CERES ES4 NPP Edition1 Data Quality Summary

Investigation:	**CERES**
Data Product:	**ERBE-like Monthly Geographic Averages (ES4)**
Data Set:	**NPP (Instruments: FM5)**
Data Set Version:	**Edition1**

The purpose of this document is to inform users of the best current understanding of the accuracy of this CERES data product, to briefly summarize key validation results, to provide cautions where users might easily misinterpret the data, to provide helpful links to further information about the data product, algorithms, and accuracy, to give information about planned data improvements, and finally to register users of this data product so that we can automate the process of keeping users informed of new validation results, cautions, or improved data sets that become available in the future.

This document is a high-level summary and represents the minimum information that all scientific users of this data product should be familiar with. We strongly suggest that users recheck this document for the latest status before publication of any scientific papers using this data product: this would apply to both authors and reviewers of such research papers.

The quality of the CERES NPP ES4 data is comparable to the quality of the ERBE ERBS single-satellite S4 data in terms of monthly mean fluxes and scene identification. The major differences between CERES/NPP and ERBE/ERBS are the field of view resolution, the spectral response of the instruments, and the local time of observation.

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1.0 Nature of the ES4 Product

The CERES ES4 data product contains the "ERBE-like" temporally and spatially averaged shortwave (SW) and longwave (LW) top-of-the-atmosphere (TOA) fluxes derived from one month of CERES data from the Aqua spacecraft. Instantaneous TOA fluxes from the ES8 product have been spatially averaged on the same 2.5° equal-angle grid used by the Earth Radiation Budget Experiment (ERBE). Temporal interpolation algorithms identical to those used by ERBE have been applied to produce daily, monthly-hourly, and monthly mean fluxes from the instantaneous gridded data. The ES4 contains the temporally averaged values of TOA total-sky LW, total-sky SW, clear-sky LW, and clearsky SW flux, total-sky albedo and clear-sky albedo for each 2.5° region observed during the month. In addition, the 2.5° regional means have been combined to produce 5° regional, 10° regional, 2.5° zonal, 5° zonal, 10° zonal, and global mean fluxes.

A full list of parameters on the ES4 is contained in the CERES Data Product Catalog (PDF) and a full definition of each parameter is contained in the ES4 Collection Guide.

When referring to a CERES data set, please include the satellite 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, data set version, and data product without regard to configuration code. These data sets may be referred to as "CERES NPP Edition1 ES4".

2.0 Processing Updates in Current Edition

The CERES NPP Edition1 data product is based on analysis of CERES NPP FM5 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 the CERES instrument on the NPP spacecraft. This is in contrast to the CERES NPP Edition1-CV product, which is produced using only static at-launch calibration coefficient with no temporal correction. The corrections implemented in the CERES NPP Edition1 ES4 product consist of:

- Corrections for on-orbit derived changes in radiometric gains calibration coefficients based on the on-board calibration sources as described in the CERES BDS NPP Edition1 Data Quality Summary.

Table 2-1 shows the flux comparisons between various all-sky parameters for NPP Edition1 ES4 and NPP Edition1-CV ES4 data product for February 2012 and February 2017. In general, the results are consistent with the calibration changes implemented in the CERES NPP Edition1 processing.

Table 2-1. Comparisons of NPP Edition1 and Edition1-CV global mean all-sky fluxes.

	February 2012			February 2017		
	Edition1 (Wm^{-2})	Edition1-CV (Wm^{-2})	Ed1-Ed1cv (Wm^{-2})	Edition1 (Wm^{-2})	Edition1-CV (Wm^{-2})	Ed1-Ed1cv (Wm^{-2})
LW	237.7	237.4	0.3	239.1	240.0	-0.9
SW	101.7	101.6	0.1	100.4	100.3	0.1
Net	12.3	12.7	-0.4	11.1	10.3	0.8

3.0 Data Accuracy Table

The CERES ES4 data uncertainties are given in Table 3-1. The mean global bias and mean regional one standard derivation for LW and SW fluxes are within the science mission requirement.

Table 3-1. Errors from Temporal Interpolation and Spatial Averaging (Young et al., 1998)

	Mean Global Bias (Wm^{-2})				Mean Regional 1 Std. Dev. (Wm^{-2})			
	July		April		July		April	
	LW	SW	LW	SW	LW	SW	LW	SW
All Latitudes 45ºN-40ºS	1.3 (0.5%)	-0.6 (6%)	0.9 (0.4%)	-0.5 (0.5%)	2.9 (1%)	9.7 (<10%)	2.7 (1%)	6.4 (6%)
Science Requirement	2 - 5	2 - 5	2 - 5	2 - 5	10	10	10	10

4.0 Differences between CERES and the ERBE Scanner

1. The resolution of CERES NPP is 24 km at nadir and the resolution of ERBE ERBS is 40 km at nadir so that the surface area observed by ERBS is 2.78 times larger than the area observed by Aqua.
2. The NPP orbit is in a sun-synchronous orbit with an equatorial crossing time of approximately 1:30 PM. The ERBS had an inclination of 57° and a precessionary period of 72 days.
3. The longwave channel on ERBE was replaced by an 8 to 12 µm 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 ERBS S4 data product is a binary file of about 15 MB. The CERES ES4 product is an HDF file of about 9 MB.
6. CERES ES8 uses a different unfiltering algorithm (Loeb et al., 2001) than ERBE S8 (Green and Avis, 1996).

5.0 Cautions When Using Data

There are several cautions the CERES Team notes regarding the use of the CERES NPP Edition1 ES4 data. These cautions are based on findings from prior studies using CERES data from TRMM, Terra, and Aqua satellite:

- CERES instrument is observing more clear sky than ERBE due in part to the difference in footprint size. The resolution of CERES Terra and Aqua is 20 km at nadir and the resolution of ERBS is 40 km at nadir so that the surface area observed by ERBS is 4 times larger than the area observed by Terra and Aqua. For March 2000, ~23% of Terra-FM1 footprints, ~22% of Terra-FM2 footprints, and ~24% of CERES-TRMM footprints are classified as clear-sky. The mean percentage of clear ERBE ERBS footprints during March 1985-1990 is only ~17%. ERBS also observed about 17% overcast and CERES Terra and TRMM observed about 16% overcast. It is not fully understood why the overcast for Terra decreased instead of increasing as for clear sky. For July to September 2002, ~22 to 23% of Aqua footprints, ~21 to 24% of Terra footprints are classified as clear-sky. During the same period, CERES Aqua and Terra also observed about 16 to 17% overcast.
- 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, Aqua, and NPP ES4 fluxes also have these biases with viewing zenith angle.
- The spectral responses of the CERES shortwave and total channels differ from that on ERBE at wavelengths below 1 μm. CERES uses silver mirrors, which offer much more uniform spectral response from 0.4 μm to 100 μm than the ERBE aluminum mirrors, but are less responsive below 0.4 μm. A new spectral unfiltering algorithm has been developed and applied to the CERES data. As a result, the CERES radiances are less sensitive to spectral correction for land, desert, and cloudy scenes. The greatest impact of this change is on SW fluxes, particularly for clear and partly cloudy ocean scenes. Overall, CERES clear-sky SW fluxes are 5-6% lower than ERBE ERBS fluxes for all scene types.
- The NPP spacecraft is in a sun-synchronous orbit with equatorial crossing times of 1:30 AM and 1:30 PM. The temporal sampling pattern of NPP is very different from temporally precessing ERBS. ERBS observed all local times over a period of 72 days. Except for polar regions, NPP will generally observe a region only twice per day. Users should be aware that this temporal sampling can cause large errors in the modeling of diurnal variations of flux, particularly for regions with pronounced diurnal cycles of cloudiness.

6.0 Validation Study Results

The CERES Team has performed the following validation and quality assurance processes on this data set:

6.1 Pre-Launch

1. The CERES ERBE-like operational code has been tested for consistency with the historical ERBE algorithm. The CERES code was run using ERBE data as input. Monthly mean SW and LW fluxes have been calculated that reproduce ERBE values to better than 0.1%.
2. An error analysis of spatial averaging and temporal interpolation errors has been performed using one month of 1-hourly, 4-km GOES data. In summary:
   - Spatial errors have been computed using simulated CERES footprints constructed by convolving the GOES pixels with the CERES point spread function. These footprints can be averaged on a grid and compared with regional averages of the GOES pixels. Currently, results are only available for the CERES 1.0° grid. For crosstrack data, the rms SW and LW flux spatial gridding errors are 10.1 Wm^{-2} (5%) and 2.3 Wm^{-2} (1%) respectively, with no bias error for either. Errors for RAP data are twice as large with SW errors of 23.1 Wm^{-2} and LW errors of 5.6 Wm^{-2}. Currently, the best estimate for instantaneous gridding error for the 2.5° ERBE-like grid is given by Stowe et al., (J. of Atmos. & Ocean. Tech, 1994). For CERES-like footprints, Stowe et al. calculated crosstrack errors of ~8.5 Wm^{-2} and ~1.3 Wm^{-2} for SW and LW, respectively.
   - Temporal errors were calculated by temporally sampling GOES data and comparing monthly means computed from these data with means from the complete time series. SW and LW rms monthly mean errors are <10 Wm^{-2} (<10%) and <3 Wm^{-2} (<1%), respectively. Bias errors for LW are < 0.5 Wm^{-2}. For SW, mean biases can be -6 Wm^{-2} due to the morning sampling from the sun-synchronous orbit. The effects of the spatial gridding errors on monthly mean errors are negligible in the LW and only increase monthly SW rms errors by ~0.5 Wm^{-2}.

6.2 Post-Launch

A) CERES TRMM, CERES Terra, and CERES Aqua results

1. The CERES TRMM ERBE-like data have been compared with ERBS non-scanner data for verification of calibration. Tropical (20° N - 20° S) monthly mean ocean total-sky LW fluxes have been averaged for all available months of ERBS scanner (1/85 - 12/89), ERBS non-scanner (1/85 - 8/98), SCARAB scanner (3/94 - 2/95), and CERES TRMM scanner (1/98 - 8/98) data. Scanner - non-scanner differences for each of the 3 scanners agree to < 1%.
2. Instantaneous CERES TRMM ERBE-like fluxes have been compared with ERBS non-scanner data. Comparisons using data from January through August 1998 have demonstrated agreement to within 0.1% for both SW flux, 0.5% for nighttime LW flux, and 2.5% for daytime LW flux. ERBS non-scanner data are not available for the CERES Terra time period.
3. The first eight months of CERES TRMM and the first three months of CERES Terra ERBE-like data have been compared with the historical ERBE ERBS scanner data from 1985-1989. The emphasis of this study has been on comparisons of tropical mean fluxes (defined as the average of all regions between 20°N and 20°S) in order to minimize temporal sampling differences.

The main results include:

- Total-sky LW flux - the CERES TRMM LW fluxes are 3.5-8.8 Wm^{-2} (1.5-3.5%) higher than ERBE. The difference maximizes in February, which is also the maximum of the 1998 El Niño event. The difference is minimized in August when El Niño has essentially disappeared. As explained above, a corresponding increase in total-sky LW flux from ERBE (1985-1989) to 1998 is also seen in the ERBS non-scanner data. During 2000, both CERES TRMM and Terra remain 2.5-3.5 Wm^{-2} greater than ERBE, with agreement between Terra FM1, Terra FM2 and TRMM better than 1 Wm^{-2}.
- Clear-sky LW flux - The CERES TRMM clear-sky LW fluxes are 1-3 Wm^{-2} (0.2-1.0%) higher than ERBE in 1998. This difference also maximizes in February and minimizes in August. The differences have been shown to be consistent with variations in sea surface temperature and atmospheric humidity associated with El Niño (Wong et al., 2000). During 2000, CERES TRMM and CERES FM1 fluxes are in agreement with ERBE means to within 0.2 Wm^{-2}. FM2 clear-sky LW fluxes are consistently ~1 Wm^{-2} less than FM1. This is believed to be caused by an inconsistency between the SW channel and the SW portion of the total channel in FM1 (for details see the Terra ES8 Data Quality Summary).
- Total-sky SW flux - The difference between CERES TRMM and the 5-year mean ERBE data varies between -0.6 and -5.0 Wm^{-2} (-0.6 and -5%). However, the 2 std. dev. bound for the month-to-month temporal sampling variability of the total-sky SW tropical mean for this time period is 5%. Seasonal (3-month) means of SW flux reduce the impact of temporal sampling to a 2 std. dev. bound of 2.5%. The CERES SW flux tropical seasonal means are lower than ERBE ERBS by 3-4% which implies that there may be a real difference between ERBE and CERES SW fluxes. This bias persists into 2000, where the CERES Terra total-sky SW fluxes are 5-6% less than the ERBE means for all 3 months. The FM1 and FM2 means agree to better than 1%. The Terra sampling produces less month-to-month variability in the bias than TRMM. However, the sun-synchronous 10:30 orbit can produce a systematically low estimate for the total-sky SW flux due to sampling at the minimum of the diurnal cloudiness cycle for convective regions.
- Clear-sky SW flux - The 1998 CERES TRMM fluxes are on the average 5.6%, 5.3%, and 6.1% lower than ERBE for ocean, land and desert regions, respectively. The clear ocean difference is reduced to ~4% when the CERES spatial resolution is reduced to simulate the ERBS field of view. The land and desert differences are reduced only slightly by changing the spatial resolution. CERES Terra fluxes are 1%-1.5% lower than TRMM and ~5.5% lower than ERBE. FM1 and FM2 fluxes agree within 1%.
- Scene identification - In general, CERES classifies more footprints as clear than ERBE. This difference is also greatest in February with CERES TRMM classifying 33% of the observations as clear, while ERBE classifies only 20% as clear. The difference in July is decreased to 22% vs. 16%. Of the remaining difference, about 2% can be attributed to the smaller CERES footprint size. For March 2000, ~23% of Terra-FM1 footprints, ~22% of Terra-FM2 footprints, and ~24% of CERES-TRMM footprints are classified as clear-sky. The mean

percentage of clear ERBE ERBS footprints during March 1985-1990 is only ~17%. ERBS also observed about 17% overcast and CERES Terra and TRMM observed about 16% overcast. It is not fully understood why the overcast for Terra decreased instead of increasing as for clear sky. April and May 2000 reveal similar results to March.

4. During March 2000, both FM1 and FM2 were scanning in crosstrack mode for 11 days. A comparison of matched gridded data from these days reveals agreement between fluxes derived from the two instruments to within 0.5% for both LW and SW. Instantaneous gridded rms flux differences are 1% for LW and 3% for SW.
5. Fluxes produced using crosstrack and rotating-azimuth data were also compared using data from March-May 2000. Biases between the instruments were statistically equivalent to the biases when both instruments are in crosstrack mode. Instantaneous gridded rms flux differences increase to 2% for LW and 9% for SW.
6. A comparison of daytime and nighttime LW fluxes was performed for March-May 2000 CERES Terra data. The mean difference for FM2 is ~0.5-1.0% greater than for FM1, which is consistent with a similar comparison of day-night radiance differences between FM1, FM2, and CERES TRMM. This is explained in more detail in the Terra ES8 Data Quality Summary.
7. Directional models of the variation of albedo with solar zenith angle (SZA) have been constructed using CERES TRMM and ERBE ERBS data for each of the 12 ERBE scene types. Comparisons of these models reveal no significant differences.
8. Data consistency checks for the four EOS CERES instruments (FM1 and FM2 on Terra and FM3 and FM4 on Aqua) were performed using data from July to September 2002.

   The main results include

   - The tropical mean all-sky LW/SW fluxes are within 0.6%/2.6% or 1.4/2.4 Wm^{-2} of each other for all four instruments, respectively.
   - the tropical mean clear-sky LW/SW fluxes are within 0.7%/3.1% or 2.0/1.4 Wm^{-2} of each other for all four instruments, respectively.
   - the global mean clear-sky LW/SW fluxes are within 0.7%/2.8% or 2.0/1.4 Wm^{-2} of each other for all four instruments, respectively.
   - The global mean all-sky LW/SW fluxes are within 0.5%/1.4% or 1.1/1.3 Wm^{-2} of each other for all four instruments, respectively. These numbers are well within the science requirements of the ERBE-like product.
   - The tropical mean day minus night all-sky LW differences are within 2.5 Wm^{-2} or 1.0% of each other for all four instruments. These results are similar to previous studies using data from TRMM and Terra.
   - For July to September 2002, ~22 to 23% of Aqua footprints, ~21 to 24% of Terra footprints are classified as clear-sky. The agreement is within 2% of each other for all four instruments.
   - During the same period, CERES Aqua and Terra also observed about 16 to 17% overcast. The agreement is within 1% of each other for all four instruments.

9. The Terra minus Aqua regional SW flux differences are consistent with the diurnal sampling biases resulted from the local time sampling differences between the Terra (10:30am LST) and Aqua (1:30pm LST) orbit.

B) CERES NPP Edition1 Results

- CERES NPP Edition1 validation results can be found in the "Processing Updates in Current Edition" section of the current CERES ES4 NPP Edition1 document.

7.0 References

Green, R. N., and L. M. Avis, 1996: Validation of ERBS Scanner Radiances. *J. Atmos. and Ocean. Tech.*, **13**, 851–862, https://doi.org/10.1175/1520-0426(1996)013<0851:VOESR>2.0.CO;2

Loeb, N. G., K. J. Priestley, D. P. Kratz, E. B. Geier, R. N. Green, B. A. Wielicki, P. O. Hinton, and S. K. Nolan, 2001: Determination of Unfiltered Radiances from the Clouds and the Earth's Radiant Energy System Instrument. *J. Appl. Meteor.*, **40**, 822–835, https://doi.org/10.1175/1520-0450(2001)040<0822:DOURFT>2.0.CO;2

Stowe, L., R. Hucek, P. Ardanuy, and R. Joyce, 1994: Evaluating the Design of an Earth Radiation Budget Instrument with System Simulations. Part II: Minimization of Instantaneous Sampling Errors for CERES-I. *J. Atmos. and Oceanic Tech*., **11**, 1169-1183, https://doi.org/10.1175/1520-0426(1994)011<1169:ETDOAE>2.0.CO;2

Wong, T., D. F. Young, M. P. Haeffelin, and S. Weckmann, 2000: On the Validation of the CERES/TRMM ERBE-like Monthly-mean Clearsky Longwave Dataset and the Effects of El Nino, *J. Climate*, **13**, 4256-4267, https://doi.org/10.1175/1520-0442(2000)013<4256:VOTCTE>2.0.CO;2

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, https://doi.org/10.1175/1520-0450(1998)037<0572:TIMFTC>2.0.CO;2

8.0 Expected Reprocessing

The current NPP Edition1 data are expected to be reprocessed into a validated/archived/publishable Edition 2 in the future. Notifications of this new Edition data will be sent to registered users.

The CERES team expects to reprocess the S4 data product for ERBS, NOAA 9, NOAA 10, and the ES4 data product for TRMM, Terra, Aqua, and NPP 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 contributions to reprocessing will be an improved set of Angular Distribution Models based on CERES data and the MLE as the scene identifier. Other improvements will be 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 CERES and ERBS footprints will be similar in size.

9.0 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.

10.0 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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