CERES SRBAVG TRMM-PFM-VIRS Edition2B Data Quality Summary

Investigation:	**CERES**
Data Product:	**Monthly TOA/Surface Averages (SRBAVG)**
Data Set:	**TRMM**
Data Set Version:	**Edition 2B**

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

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

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Nature of the SRBAVG Product

The Monthly TOA/Surface Averages (SRBAVG) archival data 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 basis. 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 VIRS cloud property retrievals
  - Mean cloud properties that are a combination of cloud retrievals from both VIRS and geostationary imagers

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

Cautions and Helpful Hints

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

- Users should be aware that the Edition 2B 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.
- 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 SRBAVG, it is limited to 48° in crosstrack mode.
    2. ERBE-like fluxes were derived using angular distribution models (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 nonGEO SW fluxes are interpolated using directional models of albedo as a function of solar zenith angle that are consistent with the new CERES ADM. This will cause additional differences with ERBE-like monthly means that used directional models based on the ERBE 12 scene types.
- The low inclination of the TRMM orbit and the scanning characteristics of the CERES and VIRS instruments combine to produce poor temporal sampling patterns. The observing time of CERES TRMM precesses through 24 hours of local time every 46 days. The combination of the ascending and descending nodes provides a sampling of each local time in 23 days at latitudes near the equator. At more poleward latitudes, the full 46-day period is necessary to sample the entire diurnal cycle. This results in uneven sampling of daytime and nighttime hours for many regions over the course of a month. Temporal sampling is also affected by the scanning patterns of the CERES and VIRS instruments. The CERES TRMM instrument scans in the RAP mode every third day. The RAP scanning mode slightly reduces the numbers of regions observed by CERES. Every 15th day, CERES operates in alongtrack scanning mode. Spatial sampling is poor in this mode, and these data are not processed for the SRBAVG thereby eliminating 2 days of data each month. Finally, the VIRS instrument scans to a maximum viewing zenith angle of 48°. Since VIRS cloud properties are necessary for a flux to be defined for a CERES footprint, this greatly reduces the CERES swath width on the SSF. As a result, the number of hours with a LW observation for a 1° region varies from 14 - 95/month for the SRBAVG compared with 45-160/month for ERBE-like. Monthly SW sampling is more uneven owing to the precession-related issues. Half of the regions viewed by CERES have fewer than 18 SW observations per month. More details and illustrations of the sampling patterns can be found in the TRMM sampling document (PDF). For TRMM, users should consider using seasonal (3 month) averages instead of monthly to minimize sampling errors.
- 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 Edition 2B. The magnitude of this correction varies with latitude and season. The maximum correction of >1.8 W/m^2 occurs at the poles during the equinoctial months of March and September. In general, the correction is less than 0.5 W/m^2 and the global mean correction is 0.2 W/m^2. 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. Adding GEO data helps 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 nonGEO clear-sky SW flux is replicated in the GEO SW flux data record.
- For some months, there is no GEO data for the entire month over certain regions (in particular, there is no GEO data between longitudes 60 - 90° E in 1998). For these regions, the GEO monthly means are filled with the nonGEO values.
- The values labeled as global mean flux should not be considered valid for the entire globe. TRMM only samples data for latitudes between latitudes 40°N and 40°S. Global mean SW flux is calculated using a combination of sampled latitudes and polar latitudes where the solar insolation is known to be zero for the entire month.
- The SW Model A surface fluxes on the Edition 2B SSF were calculated improperly due to an error in the aerososl optical depths used as input. This has been corrected on the Edition 2B SRBAVG.
- The SRBAVG will contain monthly means of all parameters currently available on the SSF product. Users should consult the 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 VIRS 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 TOA and surface fluxes. The interpolation involves several steps:

1. Narrowband GEO radiances are calibrated relative to the VIRS imager.
2. A broadband radiance is computed using a narrowband-broadband relationship based on matched VIRS 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 an 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 VIRS 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 VIRS imager using the methods of Minnis et al. 2002a & b. The GEO retrievals are a subset of the multiple channel VIRS algorithms and they share common input maps of surface emissivity and reflectance and atmospheric data.

Some differences will remain between VIRS 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 VIRS/GEO cloud property difference is presented in Table 1. The comparison is based on VIRS 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 TRMM data and for each GEO satellite. Table 1 includes the average over all 9 months and all satellites.

Table 1. Comparison of VIRS and GEO cloud properties.

	Cloud Fraction		Optical Depth		Cloud Temperature (K)	
	VIRS	**GEO**	**VIRS**	**GEO**	**VIRS**	**GEO**
Ocean Day	0.60	0.63	6.7	5.4	275.5	271.5
Ocean Night	0.60	0.55			266.5	275.9
Land Day	0.54	0.67	10.1	7.0	268.7	264.5
Land Night	0.51	0.55			251.9	266.9

In general, the cloud fractions agree well, with the exception of land daytime retrievals where GEO overestimates cloud amount by 0.13. This occurs primarily at large viewing zenith angles, but the cause of this difference is unclear and is being investigated. The optical depth compare well, with the expected low bias for GEO due to the larger pixels (4 km vs 2 km for VIRS) 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 VIRS-only cloud product for these parameters.

Inter-satellite differences have been minimized by using the VIRS imager as a calibration source. Table 2 presents the VIRS-GEO cloud fraction difference for GOES, GMS, and METEOSAT averaged over the entire 9-month TRMM period. On average, the VIRS-GEO differences are consistent within 0.02 among the various satellites. Month-to-month variations of these differences exhibit similar magnitude, which suggests that calibrating GEO imagers relative to VIRS is an effective means of producing consistent cloud retrievals from the various imagers.

Table 2. VIRS - GEO cloud fraction difference for each GEO satellite

	GOES 8/9/10	METEOSAT 5/6/7	GMS 5
Ocean Day	0.03	0.01	0.01
Ocean Night	-0.05	-0.06	-0.06
Land Day	0.13	0.13	0.14
Land Night	0.02	0.04	0.04

An estimate of flux error due to GEO imager calibration errors is shown in Table 3. A month of data (February 1998) was processed using the VIRS-derived GEO calibration. The month was rerun 4 times with 4 different changes to the imager calibration. The first case increased the visible (0.6 µm) channel radiance by 5%. Case 2 decreased the visible radiance by 5%. Cases 3 and 4 increased and decreased the IR (10.8 µm) radiance by 5%. The mean and standard deviation of the change in monthly mean TOA fluxes from the nominal case are summarized in Table 3. The results clearly demonstrate that normalization of the fluxes to the CERES observations is effective in removing calibration errors. For the LW flux, a 5% calibration error has an insignificant effect on the monthly mean of both the total-sky and clear-sky flux. For SW, a 5% error results in less than a 1% effect on flux. The calibration of the visible data using VIRS should provide calibrations to within 3% (Minnis et al 2002). A small effect on the SW flux occurs in changes to the IR calibration due to changes in cloud property retrievals resulting in changes in ADM selection.

Table 3. Mean and (standard deviation) flux difference from nominal calibration case (W/m^2)

	Mean Flux	IR + 5%	IR - 5%	Vis + 5%	Vis - 5%
Total-sky LW	257.6	0.01 (0.08)	-0.01 (0.08)	0.00 (0.00)	0.00 (0.00)
Total-sky SW	99.3	-0.04 (1.35)	0.54 (3.10)	0.94 (1.31)	-0.94 (1.31)
Clear-sky LW	284.7	-0.29 (0.69)	0.30 (0.92)	0.01 (0.27)	-0.02 (0.26)

Direct Integration of Fluxes

Since TRMM is in a temporally precessing orbit, the temporal interpolation of SW fluxes can be tested using a comparison of the SRBAVG monthly means with an average of observed fluxes compiled over complete precession cycles. This direct integration approach is analogous to the tests used to test the accuracy of the CERES ADM (see CERES SSF Data Quality Summary for details). The period May-June-July 1998 corresponds to exactly 2 TRMM 46-day precession cycles. SW fluxes were sorted by solar zenith angle and averaged over 10° latitude by 10° longitude grid boxes. The resulting albedo vs. solar zenith angle curves were then integrated using the theoretical solar insolation weighting for the 3-month period. The resulting 92-day mean TOA albedo was then compared with the weighted average of SRBAVG for the 3 months for each 10° region. The results are shown in Table 4 for cases using the SRBAVG nonGEO, SRBAVG GEO, and a special case that used the ERBE 12 scene type directional models. The mean and regional rms differences are provided as both absolute and percent difference (in parentheses). All 3 cases reveal that the interpolation techniques are producing albedo estimates that are within 0.6% of the direct integration values. The new directional models used in the SRBAVG processing are also reducing the rms errors from 4.8% to 2.7% from the old ERBE models.

These results demonstrate that both the GEO and nonGEO interpolation methods are producing unbiased estimates of the monthly mean albedo.

Table 4. SRBAVG - Direct Integration Albedo Comparison

30N - 30S	nonGEO (CERES DRM)	GEO (CERES DRM)	GEO (ERBE DRM)
Mean Albedo Difference	0.001 (0.4%)	0.002 (0.6%)	-0.001 (-0.4%)
RMS Difference	0.006 (2.6%)	0.006 (2.7%)	0.011 (4.8%)

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 recently launched METEOSAT Second Generation satellite will provide such an excellent data set. However, the GERB data were not available in the TRMM 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. Table 5 presents a comparison of instantaneous flux derived through interpolation of CERES observations compared with 30-minute averages of surface observations. These data are from the ARM extended facilities in Oklahoma from July 1998. For reference, the CERES-surface flux differences for time-matched observations over the full 9-month TRMM period are also provided (see the SSF Data Quality Summary for the source of these data). The LW mean and rms values for the interpolated data compare very favorably to the instantaneous values. The SW values are higher, but this is due in part to the higher solar insolation in July compared with the entire period. Overall, the instantaneous errors are reasonable, but the study needs to be extended to the entire TRMM period.

Table 5. Mean and (rms) CERES-surface downward flux difference over the ARM Southern Great Plains Extended Facilities from July 1998 (W/m^2)

	Interpolated fluxes	Matched observations
SW Model A Clear	35.9 (63.4)	14.0 (28.1)
SW Model B Clear	24.8 (57.0)	9.6 (61.9)
SW Model B All-sky	19.8 (116.0)	9.2 (61.2)
LW Model A Clear	2.5 (14.8)	-3.0 (24.1)
LW Model B Clear	-5.4 (14.4)	-4.9 (20.8)
LW Model B All-sky	9.4 (19.4)	-2.3 (20.9)

Monthly mean all sky surface fluxes have been compared with monthly means of surface-based measurements from the global BSRN sites. A preliminary study using only the months of February and July 1998 resulted in mean CERES-BSRN differences of 3.4 W/m^2 (1.7%) with a standard deviation of 8.9 W/m^2 (4.7%) for downward SW Model B all-sky flux. The corresponding differences for LW Model B all-sky flux are a mean of 1.8 W/m^2 (0.5%) and a standard deviation of 10.3 W/m^2 (2.8%). These are well within the expected accuracy for the surface flux estimates.

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; estimation of temporal interpolation errors using high temporal resolution GERB data from the recently launched METEOSAT Second Generation satellite; and more extensive comparisons of SRBAVG monthly mean surface fluxes with surface sites and the Surface Radiation Budget (SRB) project.

References

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

Kato, S., and N. G. Loeb, 2002: Twilight irradiance reflected by the Earth estimated from Clouds and the Earth's RadiantEnergy System (CERES) measurements, submitted to J. Climate.

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.

Minnis, P., L. Nguyen, D. R. Doelling, D. F. Young, W. F. Miller, and D. P. Kratz, 2002b: Rapid calibration of operational and research meteorological satellite imagers, Part II: Comparison of infrared channels. *J. Atmos. Oceanic Technol*., **19**, 1250-1266.

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

At this time, there are no scheduled revisions of the CERES TRMM Edition2B SRBAVG data. 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 TRMM Edition2B 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.

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

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

Feedback 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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