CERES Terra Edition2.5A Energy Balanced and Filled (EBAF) Data Quality Summary

Investigation: CERES

Data Product: CERES EBAF

Data Set: Terra (Instruments: CERES-FM1 or CERES-FM2)

Data Set Version: (Terra) Edition2.5A

Subsetting Tool Availability: http://ceres.larc.nasa.gov/order_data.php

Introduction

This document provides a high-level quality assessment of the CERES Energy Balanced and Filled (EBAF) data product. As such, it represents the minimum information needed by scientists for appropriate and successful use of the data product. For a more thorough description of the methodology used to produce EBAF, please see Loeb et al. (2009).

Description

Despite recent improvements in satellite instrument calibration and the algorithms used to determine reflected solar (SW) and emitted thermal (LW) top-of-atmosphere (TOA) radiative fluxes, a sizeable imbalance persists in the average global net radiation at the TOA from satellite observations. The 5-year global mean CERES net flux from the standard CERES SRBAVG-GEO Edition2D_rev1 product is 6.5 Wm^{-2}, much larger than our best estimate of 0.85 Wm-2 based on observed ocean heat content data and model simulations. With the most recent CERES Edition3 Instrument calibration improvements, the imbalance is reduced to 3.6 Wm^{-2}, still much larger than our expectation. This imbalance is problematic in applications that use Earth Radiation Budget (ERB) data for climate model evaluation, estimate the Earth's annual global mean energy budget, and in studies that infer meridional heat transports.

A second problem users of standard CERES Level-3 data have noted is the occurrence of gaps in monthly mean clear-sky TOA flux maps due to the absence in some regions of cloud-free areas occurring at the CERES footprint scale (~20-km at nadir).

To address these problems, we have created the CERES Energy Balanced and Filled (EBAF) dataset, which uses an objective constrainment algorithm to adjust SW and LW TOA fluxes within their range of uncertainty to remove the inconsistency between average global net TOA flux and heat storage in the Earth-atmosphere system. The problem of gaps in clear-sky TOA flux maps is addressed by inferring clear-sky fluxes from both CERES and Moderate Resolution Imaging Spectrometer (MODIS) measurements to produce a new clear-sky TOA flux climatology that provides TOA fluxes in each region every month.

This EBAF Edition2.5A version supersedes EBAF Edition1A. Firstly, it covers 10 years of CERES Terra from March 2000 through February 2010. All-sky TOA fluxes in Edition2.5A are derived from CERES Terra SYN1deg-lite_Ed2.5 data product, which uses the latest Edition3 Instrument calibration improvements. The main impact of the Edition3 calibration changes to EBAF is to improve the calibration stability of the record. Another significant difference between EBAF Edition1A and Edition2.5A is in clear-sky, particularly in the LW.

TOA Flux Error Budget

Table 1 (from Loeb et al., 2009) provides an error budget for SW, LW and net TOA flux in the CERES Terra SRBAVG-GEO Edition2_rev1 product. It includes biases of known sign such as the use of TOA solar irradiance 1365 Wm^{-2} to compute net TOA flux instead of 1361 Wm^{-2} as has recently been reported by SORCE (Kopp et al., 2005). The largest uncertainties are associated with instrument calibration, which account for 4.2 Wm^{-2} (2σ). When all uncertainties are tallied, the expected range in net TOA flux is -2.1 Wm^{-2} to 6.7 Wm^{-2}.

Table 1: Bias errors for SRBAVG-GEO global mean fluxes. Numbers in parentheses correspond to clear-sky

Bias Errors of Known Sign (Wm^{-2})					
Error Source	**Incoming Solar**	**Outgoing SW**	**Outgoing LW**	**Net Incoming**	**Comment**
Total Solar Irradiance	+1	0	0	+1	Recent solar irradiance measurement vs assumed solar irradiance in CEI
Spherical Earth Assumption	+0.29	+0.18 (+0.11)	-0.05 (-0.06)	+0.16 (+0.24)	Weighting latitude zones in geocentric vs geodedic coordinates
Near-Terminator Flux	0	-0.3	0	+0.3 (+0.15)	Discretization uncertainty in time-space averaging algorithm at θ_o >85°
Heat Storage	0	0	0	+0.85	Hansen et al. (2005)
Bias Errors of Unknown Sign (Wm^{-2})					
Source	**Incoming Solar**	**Outgoing SW**	**Outgoing LW**	**Net Incoming**	**Comment**
Total Solar Irradiance	±0.2	0	0	±0.2	Absolute Calibration (95% confidence)
Filtered Radiance	0	±2.0	±2.4 (N) ±5.0 (D)	±4.2	Absolute Calibration (95% confidence)
Unfiltered Radiance	0	±0.5	±0.25 (N) ±0.45 (D)	±1.0	- Instrument spectral response function - Unfiltering algorithm
Radiance-to-Flux Conversion	0	±0.2	±0.3	±0.4	Angular distribution model error
Flux Reference Level	0	±0.1	±0.2	±0.2	Uncertainty in assuming a 20-km reference level
Time & Space Averaging	0	±0.3	±0.3	±0.4	Geostationary instrument normalization with CERES
Heat Storage	0	0	0	±0.15	Hansen et al. (2005)
Expected Range in Net TOA Flux: -2.1 Wm^{-2} to 6.7 Wm^{-2}					

TOA Flux Adjustments

To remove the inconsistency between average global net TOA flux and heat storage in the Earth-atmosphere system, an objective constrainment algorithm was used to derive optimal adjustments to the SRBAVG-GEO Edition2_rev1 incoming solar, SW, and LW TOA fluxes. After removing the constant flux bias errors in Table 1, the constrainment algorithm assigned errors to each error source, accounting for the assessed range of uncertainty in each term and the overall difference between the average global net and the assumed heat storage in the Earth-atmosphere system. We assume the "true" global net flux imbalance is +0.85 Wm^{-2}, based on Hansen et al. (2005). The optimal adjustments were applied to SRBAVG-GEO to produce all-sky CERES-EBAF Edition1A TOA fluxes.

In the more recent EBAF Edition2.5A version, the major input for all-sky TOA fluxes is from CERES Terra SYN1deg-lite_Ed2.5 instead of SRBAVG-GEO. To ensure continuity with its predecessor, all-sky TOA fluxes in EBAF Edtion2.5A are normalized such that the net TOA flux imbalance for March 2000-February 2005 is 0.85 Wm^{-2}, consistent with EBAF Edtion1A.

High-Resolution Clear-Sky TOA Fluxes

CERES SRBAVG and SYN1deg-lite_Ed2.5 clear-sky monthly mean TOA fluxes are provided for 1°x1° latitude-longitude regions derived from CERES footprints that are completely cloud-free according to 1-km resolution MODIS data. Because of the coarse spatial resolution of CERES (20 km at nadir), this approach only considers flux contributions from cloud-free regions occurring over relatively large spatial scales and meteorological conditions and geographical regions where clouds occur less frequently. As a result, clear-sky maps from CERES SRBAVG contain many missing regions.

In EBAF Edition1A, we introduced an alternative approach that attempts to recover clear-sky flux contributions at smaller spatial scales. This approach is an extension to that used by Loeb and Manalo-Smith (2005) to estimate the SW TOA direct radiative effects of aerosols over ocean. We determine gridbox mean clear-sky fluxes using an area-weighted average of: (i) CERES broadband fluxes from completely cloud-free footprints, and (ii) MODIS-derived "broadband" clear-sky fluxes estimated from the cloud-free portions of partly and mostly cloudy CERES footprints. In both cases, clear regions are identified using the CERES cloud algorithm applied to MODIS pixel data (Minnis et al., 2003). Clear-sky fluxes in partly and mostly cloudy CERES footprints are derived using MODIS-CERES narrow-to- broadband regressions to convert MODIS narrowband radiances averaged over the clear portions of a footprint to broadband radiances. The "broadband" MODIS radiances are then converted to TOA radiative fluxes using CERES clear-sky ADMs (Loeb et al. 2005).

In EBAF Edtion2.5A, monthly mean high-resolution clear-sky SW and LW TOA fluxes are determined using a different time-space averaging technique compared to EBAF Edition1A. Each day, instantaneous clear-sky TOA fluxes are sorted by local time and averaged over an equal-area 1°×1° latitude-longitude grid. A modified version of the production code used to produce CERES SRBAVG and SSF1deg-lite_Ed2.5 clear-sky fluxes is now used to determine monthly mean high-resolution clear-sky SW and LW TOA fluxes in EBAF Edtion2.5A. In EBAF Edition1A, the monthly mean clear-sky TOA fluxes were inferred from daily means without sorting by local time first, resulting in larger uncertainties at mid-to-high latitudes where multiple overpasses per day occur at different local times.

TOA Flux Comparisons

Table 2 compares 10-year mean TOA fluxes from CERES EBAF Edition2.5A and CERES SYN1deg Edition2.5A for March 2000 through February 2010 with 5-year mean TOA fluxes from CERES EBAF Edition1A and SRBAVG-GEO for March 2000 through February 2005. Also shown for comparison are ERBE adjusted mean TOA fluxes from Trenberth 1997 for February 1985 through April 1989.

Table 2: Comparison of adjusted ERBE, CERES SRBAVG-GEO and CERES EBAF TOA fluxes.

	ERBE Adj (Trenberth1997) (02/85-04/89)	CERES SRBAVG-GEO-Ed2D_rev1 (03/00-02/05)	CERES EBAF Edition1A (Loeb et al., 2009) (03/00-02/05)	CERES SYN1deg Terra Edition2.5A (03/00-02/10)	CERES EBAF Edition 2.5A (03/00-02/10)
Solar Irradiance	341.3	341.3	340.0	340.1	340.1
LW (All-Sky)	234.4	237.1	239.6	238.8	239.6
SW (All-Sky)	106.9	97.7	99.5	97.7	99.5
Net (All-Sky)	0.0	6.5	0.90	3.6	1
LW (Clear-Sky)	264.9	264.1	269.5	267.6	266
SW (Clear-Sky)	53.6	51.1	52.5	50.1	52.4
Net (Clear-Sky)	22.8	26.2	18.1	22.4	21.7
LW CRE	30.5	27.0	29.9	28.8	26.4
SW CRE	-53.3	-46.6	-47.1	-47.6	-47.1
Net CRE	-22.8	-19.7	-17.2	-18.8	-20.7

Notes:

- CERES SRBAVG-GEO Edition2D assumes a solar constant of 1365 Wm^{-2}. In CERES EBAF Edition1A, a solar constant of 1361 Wm^{-2} was used based upon SORCE observations (Kopp et al., 2005). Edition2.5A now uses time-varying solar irradiance from SORCE that are updated daily (SORCE Level 3 Total Solar Irradiance Version 10 available from: http://lasp.colorado.edu/sorce/data/tsi_data.htm).

- CERES SRBAVG Edition2D assumes a spherical Earth when averaging TOA insolation over the Earth's surface. This gives the well-known So/4 expression for mean solar irradiance, where S_o is the instantaneous solar irradiance at the TOA.

When a more careful calculation is made by assuming the Earth is an oblate spheroid instead of a sphere, and the annual cycle in the Earth's declination angle and the Earth-sun distance are taken into account, the division factor becomes 4.0034 instead of 4. Consequently, the mean solar irradiance for CERES EBAF is ~1361/4.0034 = 340 Wm^{-2}, compared to 1365/4 = 341.3 Wm^{-2} for CERES SRBAVG. The 0.1 Wm^{-2} difference in mean solar irradiance between CERES EBAF Edition1A and Edition2.5A in Table 1 is because Edition2.5A uses a more precise time-varying set of solar irradiance values while Edtion1A assumed a constant mean value of 1361 Wm^{-2}.

- In EBAF Edition1A, all-sky SW TOA flux increased by 1.8 Wm^{-2} compared to SRBAVG Edition2D, and LW increased by 2.5 Wm^{-2}. These changes, together with a 1.3 Wm^{-2} decrease in TOA solar irradiance, result a net TOA flux imbalance of 0.9 Wm^{-2}, consistent with our best estimate for ocean heat storage.

- Calibration changes in SYN1deg Edition2.5A result in a 1.7 Wm^{-2} increase in all-sky LW TOA flux compared to SRBAVG GEO Edition2D. This increase occurs because for Edition3 the CERES Instrument team reassessed the spectral response functions (SRFs) for the SW and TOT sensors determined prior to launch. Little change was found in the SW SRF and SW portion of the TOT SRF, but a large change was made to the LW portion of the TOT SRF after reanalysis of ground-based Fourier Transform Spectrometer (FTS) measurements between 2 and 200 μm. Other contributing factors for the difference include a change in the ground-to-flight shift used in Edtion3 compared to Edition2, and improvements in how in-flight calibration changes are accounted for. This, together with the change in incoming solar irradiance, explains why the net TOA flux in SYN1deg-lite_Ed2.5 decreases to 3.6 Wm^{-2} compared to 6.5 Wm^{-2} for SRBAVG-GEO Edition2D.

- As noted earlier, EBAF Edition2.5A all-sky TOA fluxes are derived from CERES Terra SYN1deg-lite_Ed2.5 with an adjustment that ensures the all-sky global mean net flux imbalance for March 2000-February 2005 is consistent with EBAF Edtion1A. The adjustments to all-sky TOA fluxes in SYN1deg-lite_Ed2.5 are as follows:

$$\text{SW\_All-Sky(EBAF)} = (\text{SW\_All-Sky(SYN1deg)} + 0.3 - 0.18)*1.0173 \quad (1)$$

$$\text{LW\_All-Sky(EBAF)} = (\text{LW\_All-Sky(SYN1deg)} + 0.05)*1.0029 \quad (2)$$

where values in parentheses are bias errors (see Table 1).

- The EBAF TOA fluxes differ substantially from adjusted ERBE values based on Trenberth (1997). SW TOA fluxes in EBAF are 7 Wm^{-2} lower and LW TOA fluxes are 4-5 Wm^{-2} higher than the Trenberth et al. (1997) fluxes.

- The clear-sky LW TOA flux value in EBAF Edition2.5 is 3.5 Wm^{-2} lower than the value Edition1A, whereas the clear-sky SW TOA fluxes are within 0.1 Wm^{-2} of one another. The large decrease in LW clear-sky TOA flux in Edition2.5A is mainly because of a change in the time-space averaging approach used. As noted earlier, the current approach is more consistent with the production algorithm that is used in SRBAVG-nonGEO and SYN1deg. The change has little effect in the SW but a large change in the LW.

- Fig. 1 shows how including clear-sky TOA fluxes at spatial scales smaller than a CERES footprint affects regional TOA fluxes. It shows the difference between CERES/MODIS based high-resolution clear-sky TOA prior to making any adjustments like those in Eqs. (1) and (2) and SYN1deg-lite_Ed2.5 for March 2006. In the SW, differences are greatest over eastern Asia and southern Africa for land and just west of the Saharan desert over ocean. Large differences are also found over the Southern Ocean where clear-sky sampling at CERES footprint scales is low. High-resolution CERES/MODIS clear-sky LW TOA fluxes are generally lower than those in SYN1deg-lite_Ed2.5, especially in regions where precipitable water is large. Note how the regional pattern of clear-sky LW TOA flux differences closely follows the regional precipitable water distribution (Fig. 1 middle and bottom panels).

- Table 3 provides 10-year global mean clear-sky TOA fluxes for CERES SYN1deg-lite_Ed2.5, high-resolution clear-sky fluxes from CERES/MODIS, and EBAF Ed2.5 values. The difference between CERES/MODIS and SYN1deg is entirely due to sampling of cloud-free regions. Clear-sky sampling at high spatial resolution results in an increase of 1.3 Wm^{-2} in the SW, and a decrease of 2.4 Wm^{-2} in the LW. The CERES/MODIS TOA fluxes are adjusted using the same scaling factors as for all-sky, resulting in a 1 Wm^{-2} increase in SW and a 0.8 Wm^{-2} increase in LW for EBAF Ed2.5.

Table 3 SW and LW clear-sky TOA fluxes for CERES SYN1deg-lite_Ed2.5, high-resolution CERES/MODIS, and EBAF 2.5.

	SYN1deg	CERES/MODIS	EBAF Ed2.5
SW	50.1	51.4	52.4
LW	267.6	265.2	266

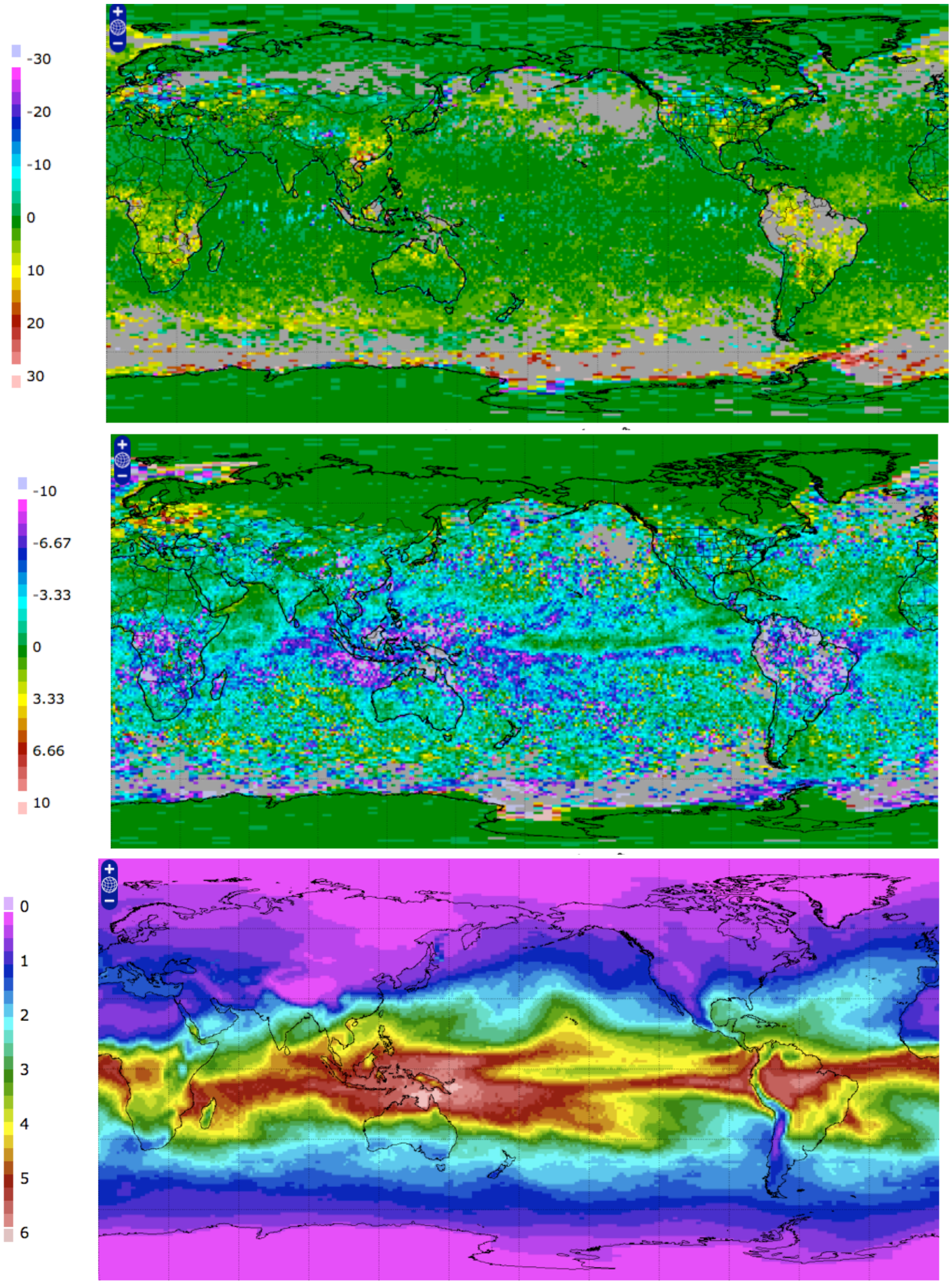

Figure 1 Clear-sky TOA flux difference between high-resolution CERES/MODIS and SYN1deg-lite_Ed2.5 for SW (top) and LW (middle). Bottom panel shows precipitable water in mm.

Contents of the Data Product

The CERES EBAF Edition2.5A data product provides 10-years of monthly mean top-of-atmosphere (TOA) radiative fluxes for March 2000 through February 2010. The fluxes are derived from the CERES Terra SYN1deg-lite_Ed2.5A data product. The CERES EBAF netCDF file contains 120 monthly means (Mar00-Feb10) and 12 monthly 10-year means (average of all Januaries, Februaries, etc.) (Mar00-Feb10), as indicated in Table 4. CERES EBAF Edition2.5A uses only CERES Terra SYN1deg-lite_Ed2.5A data in crosstrack mode. To see what CERES instrument is in crosstrack mode for any given month, please refer to the CERES Instrument Scan Modes web page.

Table 4: List of TOA fluxes, spatial grid, temporal frequency in CERES EBAF dataset

TOA Parameter	Spatial Grid	Temporal Frequency	Number of Values
SW Flux			
LW Flux			
Net Flux			
Albedo			
Solar Irradiance	All-Sky		
Clear-Sky	1° Equal Area Grid	Monthly	360x180x68
Zonal	Monthly	180x120	
Global	Monthly	120	
1° Equal Area Grid	Monthly Clim.	360x180x12	
Zonal	Monthly Clim.	180x12	
Global	Monthly Clim.	12	
SW CRE			
LW CRE			
Net CRE	-	1° Equal Area Grid	Monthly	360x180x68
Zonal	Monthly	180x120	
Global	Monthly	120	
1° Equal Area Grid	Monthly Clim.	360x180x12	
Zonal	Monthly Clim.	180x12	
Global	Monthly Clim.	12	

Cautions and Helpful Hints

Several cautions and helpful hints common to both CERES EBAF Edition2.5A and CERES SYN1deg-lite_Ed2.5 are provided in the CERES SYN1deg Data Quality Summary and are not repeated here. Rather, the following list addresses differences between CERES EBAF and SYN1deg that users of CERES EBAF should be aware of.

Adjustments to total solar irradiance associated with the spherical Earth assumption are applied zonally to improve the accuracy of incoming solar radiation at each latitude. While these adjustments are applied at the zonal level, the globally averaged correction is the same as in Table 1. Similarly, adjustments in SW TOA fluxes due to near-terminator flux biases are also applied zonally without modifying the global mean. Separate adjustments are made for clear and all-sky TOA fluxes.

References

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Browse Product Webpage

Maps of all parameters in the CERES EBAF dataset are available on the CERES Browse Products Webpage.

Expected Reprocessing

Currently no plans for reprocessing EBAF.

Attribution

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 EBAF data:

Loeb, N.G., B.A. Wielicki, D.R. Doelling, G.L. Smith, D.F. Keyes, S. Kato, N.M. Smith, and T. Wong, 2009: Towards optimal closure of the earth's top-of-atmosphere radiation budget. *J. Climate*, **22**, 748-766.

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Feedback and Questions

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