CERES Terra Edition2C SRBAVG Data Quality Summary

Investigation:	**CERES**
Data Product:	**Monthly TOA/Surface Averages (SRBAVG)**
Data Set:	**Terra**
Data Set Version:	**Edition2C**

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES Science Team. The document summarizes user applied revisions (e.g. Rev1), 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.

User applied revisions are a method CERES uses to identify improvements to existing archived data products that are simple for users to implement, and allow correction of data products that would not be possible in the archived versions until the next major reprocessing 1 to 2 years in the future. All revisions applicable to this data set are noted in the section User Applied Revisions to Current Edition.

This document is a high-level summary and represents the minimum information needed by scientific users of this data product. It is strongly suggested that authors, researchers, and reviewers of research papers re-check this document for the latest status before publication of any scientific papers using this data product.

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Nature of the SRBAVG Product

The Monthly TOA/Surface Averages (SRBAVG) archival data product contains the next generation of monthly mean gridded global Earth Radiation Budget (ERB) data averaged globally. These data represent a major improvement over previous data sets such as the Earth Radiation Budget Experiment (ERBE) and the CERES ERBE-like products (ES-4 and ES-9) in several key aspects. First, the accuracy of TOA flux is greatly improved by the use of new angular distribution models (ADM) based on improved scene identification (for more details, see: SSF TOA flux Data Quality Summary). Second, high temporal resolution imager data from geostationary satellites are used to reduce temporal sampling errors. Finally, the SRBAVG product is the first ERB data set to contain detailed cloud properties that are consistent with the fluxes.

The SRBAVG product contains monthly and monthly hourly regional, zonal, and global averages of the top of the atmosphere (TOA) and surface longwave (LW), shortwave (SW), and Window (WN) fluxes and the observed cloud conditions. The regional means for each 1° equal-angle grid box are calculated by first interpolating each parameter between the times of the CERES observations in order to produce a complete 1-hourly time series for the month. After interpolation, the time series is used to produce mean parameters on two time scales. Monthly means are calculated using the combination of observed and interpolated parameters from all days containing at least one CERES observation. Monthly hourly means are produced from the time series by dividing the data into 24 local hour bins to define a monthly mean diurnal cycle.

Two methods of interpolation are used to produce two separate sets of monthly means. The first method (termed non-GEO) interpolates the CERES observations using the assumption of constant meteorological conditions similar to the process used to average CERES ERBE-like data. This technique provides the user with monthly fluxes that are more readily compared with the ERBE-like fluxes. These fluxes represent an improvement to ERBE-like fluxes due to improvements to input fluxes, scene identification, and directional models of albedo. The second interpolation method (GEO) uses 3-hourly radiance and cloud property data from geostationary imagers to more accurately model variability between CERES observations. This technique represents a major advancement in the reduction of temporal sampling errors (Young et al. 1998).

CERES data input to the SRBAVG Subsystem is the Monthly Gridded TOA/Surface Fluxes and Clouds (SFC) product that contains gridded data from the Single Scanner Footprint TOA/Surface Fluxes and Clouds (SSF) archival data product. Geostationary data are input from the Geostationary Narrowband Radiances (GEO) data product. There is one SRBAVG product produced for each CERES instrument and one using the combination of data from all available CERES instruments.

SRBAVG contains the following data on regional, zonal, and global bases. The mean, standard deviation, and number of points used in the averaging process are provided for each parameter:

- Region-specific data such as surface properties and elevation
- Total-sky LW, SW, and WN radiative fluxes at the TOA and surface
- Clear-sky LW, SW, and WN radiative fluxes at TOA and surface
- Layer mean cloud properties for 4 pressure layers. These are calculated in 2 ways:
    - Mean cloud properties based solely on MODIS cloud property retrievals
    - Mean cloud properties that are a combination of cloud retrievals from both MODIS and geostationary imagers

A full list of parameters on the SRBAVG is contained in the CERES Data Product Catalog (PDF) and a full definition of each parameter will be contained in the SRBAVG Collection Guide (in preparation).

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 that are identical in all aspects of the filename except for the 6 digit configuration code (see Collection Guide) differ little, if any, scientifically. Users may, therefore, analyze data from the same satellite/instrument, data set version, and data product without regard to configuration code. Depending upon the instrument analyzed, these data sets may be referred to as "CERES Terra FM1 Edition2C SRBAVG" or "CERES Terra FM2 Edition2C SRBAVG."

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 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 and the latest, most recent revision to a data set includes all of the identified adjustments.

SRBAVG Edition2C-Rev1

The CERES Science Team has approved a table of scaling factors which users should apply to the Edition2C SRBAVG1 parameters.

For the ***SRBAVG1 TOA SW Fluxes (Up)***, users should use the following equation:

- $SW_{TOA}Flux_{rev1} = SW_{TOA}Flux_{orig}$ * scaling_factor

The SRBAVG1 TOA SW Fluxes (Up) are listed below:

SRBAVG1 TOA SW Flux	SRBAVG1 SDS Index
Clear-sky TOA SW Flux - Raw Data Average	9, 68
Total-sky TOA SW Flux - Raw Data Average	14, 73
Clear-sky TOA SW Flux - non-GEO Interpolation	19, 78, 127, 176, 225, 274
Total-sky TOA SW Flux - non-GEO Interpolation	24, 83, 132, 181, 230, 279
Clear-sky TOA SW Flux - GEO Interpolation	29, 88, 137, 186, 235, 284
Total-sky TOA SW Flux - GEO Interpolation	34, 93, 142, 191, 240, 289

For the ***SRBAVG1 TOA Albedos***, users should use the following equation:

- $Albedo_{rev1} = Albedo_{orig}$ * scaling_factor

The SRBAVG1 TOA Albedos are listed below:

SRBAVG1 TOA Albedo	SRBAVG1 SDS Index
Clear-sky TOA Albedo - Raw Data Average	12, 71

Total-sky TOA Albedo - Raw Data Average	17, 76
Clear-sky TOA Albedo - non-GEO Interpolation	22, 81, 130, 179, 228, 277
Total-sky TOA Albedo - non-GEO Interpolation	27, 86, 135, 184, 233, 282
Clear-sky TOA Albedo - GEO Interpolation	32, 91, 140, 189, 238, 287
Total-sky TOA Albedo - GEO Interpolation	37, 96, 145, 194, 243, 292

For the ***SRBAVG1 TOA Net Fluxes***, users should use the following equation:

- $Net_{TOA}Flux_{rev1} = Net_{TOA}Flux_{orig} - SW_{TOA}Flux_{orig} * (scaling\_factor - 1.0)$

The SRBAVG1 TOA Net Fluxes are listed below:

SRBAVG1 TOA Net Fluxes	SRBAVG1 SDS Index
Clear-sky TOA Net Flux - Raw Data Average	13, 72
Total-sky TOA Net Flux - Raw Data Average	18, 77
Clear-sky TOA Net Flux - non-GEO Interpolation	23, 82, 131, 180, 229, 278
Total-sky TOA Net Flux - non-GEO Interpolation	28, 87, 136, 185, 234, 283
Clear-sky TOA Net Flux - GEO Interpolation	33, 92, 141, 190, 239, 288
Total-sky TOA Net Flux - GEO Interpolation	38, 97, 146, 195, 244, 293

For the ***SRBAVG1 Sfc Net SW Fluxes***, users should use the following equation:

- $Net_{Sfc}Flux_{rev1} = Net_{Sfc}Flux_{orig} - SW_{TOA}Flux_{orig} * (scaling\_factor - 1.0)$

The SRBAVG1 Sfc Net Fluxes are listed below:

SRBAVG1 Sfc Net Fluxes	SRBAVG1 SDS Index
Clear-sky Sfc Net SW Flux - Mod A	39, 98, 147, 196, 245, 294
Clear-sky Sfc Net SW Flux - Mod B	40, 99, 148, 197, 246, 295
Total-sky Sfc Net SW Flux - Mod A	43, 102, 151, 200, 249, 298
Total-sky Sfc Net SW Flux - Mod B	44, 103, 152, 201, 250, 299

For the ***SRBAVG1 Sfc Down SW Fluxes***, no correction should be applied, and thus:

- $SW_{Sfc}Down_{rev1} = SW_{Sfc}Down_{orig}$

The SRBAVG1 Sfc Down Fluxes are listed below:

SRBAVG1 Sfc Down Fluxes	SRBAVG1 SDS Index
Clear-sky Sfc Down Flux - Mod A	47, 106, 155, 204, 253, 302
Clear-sky Sfc Down Flux - Mod B	48, 107, 156, 205, 254, 303
Total-sky Sfc Down SW Flux - Mod A	52, 111, 160, 209, 258, 307

Total-sky Sfc Down SW Flux - Mod B	53, 112, 161, 210, 259, 308

This revision is necessary to account for spectral darkening of the transmissive optics on the CERES SW channels. By June 2005, this darkening has reduced the average global all-sky SW flux measurements by 1.1 and 1.8 percent for Terra FM1 and FM2 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 Edition2C SRBAVG data set, users should refer to the data as Terra Edition2C-Rev1 SRBAVG.

Cautions and Helpful Hints

The CERES Science Team notes several cautions regarding the use of CERES-Terra Edition 2C SRBAVG data:

- Users should be aware that the Edition 2C SRBAVG product contains data collected from both rotating azimuth (RAP) and crosstrack scanning operating modes.

- All CERES footprints with a non-default value of either SW or LW flux have been used as input to the SRBAVG. Future versions of the SRBAVG may include restrictions on SZA for SW flux or may restrict the use of footprints with insufficient imager coverage.

  The cloud parameters other than cloud amount have not been properly weighted by cloud amount on the SRBAVG files containing the layer mean cloud properties. The monthly hourly regional results are correct and the user can easily recalculate the means using the monthly hourly regional values. The greatest differences occur at the regional mean level, whereas global differences are negligible.

- Users should be careful about comparisons of SRBAVG CERES TOA fluxes with ERBE or ERBE-like fluxes. The geographic location of a CERES flux estimate is at the surface geodetic latitude and longitude of the CERES footprint centroid. On ERBE, all fluxes are located at a geocentric latitude and longitude corresponding to the 30-km level. Other differences are expected due to:

  1. The viewing zenith angle cut-off for ERBE-like footprints is 70°. For the Terra SRBAVG, it is limited to 65° in crosstrack mode.
  2. ERBE-like fluxes were derived using ADM developed from ERBE and NIMBUS-7 data. The SRBAVG fluxes were derived using the new CERES ADM.

  An overview of flux ERBE-like/CERES flux differences can be found in the SSF TOA flux Data Quality Summary.

- The GEO SW fluxes and the surface SW fluxes are set to default on the Edition 2C SRBAVG product. Validation of these fluxes is continuing. These fluxes will be included in an upcoming reprocessing of the Terra SRBAVG product. Both GEO and non-GEO LW fluxes are contained on the Edition 2C SRBAVG.

- The non-GEO SW fluxes are interpolated using directional models of albedo as a function of solar zenith angle (sza) that are consistent with the new CERES ADM. The new models were developed from CERES Tropical Rainfall Measuring Mission (TRMM) data. Since TRMM is in a temporally precessing orbit, diurnal flux variations with sza can be modeled as a function of surface type and cloud properties. Models produced using data from the sun-synchronous Terra spacecraft do not provide an accurate representation of diurnal variations since sza is highly correlated with latitude. The use of these new models will cause differences with ERBE-like monthly means that use directional models based on the coarser ERBE 12 scene types.

- The Terra satellite is in a sun-synchronous orbit with a 10:30 AM equatorial crossing time. Most regions on earth are sampled twice a day (generally once in daylight and once at night). Polar Regions are sampled up to 14 times a day. Due to the lack of diurnal sampling over most regions of the earth, GEO cloud properties and derived broadband fluxes are computed every 3 hours and are used in the GEO SRBAVG monthly products. There are significant regional differences between the GEO and non-GEO SRBAVG products where there are strong diurnal cycles, for example sub-tropical maritime stratus in subsidence zones, afternoon convection over land, and desert regions with large surface temperature amplitudes.

- In addition to the 2 monthly mean products, the user is provided with simple averages of the observations for each parameter on both the monthly and monthly hourly time scales. These averages do not include any interpolated values and should not be considered accurate monthly means. These parameters will contain large temporal sampling errors that have not been corrected via interpolation. They are provided as a means for the user to assess the adequacy of temporal sampling for each region.

- A correction to the monthly mean SW flux for solar insolation from solar zenith angles greater than 90° has been included in Edition2C. The magnitude of this correction varies with latitude and season. The maximum correction of >1.8 W/m2 occurs at the poles during the equinoctial months of March and September. In general, the correction is less than 0.5 W/m2 and the global mean correction is 0.2 W/m2. A description of this correction can be found in Kato and Loeb 2003.

- The monthly mean SW TOA flux is calculated using an analytically derived value of the integrated solar insolation for the entire month. The assumption is that the mean albedo calculated from days with CERES observations is valid for the month. This recalculation of the SW flux removes biases due to unbalanced temporal sampling throughout the month. The correction is currently applied to both the TOA and surface monthly mean and monthly hourly mean SW flux.

- Clear-sky SW flux is only calculated using the non-GEO method. The purpose of incorporating GEO data is to more accurately define diurnal variations between the times of observations. Since the variability in SW flux is primarily caused by cloud variations, the benefit for clear-sky SW flux is minimal. The non-GEO clear-sky SW flux is replicated in the GEO SW flux data record.

- The SRBAVG will contain monthly means of all parameters currently available on the SSF product. Users should consult the Terra Edition2B SSF Data Quality Summary for information concerning the unavailability of certain parameters.

Accuracy and Validation

The primary goal of the SRBAVG product is to provide climate quality monthly mean fluxes and cloud properties. In order to achieve this, the temporal sampling errors inherent in any satellite observing system must be eliminated. For CERES, this is accomplished using narrowband imager data from geostationary satellites to provide additional information about the diurnal variations of flux and clouds. Flux/cloud consistency is maintained by using the CERES observations to normalize the less accurate narrowband data. In addition, care is taken to produce GEO cloud properties as consistent as possible with the MODIS retrievals. The validation studies have been designed to assess the accuracy of the resulting monthly means.

The results of pre-launch validation of the interpolation techniques used to produce the SRBAVG can be found in Young et al. 1998. This study demonstrated that the inclusion of GEO data reduces interpolation errors in instantaneous LW and SW TOA fluxes by more than 50%. Global monthly mean fluxes are generally unchanged on the average, but large corrections can occur for regions with poor temporal distribution of observations. Using GEO data also provides great improvement in estimates of the monthly mean diurnal cycle.

The User should consult the SSF Data Quality Summary for information on the accuracy of the Instantaneous CERES data used as input to the SFC and SRBAVG.

GEO calibration and cloud retrievals

The primary goal of including narrowband GEO imager data is the improvement of the temporal interpolation of TOA and surface fluxes. The interpolation involves several steps:

1. Narrowband GEO radiances are calibrated relative to the MODIS imager.
2. A broadband radiance is computed using a narrowband-broadband relationship based on matched MODIS and CERES data.
3. Broadband fluxes are computed using the CERES ADM.
4. The GEO broadband time series is then normalized to the CERES observations to minimize GEO calibration and narrowband-to-broadband conversion errors.

Young et al. 1998 demonstrated that flux interpolation errors are reduced an extra 10% if GEO-derived cloud properties are used for ADM selection. For this purpose, the key cloud parameter is cloud fraction, which is the property that can be most accurately derived from GEO data. Optical depth is also important for the selection of proper ADM for SW data. The simple 2-channel (0.6 and 10.8 µm) algorithm used for deriving GEO cloud properties is sufficient for this purpose.

However, a secondary goal for GEO cloud properties is to produce properties consistent with MODIS to assist in defining diurnal variations of cloud properties that are missed by limited satellite sampling. This is accomplished by first normalizing the calibration of each GEO imager to the well-calibrated MODIS imager using the methods of Minnis et al. 2002a & b. The GEO retrievals are a subset of the multiple channel MODIS algorithms and they share common input maps of surface emissivity and reflectance and atmospheric data.

Some differences will remain between MODIS and GEO retrievals due to the limited number of GEO channels. In particular, nighttime retrievals are based on only the 10.8 µm channel. Cloud height correction based on optical depth cannot be performed on these nighttime data. Daytime optical depths are also lower for GEO due to the effects of decreased spatial resolution and more retrievals from larger viewing zenith angles. For this reason, the SRBAVG includes monthly mean cloud properties with and without the GEO data.

A summary of the MODIS/GEO cloud property differences is presented in Table 1. The comparison is based on MODIS and GEO cloud properties averaged on a 1° latitude by 1° longitude grid that were observed within 15 minutes of each other. Comparisons have been performed separately for each month of Terra data and for each GEO satellite. Table 1 includes the 36-month average from March 2000 to February 2003 for all GEO satellites.

Table 1. Comparison of coincident MODIS and GEO cloud properties

	Cloud Amount (%)		Optical Depth		Cloud Temperature (K°)	
	MODIS	**GEO**	**MODIS**	**GEO**	**MODIS**	**GEO**
Ocean Day	65	65	4.2	3.6	265.0	264.9
Ocean Night	64	56			255.5	267.6
Land Day	52	61	5.6	4.2	259.8	259.8
Land Night	54	58			242.5	259.7

In general, the cloud fractions agree well for daytime scenes over ocean surfaces. Daytime retrievals over land show the greatest discrepancy with GEO cloud amount greater by 9%. This occurs primarily at large viewing zenith angles, but the cause of this difference is unclear and is being investigated. At night only the 11 µm channel is used to determine GEO clear-sky pixels. The optical depths compare well, with the expected low bias for GEO due to the larger pixels (4 km vs 1 km for MODIS) and retrievals from high viewing angles. The largest errors are in the cloud temperature retrievals. In the daytime, the cloud temperature is underestimated as a result of the underestimate of optical depth. At night, no optical depth correction can be applied to the cloud temperature. This leads to a large overestimate of temperature for thin clouds. Fortunately, cloud temperature is only used for placing clouds into layers and is not used in ADM selection.

Parameters such as cloud phase and particle size cannot be derived using GEO data. Users should use the MODIS-only cloud product for these parameters.

Inter-satellite differences have been minimized by using the MODIS imager as a calibration source. This has been verified by comparing neighboring satellite GEO radiances at the bisecting longitude. Table 2 presents the MODIS-GEO cloud amount difference and monthly rms in parenthesis for GOES, GMS, and METEOSAT averaged over the first 36-month Terra period. No statistics are given for GOES-10 land, since there are very few land regions in the GOES-10 field of view. On average, the daytime MODIS-GEO differences are within 4% for ocean and twice that for land among the various satellites. In general the METEOSAT satellite cloud amounts are consistent with one another as well as the GOES satellite cloud amounts. The GEO visible radiances have been calibrated over oceans in order to mitigate the effects of the spectral response function between GEO satellites. The month-to-month MODIS-GEO cloud amount variation is within 1% for all GEO satellites over ocean, which suggests that calibrating GEO imagers relative to MODIS is an effective means of producing consistent cloud retrievals over time. The larger month-to-month variations over land indicate seasonal variations in the clear-sky albedo. The inter-satellite variations are larger than the month-to-month variations. The cause of this error is likely due to spectral differences between MODIS and the GEO imagers.

Table 2. Coincident MODIS - GEO cloud amount (%) difference for each GEO satellite

	MET-7	MET-5	GMS-5	GOES-10	GOES-8
Ocean Day	3.4	2.9	-1.1	-1.2	-0.3
Ocean Night	-10.0	-7.7	-8.1	-9.0	-8.0
Land Day	9.6	12.1	15.1		5.0
Land Night	4.1	8.7	1.5		-0.2

Additional cloud property comparisons can be made with the ISCCP D2 product to assure reasonable SRBAVG parameter values. The ISCCP D2 product contains monthly cloud amount, optical depth and temperature obtained from the same GEO satellites. The SRBAVG GEO and ISCCP cloud parameters are based on the 0.65 µm visible (VIS) and 11µm (IR) channels during the day and IR only at night. The GEO and ISCCP optical depths are based on the visible radiance based on a similar effective particle size for ice and water clouds. Both ISCCP and SRBAVG GEO cloud top temperatures have been adjusted according to the cloud emittance based on cloud optical depth during the day. However, there are differences in the two products, which should be kept in mind, when doing comparisons. The ISCCP D2 product normalizes night-time cloud amount, cloud top temperature and pressure with the day-time derived cloud counterparts. The GEO SRBAVG computes monthly cloud property means from hourly increments or hourboxes. The hourboxes are first filled in with the 3-hourly GEO cloud observations and then filled with the MODIS cloud observations, the latter taking precedence. The observed cloud parameters are then interpolated to fill in all missing hourboxes. The SRBAVG GEO night-time cloud parameters are not normalized to the daytime cloud parameters. Given these facts, ISCCP and GEO SRBAVG cloud properties are best compared from those measured during the day. The ISCCP day-time values are the mean of the 15 day-time cloud types (D2 parameter # 41d to 115d). The GEO SRBAVG values are means from the day-time monthly hourly averages for each region. Only regions between 60°S and 60°N are utilized, which is the extent of the GEO field of view. The ISCCP D2, MODIS (non-GEO) SRBAVG3 and GEO SRBAVG2 60°N to 60°S day-time monthly mean cloud amounts, optical depths, and temperatures are shown in Fig. 1. Individual monthly global difference maps can be displayed at the TISA Data Management site under SRBAVG & ISCCP comparisons.

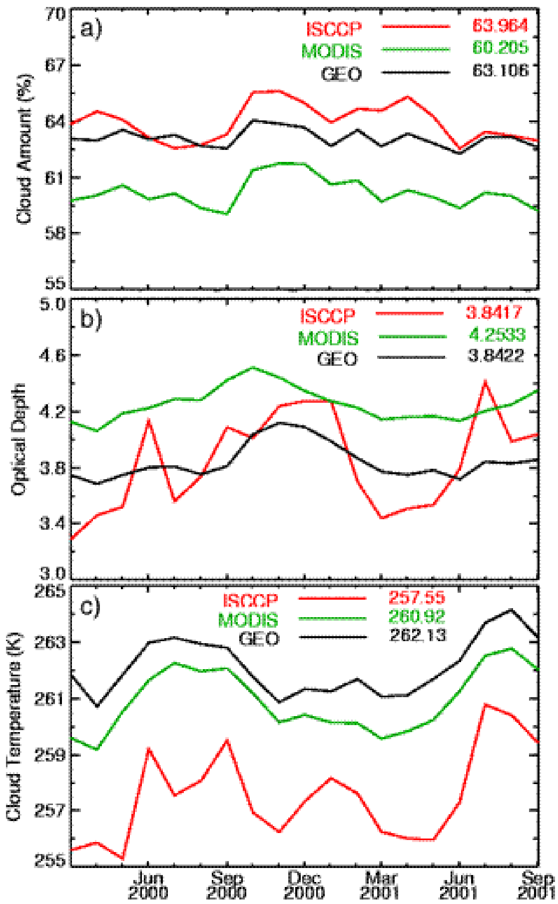

Figure 1: Comparison of monthly mean ISCCP, MODIS (non-GEO) SRBAVG3, and GEO SRBAVG2 60°N to 60°S daytime cloud amount a), optical depth b), and cloud temperature c). The March 2000 to September 2001 averages are given in the legend.

The ISCCP and GEO March 2000 to September 2001 60°N to 60°S daytime cloud amounts are within 1%. The MODIS and GEO cloud amount difference is 2.9% and is consistent from month to month. The MODIS is based on the 10:30 local equatorial crossing time of Terra, whereas the GEO samples every 3 hours during the day. Differences include the land afternoon convection and the diurnal variations of maritime stratus clouds. The ISCCP and GEO optical depth means are nearly identical, however there are pronounced seasonal and regional variations. The MODIS optical depths are 0.4 greater than the GEO, which can be attributed to the difference in pixel size. Regionally the GEO optical depth is smaller over land and southern oceans. The ISCCP cloud temperature is 4.6° K colder than GEO. The ISCCP thin cirrus is much colder than GEO or MODIS. The GEO cloud temperature is 1.2° K warmer than MODIS and the monthly differences are very consistent. In general the ISCCP cloud properties are similar to the GEO SRBAVG product and the GEO cloud properties are consistent in time with MODIS.

The effects of GEO imager calibration errors on the monthly mean fluxes have been estimated using CERES TRMM data (CER_SRBAVG_TRMM-PFM-VIRS Edition2B Data Quality Summary). It was found that a 5% error in IR calibration results in only a 0.1% error in monthly mean LW flux. A 5% visible channel calibration error results in a 1% error in SW. Errors for the Terra case will be calculated once the GEO SW algorithm is finalized and validated.

Comparison of ERBE-like and SRBAVG Fluxes

There are several significant differences between the ES-4, non-GEO SRBAVG and GEO SRBAVG monthly fluxes. Many have been mentioned under **Caution and Helpful Hints**. The ERBE-like product uses the same ERBE scene identification technique based on the shortwave and longwave flux, the ERBE ADM to convert radiances into fluxes, directional models to temporally interpolate SW fluxes over the day, linear temporal interpolation of LW fluxes over ocean, and the implementation of a day-time half sine model to take into account diurnal heating over land. This dataset is most appropriate for users who would like to combine or compare the historical ERBE data and CERES data. The non-GEO SRBAVG uses scene identification based on MODIS retrievals for a given footprint. CERES requires 99% of all MODIS pixels within a CERES footprint to be clear to be classified as clear, a more robust technique than ERBE, which is based on the LW and SW fluxes only. ERBE ADM uses only 4 cloud amount classifications; whereas the CERES ADM uses surface type, cloud amount, phase, optical depth in the SW and precipitable water, lapse rate, and emissivity (see CERES Inversion Group web page). The non-GEO-SRBAVG uses directional (albedo vs. solar zenith angle) models based on the CERES ADM scene types to temporally interpolate albedo over the day, and for longwave uses the same ERBE-like temporal interpolation technique. The GEO SRBAVG enhances the temporal interpolation by inserting 3-hourly GEO derived broadband fluxes between the CERES fluxes. These GEO fluxes are measured and are an improvement to the constant meteorology temporal models. The GEO SRBAVG Edition2C do not contain SW fluxes, but they will be included in later editions, when the GEO SW normalization routine has been finalized. To evaluate the effects of the improved ADM and directional models, the ERBE, ES-4 and non-GEO global fluxes are compared. Individual monthly global difference maps can be displayed at the TISA Data Management site under SRBAVG and ES-4 comparisons. The all-sky and clear-sky longwave and shortwave global monthly mean fluxes are shown in Fig. 2.

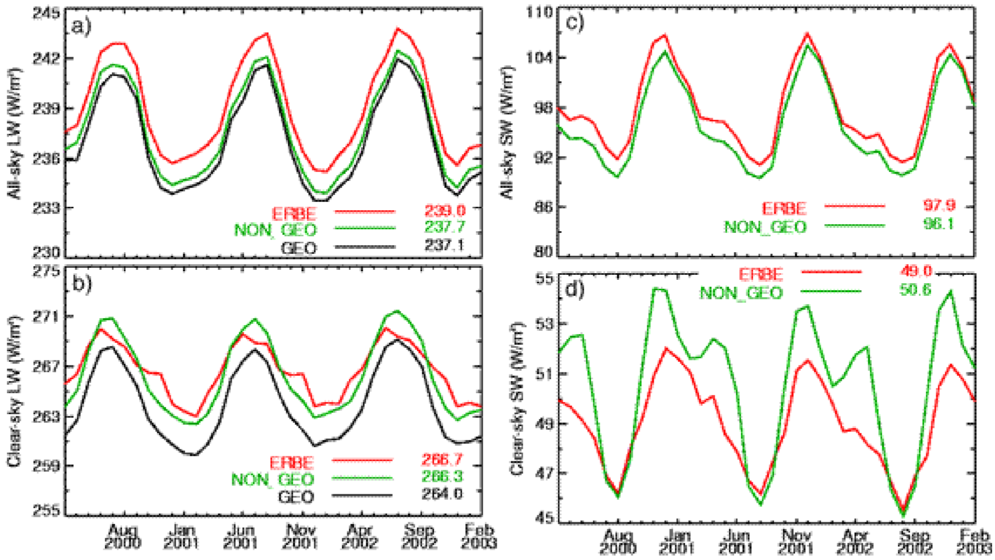

Figure 2. Comparison of monthly mean ERBE-like, non-GEO, and GEO SRBAVG global all-sky longwave a), clear-sky longwave b), all-sky shortwave c), and clear-sky shortwave d). The March 2000 to February 2003 averages are given in the legend.

The non-GEO global all-sky longwave is 1.3 Wm^{-2} less than the ERBE-like (Fig. 2a). This difference is attributed to the CERES longwave ADMs, since the longwave fluxes are temporally interpolated between measurements in the same manner for both ERBE-like and non-GEO. This difference is also consistent zonally, indicating that the net effect of the CERES ADMs produces colder fluxes than ERBE-like for most scene types. The GEO all-sky longwave flux is 0.6 Wm^{-2} less than the non-GEO and the difference is greatest over desert regions (Fig. 2a). The non-GEO clear-sky land regions are temporally interpolated using a daytime half sine model and a constant night-time flux regressed onto observed fluxes. The GEO fluxes reveal much colder fluxes in the early morning than the constant night time flux. This effect is more dominant than the daytime heating peak being underestimated by the half sine model. All observed longwave clear-sky fluxes are temporally interpolated regardless of cloud amount. The ERBE-like and non-GEO fluxes identify clear scenes differently. The ERBE-like clear-sky thresholds are based entirely on the broadband fluxes, whereas the CERES cloud mask is based on the MODIS imager. The ERBE scene identification over snow was less than ideal and the ice coverage over the southern ocean was not taken into account, whereas CERES uses daily snow and sea ice maps. ERBE uses a zonal longwave clear-sky threshold, making it difficult to classify cold clear-sky land and humid ocean scenes as clear. ERBE-like retains the ERBE 2.5° grid increasing the area that is considered coastal, where scene identification is more difficult than over homogeneous geo-types. Overall the global 3-year non-GEO clear-sky longwave flux is 0.4 Wm^{-2} less than the ERBE-like (Fig. 2b). However the non-GEO ERBE-like difference changes seasonally ±1.5 Wm^{-2} and regional differences can be quite large especially over snow. The GEO clear-sky flux is 2.3 Wm^{-2} less than the non-GEO flux and is constant over time. Again the greatest differences occur over clear-sky land where the diurnal heating is strong. The GEO clear-sky fluxes are also colder over very cloudy southern oceans and are being investigated.

The non-GEO global all-sky shortwave flux is 1.8 Wm^{-2} less than the ERBE-like (Fig. 2c). The difference in shortwave flux is a result of the differences in the CERES and ERBE ADM and directional models. There is a distinct zonal variation in the shortwave flux difference. The non-GEO fluxes are greater than ERBE-like in the overhead sun zones. The non-GEO subtropical maritime stratus regions off of the west coast of continents are darker than ERBE-like in general. The mid-latitude summer ocean non-GEO regions are darker than their ERBE counterpart. The CERES directional models in these high albedo regions are less a function of solar zenith angle than the ERBE models. The GEO non-GEO SW flux differences should reveal large regional variations, when they become available, since the 10:30 AM Terra orbit misses the land afternoon convection and the afternoon reduction of maritime stratus clouds. The non-GEO global clear-sky shortwave flux is 1.6 Wm^{-2} greater than ERBE-like (Fig. 2d). The seasonal ERBE-like non-GEO difference varies from -3.5 to 0.5 Wm^{-2}. This is mainly due to differences in the identification of clear-sky over snow, the differences discussed in the previous paragraph. Also the ERBE-like clear-sky albedo is contaminated over maritime stratus regions and the effects of the large ERBE-like coastal regions are easily identified.

The global net 3-year flux means are summarized in Table 3. The global net flux imbalance is addressed in the next section.

Table 3. TOA global 3-year flux means for CERES and ERBE products

Wm^{-2}	CERES Mar 2000 - Feb 2003			1986-1988
All-Sky	**ERBE-like**	**non-GEO**	**GEO**	**ERBE**
OLR	239.0	237.7	237.1	236.3
SW	97.9	96.1		100.1
NET	4.4	7.5		4.9

Global Net Flux Error Budget: ERBE-Like ES-4/9, and SRBAVG Non-Geo.

CERES has gone to great lengths to reduce and quantify errors from each of the 9 critical "dimensions" of radiation balance observations: time, latitude, longitude, altitude, wavelength, solar zenith angle, viewing zenith angle, viewing azimuth angle, and absolute calibration. In general, these error sources have been reduced to 1 Wm^{-2} or less for global averages. But after all of the elements of the radiation balance have been worked, there remains a final sanity check: global annual average energy balance.

Table 4 below summarizes our current understanding of both known global average systematic errors as well as 95% confidence bounds on errors for which the uncertainty has no known sign. The sign convention in the table is that the systematic errors are signed positive if they tend to "heat" the planetary energy system by either a) reducing upward TOA reflected solar (SW) or emitted thermal infrared (LW) flux, b) increasing solar insolation (solar constant), c) act to store heat in the oceans. Errors are shown both for the more accurate CERES Non-geo fluxes on the SRBAVG data product, as well as for the ERBE-Like TOA fluxes on ES-4 and ES-9 products. In all cases, the Revision 1 Terra FM1 instrument SW channel time series corrections have been made: they add 0.7 Wm^{-2} to global average SW flux for the first 3 years of the standard Edition2 CERES data products.

Table 4: CERES Error Budget for Global Net Radiative Imbalance
Data Products: CERES Edition 2 Rev 1 for SRBAVG, ES-4 and ES-9
Instrument: Terra CERES FM1

Systematic Sources of Global Net Imbalance "+" sign is heating the earth system (i.e. less outgoing flux or more incoming flux)				
Source	**SW**	**LW**	**Net**	**Comments**
Ocean Heat Storage	-	-	0.7	Willis et al., 2004 (JGR) for years 2000 through 2002
Solar Constant	0.5	-	0.5	Half of the difference between 1365 and new SORCE 1361 value
Calibration Absolute Accuracy	0	0	0	Vacuum ground cal to 0.999 blackbody and active cavity transfer to SW
Spectral Correction	0	0	0	
Angle Sampling (ADMs) Non-Geo	0.1	-0.1	0	Biases verified using hemispheric radiance direct integration (Loeb et al., 2003; JAM)
Cloud tau bias in albedo (solzen)	0.7	0	0.7	Plane parallel cloud tau retrievals bias solar zenith ADM albedo dependence
Spherical Shell Atmosphere	0.5	0	0.5	Finite thickness atmosphere effects on definition of albedo near sunrise/sunset
Twilight SW flux	0.3	0	0.3	ERBE Like missing twilight reflected flux at solar zenith greater than 90 degrees
Improved 20km TOA reference alt	0	0	0	Using an improved reference altitude (Loeb et al., 2002; JClimate)
Spatial Sampling	0	0	0	No significant spatial sampling errors for global means
Diurnal Cycle: 1030am Terra	1	-0.6	1	Final confirmation awaits merged geo/CERES SW fluxes and GERB validation
Total (CERES non-geo)	**3.1**	**-0.7**	**3.7**	**Simple sum of all terms above**
Angle Sampling ERBE-Like	-1.8	-1.3	-3.1	Biases in ERBE-Like angular models are larger than CERES ADMs in Non-Geo and Geo
Total (CERES ERBE-Like)	**1.3**	**-2.0**	**-0.7**	**Same as CERES non-geo**

				but with ERBE ADMs and directional models
Uncertainties with Variable Sign: "+/-" 95% Confidence Interval				
Source	**SW**	**LW**	**Net**	**Comments**
Ocean Heat Storage			0.3	Willis et al., 2004 uncertainty for 3-year average
Solar Constant			0.5	Encompass range from 1365 to 1361
Calibration Absolute Accuracy	1	1	2	Errors in absolute accuracy will tend to be same sign for SW and LW
Spectral Correction	0.5	0.3	0.6	Spectral correction errors not likely to be correlated
Angle Sampling (ADMs)	0.1	0.1	0.1	
Cloud tau bias in albedo (solzen)	0.3	0	0.3	Rough estimate of uncertainty in this bias
Spherical Shell Atmosphere	0.2	0	0.2	Finite thickness atmosphere effects on definition of albedo near sunrise/sunset
Twilight SW flux	0.1	0	0.1	ERBE Like missing twilight reflected flux at solar zenith greater than 90 degrees
Improved 20km TOA reference alt	0.1	0.2	0.2	Using an improved reference altitude (Loeb et al., 2002; JClimate)
Spatial Sampling	0	0	0	No significant spatial sampling errors for global means
Diurnal Cycle: 1030am Terra	1	0.3	1.0	Final confirmation awaits merged geo/CERES SW fluxes and GERB validation
Total	1.5	1.1	2.4	Assume each source independent: sqrt(sum of each value squared)

	Net Obs	**Net Predict**	**Net Flux 95% Conf. Interval**		**Comments**
			Min	**Max**	
CERES Non-geo (3/00 to 2/03) (SRBAVG data product)	6.8	3.7	1.3	6.1	Includes improved CERES ADMs and solar zenith albedo dependence
					Primary sources of difference from zero are SW errors, Solar Constant, and Heat Storage
CERES ERBE-Like (3/00 to 2/03) (ES-4 and ES-9 data products)	3.7	-0.7	-3.1	1.7	Major difference from Non-Geo is less accurate ERBE ADMs, solar zenith dependence
					The fact that ERBE-Like is "closer to zero" is a coincidence of opposite sign errors

In general, heat storage, solar insolation, and TOA SW reflected flux dominate the systematic errors. Almost all systematic errors appear as planetary heating in the global net balance. Some of the errors like diurnal sampling biases await final confirmation using combined global 1030 Terra, 130 Aqua, as well as 3-hourly and 1-hourly geostationary data sources for SW fluxes, and GERB 30-minute broadband data from Meteosat for SW and LW flux diurnal cycles.

When all errors are combined, CERES SRBAVG Non-Geo global Net flux is 6.8 Wm^{-2} versus a predicted range of 1.3 to 6.1 Wm^{-2}. The ERBE-Like global Net flux is 3.7 Wm^{-2} versus a predicted range of -3.1 to 1.7 Wm^{-2}. The less accurate ERBE-Like global net flux comes closer to zero. The reason, however, is not more accurate TOA fluxes, but fortuitous cancellation of errors of opposite sign. The ultimate goal is of course to get the right answer for the right physical reasons. For example, the improved CERES angular dependence models improve the accuracy of the equator to pole gradient of reflected SW fluxes, especially in polar regions.

Until more of the systematic uncertainties are resolved and explicitly included in future data products, how should users modify the data to achieve the current best estimate of global TOA fluxes that are in agreement with ocean heat storage? Since SW flux uncertainties dominate the error budget for global net, the simplest current suggestion is to adjust all SW fluxes by a constant factor to achieve the required global net flux. For example, using CERES non-Geo, SW fluxes would be increased by a factor of (96.8 + 6.8 - 0.7) / 96.8 = 102.9 / 96.8 = 1.063. 96.8 is the FM1 SRBAVG Rev 1 Non-geo global average TOA SW flux from March 2000 through Feb 2003, 6.8 is the global imbalance, and 0.7 is the ocean heat storage estimate for the same three years. For CERES FM1 ERBE-Like ES-4 or ES-9 fluxes, SW fluxes would be increased by (98.6 + 3.7 - 0.7) / 98.6 = 101.6 / 98.6 = 1.030. Note that all CERES and ERBE data products assume a solar constant value of 1365, and the adjustments above would not change this value.

We note, however, that the simple adjustment suggested above assumes that the SW flux changes act as if they were a simple instrument gain factor and not dependent on latitude, solar zenith, or season. Examination of the error sources in the global net error budget table indicates that this approach is an oversimplification: for example effects that dominate near sunset/sunrise will show peak amplitude in the polar regions. As more is learned about the global net error sources, and more accurate later additions include these corrections, this data quality summary will be updated.

Direct Integration of Fluxes

Since TERRA is in a sun-synchronis orbit, the temporal interpolation of SW fluxes cannot be tested using a comparison of the SRBAVG monthly means with an average of observed fluxes compiled over complete diurnal cycles, as was the case with the temporally precessing TRMM orbit. Results of direct integration performed on the TRMM SW fluxes are contained in the CER_SRBAVG_TRMM-PFM-VIRS_Edition2B Data Quality Summary.

Surface Flux Comparisons

The truest test of the temporal interpolation techniques used to produce the SRBAVG monthly means would be a comparison with an independent high temporal resolution broadband instrument. The Geostationary Earth Radiation Budget (GERB) instrument on the METEOSAT Second Generation satellite will provide such an excellent data set. However, validated GERB data were not available in the Terra time period. The only high temporal resolution data available from this time period are surface-based measurements of downwelling surface flux. Comparisons of the surface fluxes from the SRBAVG have been made with these surface data on both an instantaneous and monthly mean time scale.

Surface fluxes are highly dependent on the cloud conditions. Cloud interpolation errors can lead to large errors in estimations of surface downwelling flux. Therefore, these surface flux comparisons provide an estimate of the integrated effect of flux and cloud property interpolation errors on a monthly time scale. This was preformed during the TRMM time period with surface fluxes from the ARM CART site and the results are in the CER_SRBAVG_TRMM-PFM-VIRS_Edition2B Data Quality Summary.

For Edition 2B, no GEO SRBAVG SW surface fluxes are available and the surface flux comparisons are limited to longwave. Model A and B surface downwelling longwave flux are decoupled from the top of the atmosphere and are based on the Goddard Earth Observing System (GEOS) atmospheric state vertical profiles and GEO-low cloud amount and base heights. The Model A and B surface net longwave flux utilizes the GEOS skin temperature. Figure 3 displays the monthly downwelling Model B flux and the corresponding station surface flux from the CERES ARM Validation Experiment (CAVE) database. The CAVE surface broadband flux measurements are from ARM, SURFRAD, CMDL, and BSRN networks and have been quality controlled. Three years of monthly mean fluxes from 36 stations were used from March 2000 to February 2003. The mean CAVE surface LW downwelling flux is 316.7 Wm^{-2} and the SRBAVG GEO Model B overestimates the flux by 2.1 Wm^{-2} or 0.7% and the rms error is 11.4 Wm^{-2} or 3.6%. The agreement is well within the expected accuracy for surface LW flux estimates. Six stations had biases greater than 15 Wm-2 and are the Chesapeake Lighthouse (Virginia Beach, VA), Fort Peck (Montana), Manus (Tropical Western Pacific), South Pole (Antarctica), Syowa (Antarctica), and Tamanrasset (Algeria). The biases (SRBAVG-CAVE) are 17.1, 19.6, 16.1, 14.7, -22.1, 15.4 Wm^{-2}, respectively. The inconsistencies between the SRBAVG and CAVE downwelling fluxes have not been fully investigated, but probable causes are coastal sites where the station is not representative of the 1° by 1° SRBAVG region, over the poles where the GEOS profile may not be representative of the station, and radiometer calibration.

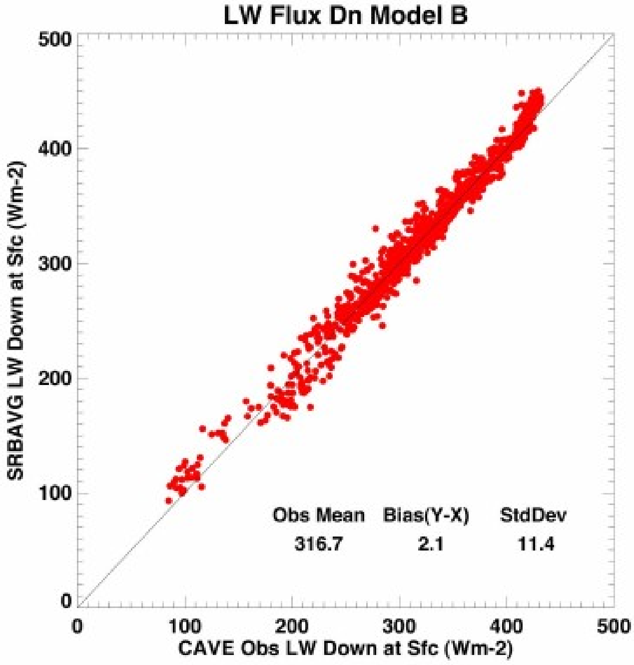

Figure 3: Monthly downwelling Model B flux and the corresponding station surface flux from the CERES ARM Validation Experiment.

Future Validation Studies

Future validation efforts will focus on consistency of both instantaneous and monthly mean fluxes and cloud properties from TRMM and Terra for March 2000 and for coincident Terra and Aqua months; estimation of temporal interpolation errors using high temporal resolution GERB data from the recently launched METEOSAT Second Generation satellite; more extensive comparisons of SRBAVG monthly mean surface fluxes with surface sites and the Surface Radiation Budget (SRB) project; and consistency of SRBAVG fluxes and Fu-Liou radiative transfer derived TOA fluxes using SRBAVG cloud properties in conjunction with the CERES Surface and Atmosphere Radiation Budget (SARB) working group.

References

An overview of the temporal interpolation and spatial averaging algorithms used for CERES can be found in the following reference:

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5. Loeb, N.G., S. Kato, and B.A. Wielicki, 2002: Defining Top-of-the-Atmosphere Flux Reference Level for Earth Radiation Budget Studies, *J. Climate*, **15**, 3301-3309.

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7. Young, D. F., P. Minnis. D. R. Doelling, G. G. Gibson, and T. Wong, 1998: Temporal Interpolation Methods for the Clouds and Earth's Radiant Energy System (CERES) Experiment. *J. Appl. Meteorol*., **37**, 572-590

Expected Reprocessing

A revision of the CERES TERRA Edition2C SRBAVG dataset is due shortly, when the GEO SW flux algorithm has been finalized. The CERES Team will continue detailed examination and documentation of the ground calibration and characterization data, as well as the in-flight calibration opportunities. Notification of any changes will be sent to registered users.

An additional SRBAVG product may be issued in the future that includes daily mean fluxes and cloud products.

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 TERRA Edition2C SRBAVG 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.

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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.

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