, humidity and aerosol that are consistent with radiative fluxes from the surface to the Top Of the Atmosphere (TOA); for example, studies of cloud and aerosol forcing at both TOA and surface, or investigations of possible errors in retrievals of TOA fluxes, cloud properties, surface skin temperature, etc. It is quite a task to manipulate the huge files of this ungridded data set, which spans the globe with about 100 megabytes per day. Potential users are strongly encouraged to visit the CAVE web site which is a gateway to a point and click version of the radiative transfer code used here; user-friendly time series of subset (small) files at a few locations; validation at ~50 independent ground-based sites (ARM, BSRN, and SURFRAD); and an ocean albedo look up table (LUT) for GCMs. Gridded forms of CRS have the name "FSW". Some users will prefer to wait for the arrival of the gridded and time-averaged (3-hourly) "SYN" product, in which geostationary imager data, in addition to MODIS, will be used as inputs for cloud optical properties in SARB calculations. Potential users may also benefit from the CERES Archival Data web site when attempting to determine the CERES data product of interest.

CRS software is developed and managed by the CERES Surface and Atmospheric Radiation Budget (SARB) Working Group (WG); the above "CAVE" URL is an operating environment for the WG and its users. Like its parent Single Scanner Footprint (SSF), CRS corresponds to an instantaneous CERES broadband footprint. The footprint has nominal nadir resolution of 20 km for half power points but is larger at other view angles (Figure 2). The major inputs (Figure 3) to the CRS software are the instantaneous scene identification, cloud and aerosol properties from the MODIS cloud imager pixels (resolution ~1 km), and TOA radiation (from the CERES instrument) contained on the respective SSF footprint; along with 6-hourly gridded fields of temperature, humidity, wind, and ozone, and climatological aerosol data contained on the Meteorological, Ozone, and Aerosol (MOA) product. MOA includes meteorological data provided by GEOS4 and the Stratospheric Monitoring Group Ozone Blended Analysis (SMOBA, Yang et al., 2000) ozone profiles from NCEP. Aerosol information is taken from MODIS and from MATCH. The CRS product contains the SSF input data; through-the-atmosphere radiative flux profiles calculated by SARB algorithms that partially constrain to CERES TOA observations; adjustments to key input parameters (i.e., optical depth for cloudy footprints and skin temperature for clear footprints); and diagnostic parameters. CRS fluxes are produced for shortwave (SW), longwave (LW), the 8.0-12.0 µm window (WN), both upwelling and downwelling at TOA, 70 hPa, 200 hPa, 500 hPa, and the surface (Figure 3). To permit the user to infer cloud forcing and direct aerosol forcing, we include surface and TOA fluxes that have been computed for cloud-free (clear) and aerosol-free (pristine) footprints; this accounts for aerosol effects (SW and LW) to both clear and cloudy skies.

Aqua CRS Edition 2A software is very similar to that used in Terra CRS Edition 2B, which entered production earlier. Charlock et al. (2006) and Rutan et al. (2006) describe characteristics of Terra CRS Edition 2B, while Rose et al. (2006) notes the coming CERES product SYN, which will have gridded and 3-hourly SARB fields. Aqua CRS Edition 2A software differs from Terra CRS Edition 2B in a few ways. First, Aqua CRS Edition 2A has an improved treatment of surface albedo in coastal regions. Surface albedo in some coastal regions in Terra CRS Edition 2B was very coarse, rendering even the unique CERES Ocean Validation Experiment (COVE) ocean station of marginal use for validation. Aqua CRS Edition 2A results are favorable over COVE. Second, Aqua CRS Edition 2A has a more sophisticated scheme to account for the effects of cloud properties on the surface albedo of snow and ice. Third, Aqua CRS Edition 2A produces photosynthetically active radiation (PAR) in the traditional 400-700 nm band, rather than the crude approximation of 357.5-689.6 um used in Terra CRS Edition 2B; the new CERES algorithm for PAR is documented by Su et al (2006). Fourth, Aqua CRS Edition 2A has a 2-stream solver that handles the forward scattering peak for ice clouds more realistically than in Terra CRS Edition 2B. The simulated direct beam at the surface has more fidelity in Aqua CRS Edition 2A. Fifth, some of the Aqua CRS Edition 2A interpolation of aerosol inputs for radiative transfer is defective; see the section "Treatment of Aerosols" below. For more details, seek the phrase "differs from Terra CRS Edition 2B" in the remainder of this document.

Some of the essential characteristics of the SARB computed in Aqua CRS Edition 2A are similar to those in Terra CRS Edition2B. Computed SW fluxes at TOA are generally larger than those observed by the CERES broadband instrument; tuning (mostly by way of adjusting cloud optical properties away from the MODIS-based inputs on SSF) reduces these discrepancies. Computed SW surface insolation and upwelling LW surface flux from the surface usually compare well with independent ground-based measurements. Computed downwelling LW fluxes at the surface are too low during daytime because the input for surface air temperature is a bit cool. The daytime OLR computed for Terra CRS Edition 2B showed a bias with respect to CERES observations that slowly increased with time, suggesting a need to correct the instrument-based OLR record for a drift; this is not the case in Aqua CRS Edition2A.

THIS IS IMPORTANT: When Aqua CRS Edition2A (and also Terra CRS Edition2B) were processed, only an older form of CERES observations were available for broadband TOA fluxes, namely Aqua SSF Edition 2A. The CERES Science Team now recommends a set of "Rev1" corrections (see the SSF Quality Summaries) to SW observations at TOA. Rev1 corrections are time dependent and can exceed 1%. THE USER IS CHARGED TO CORRECT THE CERES TOA OBSERVATIONS AS PER REV1. Aqua CRS Edition 2A (and Terra CRS Edition2B) do not account for the Rev1 correction. The end product of Aqua CRS Edition2A (and Terra CRS Edition 2B), is a "tuned" flux, which has been constrained to more closely approach CERES observations at TOA by modifying inputs like cloud optical depth, surface albedo, etc. Tuned CRS fluxes are hardly ever equal to observed SSF fluxes. Untuned CRS fluxes can be obtained by subtracting the "adjustment" from the "tuned" flux; the tuned fluxes and the adjustments are archived. Over land and over the cryosphere, even the untuned fluxes are affected by the CERES TOA observations of SW, as they are used to estimate surface albedo. Over the ice-free ocean, CERES TOA SW observations do not affect untuned CRS calculations. In the mean over Ice-free ocean, CRS untuned SW calculations at TOA are closer to the Rev1 corrected observations, than they are to original SSF observations. See the table of Rev1 corrections. When a user orders a CRS file, an SSF file will come automatically attached; the file has SSF parameters first, then CRS parameters. The broadband SSF observations should be corrected as per the Aqua SSF Edition2A Quality Summary.

The user can refer to the application of the earlier TRMM SARB product in the following: where Charlock et al. (2002) compare time series of computed fluxes at TOA with CERES observations to illustrate how the flux profiles are related to the tropical circulation. Rutan et al. (2002) point out that the present results do not support "anomalous absorption" of SW by clouds. Rose and Charlock (2002) note further advances in the radiative transfer code which are used in this Terra product (but not in TRMM). The surface insolation in TRMM CRS has a larger bias with respect to independent ground-based measurements, than does the surface insolation in Terra CRS; this is due to both the advances in the radiative transfer code and the introduction of satellite retrievals of aerosols over land in Terra.

A full definition of each parameter will be contained in the CRS Collection Guide, which has not been written yet. The present lengthy document should make the definitions clear to a reader having the CRS Data Product Catalog in hand. Informal extensions to the CRS Data Quality Summary will be posted under "CRS Advice" at the web page http://www-cave.larc.nasa.gov/cave.

The SSF parent of this data set is CER_SSF_Aqua-FM3-MODIS_Edition2A and CER_SSF_Aqua-FM4-MODIS_Edition2A. The first few hundred parameters on a CRS file are duplicates of SSF. (See SSF Data Products Catalog (PDF).) Before using these parameters, please consult the Aqua SSF Edition2A Quality Summary. Definitions of these parameters are available in the SSF Collection Guide.

When referring to a CERES data set, please include the satellite name and/or the CERES instrument name, the data set version, and the data product. Multiple files which are identical in all aspects of the filename except for the 6 digit configuration code (see Collection Guide - when available) differ little, if any, scientifically. Users may, therefore, analyze data from the same satellite/instrument (here Aqua/CERES/MODIS), data set version (here Edition2A), and data product (here CRS) without regard to configuration code. This CRS data set may be referred to as "CERES Aqua Edition2A CRS".

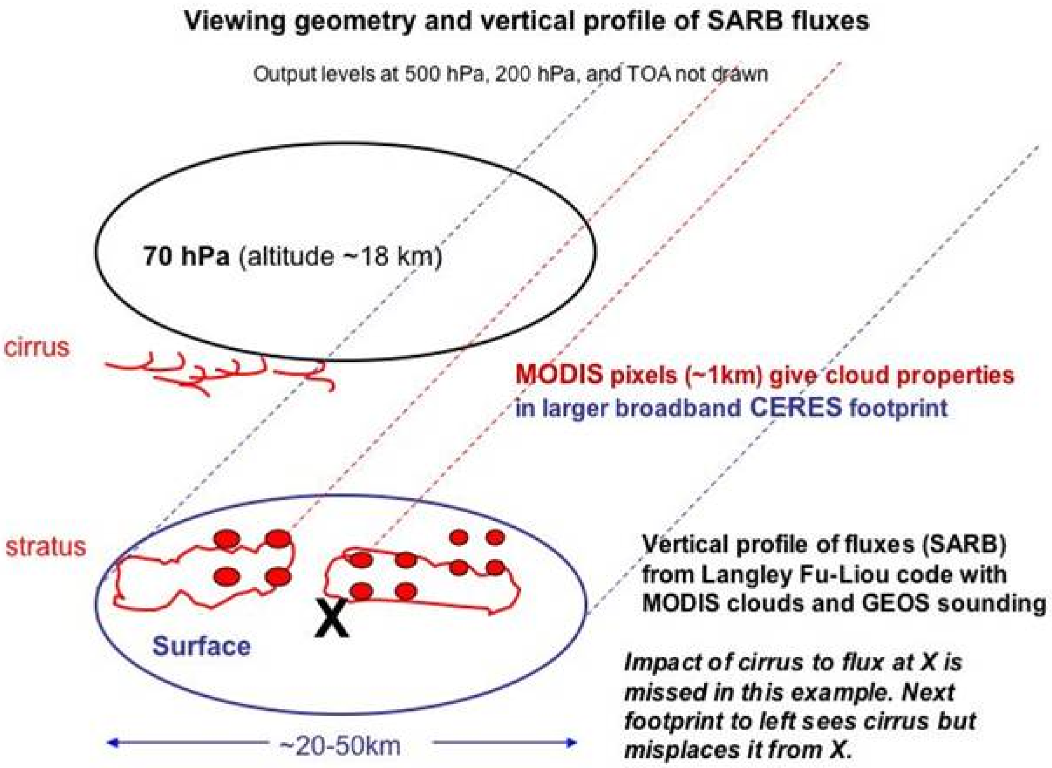

Figure 2: Typical viewing geometry showing small MODIS pixels within large CERES footprints

Constrainment (tuning)

In short, the SARB flux profile in the CRS product is the output of a highly modified Fu and Liou (1993) radiative transfer code. The code is run at least twice for each broadband CERES footprint, in order to adjust inputs that determine the vertical profile of radiative fluxes. The constrainment (or tuning) algorithm does NOT yield a perfect match to CERES broadband observations at TOA. Constrainment (Rose et al. 1997; Charlock et al. 1997) is an approach to minimize the normalized, least squares differences between (1) computed TOA parameters and adjusted values for key inputs and (2) observed TOA parameters and initial values for key inputs. The algorithm assigns an a priori numerical "sigma" (uncertainty) to each TOA parameter and key input parameter. The "sigmas" for TOA parameters (first group in Table 1) are the anticipated rms differences between observations based on the core CERES instrument and the outputs of radiative transfer calculations. The sigmas for key input parameters (the second and third groups labeled "cloud" and "other" in Table 1) are the anticipated rms differences between the initial (untuned) and final values of those key input parameters (tuned).

The inputs for radiative transfer calculations are depicted in Figure 3. The initial values of cloud parameters are taken from the SSF; they are narrowband imager-based retrievals of cloud properties. Initial values of other key input parameters such as PW and UTH are based on GEOS4. Aerosol information is taken from MODIS when available for the instantaneous CERES footprints. If the MODIS instantaneous AOT is not available for the footprint, we interpolate AOT from a file of the MODIS Daily Gridded Aerosol for the calendar month of processing. When cloudiness in the footprint exceeds 50%, or when there is no MODIS AOT, we use AOT from the NCAR Model for Atmospheric Transport and Chemistry (MATCH).

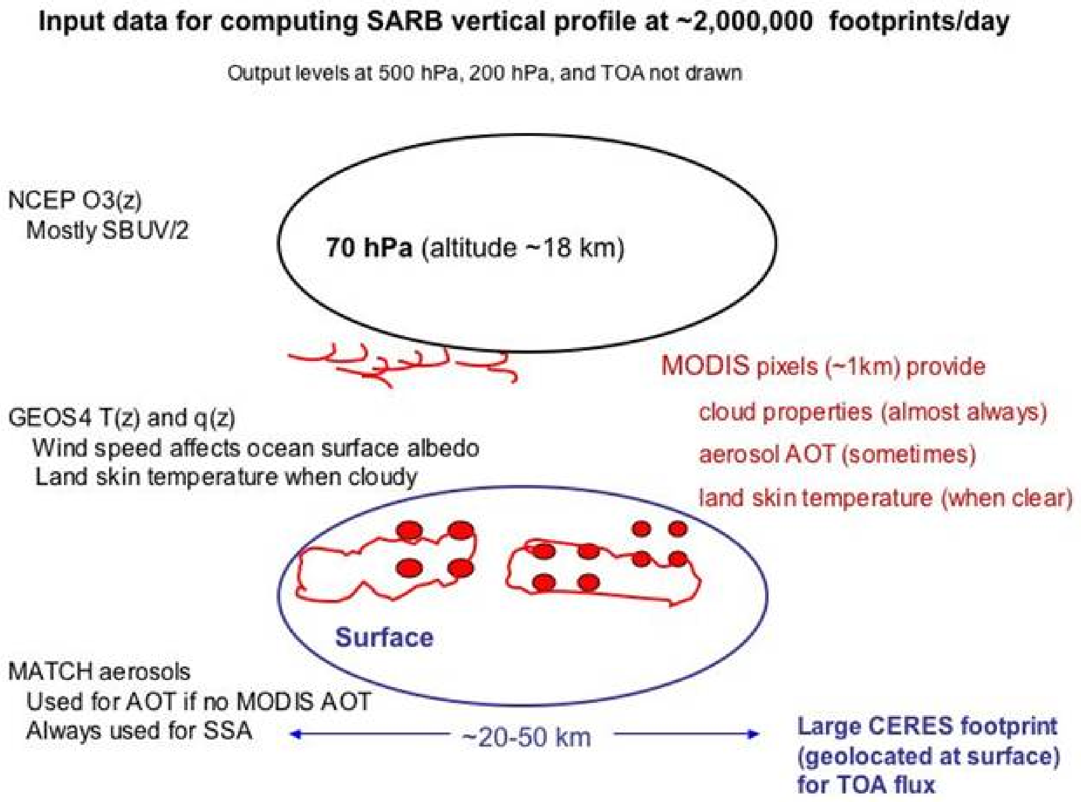

Figure 3. Inputs for determining the Surface and Atmosphere Radiation Budget (SARB)

If the reported fraction of cloudiness on the SSF file exceeds 0.05, the values of the third group of "other" (Table 1) parameters are frozen. The cloud optical depth, cloud fractional area, and cloud top height (second group in Table 1) are adjusted instead. Cloud optical depth is modified by adjusting liquid water path (LWP) or ice water path (IWP), rather than droplet or crystal size.

If the reported fraction of cloudiness on the SSF file is less than 0.05, the cloud parameters (second group in Table 1) are frozen, and the constrainment algorithm adjusts parameters from the third ("other") group in Table 1. For such clear and almost clear footprints over the ocean (note "ocean" column at the bottom of Table 1), the constrainment adjusts the surface skin temperature, lower tropospheric humidity (LTH), upper tropospheric humidity (UTH), and aerosol optical thickness (AOT). For such clear and almost clear footprints over land, the surface albedo is also adjusted; and the sigma (a priori uncertainty) for skin temperature is increased, causing a larger adjustment in skin temperature over land than over ocean. The SARB algorithm does not adjust temperature above the surface.

Every CRS footprint has TOA parameters (first box in Table 1) with observed values taken from SSF, tuned values for the fluxes, and adjustments to the fluxes from the constrainment process. Every CRS footprint has input values for cloudy parameters (second box in Table 1) which are taken from SSF and "other" parameters (third box in Table 1); and it has slots for the adjustments to each of these parameters by the constrainment process. This is summarized in Figure 1. For a discussion of observed TOA parameters (first box in Table 1) or unadjusted cloudy or clear parameters (second and third boxes in Table 1), note the SSF Quality Summary. A single SSF FOV can consist of a fraction which is free of clouds, a second fraction with cloud 1, and a third fraction with cloud 2; clouds 1 and 2 would have different distributions of optical depth, different altitudes of top and base and particle size; clouds 1 and 2 could have different phases. A single SSF FOV may also consist of clear sky only; clear sky and cloud 1 only; or cloud 1 only. At present, clouds 1 and 2 do not overlap.

What is the implication of an assigned sigma of 1.0% for broadband LW flux versus 2.0% for window WN flux versus 5.0% for filtered window radiance (top group in Table 1)? Among those 3 parameters, broadband LW flux (OLR) has the smallest sigma. Thus OLR is the tightest constraint among those 3 parameters. Adjustable parameters like cloud optical depth and surface skin temperature are pulled more toward new values causing a better match between computed and observed OLR (sigma 1%), than they are pulled to new values causing a better match between computed and observed filtered window radiance (sigma 5%). The large sigmas of 5% for the broadband LW and filtered window radiances in Table 1 in fact produce hardly any adjustments in direct response to the radiances. The smallest sigmas (1%) are assigned to broadband reflected SW and to broadband LW fluxes, as they are the primary earth radiation budget (ERB) observables. If we had less confidence in the inversion from radiance ($Wm^{-2}sr^{-1}$) to flux (Wm^{-2}) on the CERES SSF record, the sigmas of broadband LW flux and broadband LW radiance could hypothetically be reversed. There is no sigma for reflected SW radiance because our fast radiative transfer code does not simulate SW radiance.

Table 1: The a priori uncertainty ("sigma") for each adjustable parameter in the constrainment (tuning) algorithm that produces the Surface and Atmosphere Radiation Budget (SARB) for CERES footprints

Observed by CERES at TOA (SSF record)			
TOA parameters	**Sigma (%)**	**Minimum sigma (MKS)**	**Parameter**
	1.0 %	2.0 Wm^{-2}	reflected SW flux
	1.0 %	2.0 Wm^{-2}	broadband LW flux
	2.0 %	1.0 Wm^{-2}	window WN flux
	5.0 %	0.3 Wm^{-2} sr^{-1}	broadband LW radiance
	5.0 %	0.3 Wm^{-2} sr^{-1}	filtered window radiance
From MODIS imager (SSF record)			
Cloud parameters	**Sigma**		**Adjustable parameter**
	0.15		d ln(τ) τ = cloud optical depth
	2.0		cloud top temperature
	0.05		total cloud fraction in footprint
	0.025		fraction swap of 2 types in footprint (i.e., increase Cu and decrease Ci)
From various sources			
Other parameters	**Ocean**	**Land**	**Adjustable parameter**
	1.0 K	4.0 K	surface skin temperature
	0.15	0.10	d ln(PW) PW: surface to 500 hPa
	0.15	0.10	d ln(UTH) upper tropos. humidity
	0.002	0.015	surface albedo
	0.50	0.10	d ln(τ) τ = aerosol optical depth

Definitions of SW, LW, and Window

CERES geophysical products define SW (shortwave or solar) and LW (longwave or thermal infrared) in terms of physical origin, rather than wavelength. We refer to the solar energy which enters and exits (overwhelmingly by reflection) the earth-atmosphere system as SW. LW is regarded as the thermal energy which is emitted by the earth-atmosphere system. There is no wavelength of demarcation, for which all radiation at shorter (longer) wavelengths is called SW (LW). Thus defined, roughly 1% of the incoming SW at TOA is at wavelengths longer than 4 µm. A small amount of radiation from the sun enters the troposphere at 10 µm. This too is regarded as SW, and we strive to account for it in successive SW products. Less than 1 Wm^{-2} of OLR is at wavelengths below 4 µm. If the radiation was originally emitted by a thermal process in the earth-atmosphere system, we regard it as LW, even if it is subsequently scattered. When a small amount of thermal radiation is emitted from the surface of the Sahara at 6 µm, and a portion of that is scattered upward to space through a cirrus cloud, said portion is regarded as LW. The 8.0-12.0 µm window (WN) products are a repository of the thermal radiation in the window. We strive to eliminate any signal of solar contamination in an 8.0-12.0 µm window or broadband LW product.

The official CERES window (WN) spans 8.0 µm to 12.0 µm (1250 cm^{-1} to 833.333 cm^{-1}). The TOA observed SSF window products use this interval, as do the TOA emulated window product. CRS users should be aware that the vertical profiles of window flux use a DIFFERENT spectral interval, 8.0 µm to 12.5 µm (1250 cm^{-1} to 800 cm^{-1}), as explained in the next section.

Radiative Transfer Code

CRS uses a fast, plane parallel correlated-k radiative transfer code (Fu and Liou, 1993, Fu et al., 1997, 1999) which has been highly modified. It is referred to as the "Langley Fu-Liou code". An economical 2 stream calculation is used for SW. The LW calculation employs a 2/4 stream version, wherein the source function is evaluated with the quick 2-stream approach, while radiances are effectively computed at 4 streams. Constituents for the thermal infrared include H_2O, CO_2, O_3, CH_4 and N_2O. A special treatment of the CERES 8.0-12.0 µm window includes CFCs (Kratz and Rose, 1999) and uses the Clough CKD 2.4 version of the H_2O continuum (the original Fu-Liou employed the Roberts continuum). In collaboration with Dr. Qiang Fu, the Fu-Liou code was modified to include 10 separate bands between 0.2-0.7 µm to better account for the interaction of Rayleigh scattering, aerosols, and absorption by O_3 and a minor band of H_2O. In cooperation with Dr. Seiji Kato, we have included the HITRAN2000 data base for the determination of correlated k's in the SW (Kato et al., 1999). We make a first order accounting for the inhomogeneity of cloud optical thickness (using the gamma weighted two stream approximation of Kato et al., 2005) in the SW; the gamma distribution is parameterized with the logarithmic mean and standard deviation of the cloud optical depth from SSF. The original code included SW from 0.2 to 4 µm. In addition, we cover the SW at wavelengths larger than 4 µm by simply stuffing the solar insolation beyond 4 µm into a near IR band with strong absorption by H_2O. Downwelling solar photons at wavelengths larger than 4 µm are then mostly absorbed by the model before reaching the middle troposphere. Scattering by cloud particles, aerosols, and a non-black surface is parameterized in LW, as well as SW. For example, the desert surface has reduced thermal emission as it is non-black. As its emissivity is less than unity, the reduction in upward LW emitted by the surface is partly compensated by reflection of the downwelling LW to the surface. The code has been extended with a new band to cover thermal emission from 2200-2850 cm^{-1}.

The Fu-Liou code covers the window with 3 bands from 8.0 µm to 12.5 µm (1250 cm^{-1} to 800 cm^{-1}); vertical profiles of window flux use this interval. A different window interval, 8.0 µm to 12.0 µm (1250 cm^{-1} to 833.333 cm^{-1}), is used for TOA observations on SSF and for the formal TOA emulations. The 8.0 µm to 12.0 µm TOA window parameters on SSF are emulated (modeled) as follows with the Langley Fu-Liou code. First, the code produces window radiance and flux for 8.0 µm to 12.5 µm at TOA; the modeled radiance and flux constitute a theoretical Angular Distribution Model (ADM relating radiance to flux) for the footprint. Second, a straightforward parameterization based on MODTRAN4 is then applied; the inputs are view zenith angle and radiance. The parameterization maps the 8.0 µm to 12.5 µm Fu-Liou radiance to an "unfiltered" (geophysical) 8.0 µm to 12.0 µm emulated radiance and also to a "filtered" 8.0 to 12.0 µm emulated radiance. Recall that the spacecraft itself observes a filtered radiance, a signal which includes the effect of the spectral response of the instrument. It is the task of SSF to account for the spectral response and produce an unfiltered radiance. In the second step here, the spectral response (filter function) of the instrument is modeled, producing an emulated filtered window radiance. Third, the theoretical ADM (based on 8.0 µm to 12.5 µm) converts the unfiltered 8.0 µm to 12.0 µm emulated radiance into an emulated window flux. The unfiltered, emulated window radiance is not archived.

While the original Fu-Liou code offered empirical droplet size spectra based on early field campaign data, we now use theoretical, gamma distributions for the radii of cloud water droplets (Hu and Stamnes, 1993), consistent with the Minnis et al. (2002) retrievals on CERES SSF input stream. The code treats all ice cloud crystals as randomly oriented hexagons characterized by a generalized effective diameter D_{ge}. The SSF cloud retrievals also assume randomly oriented hexagons but express them as effective diameter D_e. Caution is advised when interpreting CRS results for ice clouds, as both the input cloud retrievals (SSF) and the radiative transfer calculations do not account for the enormous variation of crystal shapes found in nature.

The typical CRS calculation uses 30 atmospheric layers with fixed thickness layers of 10 hPa and 20 hPa nearest the surface. The remainder are placed on a sliding scale following the input value for surface pressure. Additional layers, at levels "custom made" for each footprint, are inserted in the radiative transfer calculation for cloud top and cloud bottom. Edition2B CRS places the cloud top as per the pressure top retrieved by SSF. The SSF estimate for cloud geometrical thickness is used to specify cloud bottom.

Reflection of SW by Surface

Optical properties of the ocean are assumed rather an retrieved. In contrast, broadband albedos of the land and cryosphere are retrieved with CERES data; but the broadband albedo retrieval employs a fixed spectral shape for each type of surface.

Ocean spectral albedo is obtained using a look up table (LUT) based on discrete ordinate calculations with a sophisticated coupled ocean atmosphere radiative transfer code (Jin et al., 2002, Jin and Stamnes, 1994). Inputs to the look-up table for ocean spectral albedo include cosine of the solar zenith angle (cosSZA), wind speed (from GMAO), chlorophyll concentration (which has a minor effect on broadband flux), and SW optical depth of clouds and aerosols (from SSF) for the respective spectral interval. There is an empirical correction for surface foam based on wind speed.

The spectral dependence of surface reflectivity for land surface albedos are specified according to the CERES Surface Properties maps (from CERES/SARB Surface Properties web site) following Rutan and Charlock (1997 and 1999). CRS uses the Wilber et al. (1999) surface LW spectral emissivity maps (which are available at the same URL). Both SW and LW surface maps are keyed to International Geophysical Biospherical Project (IGBP) land types. For the category of Permanent Snow and Ice, the spectral shape of reflectance is taken from a model by Jin et al. (1994) assuming 1000 µm snow grains; a grain size of 50 µm is assumed for the spectral shape of fresh snow. The spectral shape of sea ice also employs Jin et al. (1994).

For clear footprints over land during daytime, the broadband surface albedo is explicitly retrieved using TOA observations and iterations of the Langley Fu-Liou code with the constrainment algorithm; the broadband albedo is then simply a ratio of upwelling to downwelling SW at the surface. When a CRS footprint contains clouds, the broadband surface albedo is assumed using the Surface Albedo History (SAH) procedure. The SAH algorithm is run at the start of each month of CRS processing. SAH identifies the clear SSF footprints during the month with the most favorable geometry for the retrieval of surface albedo: those with large values of cosSZA. SAH uses a quick table look-up to the Langley Fu-Liou code that relates TOA albedo, surface albedo, cosSZA, precipitable water (PW), and aerosol optical thickness (AOT). Using the footprint AOT (from MODIS or the MATCH aerosol assimilation), the look-up retrieves a first guess surface albedo for the month. This first guess surface albedo corresponds to a clear SSF/CRS footprint. The monthly value for the first guess surface albedo is then written to a SAH file for each of the 10 by 10 minute gridded tiles, whose center points are contained in the clear footprint. Each 10 by 10 minute gridded tile of land is thus given an initial broadband surface albedo for the month. The SAH albedo is stored internally as a reference value A_o using the Dickinson (1982) relationship

$$A(\cos SZA) = A_o(1 + d)/(1 + 2d \cos SZA)$$

where d is specified for each IGBP type and A_o is the albedo at cosSZA of 0.5. The look-up, first guess values of A_o for the various 10 by 10 minute tiles are then available to construct a fixed broadband surface albedo as an input for radiative transfer calculations with any cloudy footprint, for which we assume A(cosSZA=0.5). The quality of the surface albedo retrieval depends heavily on the value of the observed TOA flux reported on SSF, and on the realism of simulation of AOT and the CRS assignment of the corresponding single scattering albedo (see next section). The most reliable CRS values of surface albedo are expected for clear footprints under high sun, in regions and seasons with low AOT.

Treatment of Aerosols

Aerosol AOT is taken from MODIS when available. The aerosol height profile and other characteristics are based on the NCAR Model for Atmospheric Transport and Chemistry (MATCH, an assimilation that here also employs MODIS, see Fillmore et al., 2004 and Collins et al., 2001).

Each footprint accounts for the effect of aerosols on SW fluxes, LW fluxes and 8.0-12.0 µm window fluxes at all levels, and on broadband LW and filtered window radiance at TOA. Aerosol information is taken from MODIS (MODIS Atmospheres Aerosol product described by Kaufman et al., 1997) when available for the instantaneous CERES footprints. Over the ocean, MODIS aerosol is used for 7 wavelengths; the AOT is interpolated to the remainder of the spectrum using the selected aerosol type, as specified below. Over land, MODIS aerosol provides AOT at 3 wavelengths, and the MODIS aerosol Angstrom exponent is used to guide the extension over the spectrum. If MODIS aerosol instantaneous AOT is not available for the footprint, we temporally interpolate from a file of the MODIS Daily Gridded Aerosol as noted earlier.

Aqua CRS Edition 2A differs from Terra CRS Edition 2B in having a flawed interpolation scheme for MODIS Daily Gridded Aerosol. The integer default value used in Aqua processing has contaminated the interpolation for a very small number of footprints, for which it produces erroneously large values for the input AOT. The defect is a result of an algorithm applied for CERES CRS processing and is not due to a faulty Daily Gridded Aerosol product from the MODIS Atmosphere team. Footprints using the instantaneous MOD04 aerosol retrieval are not affected. The defect is not readily apparent every day. In the rows of Table 2 for Interpolated MODIS Daily Average AOT, note the unrealistic biases for the computed SW at TOA for clear-sky ocean conditions 13 July 2002 and 2 March 2003 (but less so on 1 September 2002). We will return to this issue in the next section.

Table 2: Clear Ocean During Day: Bias of Calculated SW and AOT Source

Aqua CRS Edition 2A (here all FM4)
Bias = (Untuned SW at TOA) - (Observed SW at TOA)
Conclusion: Aqua CRS interpolation for MODIS Daily Average AOT has defects.

Source of AOT for Calculation		**Bias (Wm^{-2})**	**RMS (Wm^{-2})**	**AOT vis**	**# FOVs (N)**
13 July 2002	MOD04 Instantaneous	2.7	5.4	0.08	13872
	Interpolated MODIS Daily Average	17.2	28.5	0.32	9549
1 September 2002	MOD04 Instantaneous	4.9	6.8	0.09	12665
	Interpolated MODIS Daily Average	3.0	9.5	0.14	12116
2 March 2003	MOD04 Instantaneous	3.9	6.0	0.10	11421
	Interpolated MODIS Daily Average	23.8	35.1	0.44	3275

When footprint cloudiness exceeds 50%, or when there is no MODIS AOT, we use AOT from MATCH. MODIS aerosol does not span the entire globe; it does not include the cryosphere and most deserts, for example. When AOT is taken from MATCH, we assume it for one wavelength only, 0.63µm. MATCH provides aerosols on a daily basis over the globe for all sky conditions. Sources of aerosol in MATCH include formation from industrial emissions (as a climatology). More timely MATCH AOT inputs include MODIS aerosol-based retrievals over clear regions; and an algorithm for wind-blown dust. MATCH itself accepts the NCEP analysis as an meteorological input. MATCH advects aerosols and removes aerosols with wet (cloudy) and dry (deposition) processes.

While AOT is based on either MODIS aerosol (a satellite retrieval) or MATCH (a model), aerosol type is always taken from MATCH. Aerosol type here guides the selection of the asymmetry factor (g) and the single scattering albedo (SSA). CRS distributes the MATCH aerosols into 7 types: small desert dust, large desert dust, black carbon (soot), soluble organic carbon, insoluble organic carbon, sulfate, and sea salt. In the earlier Terra CRS Edition 2A, the spectral single scattering albedos and asymmetry factors are assumed from the Tegen and Lacis (1996) and OPACS-GADS (Hess et al., 1998; d'Almeida et al., 1991) models. The Terra Edition 2B uses a revised treatment of desert dust, courtesy of Dr. Andrew Lacis at NASA GISS (personal communication), which has reduced absorption in SW (Charlock et al., 2005). The earlier Terra CRS Edition 2A placed each of the 7 aerosol types in the vertical column using their respective global mean scale heights; the Terra Edition 2B uses explicit height profiles from MATCH which are typically different for each aerosol type, each day, and each location. The height profile effects the LW forcing, which can be significant regionally for larger aerosol particles like dust and sea salt, at both surface and TOA. The vertical placement of aerosols relative to clouds can have a strong effect on the absorption of SW by dust, black carbon, and insoluble organic carbon. The 7 aerosol types are treated as external mixtures, as are aerosols and clouds.

Recent studies with the fairly reliable inversions of ground-based AERONET data (i.e., Dubovik et al., 2002) suggest that absorption of SW by desert dust has a strong regional dependence which cannot be explained by simple differences in size distribution alone. CRS does not account for such regional dependence, nor does it account for the effect of internal mixing of constituents like sulfate and black carbon. Such internal mixtures can increase absorption by a factor of two or more (Fuller et al., 1999).

Comparison of CRS with Observations at TOA and Surface

Recall (previous section) the defective interpolation in a portion of the CRS data stream which employs MODIS Daily Average AOT. This is one cause for the larger bias, for clear-sky conditions over ocean, in computed reflected SW flux at TOA in Aqua CRS Edition 2A (solid red lines in Figure 4), as opposed to Terra CRS Edition 2B (solid blue line in Figure 4). The dashed lines in Figure 4 compare the untuned CRS calculations with observations corrected as per Rev1 (see SSF Quality Summary).

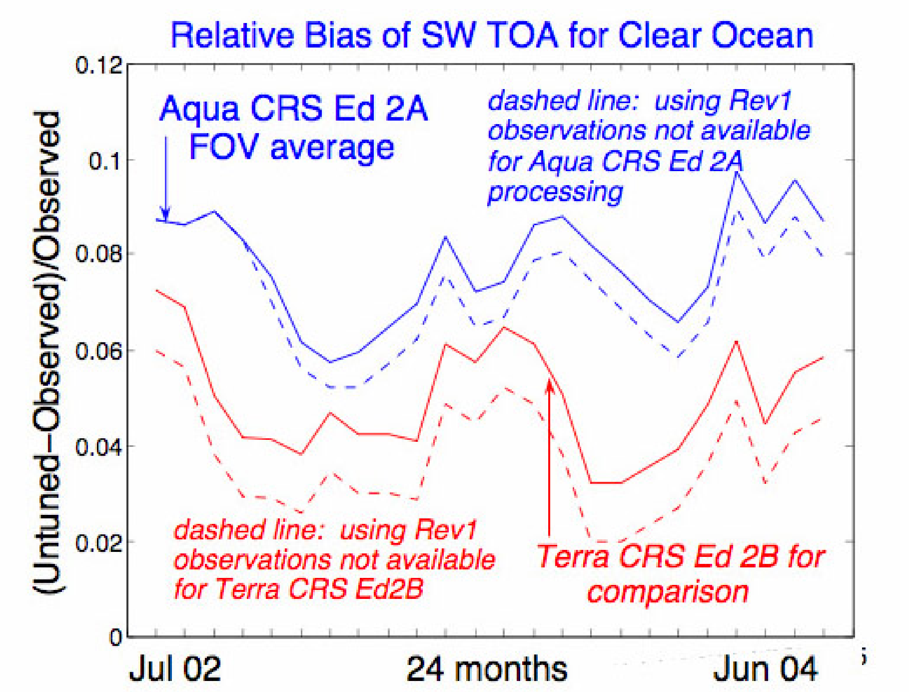

Figure 4. Relative Bias of SW TOA for Clear Ocean

As noted earlier, Rev1 corrections to SSF observations were not available as CRS was actually produced. Had Rev1 corrections been available, they would have influenced CRS calculations over land and over the cryosphere, where SSF observations of SW reflected at TOA for clear footprints are used to infer the surface albedo for CRS. Untuned CRS LW fluxes over the whole globe, and also untuned CRS SW calculations over the ice-free oceans, are independent of the observed TOA fluxes produced by the CERES instrument and recorded on SSF. In Figure 5, we compare Aqua CRS Edition 2A untuned calculations for reflected SW at TOA with CERES observations over the ocean for all-sky conditions (Figure 4 covers clear-sky ocean). The bias of untuned SW at TOA is larger for Aqua CRS Edition 2A than for Terra CRS Edition 2B. Only a portion of the excess bias of Aqua CRS Edition 2A (relative to Terra CRS Edition 2B) can be ascribed to the faulty interpolation of MODIS Daily Average AOT in Aqua.

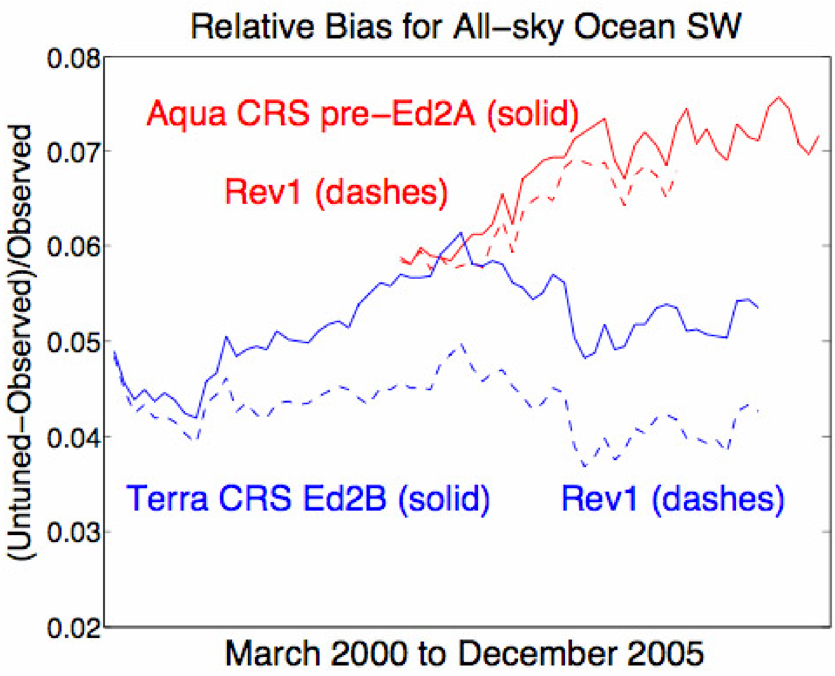

Figure 5. Relative Bias for All-sky Ocean SW

CRS is routinely compared with independent ground-based measurements at scores of CERES ARM Validation Experiment (CAVE) sites. Web search for "CERES CAVE" and then seek the CAVE Home Page for a resource that enables on line plotting at these sites, downloading of easy-to-use subset time series of CRS and independent measurements, "point and click" radiative transfer calculations, etc. Tables 3 (all sky) and 4 (clear sky) summarize the surface and TOA validation for calendar year 2003. We stress that the surface observations are totally independent of CRS calculations. Earlier, we ascribed the large CRS bias for LW down at surface (-11.2 Wm^{-2} in Table 4 for clear-sky conditions) to a "cool" input for surface air temperature. Over the gross mean of these ground sites for 2003, the clear-sky SW insolation bias of 1.2 W^{-2} is quite good. As over the ocean (Figure 5), the CRS all-sky calculations over the ground sites (most are over land) exceed CERES observations; the relative error for all-sky insolation is less than that reflected TOA flux. There is a huge error (-23.4 Wm^{-2} out of 107.3 Wm^{-2} observed for all-sky) in upwelling SW. We assume that surface observations of upwelling SW, which are typically made from towers a mere 10 m above the surface of fenced yards, are not spatially representative of the large CERES footprints.

Table 3: Untuned Aqua CRS Ed2A for 2003 at CAVE Validation Sites (CVS)

All-sky flux	**Observed (Wm^{-2})**	**Sample (N)**	**Bias CRS-Observed**	**RMS**
LW Down Surface	274.6	21288	-7.3	24.7
LW Up Surface	310.7	10911	-4.9	23.8
SW Down Surface	454.1	12385	6.8	105.9
SW Up Surface	107.3	6195	-23.4	50.2
LW Up TOA	219.6	25582	0.4	8.8
SW Up TOA	259.7	12220	7.1	25.0

Table 4: Untuned Aqua CRS Ed2A for 2003 at CAVE Validation Sites (CVS)

Clear-sky flux	**Observed (Wm^{-2})**	**Sample (N)**	**Bias CRS-Observed**	**RMS**
LW Down Surface	239.3	3179	-11.2	19.5
LW Up Surface	284.0	2147	-0.3	14.8
SW Down Surface	645.6	1406	1.2	33.9
SW Up Surface	135.5	679	-25.6	36.9
LW Up TOA	246.0	4029	0.0	5.2
SW Up TOA	201.7	1402	-0.4	6.0

Validation of upwelling SW at the surface is quite good for both tuned (Table 5) and untuned (Table 6) Aqua CRS Edition 2A at the unique CERES Ocean Validation Experiment (COVE) sea platform, which is located 25 km due east of Virginia Beach. But this is a coastal region, and the large biases for LW down and LW up at the surface suggest that inputs for surface air temperature and (surprisingly also for) skin temperature are problematic. The tuning (Table 6) of satellite-based cloud optical properties, which employs no surface measurements, reduces the all-sky SW insolation bias to only 2.7 Wm^{-2} (~0.5%); but the tuned SW reflection to TOA then still exceeds CERES by 5.7 Wm^{-2} (~2%).

Table 5: Untuned Aqua CRS Ed2A for 2003 at COVE Ocean Site

All-sky flux	Observed (Wm^{-2})	Sample (N)	Bias CRS-Observed	RMS
LW Down Surface	334.0	660	9.3	18.8
LW Up Surface	389.0	581	20.1	25.2
SW Down Surface	537.9	300	-13.9	80.8
SW Up Surface	29.9	260	1.7	18.9
LW Up TOA	232.7	676	3.8	9.3
SW Up TOA	253.0	321	20.2	29.6

Table 6: Tuned (Constrained) Aqua CRS Ed2A for 2003 at COVE Ocean Site

All-sky flux	Observed (Wm^{-2})	Sample (N)	Bias CRS-Observed	RMS
LW Down Surface	334.7	660	9.3	18.7
LW Up Surface	389.0	581	18.1	23.6
SW Down Surface	537.9	300	2.7	85.7
SW Up Surface	29.9	260	2.6	19.0
LW Up TOA	232.7	676	2.6	5.2
SW Up TOA	253.0	321	5.7	11.0

User Applied Revisions for Current Edition

The purpose of User Applied Revisions is to provide the scientific community early access to algorithm improvements which will be included in the future Editions of the CERES data products. The intent is to provide users simple algorithms along with a description of how and why they should be applied in order to capture the most significant improvements prior to their introduction in the production processing environment. ***It is left to the user to apply a revision to data ordered from the Atmospheric Science Data Center.*** Note: Users should never apply more than one revision. Revisions are independent.

CRS Edition2A-Rev1

The end product of Aqua CRS Edition2A, is a "tuned" flux, which has been constrained to more closely approach CERES observations at TOA by modifying inputs like cloud optical depth, surface albedo, etc. Tuned CRS fluxes are hardly ever equal to observed SSF fluxes. Untuned CRS fluxes can be obtained by subtracting the "adjustment" from the "tuned" flux; the tuned fluxes and the adjustments are archived. Over land and over the cryosphere, even the untuned fluxes are affected by the CERES TOA observations of SW, as they are used to estimate surface albedo. Over the ice-free ocean, CERES TOA SW observations do not affect untuned CRS calculations. In the mean over Ice-free ocean, CRS untuned SW calculations at TOA are closer to the Rev1 corrected observations, than they are to original SSF observations.

The CERES Science Team has approved a table of scaling factors known as Rev1. When a user orders a CRS file, an SSF file will come automatically attached; the file has SSF parameters first, then CRS parameters. The broadband SSF observations should be corrected as per the Aqua SSF Edition2A Quality Summary.

This revision is necessary to account for spectral darkening of the transmissive optics on the CERES SW channels. By March 2005, this darkening has reduced the average global all-sky SW flux measurements by 0.9 and 0.7 percent for Aqua FM3 and FM4 data respectively. A complete description of the physics of this darkening appears in the CERES BDS Quality Summaries under the Expected Reprocessing section. After application of this revision to the Edition2A CRS data set, users should refer to the data as Aqua Edition2A-Rev1 CRS.

Cautions and Useful Hints

Informal additions to this document will be posted at the CAVE web site under "CRS Advice". This is the first release of a Aqua CRS, and documentation is sparse. The Quality Summary of Terra CRS Edition2B is more extensive and may be a helpful guide at this stage.

- To reduce the effect of electronic crosstalk signals in Window channel measurements induced by high Shortwave (bright) scenes, a bridge balance memory patch was developed and uploaded on September 30, 2004 and unloaded on October 12, 2004. This patch was intended to modify the Window bridge balance set to point to midrange (2048). This patch, however, inadvertently set the bridge balance set points to midrange (2048) for all 3 channels. This reduced the dynamic range for the Total and Shortwave channels leading to saturated radiometric measurements. Saturations typically occurred for the brightest earth-viewing scenes, resulting in data dropout at high radiance values. This will affect users who produce their own monthly means from the instantaneous values contained on this product and users studying SW and LW fluxes for deep convective clouds.

- One useful hint concerning Aqua CRS Beta1 (and Terra CRS Editions 2A and 2B, as well): The computed SARB reflects too much SW flux at TOA, when compared with CERES broadband observations for overcast conditions. Tuning reduces the SW bias at TOA but apparently transfers it to the surface. This SW TOA problem was not so evident in the TRMM CRS Edition2C, which used the VIRS imager (rather than MODIS on Aqua and Terra) for the cloud property retrieval. CAVE shows that the biases in surface SW insolation in Terra Editions 2A and 2B are less than those in TRMM Edition2C. Compared with TRMM CRS, Aqua and Terra CRS benefit from both (a) a more up to date parameterization of gaseous absorption of SW and (b) explicit satellite-based retrievals of AOT over land.

Accuracy and Validation

Accuracy and validation discussions are found in the following sections of Nature of the CRS Product.

- Comparison of CRS with Observations at TOA and Surface

References

- List of CERES CRS References

Expected Reprocessing

Aqua CRS Edition2A will be reprocessed to correct the interpolation bug noted in the section Treatment of Aerosols. The subsequent version will have the name Aqua CRS Edition2B.

In the longer term, yet more advanced versions of CRS are expected. A future run will use a "frozen" NWP analysis. There will be advances in the TOA fluxes. SSF will use new techniques to identify multilayer clouds. For an indefinite time, however, we anticipate continuing, significant uncertainties in CRS products for

- surface SW and atmospheric absorption of SW because of mixed phase clouds (land and sea), aerosol single scattering albedo (land and sea) and AOT (land);
- LW fluxes at the surface and at 500 hPa because of multiple layer clouds (land and sea).

Referencing Data in Journal Articles

The CERES Team has gone to considerable trouble to remove major errors and to verify the quality and accuracy of this data. Please provide a reference to the following paper when you publish scientific results with the CERES Aqua Edition2A CRS data:

> Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee III, G. L. Smith, and J. E. Cooper, 1996: Clouds and the Earth's Radiant Energy System (CERES): An Earth Observing System Experiment, Bull. Amer. Meteor. Soc., 77, 853-868.

When Langley ASDC data are used in a publication, we request the following acknowledgment be included: "These data were obtained from the NASA Langley Research Center EOSDIS Distributed Active Archive Center."

The Langley ASDC requests two reprints of any published papers or reports which cite the use of data that we have distributed. This will help us determine the use of data that we distribute, which is helpful in optimizing product development. It also helps us to keep our product related references current.

Feedback

For questions or comments on the CERES Quality Summary, contact the User and Data Services staff at the Atmospheric Science Data Center.

Informal contact to the SARB WG is accessible by clicking "The Group" at the CAVE web site.

Document Creation Date: June 21, 2005
Modification History: Dec 2008
Most Recent Modification: December 11, 2008

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