CERES ES8 Aqua Edition3
Data Quality Summary

Investigation:	**CERES**
Data Product:	**ERBE-like Instantaneous TOA Estimates (ES8)**
Data Set:	**Aqua (Instruments: FM3, FM4)**
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, and 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.

The deep space calibration maneuvers planned for early in the Aqua mission continue to be delayed, resulting in larger uncertainties in the CERES Aqua scan angle dependent offsets (zero-level counts) used in the level 1b BDS data product. BDS level 1b data is the input to the ES8 data product. The early unavailability of deep space scans puts a larger uncertainty on the CERES archived data products, and the BDS Aqua Edition3 archived Data Quality Summary gives an estimate of this uncertainty. Both the BDS and ES8 Aqua Edition3 Data Products use offsets determined using ground calibration data. While CERES/TRMM/Terra showed consistency of ground and in-space determined offsets of 1 digital count or better (roughly 0.5% or better) further indirect analysis as well as final deep space scans are required to confirm this level of consistency on the Aqua instruments.

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Nature of the ES8 Product:

This document discusses the Aqua **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. The current data set may be referred to as "CERES Aqua FM3 Edition3 ES8" or the "CERES Aqua FM4 Edition3 ES8."

Please note that there is no CERES Aqua FM4 Edition3 ES8 data after March 29, 2005 due to CERES FM4 shortwave sensor failure. However, users can continue to obtain CERES Aqua Edtion3 ES8 data through the FM3 instrument after that date. The CERES FM3 instrument continues to operate till the present time.

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 Aqua 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 Corrections

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/Aqua Sensor Radiometric Gains

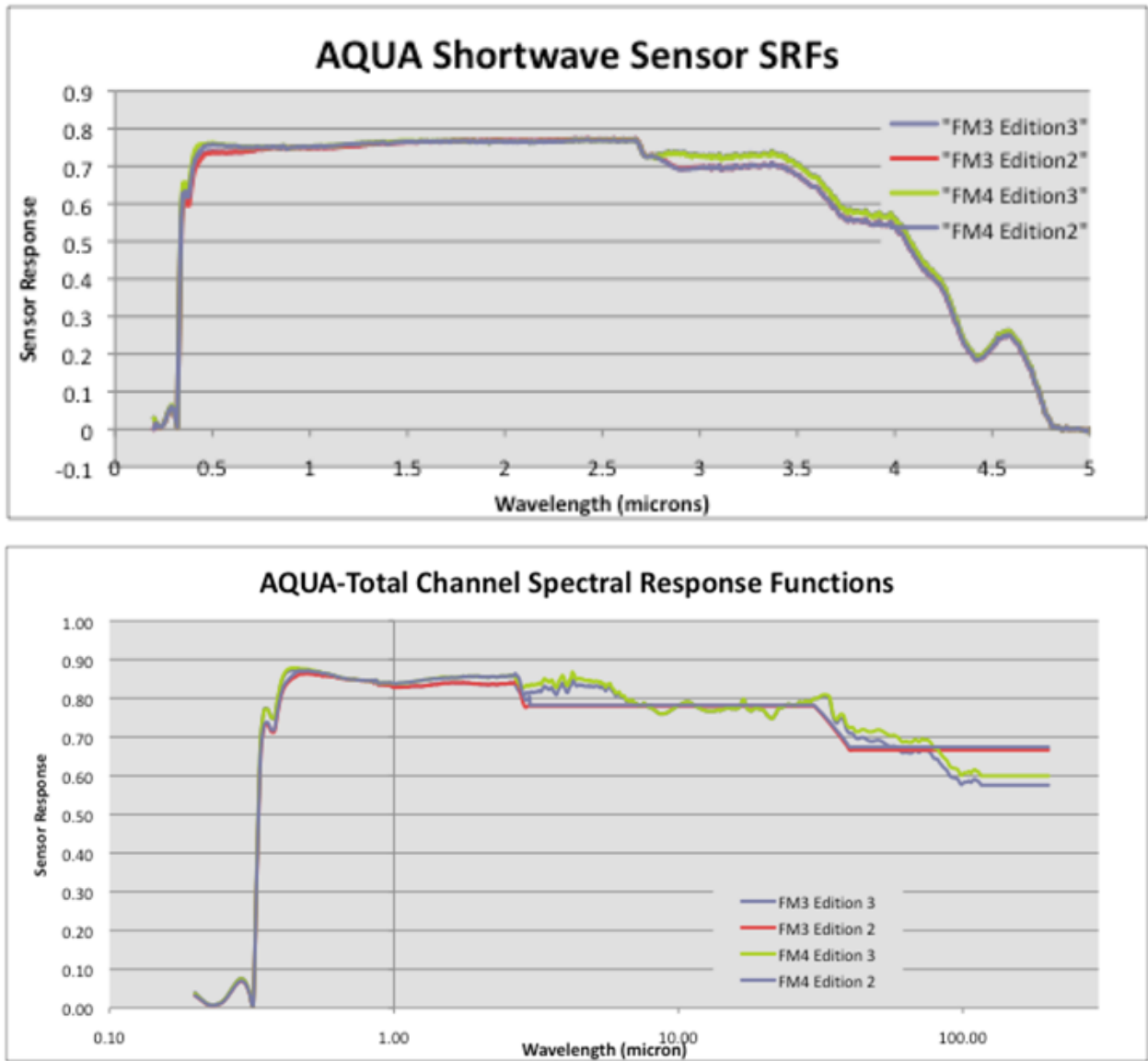|	FM3 (%)		FM4 (%)	
	Edition2	Edition3	Edition2	Edition3
Total	< 0.2	0.08	< 0.2	1.05
Window	n/a	-0.06	n/a	0.96
Shortwave	0.3	-8.00	0.3	1.96

Figure 1: CERES/Aqua (FM3 and FM4) Edition2 and Edition3 spectral response function for both shortwave (top) and total (bottom) sensor

Common Radiometric Scaling

Using the new beginning of mission gains and spectral response an adjustment was made to place Flight Models 3 and 4 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)
FM3	1.6%	n/a	0.26%	2.7%
FM4	2.0%	0.36%	0.52%	2.7%
• 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 July 2002, 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 0.18 to 1.36%, depending on instrument Flight Model number and flux parameters.

Table 3: Comparison of Edition2 and Edition3 all-sky global mean for July 2002

	FM3			FM4		
	Edition3 (Wm^{-2})	Edition2 (Wm^{-2})	Ed3-Ed2 (%)	Edition3 (Wm^{-2})	Edition2 (Wm^{-2})	Ed3-Ed2 (%)
LWday	250.44	248.46	0.80	250.35	249.19	0.46
LWnite	218.48	217.96	0.24	218.39	217.99	0.18
SW	239.88	237.10	1.17	240.14	236.92	1.36

On-orbit Radiometric Gains Correction

The CERES sensors' 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 FM3 and FM4 through October 2012.

The *total* sensor gain from FM3 show a rise from the beginning of the mission of between 0.6-0.8% and FM4 show a change of about 1%. The yearly seasonal variations are clearly seen in the responses of FM3 and FM4. The *shortwave* sensors from FM3 and FM4 instruments show about 0.5% and 0.6% change, respectively. However, the *shortwave* sensor on FM4 became non-operational in March 2005. On the FM3 instrument, the *window* gain shows a downward trend of about 0.5%. The FM4 instrument *window* sensor gain shows a slight linear upward trend of about 0.2%.
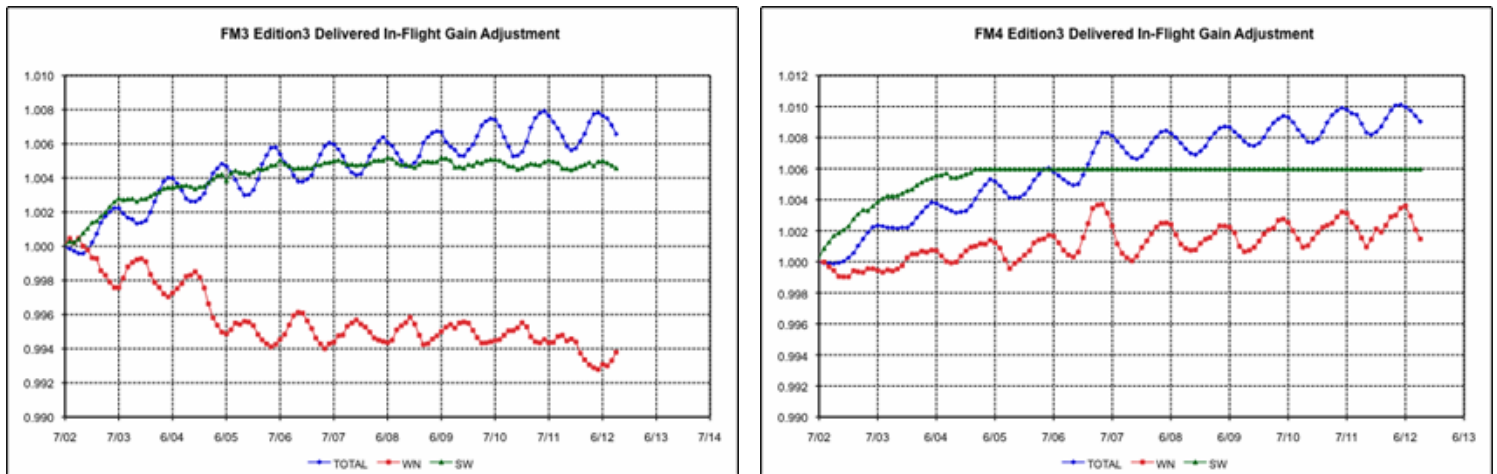
Figure 2: CERES/Aqua FM3 and FM4 Edition3 ES8 Gain Correction

On-orbit Spectral Response Function Correction

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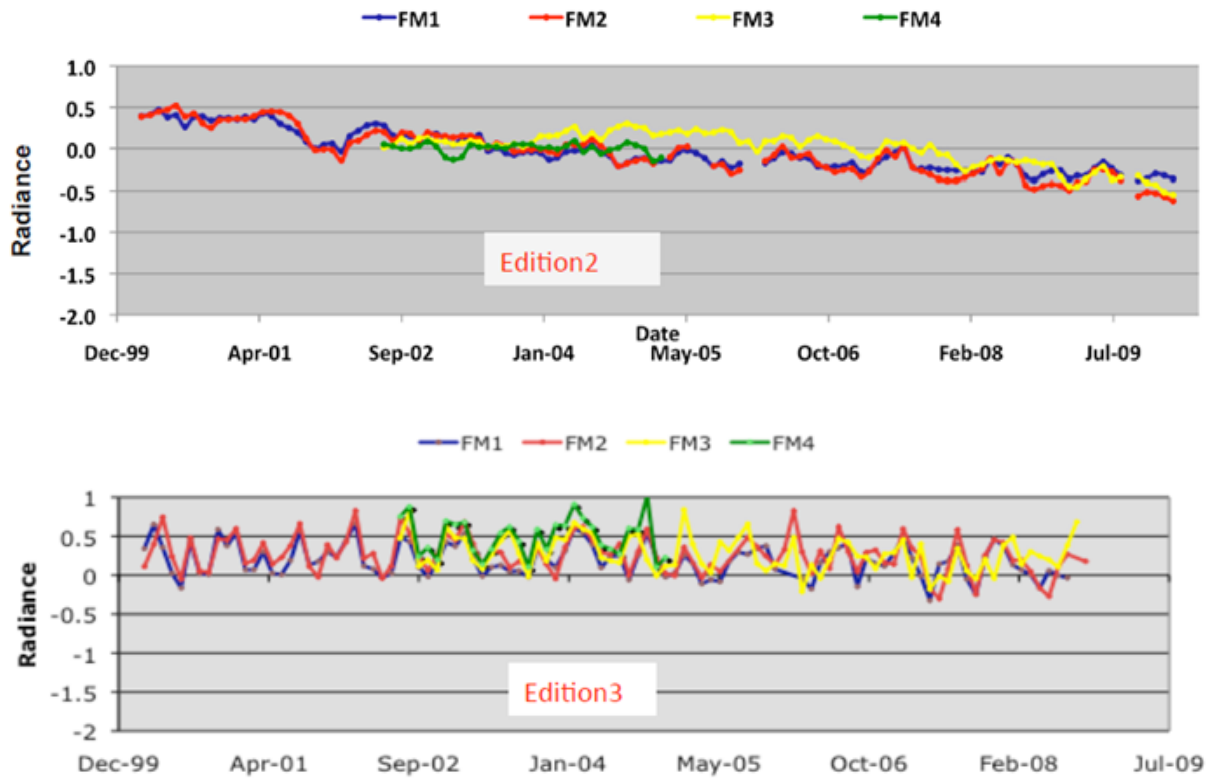
Figure 3: Time series of nadir-only day minus night unfiltered all-sky longwave radiance differences for 20N to 20S region as a function of CERES instrument (FM1 to FM4) and time for Edition2 (top) and Edition3(bottom) data.

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

Instrument Channel	Typical Value[a] $Wm^{-2}sr^{-1}$	Systematic Bias Error (Accuracy)			Mean Zero Random Error Standard Deviation (Precision)		Instantaneous RMS error
		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 Aqua 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-Aqua 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-Aqua.
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°. Aqua is in a 1:30 p.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 Aqua Edition3 ES8 data:

- 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. This will affect users who produce their own monthly means from the instantaneous values contained on this product and users studying SW and LW fluxes for deep convective clouds.
- CERES-Aqua is observing more clear sky than ERBE due in part to the difference in footprint size. The resolution of CERES-Aqua 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-Aqua.

- 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-Aqua 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 Aqua 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 FM3 and FM4 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 FM3 and FM4 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 FM3 and FM4 compared to PFM. For most scenes, FM3 and FM4 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 FM3 and FM4 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.

References

1. Green, R. N., and L. M. Avis, 1996: Validation of ERBS Scanner Radiances. *J. Atmos. and Ocean. Tech.*, **13**, 851-862.
2. 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.

Expected Reprocessing

The current "Edition3" data are expected to be reprocessed into a validated/archived/publishable Edition4 after the Aqua 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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