CERES Terra Edition2D SRBAVG
CERES Aqua Edition2A SRBAVG
Data Quality Summary

Investigation:	**CERES**
Data Product:	**Monthly TOA/Surface Averages (SRBAVG)**
Data Set:	**Terra (Instruments: CERES-FM1 or CERES-FM2)** **Aqua (Instruments: CERES-FM3 or CERES-FM4)**
Data Set Version:	**(Terra) Edition2D** **(Aqua) Edition2A**

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

This document discusses SRBAVG versions Terra Edition2D and Aqua Edition2A. This document was written for the Terra Edition2D SRBAVG product, however the results should be of similar quality for the Aqua Edition2A SRBAVG product. Any reference to the Terra specific CERES data products such as the SSF can be easily interchanged with the appropriate Aqua CERES product. For example the SSF Data Quality Summary can be obtained from either the CERES Terra Edition2B SSF or CERES Aqua Edition2B depending on the given satellite. The CERES product edition naming convention is a function of input and algorithm differences. Consistent input and algorithms are necessary to avoid algorithm shock to the output parameters in order to retain a consistent climate quality record. See the table of CERES Edition2 product versions. There are no algorithm or coding changes between Terra Edition2D and Aqua Edition2A. Any differences are due entirely to changes from the input, such as differences in the Terra or Aqua SSF. **The user should always use the latest Edition that is available.** Both Terra and Aqua SRBAVG use the same GEO cloud property retrievals, however the GEO fluxes are normalized to the specific CERES instrument given in the product name.

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. There are plans for multi-satellite SRBAVG products in the future, which are currently available for the CERES-ERBElike product.

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:

- SRBAVG1 monthly radiative flux products
  - Region-specific data such as surface properties and elevation
  - TOA all-sky and clear-sky LW,SW, WN, and net radiative fluxes
  - Surface all-sky and clear-sky LW, SW, downwelling and net radiative fluxes
- SRBAVG2 Layer mean cloud properties for 4 pressure layers:
  - Mean cloud properties that are a combination of cloud retrievals from both MODIS and geostationary imagers
- SRBAVG3 Layer mean cloud properties for 4 pressure layers:
  - Mean cloud properties based solely on MODIS cloud property retrievals

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 Edition2D SRBAVG", "CERES Terra FM2 Edition2D SRBAVG, "CERES Aqua FM3 Edition2A SRBAVG" or "CERES Aqua FM4 Edition2A 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 Edition2-Rev1

The Edition2-Rev1 is applicable to all Aqua and Terra Edition2 SRBAVG parameters regardless of Edition2 letter. The CERES Science Team has approved a table of scaling factors for Terra and a table of scaling factors for Aqua which users should apply to the SRBAVG1 Edition2 parameters.

For the ***SRBAVG1 TOA SW Fluxes (Up)***, users should utilize 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 utilize 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 utilize 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. By June 2005, this darkening has reduced the average global all-sky SW flux measurements by 1.1 and 1.8 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 SRBAVG Edition2 append Rev1 to the product name, when referring to the SRBAVG Edition2 dataset. For example, Terra Edition2D SRBAVG product would be referred to as Terra Edition2D SRBAVG-Rev1.

Cautions and Helpful Hints

The CERES Science Team notes several **CAUTIONS** regarding the use of CERES SRBAVG data (applicable to both Terra Edition2D and Aqua Edition2A SRBAVG):

Applicable to CERES Edition2 SRBAVG Terra Edition2D and Aqua Edition2A only:

- As of December 2008 there are no plans to generate the Aqua Edition2A October 2004 SRBAVG product. 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.

- The Terra RAPS mode instrument based SRBAVG Ed2 "Total-sky SW flux - GEO" was computed with insufficient GEO/CERES matches during the SW normalization process. This caused a 0.5 Wm^{-2} global mean deficit and a ~ 4 Wm^{-2} regional monthly mean rms error. The "Total-sky SW flux - GEO" net flux is also effected. This error can be avoided by using the XTRK instrument GEO-product. There is a scheduled reprocessing of the Terra SRBAVG product to correct this error and should be available Summer 2008.

Applicable to all CERES SRBAVG Edition2 products (except Terra Edition2C and TRMM Edition2B):

The Terra GEO based cloud retrievals are used in the Aqua SRBAVG GEO product. There is no reprocessing of the GEO cloud retrievals based on the Aqua-MODIS calibration. The Terra and Aqua GEO cloud products are identical. However the GEO derived fluxes are normalized with Aqua CERES fluxes for the Aqua product and Terra CERES fluxes for the Terra product.

The SRBAVG "snow/ice percentage coverage" is not correct. To obtain the percentage, sum the 15th, 19th and 20th "Surface Type Percent Coverage" (IGBP surface types). The snow/ice percentage coverage is based on SSF-30, however when the footprint was considered overcast a coverage of 0% was returned and these were unfortunately also averaged into the monthly mean coverage.

The user should be aware that the CERES Edition2 Terra FM1 LW calibration has a 1% or 2.4 Wm^{-2} decrease per decade in the daytime - minus nighttime LW flux difference. This artifact represents a ~ 1Wm^{-2} per decade decrease in the long-term trend in SRBAVG LW TOA monthly mean fluxes. This artifact will be removed in the next release SRBAVG (Edition3) in early 2010.

The CERES Science Team has provided the following **HELPFUL HINTS** regarding the use of CERES SRBAVG Edition2 data:

- The **SRBAVG** product format and data archive.

  The SRBAVG products are in HDF format. The SRBAVG files may be accessed at (Langley DAAC CERES products). A subset of the SRBAVG products can be accessed on the GEWEX homepage. Monthly global plots of the SRBAVG parameters can be viewed on the CERES-TISA web site under SRBAVG comparisons.

- The **SRBAVG** product contains the 1° gridded monthly means of the **SSF** instantaneous parameters.
  1. Further information, cautions and accuracy of SRBAVG parameters that are not contained in this document can be obtained from the SSF Edition2 Data Quality Summary.
  2. The full list of parameters are contained in the SRBAVG CERES Data Product Catalog.
  3. The means, standard deviation and number of values used in the temporal and spatial grid averaging process are provided for each parameter.
  4. All footprints with a non-default LW and SW values are used as input to the SRBAVG.

- The **SRBAVG** parameters are divided into the following **products**.
  1. The **SRBAVG1** HDF files contain TOA and surface fluxes and are ~250MB/month.
     a. **TOA measured** total and clear-sky **shortwave reflected** (SW 0.2-5µm), albedo, outgoing longwave radiation (OLR) (LW 5-100µm), window (WN 8-12µm) and net (0.2-100µm) fluxes. The SRBAVG Edition2-Rev1 user applied revisions need to be applied to all SW and net fluxes.
     b. Regions with no clear-sky SSF footprints will have default clear-sky monthly fluxes. No attempt is made to fill in the missing regional clear-sky fluxes.
     c. The **incoming solar radiation** can easily be derived by dividing the SW by the albedo. CERES uses a solar constant of 1365 Wm^{-2}
     d. The **SW absorbed** can be computed by subtracting the SW (reflected) by the incoming solar radiation.
     e. **Surface parameterized** total and clear-sky SW, LW, WN downwelling and net fluxes. The SRBAVG Edition2-Rev1 user applied revisions need to be applied to all SW fluxes.
     f. CERES apriori land types, altitude and longwave emissivities are included as well as column precipitable water and aerosols.
  2. The **SRBAVG2** HDF files contain the **MODIS & GEO** cloud properties and are ~ 500MB/month.
     a. 4 layer **(Layer 1, high cloud, 300mb to 50mb; Layer 2, upper-mid, 500mb to 300mb; Layer 3, lower-mid, 700mb-500mb; Layer 4, low cloud, surface-700mb)** mean cloud properties that are a combination of MODIS and geostationary derived cloud retrievals. Not all MODIS cloud properties are retrieved with GEO. GEO day and night cloud properties are summarized.
  3. The **SRBAVG3** HDF files contain the **MODIS-only** cloud properties and are ~ 500MB/month.
     a. 4 layer **(Layer 1, high cloud, 300mb to 50mb; Layer 2, upper-mid, 500mb to 300mb; Layer 3, lower-mid, 700mb-500mb; Layer 4, low cloud, surface-700mb)** mean cloud properties based solely on MODIS retrievals. Currently there are 15 MODIS retrieved cloud parameters. The vertical aspect ratio is not retrieved in SRBAVG Edition2 and the values are set to default
  4. A **daily mean product** of SRBAVG parameters is **planned**. An **ISCCP_D2 like cloud type_product** of MODIS and GEO cloud property retrievals stratified by ISCCP's cloud classification (3 atmospheric layers and 3 optical depth bins) is also **planned**.

- The SRBAVG product contains the following temporal and spatial resolutions. All SRBAVG products are values given in local time.
  1. The SRBAVG processing is performed on a nested grid. This grid uses 1° equal-angle regions between 45°N and 45°S and maintains area consistency at higher latitudes. The SRBAVG product contains a complete 360x180 1° grid created by replication.
  2. All observed input parameters are placed into the appropriate day and local hour increment. If the month has 31 days there would be 744 hourly increments for the month. All values in the SRBAVG products are processed in local time.
  3. The non-observed hourly increments are estimated by interpolating between measurements
  4. The **regional means** are the average of all hourly increment values whether they are observed or temporally interpolated. Parameters with no observed values during the month are given default values in SRBAVG product.
  5. The **monthly hourly** (local time) means are derived from the average of all daily values for a given local hour increment. This represents the monthly diurnal cycle for each parameter.
  6. **Zonal means** are the average of all non-default regional values along a latitude band. Caution must be taken when using zonal means, where there are many regional default values. No spatial interpolation is performed in the SRBAVG product.
  7. The **global mean** is the area weighted average of all 180 zonal means. Zonal means, where all the regional values are default, are interpolated between neighboring zones. This interpolation occurs most frequently with SW flux near the polar night terminator. For SW flux the interpolation assumes constant albedo from the last available latitude. SW flux is calculated as the

product of this albedo with analytically computed monthly mean solar insolation.

- There are SRBAVG files for each of the 5 CERES instruments. The PFM is on TRMM, FM1 & FM2 are on Terra, and FM3 & FM4 are on Aqua. The Edition3 products will have a combined Terra and Aqua satellite product during the overlap time period.

- For a given month one instrument is usually in cross-track (XTRK), otherwise referred to as fixed azimuth plane scan (FAPS), and the other is in rotating azimuth plane scan (RAPS) scanning modes onboard the Terra and Aqua satellites. See examples of the satellite instrument scan modes.
  1. In **RAPS** mode the individual footprints are of varying resolution, are not equally spaced, and may not completely spatially sample a given 1° region. The spectral darkening of the transmissive optics is greater in RAPS mode than in XTRK. Both scan modes are processed in order to isolate calibration differences between the two instruments as well as the ADM differences derived from fixed and random viewing conditions.
  2. In **XTRK** mode the spatial distribution of footprints is relatively uniform. An additional test during XTRK scan mode is applied to allow only uniformly sampled regions as input in SRBAVG processing. Only a very small percentage of the regional fluxes are not used as input, due to default values of either LW or SW footprint level fluxes.
  3. It is recommended using FM1 to monitor multiyear global flux trends, since it was usually in XTRK mode and more stable than FM2. However for the GEO SW flux product the XTRK mode instrument is recommended, since there was an error discovered in the SW regional normalization processing code when the instrument was operating in RAPS mode. When monitoring short-term regional fluxes use the Recommended scan mode monthly table to determine the instrument in XTRK mode for the desired month.
  4. The CERES Instrument group maintains a CERES Operations in Orbit web page with the daily scan pattern of all CERES instruments.

- There are **3 types** of monthly **TOA fluxes** in the SRBAVG product. See the differences between the 3 categories of CERES monthly flux products. The CERES ERBE-like product is also discussed.
  1. The **Raw Data Average** provides simple averages of the observations on a monthly and monthly hourly time scales and **should not be considered accurate monthly means**, since they do not take into account the diurnal flux variation and are sampled only at the times of the Terra (10:30 AM LT) overpass. They are provided as means for the user to assess the adequacy of temporal sampling for each region.
  2. The **non-GEO Interpolation** provides monthly means based only on CERES 1° gridded fluxes from the Terra satellite. The Terra satellite is in a sun-synchronous orbit with a 10:30 AM equatorial crossing time. Most regions on the earth are sampled twice a day (generally once in daylight and once at night). Polar regions are sampled up to 14 times a day. **The non-GEO monthly product assumes constant meteorology between Terra measurement times (10:30 & 22:30 LT).** The non-GEO SW fluxes are interpolated using directional models of albedo as a function of solar zenith angle that are consistent with the TRMM-CERES ADM. The SW non-GEO monthly product assumes constant meteorology (cloud amount, optical depth, etc.) for the day based on the daytime Terra measurement. The LW non-GEO monthly product uses the same interpolation techniques employed on the ERBE-like product. Linear interpolation of the LW fluxes between measurements is used for all regions with the exception of interpolation using a simple half-sine fit during the day in land and desert regions to take into account diurnal heating.
     a. A **twilight correction** to the monthly mean SW flux for solar insolation from solar zenith angles greater than 90° has been included in Edition 2D. The magnitude of this correction varies with latitude and season. The maximum correction of <1.8 Wm^{-2} occurs at the poles during the equinoctial months of March and September. In general, the correction is < 0.5 Wm^{-2} and the global mean correction is 0.2 Wm^{-2} (Kato and Loeb 2003).
     b. The monthly mean SW TOA flux is calculated using an analytical derived value of the integrated solar insolation for the entire month. The mean albedo calculated from days with CERES observations is assumed to be valid for the month. The **SW analytical correction** is a recalculation of the SW flux that removes biases due to the unbalanced temporal sampling throughout the month.
  3. The **GEO Interpolation** provides monthly means that use **both the 3-hourly GEO derived (geostationary) and CERES fluxes** and cloud properties between 60°N and 60°S to take into account the diurnal variability of the region. The regions poleward of 60°N and 60°S replicate the non-GEO product. The remaining hourly fluxes are temporally interpolated using the same non-GEO methods. **There are significant regional differences between the GEO and the non-GEO products** where there are strong diurnal cycles, for example sub-tropical maritime stratus in subsidence zones and afternoon convection over land, and desert regions with large surface temperature amplitudes. See an example difference between non-GEO and GEO December 2002. The twilight correction and SW analytical correction are applied. **The SRBAVG GEO product is the most robust CERES TOA monthly mean flux product**.
     a. **Clear-sky SW flux is only calculated using the non-GEO method and the non-GEO flux is replicated in the GEO flux data record**. Since the variability in the SW flux is primarily caused by cloud variations, the benefit to clear-sky is minimal. The current GEO derived clear-sky SW fluxes cannot resolve diurnal variations of aerosols, land moisture, etc., due to shortcomings in the narrowband to broadband algorithm and inaccuracies in the GEO clear-sky mask.
     b. **SW fluxes over snow covered regions are computed using the non-GEO method**. The 2-channel GEO cloud retrievals are suspect over snow covered regions making scene identification difficult. The diurnal variability of clouds over snow has a small effect on the TOA SW flux since it is modulated primarily by a very bright surface.
  4. The **ERBE-like monthly mean fluxes are based on the ERBE algorithm and should be used when comparing with the 1985-1989 ERBE scanner product**, because the algorithm is constant between the ERBE and CERES-ERBE-like datasets. The ERBE-like dataset is available as the CERES ES-4 and ES-9 products and not included in the SRBAVG. See the differences between the 3 categories of CERES monthly flux products.

- **CERES surface fluxes** include SW, LW, and WN (Window) surface downwelling and net fluxes using two surface parameterization algorithms (Model A and B). **CERES does not measure the surface fluxes directly**; they are calculated using parameterizations based on CERES TOA fluxes, cloud properties, and GEOS atmospheric vertical model profiles. For each hourly increment, the surface flux is computed from the SRBAVG GEO time series of TOA fluxes, whether observed or interpolated, over the course of a month. The monthly statistics are then taken from the hourly surface fluxes, The SW analytical correction is applied to the SW surface daily fluxes. **There are no Model A all-sky algorithms and therefore all the model A all-sky fluxes are set to default**. The SSF and SRBAVG use the same algorithm to obtain surface fluxes. Further information on the Model A and B fluxes is located on the SSF Edition2 Data Quality Summary.

- The SRBAVG1 product contains the apriori regional IGBP surface type percentages, altitude, LW and WN emissivities. The monthly mean snow/ice percentage and GEOS atmospheric profile precipitable water are also included. The 0.63µm aerosol visible optical depth is the combined land and water based on (Edition 2) SSF-137 and 151. The 1.6µm aerosol visible optical depth is based on (Edition 2) SSF-154. The SRBAVG "snow/ice percentage coverage" is not correct. To obtain the percentage, sum the 15th, 19th and 20th "Surface Type Percent Coverage" (IGBP surface types). The snow/ice percentage coverage is based on SSF-30, however when the footprint was considered overcast a coverage of 0% was returned and these were unfortunately also averaged into the monthly mean coverage.

Accuracy and Validation

The validation of the SRBAVG Edition2 product given in this Data Quality Summary was performed on the first 3 years of Terra Edition2D SRBAVG (written in September 2006) and should be similar for the Aqua SRBAVG Edition2 product. Any generic SRBAVG reference in the Accuracy and Validation section is from the Terra Edition2D SRBAVG product.

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 fluxes 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 coincident MODIS and CERES measurements.
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 Terra 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 versus 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.

Using the MODIS imager as a calibration source has minimized inter-satellite differences. 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 Terra 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 SRBAVG GEO 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 SRBAVG GEO cloud properties are best compared from those measured during the day. The ISCCP daytime values are the mean of the 15 daytime cloud types (D2 parameters # 41d to 115d). The SRBAVG GEO values are means from the daytime 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, SRBAVG2 GEO and SRBAVG3 MODIS (non-GEO) 60°N to 60°S daytime monthly mean cloud amounts, optical depths, and temperatures are shown in Fig. 1. Individual monthly global difference maps are displayed at the CERES-TISA web site under SRBAVG & ISCCP comparisons.

The ISCCP and GEO March 2000 to February 2003 60°N to 60°S daytime cloud amounts are within 1.4% (Fig. 1a). The MODIS and GEO cloud amount difference is 2.8% 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 (Fig. 1b) 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 4.7° K colder than GEO (Fig. 1c). The ISCCP thin cirrus is much colder than GEO or MODIS. The GEO cloud temperature is 1.3° K warmer than MODIS and the monthly differences are very consistent. In general the ISCCP cloud properties are similar to the SRBAVG GEO product. Note the relative smoothness of the MODIS-GEO differences relative to the ISCCP-MODIS difference for all parameters. This smoothness reinforces the GEO cloud properties are consistent with MODIS.

Comparison of ERBE-like and SRBAVG Fluxes

There are several significant differences between the ES-4, SRBAVG non-GEO and SRBAVG GEO monthly fluxes. Many have been mentioned under Caution and Helpful Hints and difference between the 3 categories of monthly mean flux products. To evaluate the effects of the improved ADM and directional models, the ERBE-like, ES-4 and SRBAVG non-GEO global fluxes are compared. Individual monthly global difference maps are displayed at the CERES-TISA web 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.

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 is lower 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 are greater in the early morning than those estimated assuming a 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 LW difference changes seasonally ±1.5 Wm^{-2} and regional differences can be quite large especially over snow. The GEO LW 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 1.9 Wm^{-2} greater than ERBE-like (Fig. 2d). The seasonal ERBE-like/non-GEO difference varies from -3.1 to 0.5 Wm^{-2}. This is mainly due to differences in the identification of clear-sky over snow, which were 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. The SRBAVG Edition2-Rev1 user applied revisions have been implemented on the CERES ERBE-like, non-GEO, and GEO fluxes.

Table 3. TOA global 3-year flux means for CERES Terra Edition2D 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	98.5	96.7	97.8	100.1
NET	3.8	6.9	6.4	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 SRBAVG Edition2D-Rev1 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 Edition2 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 relatively 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; J Climate)
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)	6.9	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)	3.8	-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 Terra SRBAVG Edition2 non-GEO global Net flux is 6.9 Wm^{-2} versus a predicted range of 1.3 to 6.1 Wm^{-2}. The ERBE-like global net flux is 3.8 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 Terra CERES non-GEO, SW fluxes would be increased by a factor of (96.7 + 6.9 - 0.7) / 96.7 = 102.9 / 96.7 = 1.064. 96.7 is the FM1 SRBAVG Rev 1 non-GEO global average TOA SW flux from March 2000 through Feb 2003, 6.9 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 (98.5 + 3.8 - 0.7) / 98.5 = 101.6 / 98.5 = 1.031. 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.

Comparison of CERES and Other Global TOA Flux Datasets

The monthly global CERES SRBAVG GEO fluxes are used as reference and compared during 2000 to 2003 with the previously compared CERES ERBE-like and non-GEO fluxes in Fig 3. The SRBAVG GEO fluxes are also compared with other global datasets, which are generally known and publicly available. The other global datasets vary by the amount of observed or modeled input data to compute the TOA fluxes. Only the CERES project measures broadband TOA radiances directly. The differences between the 3 categories of CERES monthly product TOA fluxes have been previously explained. The GEWEX-SRB fluxes are based on narrowband to broadband from ISCCP radiances, GEOS-4 profiles, and ISCCP cloud properties. The ISCCP-FD fluxes are based on radiative transfer computations using TOVS profiles, and ISCCP cloud properties. NCEP-reanalysis and ECMWF-ERA40 are fluxes taken from Global Climate Models.

Part of the difference in the TOA fluxes can be attributed to the spectral range of the SW and LW flux between the datasets. The CERES instrument measures the SW flux (0.2-5µm) and the LW flux (5-100µm). CERES also assumes a solar constant of 1365 Wm^{-2}. Other datasets have differing spectral ranges and solar constants. No attempt has been made to normalize the fluxes. The comparison of the global net flux may be premature with the data presented here. The objective of this comparison is not to explain the differences, but to highlight the differences between the various products

Comparison of CERES and Other Global Surface Flux Datasets

The monthly global CERES SRBAVG surface fluxes are used as a reference and compared during 2000 to 2003 with the datasets utilized in the TOA comparisons in Fig. 4. The ISCCP-FD surface fluxes are based on radiative transfer computations using TOVS profile and ISCCP cloud properties. The NCEP-reanalysis and ECMWF-ERA40 are surface fluxes taken from Global Climate Models. The all-sky and clear-sky surface monthly mean fluxes of GEWEX-SRB, GEWEX-SRB-QC, ISCCP-FD, NCEP-reanalysis, ECMWF-ERA40 are compared with CERES-SRBAVG during 2000 to 2003 are shown in Figure 4. The GEWEX-SRB uses the *Lazlo Pinker* and *Fu-Liou* radiative algorithm to compute the SW and LW surface fluxes respectively, using GEOS profiles and ISCCP cloud properties. The **GEWEX-SRB-QC** uses the *LPSA* and *LPLA*, which are the same as the CERES-SRBAVG Model B algorithms, to compute SW and LW surface fluxes respectively, using GEOS profiles and ISCCP cloud properties. No discussion is presented on the differences other than to let the user note the differences between the datasets. It must be mentioned that the CERES does not measure the surface fluxes directly.

Validation of GEO-derived SRBAVG TOA SW and LW Fluxes

Introduction

3-hourly GEO derived broadband fluxes are introduced into the SRBAVG GEO dataset to account for the diurnal cycle not sampled by either the Terra (10:30 LT) or Aqua (1:30 LT) orbits in order to produce a climate quality regional and global monthly flux means. In order to implement the GEO fluxes, the GEO-derived fluxes must uphold the CERES instrument calibrations. Also, consistency between GEO and CERES TOA fluxes, cloud properties and surface fluxes should be maintained. For this edition (2D) the GEO-SW fluxes were obtained by implementing a SW regional normalization technique. This technique regressed instantaneous matched gridded fluxes from CERES and GEO over a month from the 5x5 surrounding regions. This technique eliminated all biases as a function of cloud amount, solar and view zenith angles as well as regional dependencies. The GEO-LW fluxes are identical to those values in Edition2 and employ regional instantaneous normalization. All major aspects of the derivation of GEO fluxes have been examined. These aspects include GEO imager calibration, GEO cloud retrievals, narrowband-broadband conversion, ADMs and directional models, twilight correction, and GEO-CERES normalization.

To ensure that the GEO derived fluxes were consistent with CERES and are not the cause of the net global imbalance in the SRBAVG GEO product, the GEO derived fluxes were validated using the following methods. The GEO normalized to Terra interpolated fluxes were compared with Aqua measured fluxes at Aqua observation times. One would expect better agreement with GEO than with the non-GEO product. Regional monthly mean GEO Terra Aqua differences were compared with their respective non-GEO means. The GEO visible (0.65 µm) and IR (11µm) radiances were artificially modified by ± 5%, well beyond the calibration accuracy of the GEO radiances, to test the effectiveness of the GEO-CERES normalization. The differences using 1-hourly and 3-hourly GEO data were evaluated. The GEO surface fluxes were compared with monthly means from 36 surface stations distributed across the globe. The GEO fluxes and associated cloud properties were compared for consistency against radiative transfer calculations. A principal component analysis was performed on the regional monthly GEO means to facilitate identifying any GEO artifacts. The GEO derived SW directional models were compared with the CERES-TRMM models. Each of the validation procedures is outlined below. An overall statistical summary is also given.

Aqua/Terra Comparisons

In the Aqua Terra comparisons, the flux observations from one satellite are used as an independent data set to test the interpolated fluxes from the other and presented in Fig. 5. The difference between the measured and interpolated fluxes represents at the measured time the collective error from GEO calibration, GEO cloud properties, NB-BB conversion, ADMs, and GEO-CERES normalization, assuming minimal Aqua Terra CERES flux differences (Fig. 5a). The Terra/Aqua time sampling difference can be as little as an hour at 60°N and 6 hours at 60°S. Instantaneous flux differences between 60°N to 60°S during July 2002 and February 2003 were computed for both GEO and non-GEO products. The SRBAVG Edition2-Rev1 were not applied. The LW results were separated between day and night, since day and night differences tend to cancel each other out. Statistics are based on the mean from Terra interpolated (compared with Aqua measurements) and Aqua interpolated results. The instantaneous GEO RMS differences are 35.4 Wm^{-2} (14.6%) (Fig. 5c), 11.4 Wm^{-2} (4.6%) (Fig. 5e), and 11.4 Wm^{-2} (4.7%) (Fig. 5g), for SW, LW day, LW night respectively, which is a 50% reduction from non-GEO for both SW and LW. The magnitude of the 60°N-60°S mean SW bias for non-GEO was > 2% for ocean and land, but for GEO was < 1.1% (Fig. 5c). Globally the ocean and land biases offset each other. The LW GEO biases are comparable to the non-GEO except for a slight improvement in GEO over daytime deserts. There is a possible negative bias (~1.0% instantaneous) over deserts for GEO LW-night. Overall, the 60°N-60°S mean instantaneous SW and LW GEO differences are within 1%.

The Aqua/Terra monthly mean fluxes were also tested for consistency between 60°N to 60°S during July 2002 and February 2003. The Edition2-Rev1 corrections were applied to both Aqua and Terra monthly mean fluxes. The monthly mean regional GEO RMS differences are 4.1 Wm^{-2} (4.4%) and 2.3 Wm^{-2} (1.0%) for SW (Fig. 5h) and LW (Fig. 5i) respectively, a 60% and 30% respective reduction from non-GEO. The monthly mean 60°N-60°S SW GEO bias differences are 0.7 Wm^{-2} (0.7%) and are less than non-GEO by 50% (Fig. 5h). Although there is no discernable improvement (reduction in the bias) in the monthly mean 60°N-60°S LW GEO over non-GEO the bias is -0.4 Wm^{-2} (-0.2%) (Fig. 5i). The LW GEO fluxes at night over desert may be biased (-0.2% monthly). The Terra Aqua comparisons conclude that the GEO regional diurnal cycle error is 50% instantaneously and 30% monthly of that from the non-GEO product, while maintaining a bias of less than 1% (Fig. 5j).

GEO Calibration Sensitivity

The GEO calibration sensitivity study measured the effectiveness of the GEO-CERES normalization. Without GEO-CERES normalization errors in the GEO calibration would directly impact the GEO fluxes, and ultimately the accuracy of the CERES monthly mean fluxes. GEO imager radiances are calibrated against MODIS, with an accuracy of 3-5% in the VIS and about 1% in the IR. The GEO visible channels do not have onboard calibration. In this test, the GEO radiances (first calibrated against MODIS) were artificially altered by ±5%, after which the GEO cloud analysis and GEO derived fluxes were reprocessed. This would represent a change of more than twice the expected calibration error. Modifying the GEO radiances also alters the cloud property retrievals. The monthly mean regional flux differences of (VIS+5%) - (VIS-5%) and (IR+5%) (IR-5%) were compared to assess a 10% change in calibration during July 2002 (Terra-based fluxes) (Fig. 6). The total-sky flux global bias difference is <0.1% (<1% regional RMS) for SW (Fig. 6b). SW regional differences can exceed 2% in limited areas. Areas of deep convection and at northern latitudes are affected. The all-sky LW (Fig. 6c) and clear-sky SW (Fig. 6d) bias and RMS differences are negligible. The clear-sky LW bias is -0.93 Wm^{-2} or 0.35% mainly due to IR calibration errors. The IR+5% case modified the cloud amount and thereby the LW clear-sky fluxes and causing a systematic bias. For the global mean flux, the GEO-CERES normalization removes any sensitivity to the GEO calibration.

GEO Sampling Sensitivity

Currently, GEO-derived fluxes are based on 3-hourly GEO derived data. Although 1-hourly data is available, the inclusion of this data set is quite large. In order to justify the inclusion of hourly data there must be a significant improvement in monthly mean regional flux compared with the 3-hourly GEO flux. Just as important, there should be no global mean flux differences between the 1-hour and 3-hour datasets. The monthly mean all-sky regional fluxes were produced for both the 1-hourly and 3-hourly resolution GEO datasets for December 2002 (Fig. 7). The most significant SW regional differences occurred primarily in the glint regions (Fig. 7b). In convective regions the LW differences were noisier than elsewhere, and the only geographic features occurred over the Sahara and Tibet (Fig. 7c). The all-sky global flux bias difference is <0.1% for both SW and LW. The SW and LW RMS are 2.6 Wm^{-2} (2.5%) and 1 Wm^{-2} (0.4%) respectively. The 3-hourly GEO dataset sufficiently captures the regional diurnal cycle when compared with 1-hourly GEO.

Surface Flux Comparison

The ground site surface flux data is one of the few independent high-resolution broadband datasets available for comparison with CERES. The surface fluxes used in this study are available at the CERES ARM Validation Experiment (CAVE) website using ARM, SURFRAD, CMDL, and BSRN quality controlled surface radiometer networks. SRBAVG surface fluxes are only available on the GEO product. The CERES SRBAVG all-sky monthly surface fluxes are calculated with Model-B LPSA/LPLA (Gupta model). The LPSA SW surface fluxes are highly dependent on the TOA fluxes as well as cloud amount and optical depth. The LPLA LW surface fluxes are mainly a function of GEOS-4 lower atmospheric profiles and GEO/MODIS satellite derived cloud base heights. Although surface LW fluxes are independent from the TOA it is still worthwhile to check their accuracy. The GEO product surface fluxes are computed using both measured and interpolated TOA fluxes.

The comparisons were performed for 32 globally distributed (Fig. 8a) stations from March 2000 to February 2003. The ground-based monthly mean surface fluxes are computed from 15-minute mean measurements of which 75% of all 15-minute bins had to be present. The SRBAVG monthly fluxes were inconsistent with ground-based measurements at two Antarctic 2 stations: Syowa and Georg von Neumeyer. It isn't fully understood why these Antarctic stations don't match well. This could be caused by the fact that ground-based measurements are point measurements and not necessarily representative of 1 x1 degree regions, such as coastal and mountainous sites. After the exclusion of the 2 inconsistent sites, the SW and LW bias is 7.3 Wm^{-2} (3.9%) and 0.5 Wm^{-2} (0.2%) (SRBAVG-ground) and the corresponding RMS is 21.1 Wm^{-2} (11.3%) and 9.7 Wm^{-2} (3.0%) respectively (Fig. 8c).

The ground-based fluxes were then compared with instantaneous CERES-SSF footprint (20km nominal) Model B (SOFA) fluxes using the same LPSA/LPLA models. The comparison used the same ground site station fluxes with 63 months of Terra data from March 2000 to May 2005. The same two Antarctic sites were excluded. For the SSF surface footprint data, 1-minute averages were used. The SW and LW bias is

3.3% and -0.6% and the corresponding RMS is 15.0% and 7.4% respectively (Fig. 8d). The SW bias is ~3.5% for both SRBAVG and SOFA. The SW bias is large but consistent. We expect larger RMS errors because it is an instantaneous comparison. The monthly SRBAVG surface (Model B) regional and ground fluxes are within the bias and RMS errors derived from instantaneous CERES footprint Model B SOFA fluxes.

Comparison of GEO BB Fluxes with Radiative Transfer Calculations

To check the consistency between the fluxes, cloud properties, and atmospheric inputs, the computed TOA flux based on the MODIS/GEO cloud properties and GEOS atmospheric profiles from a radiative transfer model is compared to the measured flux. Future CERES-SYN (synoptic) products will include radiative transfer calculations. The CERES SARB (Surface and Atmospheric Radiation Budget) working group responsible for the SYN product has a tentative release set for the spring 2006. The radiative flux calculations are based on the Fu-Liou 2-stream SW, 4-stream LW, correlated-k algorithm. A preliminary SYN product was computed for July 2002 for an equatorial latitude band. Differences between CERES and model derived fluxes from MODIS cloud properties were compared with GEO and model derived fluxes from GEO cloud properties. The differences should be similar if there is consistency between GEO and CERES fluxes and MODIS and GEO cloud properties.

Preliminary results show in Fig. 9b the instantaneous SW bias differences to be 3.6% and 4.5% for GEO and CERES respectively and the corresponding RMS is 18.0% and 10.8%. Although the GEO and CERES bias differences are 3.6% and 4.5%, respectively, they are significantly large. It is unclear what is causing the bias in SW comparison, but it is consistent with SARB results presented at the November 2005 CERES Science Team Meeting, (PDF, page 12). GEO SW fluxes underestimate the modeled fluxes for large fluxes. The CERES fluxes have the same tendency but less pronounced. Some differences are due to 2-channel GEO and 4-channel MODIS cloud retrievals. The instantaneous LW bias differences are shown to be <0.1% and 0.3% for GEO and CERES respectively and the corresponding RMS is 3.6% and 2.5% (Fig. 9c). Again, the bias differences are similar, although the difference between GEO and MODIS cloud emissivity is apparent. Only daytime GEO LW measured and modeled differences are used, since the GEO emissivity is set to one at night due to the limitation of the single IR channel retrieval. A more thorough study will be performed as soon as the SYN product becomes available. Preliminary radiative transfer model results show consistency between GEO and CERES fluxes and MODIS and GEO cloud properties (Fig. 9d).

Principal Component Analysis

The introduction of GEO derived fluxes could cause systematic regional biases over long time periods, due to the unchanging GEO viewing geometry. In order for CERES to be used as a climate-type data set, the GEO-derived fluxes cannot contain any GEO artifacts. A Principal Component Analysis is used to identify potential GEO viewing geometry artifacts. Empirical Orthogonal Functions (EOF) were computed for 3 years (March 2000 to February 2003) of regional monthly mean LW and SW all-sky fluxes and demonstrated in Fig. 10b,c,d,e. The first 10 EOF from GEO and non-GEO are compared (Fig. 10b,c). The non-GEO product is used as a reference since it would not contain any GEO artifacts. Upon analyzing the data it was found the first 6 SW (Fig. 10b,c) and first 10 LW (Fig. 10d,e) EOF for non-GEO and GEO were identical. The corresponding explained variances were 91.1% and 85.4%, respectively. Only after the 6th SW EOF did any differences occur in either the time series coefficients or in the regional variations (Fig. 10c). Although the remaining 4 SW EOF were different, no viewing GEO artifacts were found. This would imply that including the diurnal signal in the long-term monthly CERES datasets is not crucial. No GEO artifacts were identified in the principal component analysis.

GEO-Derived Directional Models

Since the GEO SW fluxes were normalized during TERRA observation times (10:30LT), it is important to evaluate the SW regional normalization technique at other times. Since directional models are a function that relates albedo to solar zenith angle (SZA), the GEO derived models can be compared with those derived from CERES. This comparison tests the consistency of the SZA dependence with each of the 5 (satellite) GEO derived directional models with the corresponding CERES-TRMM direction models. The GEO directional models were derived from 3-hourly GEO fluxes normalized with CERES-Terra fluxes during March 2000 to February 2003. The SZA functionality is robust across latitudes and local time. The ocean directional models are similar across GEO-satellites indicative of proper GEO calibration. Most differences can be attributed to GEO and MODIS cloud property differences for a given scene. Qualitatively, the GEO directional models are in very good agreement with the CERES models after normalization.

CERES-GERB Comparison

The truest test of 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 15-minute full disc (nominal 60 km footprints) fluxes. Currently there are issues with the GERB data including CERES/GERB calibration differences and spectral correction uncertainties. It is expected the GERB fluxes will be released shortly. GERB will ultimately provide the best independent high-resolution data set for testing the interpolation of CERES data.

Direct Integration of Fluxes

Since Terra is in a sun-synchronous 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.

Summary of Validation Techniques

The comprehensive validation activities support that there were no systematic biases introduced when incorporating GEO fluxes into the SRBAVG product. The Terra Aqua instantaneous validation concludes that the GEO product reduces the regional diurnal flux error by 50%

over the non-GEO product, which is based entirely on the CERES fluxes. Table 5 summarizes the RMS (regional) and bias (global) differences in percent.

Table 5: Summary of GEO Flux Validation Tests

	SW		LW	
(%)	**Bias**	**RMS**	**Bias**	**RMS**
Terra-Aqua (instantaneous) (Terra int/Aqua int)	0.4/1.0	14.4/14.6	0.2/0.7 -0.5/-0.3	4.6/4.6 day 4.3/4.7 night
Terra-Aqua (monthly)	0.7	4.4	-0.2	1.0
Surface (monthly)	3.9	11.3	0.2	3.0
SARB (instantaneous)	3.6	18.0	<0.1	3.6
GEO Calibration (monthly)	<0.1	<1.0	<0.1	<1.0
1 vs 3 hourly (monthly)	<0.1	2.5	<0.1	0.4
EOF	No GEO artifacts			
GEO directional model	Consistent with CERES			

Future Validation Studies

Future validation efforts will focus on estimation of temporal interpolation errors using high temporal resolution GERB data from the 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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2. Minnis, P., L. Nguyen, D. R. Doelling, D. F. Young, W. F. Miller, and D. P. Kratz, 2002a: Rapid calibration of operational and research meteorological satellite imagers, Part I: Evaluation of research satellite visible channels as references. *J. Atmos. Oceanic Technol*., **19**, 1233-1249.

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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

There is a scheduled reprocessing of the Terra and Aqua SRBAVG products to remove the error in the SW normalization algorithm while the

CERES instrument was in RAPS mode. The reprocessing should be available summer 2008 and will be named either Terra Edition2E SRBAVG or Aqua Edition2B SRBAVG. Daily means of the SRBAVG1 products will also be given in the reprocessing. An ISCCP like cloud type product of MODIS and GEO cloud property retrievals stratified by ISCCP's cloud classification (3 atmospheric layers and 3 optical depth bins) is also scheduled for summer of 2008.

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 SRBAVG Edition2 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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