CERES ES8 Terra Edition3
Data Quality Summary

Investigation:	**CERES**
Data Product:	**ERBE-like Instantaneous TOA Estimates (ES8)**
Data Set:	**Terra (Instruments: FM1, FM2)**
Data Set Version:	**Edition3**

The purpose of this document is to inform users of the accuracy of this data product which has been determined by the CERES Team. This document briefly summarizes key validation results, provides cautions where users might easily misinterpret the data, provides helpful links to further information about the data product, algorithms, and accuracy, gives information about planned data improvements, and, finally, 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 information for 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 ES8 Product:

This document discusses the Terra **E**RBE-like **S**cience Product **[ES8]** data set version **Edition3**. Additional information is in the Description/Abstract Guide. The files in this data product contain one day (24 hours) of filtered and unfiltered radiances, top-of-the-atmosphere (TOA) fluxes, and scene identification. Each radiance and its associated viewing angles are located in colatitude and longitude at a reference level of 30 km. The unfiltering algorithm produces radiances for three spectral bands for each measurement point or footprint: the longwave (LW) band measures energy emitted by the Earth's surface and atmosphere predominantly from wavelengths >5 microns, the shortwave (SW) band measures reflected sunlight primarily from wavelengths <5 microns, and the window (WN) band measures energy emitted mostly from the Earth's surface over the wavelength range from about 8 microns to about 12 microns. Radiances are converted to fluxes at the TOA for the SW and LW bands. For the WN band, only filtered and unfiltered radiances are recorded on this product.

The data are organized in time of observation. The three principal scan modes are the Fixed Azimuth Plane (FAP) mode, the Rotating Azimuth Plane (RAP) mode and the Along-Track mode. In all cases, the instrument scans across the Earth with views of space on either side which gives a full Earth view. The FAP mode produces uniform area sampling while the RAP mode produces angular sampling of the radiances.

A full list of parameters on the ES8 is contained in the CERES Data Product Catalog (PDF) and a full definition of each parameter is contained in the ES8 Collection Guide.

When referring to a CERES data set, please include the satellite name and/or the CERES instrument name, the data set version, and the data product. Multiple files which are identical in all aspects of the filename except for the 6 digit configuration code (see Collection Guide) 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 Edition3 ES8" or "CERES Terra FM2 Edition3 ES8."

Processing Updates in Current Edition

The CERES Edition3 data product is based on a completed in-depth reanalysis of all CERES instrument calibration information collected up to this point. The primary goal of this edition is to provide the most accurate and consistent data product to the users by removing all known instrument related artifacts from all four CERES instruments on Terra and Aqua spacecraft. The corrections implemented in the CERES Terra Edition3 BDS and ERBE-Like ES8 products consist of:

- Corrections for ground to flight beginning-of-mission spectral response function and radiometric gains calibration coefficients.
- Establish a common radiometric scale for all CERES instruments using Flight Model 1 (FM1) as the reference.
- Corrections for on-orbit derived changes in radiometric gains calibration coefficients based on the on-board calibration sources.
- Corrections for on-orbit darkening on the Short wavelength portion of the spectral response functions

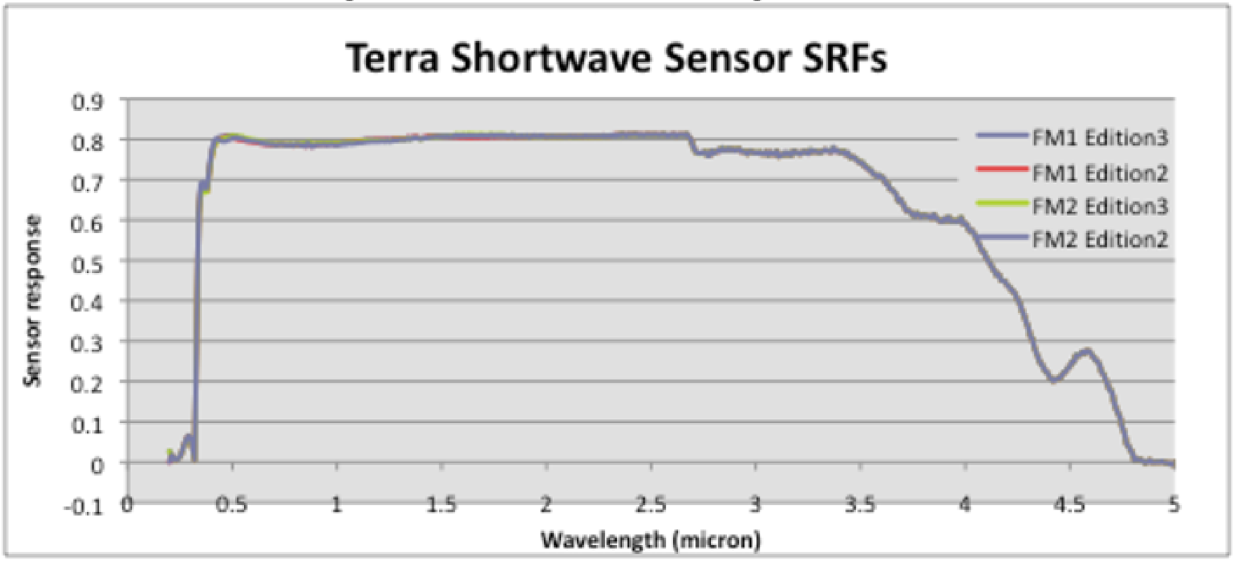
A brief discussion of these corrections is given below. Additional information can be found in the following CERES science team meeting presentation: CERES FM1-FM4 Edition3 Calibraion Update (PDF).

Beginning-of-Mission Correction

Measurements from the pre-launch calibration test data were re-examined to determine the optimal Spectral Response Function (SRF) for CERES sensors. This was accomplished by revaluating the component Silver measures from different coating runs and assessing the impact of shortwave reference source (SWRS) spectral throughput on band-pass filters used in the determination of gains and SRF. Additional analysis of Total sensor measurements with the Fourier Transform Spectrometer (FTS) were used to determine the SRF in the longwave region that predominately measures emitted thermal data. Figure 1 shows the pre-launch SRF used in both the CERES shortwave and total sensor, for both Edition2 and Edition3 data product. A reanalysis of the sensor performance using on-board calibration sources during pre-launch calibration tests was performed. Results were compared to response changes between ground and start-of-mission calibrations. Table 1 shows the comparison results in the ground to flight Sensor Response Changes for both Edtion2 and Edition3 product.

Table 1: Comparison of Edition2 and Edition3 Ground to Flight Changes in CERES/Terra Sensor Radiometric Gains

	FM1 (%)		FM2 (%)	
	Edition2	**Edition3**	**Edition2**	**Edition3**
Total	0.20	-0.13	0.12	-0.21
Window	0.48	0.40	1.3	1.61
Shortwave	-0.26	-0.50	0.16	-0.01



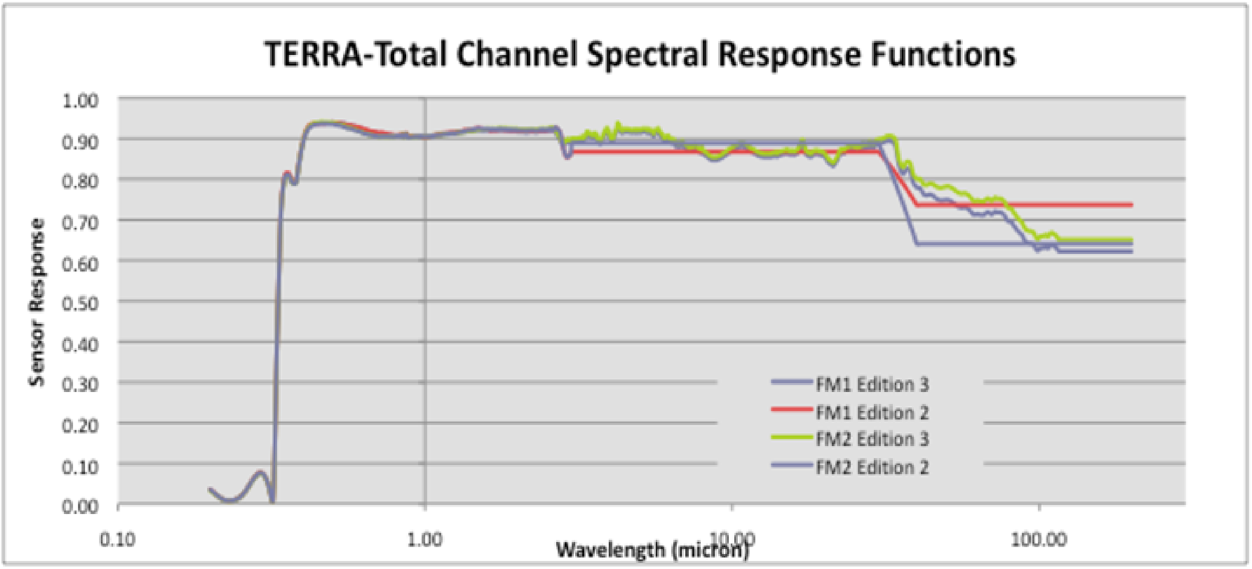


Figure 1: CERES/Terra (FM1 and FM2) Edition2 and Edition3 spectral response function for both shortwave (top) and total (bottom) sensor

Common Radiometric Scaling Correction

Using the new beginning-of-mission gains and spectral response an adjustment was made to place Flight Model (FM) 2 to be on the same radiometric scale as the reference Flight Model 1. A comparison of unfiltered all-sky radiances with matched geometry of measurements, using a Viewing Zenith Angle (VZA) < 60° and averaging over a 1x1 degree grid resulted in the following CERES sensor scaling factors in Table 2:

Table 2: Edition3 Radiometric Scaling Factors

	Shortwave	Window	Total	Total (<3 µm)
FM1	n/a	n/a	n/a	n/a
FM2	0.08%	0.2%	0.28%	-0.22%

- Positive Factor is a drop in SRF yielding a rise in radiances.
- Negative Factor is a rise in SRF yielding a drop in radiances.

A comparison of Edition2 and Edition3 at-launch all-sky global flux values for March 2000, based on ERBE-like ES8 Nadir-only data, using the beginning-of-mission corrections and the scaling factors above is shown in Table 3. In general, the Edition3 at-launch values for SW, LWday, and LWnite are higher than those from the Edition2 data by 0.05 to 0.8%, depending on instrument Flight Model number and flux parameters.

Table 3: Comparison of Edition2 and Edition3 all-sky global mean for March 2000

	FM1			FM2		
	Edition3 (Wm^{-2})	Edition2 (Wm^{-2})	Ed3-Ed2 (%)	Edition3 (Wm^{-2})	Edition2 (Wm^{-2})	Ed3-Ed2 (%)
LWday	230.62	228.72	0.8%	230.44	229.80	0.28%
LWnite	224.7	223.86	0.38%	224.60	223.52	0.49%
SW	256.36	256.24	0.05%	256.6	256.09	0.2%

On-orbit Radiometric Gains Correction

The CERES sensors on-orbit radiometric stability is primarily monitored through the change in the sensor gain during the course of the mission. For edition3, the gains are averaged for the month and a 5-month running mean centered on the current month is obtained in order to reduce the noise in the monthly averaged gains. Figure 2 shows the on-orbit gain changes normalized to the start of the mission for the all three sensors on FM1 and FM2 through October 2012.

The total sensor gain from FM1 and FM2 show a rise from the beginning of the mission of between 0.6 and 0.8%, respectively. The yearly seasonal variations are clearly seen in the responses of FM2. The FM1 *total* sensor shows roughly a linear rise in its gain. The shortwave sensors from FM1 and FM2 show negligible change. The window sensor gain shows an upward trend for FM1. The gain of the window sensor on FM2 shows a downward trend initially and then rises.

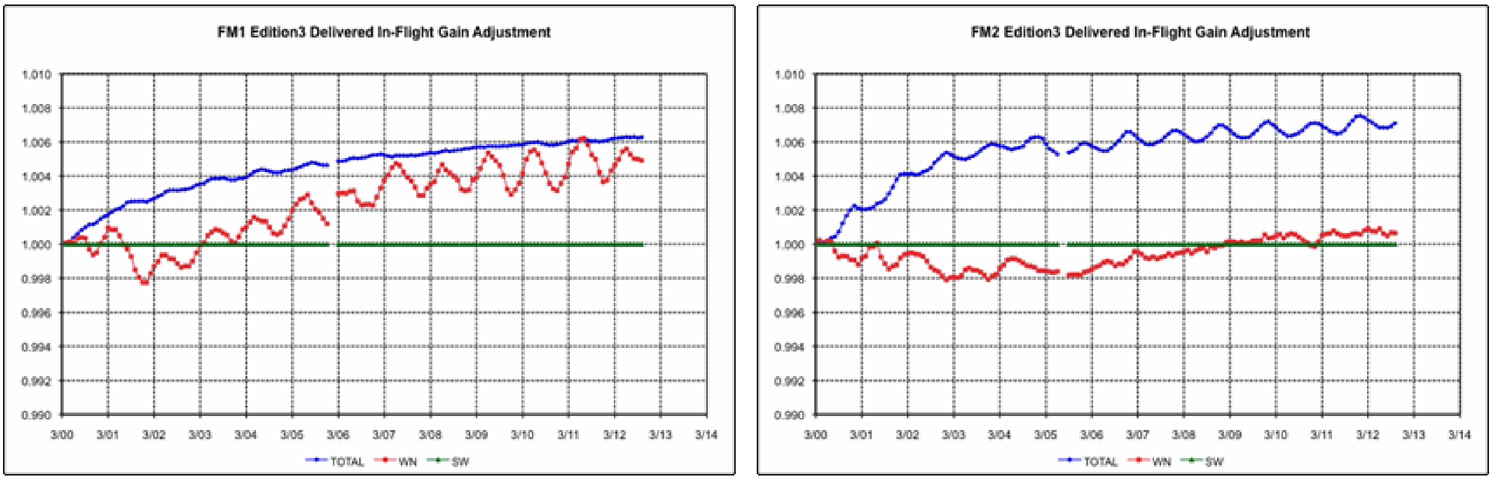
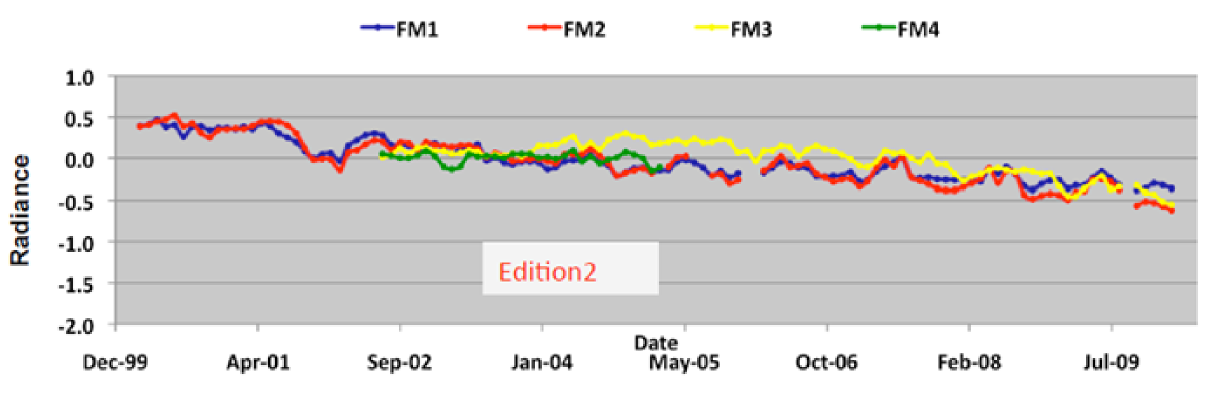


Figure 2: CERES/Terra FM1 and FM2 Edition3 ES8 Gain Correction

On-orbit Spectral Response Function Correction

The CERES Terra shortwave and total sensors had experienced significant on-orbit spectral darkening in the reflected solar spectral regions during early part of its mission due to exposure to sunlight when the CERES instruments were operating in the FAP or RAP mode. In addition, this spectral darkening effect also increases with decreasing shortwave wavelength with the largest effect occurring for blue scene. Since the daytime CERES longwave data is determined by subtracting the shortwave measurements from the total measurement, this on-orbit spectral darkening of shortwave and total sensors also aliased into daytime CERES longwave values. This on-orbit spectral degradation feature is most clearly shown as a decreasing trend in the time series of day minus night longwave difference. A special on-orbit spectral response function correction is developed for the Edition3 data to account for this spectral darkening with time. Figure 3 shows a comparison of day minus night longwave difference for both CERES Edition2 data (without on-orbit spectral correction) and CERES Edition3 data (with on-orbit spectral correction). The large negative trend in day minus night longwave differences found in Edition2 data has been eliminated in the new Edition3 data.



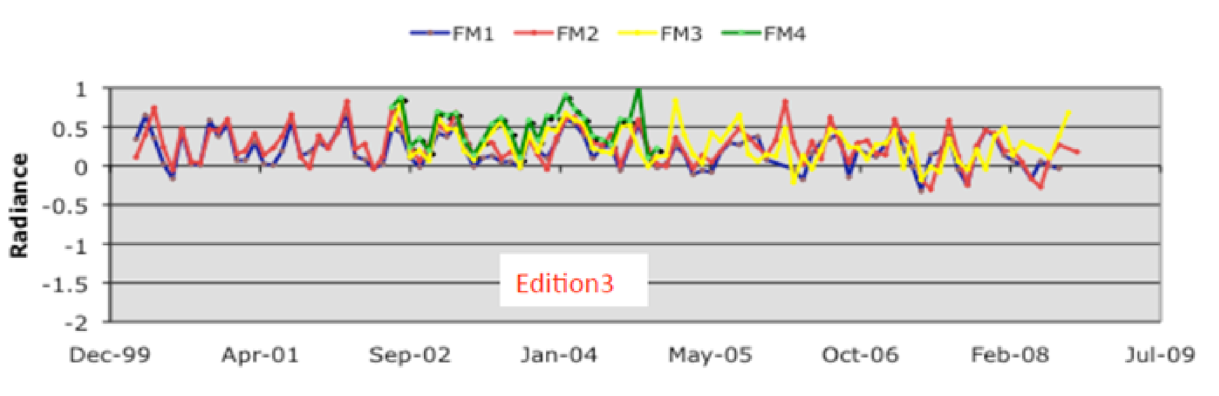


Figure 3: Time series of nadir-only day minus night unfiltered all-sky longwave radiance differences for 20N to 20S region as a function of CERES instrument (FM1 to FM4) and time for Edition2 (top) and Edition3(bottom) data.

Data Accuracy Table

The ES8 products contain estimates of instantaneous filtered radiance, unfiltered radiance, TOA flux, and scene type. The nature of an estimate is that it is uncertain with a bias error and a random error above the bias which can be measured by its standard deviation. Thus, an understanding of the uncertainty in an instantaneous estimate must consider both biases and standard deviations. Often the uncertainty is given in terms of the RMS error which includes both the bias and standard deviation.

Uncertainties in the filtered radiances are given in Table 4. The total (TOT) channel errors are given separately for night and day since daytime TOT contains both shortwave and longwave radiance while nighttime contains only longwave. The filtered radiances are determined from the instrument counts by multiplying by a gain. If this gain is in error, then the filtered radiances appear to be biased. The measurements are also subject to random measurement noise. All of these errors are combined and given as RMS errors.

Table 4: Uncertainty of Filtered Radiances

		Systematic Bias Error (Accuracy)			Mean Zero Random Error Standard Deviation (Precision)		Instantaneous RMS error
Instrument Channel	**Typical Value[a] $Wm^{-2}sr^{-1}$**	**Instrument Requirements[b] 1 std dev**	**Ground Cal. Gain error[c] 3 std dev**	**Instrument Drift over 6 months**	**Instrument Requirements[b] 3 std dev**	**Instrument Noise[d] 1 std dev**	
SW	45	1.0%	1.0%	0%	1%	0.3%	0.45%
TOT-day	125	0.5%	0.5%	0%	1%	0.1%	0.19%
TOT-night	70	0.5%	0.1%	0%	0.5%	0.1%	0.11%
WN	4.6[e]	0.3 $Wm^{-2}sr^{-1}$	1.0%[f]	0%	-	0.5%	1.0%

a. January 12, 1998, TRMM
b. Lee et al., *J. Atmos. Oceanic Technol*, **13**, 1996
c. Estimated from validation studies
d. Determined from space view
e. $Wm^{-2}sr^{-1}\mu m^{-1}$
f. See the CERES BDS Terra Edition3 Quality Summary

Uncertainties in the unfiltered radiances are given in Table 5. The unfiltered radiances are linearly related to the filtered radiances by coefficients which are denoted "Spectral Correction Coefficients" (SCC). These are mean coefficients and introduce random error. The nighttime unfiltered LW radiance is determined from the TOT filtered channel radiance at night. The daytime longwave, however, is derived from the TOT, SW and WN filtered radiances.

Table 5: Uncertainty of Unfiltered Radiances

Spectral Band	Typical Value[a] $Wm^{-2}sr^{-1}$	Spectral Correction Bias Error	Spectral Correction Random Error 1 std dev	Instantaneous RMS error
SW	60	0	0.4%	0.6%
LW-day	85	0	0.1%	0.2%
LW-night	80	0	0.1%	0.15%
WN	6.4[b]	0	0.6%	1%

a. January 12, 1998, TRMM
b. $Wm^{-2}sr^{-1}\mu m^{-1}$

Uncertainties in the TOA fluxes are given in Table 6. The fluxes are derived by multiplying radiance by π and dividing by an anisotropic factor from the Angular Distribution Models (ADM). These ADMs are mean models and introduce random error which is the dominant error for flux.

Table 6: Uncertainty of TOA Flux

Spectral Band	Typical Value[a] Wm^{-2}	ADM Bias Error[b]	ADM Random Error[c] std dev	Instantaneous RMS error
SW	210	1.0%	12%	12.1%
LW-day	265	0.5%	5%	5.0%
LW-night	250	0.5%	5%	5.0%

a. January 12, 1998, TRMM
b. Suttles, et al., *J. Appl. Meteor.*, **31**, 1992
c. Wielicki, et al, *Bull. Amer. Meteorol. Soc.*, **76**, 1995

Differences between CERES and the ERBE Scanner

1. The resolution of CERES-Terra is 20 km at nadir, and the resolution of ERBE-ERBS is 40 km at nadir so that the surface area observed from ERBS is 4 times larger than the area observed from CERES-Terra.
2. The nominal scan mode for ERBE was crosstrack to provide good area coverage. CERES has three scan modes. The Fixed Azimuth Plane (FAP) scan mode is similar to the ERBE scan mode. The Rotating Azimuth Plane (RAP) scan mode is used by CERES to provide angular coverage to construct Angular Distribution Models. The along-track scan mode is used for validation of CERES instantaneous fluxes.
3. The longwave channel on ERBE was replaced by an 8 to 12 micron window channel on CERES.
4. The data rate on ERBE was 30 measurements per second. The data rate on CERES is 100 measurements per second.
5. The ERBE S8 data product was about 36 MB in size. The CERES ES8 data product is about 290 MB.
6. ERBS has an orbital inclination of 57°. Terra is in a 10:30 a.m. sun-synchronous orbit.
7. ES8 uses a different unfiltering algorithm (Loeb et al., 2001) than ERBE S8 (Green and Avis, 1996).

Cautions When Using Data

There are several cautions the CERES Team notes regarding the use of the CERES Terra Edition3 ES8 data:

- CERES-Terra is observing more clear sky than ERBE due in part to the difference in footprint size. The resolution of CERES-Terra is 20 km at nadir and the resolution of ERBE-ERBS is 40 km at nadir so that the surface area observed by ERBS is 4 times larger than the area observed by CERES-Terra. For March 2000 in the tropics (±20° ; latitude), ERBS observed about 17% clear sky and CERES-Terra observed about 23% clear sky. ERBS also observed about 17% overcast and CERES-Terra observed about 16% overcast. It is not fully understood why the overcast for CERES-Terra decreased instead of increasing like clear sky.
- The ERBE scene identification algorithm (Maximum Likelihood Estimator, MLE) in conjunction with the ERBE angular distribution models (ADMs) are known to erroneously produce albedo growth from nadir to the limb. The ERBE ADMs are probably insufficiently limb-darkened in longwave and insufficiently limb-brightened in shortwave. The CERES-Terra fluxes also have these biases with viewing zenith angle.
- Some applications of the ES8 data will need to make the distinction between Fixed Azimuth Plane (FAP), Rotating Azimuth Plane

(RAP) and along-track scan data. All 3 scan modes can occur on the same day so that the data parameter "Scanner Operation Flag Word" (see ES8 Collection Guide) must be examined for each data record to properly identify the scan mode for each footprint.
- Data users are strongly urged to examine the flags for each footprint in order to determine if the data for that footprint are good or bad.

Validation Study Results

The validity of the filtered radiances, unfiltered radiances, TOA fluxes, and identified scene types has been examined with various validation studies and quality checks.

Unfiltered Radiances

The unfiltered radiances are linear functions of the filtered radiances where the coefficients are the Spectral Correction Coefficients (SCC). The SCCs are based on the spectral response of the instrument channel, S^i_λ, where λ is wavelength and i = SW, TOT, WN for shortwave, total, and window channel, respectively. The S^i_λ has been measured as part of the instrument calibration and characterization. The SCCs are based on a database of spectral radiances from typical surfaces, such as ocean, land, desert, snow, and cloud. The methodology used in producing Terra Edition3 unfiltered radiances is the same as that used in the CERES TRMM Edition2 ES8 product and is outlined in Loeb et al., (2001). This method differs from that used on ERBE. To unfilter SW radiances, the ERBE unfiltering algorithm used a theoretical ratio between unfiltered and filtered radiances defined at various angles in overcast and cloud-free conditions over ocean, land, desert and snow. Interpolation between these theoretical ratios was used to determine coefficients under partly and mostly cloudy conditions. The ERBE approach has been shown to produce large errors when applied to CERES due to the differences between the CERES and ERBE spectral response functions (see Loeb et al., 2001).

Theory

To estimate uncertainties in instantaneous unfiltered radiances for each channel, the unfiltering algorithm was used to estimate radiances from approximately 10,000 theoretical test cases representative of clear and cloudy conditions over ocean, land and snow. The test calculations were determined from MODTRAN + DISORT radiative transfer calculations at high spectral resolution and represent a wide range of cases.

Errors in instantaneous SW unfiltered radiances from both FM1 and FM2 were found to be <0.5% (relative). By comparison, uncertainties in PFM instantaneous unfiltered SW radiances were generally <1%. The reduction in error was particularly marked for clear oceanic scenes because the FM1 and FM2 spectral response functions are flatter than PFM at wavelengths between 0.3-0.4 microns.

In contrast, the theoretical results revealed slightly larger uncertainties in unfiltered LW radiances from FM1 and FM2 compared to PFM. For most scenes, FM1 and FM2 uncertainties remain less than 0.4% (relative) compared to 0.2% for PFM. However, for extremely cold clouds (e.g. deep convective clouds), uncertainties in FM1 and FM2 unfiltered radiances can reach 1% for both daytime and nighttime conditions.

In the WN channel, all three instruments showed very small uncertainties in unfiltered radiances (<0.2%) for all scenes.

Observations

Coincident FM1 and FM2 unfiltered radiances from four days in March 2000 were compared. Both instruments operated in cross-track scan mode during these days and thus viewed the same scenes from the same viewing geometry. Results were stratified by scene type and solar zenith angle.

Unfiltered radiances measured by FM1 and FM2 on Terra are also compared to radiances measured by the CERES Proto-Flight Model (PFM) on TRMM. The measurements are matched in time, space and viewing geometry to provide comparisons independent of angular and diurnal models. Comparisons of SW radiances require both the zenith and the relative azimuth angles to be matched. This match is obtained by rotating the scanning plane of one of the instruments to scan parallel to the other instrument. For LW and nighttime WN comparisons, we match the zenith angles only. Daytime WN radiances are compared for matched zenith and relative azimuth because heating of land surfaces can vary with azimuth.

Observations from the two instruments are considered coincident if made within +/-15 minutes of each other. Spatial resolution discrepancy between FM1/FM2 and PFM is reduced by averaging the radiances on a 1-deg grid. Zenith angles are matched to +/-5 deg and relative azimuth angles are required to be within +/-10 deg. Any differences found between FM1/FM2 and PFM can be attributed to uncertainties in either radiometric calibration or spectral unfiltering process described above. A more detailed description of this comparison method can be found in Haeffelin et al. (2001).

DCC SW Albedo and 3-Channel Checks

A 3-channel intercomparison of Tropical Deep Convective Clouds was used in conjunction with direct measurements of Tropical DCC SW Albedo to assess both the consistency of the SW channels and SW portion of the total channels and to rigorously determine which channel is responsible for any apparent inconsistencies (i.e. SW or SW/TOT). Additionally these studies determine whether any inconsistencies are changing with time or remaining stable. Further details on these two studies may be found in Priestley et al. (2000) and Currey and Green (1998).

References

1. Currey, C. and Green, R., 1998,"Validation of the CERES shortwave measurements over desert and cloud scenes", *Am. Meteor. Soc.*, 10th conference on atmospheric radiation, 567-570.
2. Green, R. N., and L. M. Avis, 1996: Validation of ERBS Scanner Radiances. *J. Atmos. and Ocean. Tech.*, **13**, 851-862.
3. Haeffelin, M., B. Wielicki, J. P. Duvel, K. Priestley, M. Viollier, 2001: "Inter-calibration of CERES and ScaRaB Earth radiation budget datasets using temporally and spatially collocated radiance measurements". *Geophysical Research Letters*, **28**, 167-170.
4. Loeb, N. G., K. J. Priestley, D. P. Kratz, E. B. Geier, R. N. Green, B. A. Wielicki, P. O'R. Hinton, and S. K. Nolan, 2001: Determination of unfiltered radiances from the Clouds and the Earth's Radiant Energy System (CERES) instrument. *J. Appl. Meteor.* **40**, 822-835.
5. Priestley, K. J., and co-authors, 2000: Post launch Radiometric Validation of the Clouds and the Earth's Radiant Energy System (CERES) Proto-Flight Model on the Tropical Rainfall Measuring Mission (TRMM) Spacecraft through 1999, *J. Appl. Meteor.*, **39 (12)**, 2249-2258, December 2000.

Expected Reprocessing

The current "Edition3" data are expected to be reprocessed into a validated/archived/publishable Edition4 after the Terra mission is completed.

The CERES Team expects to reprocess the ERBE S8 data product for ERBS, NOAA-9, NOAA-10, and the ES8 data product for TRMM in the future. The purpose of the reprocessing is to generate a consistent, long-term climate record, where advances in the data calibration and processing will be incorporated to remove former errors. The major contribution to reprocessing will be an improved set of Angular Distribution Models (ADMs) based on CERES data and the MLE as the scene identifier. Other improvements include more accurate scanner offsets for NOAA-9 and NOAA-10, correction of the low daytime longwave flux for NOAA-9, drift corrections, and a possible resolution correction for CERES so that the CERES and ERBE footprints will be similar in size.

Referencing Data in Journal Articles

The CERES Team has gone to considerable trouble to remove major errors and to verify the quality and accuracy of these data. **Please provide a reference to the following paper when you publish scientific results with the 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 data from the Langley Data Center are used in a publication, **we request the following acknowledgment be included:**

> "These data were obtained from the Atmospheric Science Data Center at NASA Langley Research Center."

The Data Center at Langley requests a reprint of any published papers or reports or a brief description of other uses (e.g., posters, oral presentations, etc.) of data that we have distributed. This will help us determine the use of data that we distribute, which is helpful in optimizing product development. It also helps us to keep our product-related references current.

Feedback

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

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