CERES ES9 Terra Edition3
Data Quality Summary

Investigation:	**CERES**
Data Product:	**ERBE-like Monthly Regional Averages (ES9)**
Data Set:	**Terra (Instrument Mode: Xtrk)**
Data Set Version:	**Edition3**

The purpose of this document is to inform and to update 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 re-check 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 Terra ES9 data is comparable to the quality of the ERBE ERBS single-satellite S9 data in terms of instantaneous gridded and monthly mean fluxes and scene identification. The major differences between CERES/Terra and ERBE/ERBS are the field of view resolution, the spectral response of the instruments, and the local time of observation of CERES/Terra.

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Nature of ES9 Product

The CERES ES9 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 Terra 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 ES9 files contain both the temporally averaged and the instantaneous gridded mean values of TOA total-sky LW, total-sky SW, clear-sky LW, and clear-sky SW flux, total-sky albedo and clear-sky albedo for each 2.5° region observed during the month.

A full list of parameters on the ES9 is contained in the CERES Data Product Catalog (PDF) and a full definition of each parameter is contained in the ES9 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 Terra Xtrk Edition3 ES9."

Processing Updates in Current Edition:

The new CERES Terra Xtrk Edition3 ES9 data product contains two major changes to the older Edition2 product. They are (1) instrument calibration updates for both FM1 and FM2 instruments and (2) based exclusively on crosstrack measurements from CERES FM1 and/or FM2 instrument.

Edition3 Instrument Calibration Update

The CERES Edtion3 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 know instrument related artifacts form all four CERES instruments (FM1 to FM4) on Terra and Aqua spacecraft. These corrections are explained in details in the CERES Terra Edition3 ES8 Data Quality Summary and consist of:

- Corrections for ground to flight beginning-of-mission spectral response function and radiometeric gains calibration coefficients.
- Establishment of a common radiometric scale for all CERES instruments using FM1 as reference.
- Corrections for on-orbit derived changes in radiometric gain calibration coefficients based on on-orbit calibration sources.
- Corrections for on-orbit darkening on the short wavelength portion of the spectral response functions.

Table 1 shows the 3-month averaged (May, June, and July 2000) global mean fluxes from the CERES Terra FM1 instrument for both Edition3 and Edition2_Rev1 along with their differences near the beginning-of-mission (BOM). The net effect of FM1 instrument BOM calibration changes include (1) a small increase (~ +0.6%) in all-sky longwave fluxes, (2) a very small decrease (~ -0.03%) in all-sky shortwave fluxes, and (3) a decrease in all-sky net flux (~ -1.4 Wm^{-2}). The changes in clear-sky fluxes are on the order of +0.4% for clear-sky longwave, +0.8% for clear-sky shortwave, and -1.4 Wm^{-2} for clear-sky net radiation. The all-sky monthly mean changes are consistent with the instanteneous changes outlined in the CERES Terra Edition3 ES8 data quality summary.

Table 1: Comparison of Edition3 and Edition2_Rev1 3-month averages (May, Jun., Jul., 2000) global mean fluxes.

	All-sky			Clear-sky		
	Ed3 (Wm^{-2})	Ed2Rev1 (Wm^{-2})	Ed3-Ed2Rev1 (Wm^{-2})	Ed3 (Wm^{-2})	Ed2Rev1 (Wm^{-2})	Ed3-Ed2Rev1 (Wm^{-2})
LW	243.22	241.76	1.46 (0.60%)	270.33	269.31	1.02 (0.38%)
SW	96.27	96.30	-0.03 (-0.03%)	48.93	48.55	0.38 (0.78%)
Net	-5.96	-4.53	-1.43 (n/a)	14.13	15.53	-1.40 (n/a)

Crosstrack-only Data

From launch through October 2001, the Terra FM1 and FM2 instruments alternated between Rotating Azimuth Plan (RAP) and Fixed Azimuth Plane Scanning modes on a 3-month cycle. Edition1 and Edition2 ERBE-like ES9 data products are produced using a mixture of both crosstrack and RAP CERES data. Since the RAP CERES data has gaps in spatial sampling caused by its full azimuth sampling, these gaps can potentially increase spatial sampling errors for a single 2.5 degree grid box on a single satellite overpass to about 10 Wm^{-2} (1 sigma) and for monthly mean grid box values to about 2 Wm^{-2} (1 sigma). In order to reduce these spatial sampling noises in the CERES ERBE-like data, the Terra Edtion3 ES9 data will contain measurements exclusively from the crosstrack mode, which includes data from CERES FM1 and/or FM2 instrument. Table 2 lists the crosstrack instrument used in the production of the CERES Terra Xtrk Edtion3 ES9 dataset. With this Edition3 production change, CERES ES9 data based on individual instrument Flight Model will no longer be produced.

Table 2: CERES instrument used in the production of CERES Terra Xtrk Edtion3 ES9 dataset.

Month	CERES Flight Model (FM)
03/2000	FM1 and FM2
04/2000	FM2
05/2000 to 07/2000	FM1
08/2000 to 10/2000	FM2
11/2000 to 01/2001	FM1
02/2001 to 04/2001	FM2
05/2001 to 07/2001	FM1
08/2001 to 10/2001	FM2
11/2001 to 12/2005	FM1
01/2006 to 02/2006	FM2
03/2006 to current	FM1

Figure 1 shows the difference time series of global averaged all-sky shortwave fluxes between Terra Xtrk Edition3 ES9 and Terra FM1 Edition2_Rev1 ES9. The large up-and-down feature in the beginning of the time series is caused mostly by spatial sampling noise from RAP sampling in Edition2 data. This noisy feature had been eliminated in the new Xtrk Edition3 ES4 data product.

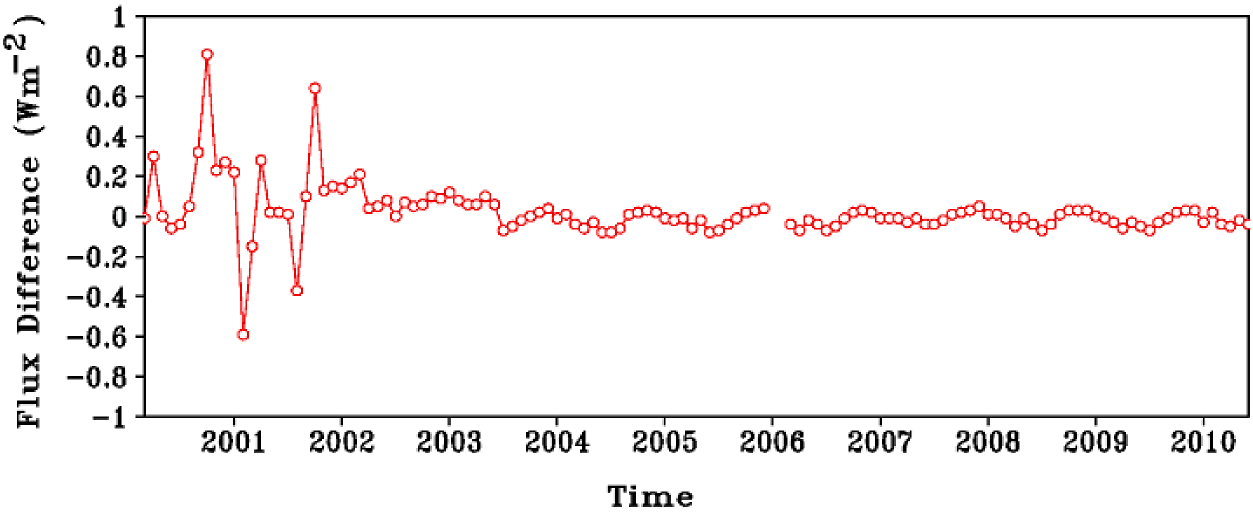

Figure 1. Time sereis of Terra Xtrk Edition3 minus FM1 Edition2_Rev1 global averaged monthly mean shortwave fluxes.

Data Accuracy Table

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 45°N - 40°S	1.3 (0.5%)	-6.0 (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

Differences Between CERES and ERBE

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 by ERBS is 4 times larger than the area observed by Terra.

2. The nominal scan mode for ERBE was crosstrack to provide good area coverage. Terra has three scan modes. The Fixed Azimuth Plane scan mode is similar to ERBE. The Rotating Azimuth Plane (RAP) scan mode was added to Terra to provide angular coverage for Angular Distribution Models construction. Along-track scan mode data are used for validation of CERES instantaneous fluxes and are not included on the monthly mean ES9 products. While early CERES ES9 Editions (Edition1 and Edition2) provide data for both crosstrack and RAP mode, the new CERES Edition3 Xtrk ES9 product only contains data from the crosstrack mode to be consistent with ERBE product.

3. The Terra orbit is in a sun-synchronous orbit with an equatorial crossing time of approximately 10:30 AM. The ERBS had an inclination of 57° and a precessionary period of 72 days.

4. The longwave channel on ERBE was replaced by an 8 to 12 µm window channel on Terra.

5. The data rate on ERBS was 30 measurements per second. The data rate on CERES is 100 measurements per second.

6. The ERBE ERBS S9 data product is a binary file of about 75 MB. The CERES ES9 product is an HDF file of about 72 MB.

7. ES8 uses a different unfiltering algorithm (Loeb et al., 2001) than ERBE (Green and Avis, 1996).

Cautions When Using Data

There are several cautions the CERES Team notes regarding the use of the CERES Terra Xtrk Edition3 ES9 data:

1. 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 ERBS is 40 km at nadir so that the surface area observed by ERBS is 4 times larger than the area observed by Terra. 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.

2. The ERBE scene identification algorithm (MLE) in conjunction with the ERBE angular distribution models (ADM) 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 angle.

3. 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.

4. The Terra spacecraft is in a sun-synchronous orbit with equatorial crossing times of 10:30 AM and 10:30 PM. The temporal sampling pattern of Terra is very different from temporally precessing ERBS. ERBS observed all local times over a period of 72 days. Except for polar regions, Terra will generally observed 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.

5. During March 2000, the CERES Terra instruments operated in a standard mode of 2 days of crosstrack scanning followed by 1 day of rotating azimuth plane (RAP) scanning. Beginning in April 2000, the standard operation was for one instrument scanning in crosstrack mode for the entire month with the other instrument in RAP scanning mode. Both the crosstrack and RAP data have been used in the computation of CERES Edition1 and Edition2 monthly mean fluxes. ERBE data were exclusively crosstrack. Beginning with the Edition3 product, the CERES ERBE-like monthly mean fluxes are exclusively crosstrack to be consistent with ERBE monthly mean fluxes.

Validation Study Results

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

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 < 0.5Wm^{-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}.

Post-Launch

A) Edition1 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 CERS 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 CERES ES8 Terra Edition2 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 CERES ES8 Terra Edition2 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.

B) Edition2 Results

- Edition2 validation results can be found in the "Processing Updates in Current Edition" section of the ES9 Terra Edition2 Data Quality Summary Document.

C) Edition3 Results

- Edition3 validation results can be found in the "Processing Updates in Current Edition" section of the current document.

References

1. Green, R. N., and L. M. Avis, 1996: Validation of ERBS Scanner Radiance. *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.

3. 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.

4. Wong, T., D. F. Young, M. P. Haeffelin, and S. Weckmann, On the Validation of the CERES/TRMM ERBE-like Monthly-mean Clear-sky Longwave Dataset and the Effects of El Nino, *J. Climate*, **13**, 4256-4267, 2000.

5. 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

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

The CERES team expects to reprocess the ESS9 data product for ERBS, NOAA 9, NOAA 10, and the ES9 data product for TRMM and Terra 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.

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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