CERES_SSF_Terra-Aqua_Edition4A

Data Quality Summary (6/30/2016)

Investigation: **CERES**
Data Product: **Single Scanner Footprint TOA/Surface Fluxes and Clouds (SSF)**

Data Set: **Terra CERES-FM1, MODIS 3/2000 – Current**
Terra CERES-FM2, MODIS 3/2000 – Current
Aqua CERES-FM3, MODIS 7/2002 – Current
Aqua CERES-FM4, MODIS 7/2002 – 3/2005

Data Set Version: Edition4A

Subsetting Tool Availability: http://ceres.larc.nasa.gov/order_data.php

The purpose of this document is to inform users of the accuracy of this data product as determined by the CERES Science Team. The document summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data product, algorithms, and accuracy, and gives information about planned data improvements.

This document is a high-level summary and represents the minimum information needed by 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.

Note to Users:

- CERES Single Scanner Footprint (SSF) Edition4A incorporate improved imager cloud property algorithms, new Angular Distribution Models (ADM) generated from the cloud properties, updated CERES gains and spectral responses, and surface models.
- The same MODIS collection, 005, (5.1 for aerosols) and a consistent Global Modeling and Assimilation Office (GMAO) reanalysis product, Goddard Earth Observing System (GEOS) Model 5.4.1, are used throughout.
- For a more detailed discussion on changes between Edition4A and previous editions, please see Section 5.0 of this document.

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TABLE OF CONTENTS

Section Page

LIST OF TABLES

1.0 Nature of the CERES SSF Edition4A Product

The CERES Single Scanner Footprint (SSF) is a unique product for studying the role of clouds, aerosols, and radiation in climate. Each CERES footprint (nadir resolution 20-km equivalent diameter) on the SSF includes reflected shortwave (SW), emitted longwave (LW) and window (WN) radiances and top-of-atmosphere (TOA) fluxes from CERES with temporally and spatially coincident imager-based radiances, cloud properties, and aerosols, and meteorological information from a fixed 4-dimensional analysis provided by the Global Modeling and Assimilation Office (GMAO). Each file in this data product contains one hour of full and partial-Earth view measurements or footprints at a surface reference level.

Cloud properties are inferred from the Moderate-Resolution Imaging Spectroradiometer (MODIS) imager, which flies along with CERES on the Terra and Aqua spacecraft. MODIS is a 36-channel; 1-km, 500-m, and 250-m nadir resolution; narrowband scanner operating in crosstrack mode. To infer cloud properties, CERES uses a 1-km resolution MODIS radiance subset that has been subsampled to include only the data that corresponds to every fourth 1-km pixel and every second scanline. The SSF retains footprint imager radiance statistics for 12 of the 19 MODIS channels (SSF-115 through SSF-131e).

The Edition4A SSF contains footprint aerosol parameters from both the 10-km spatial resolution MODIS aerosol product (SSF-132 through SSF-145m) and the NOAA/NESDIS algorithm (SSF-73 through SSF-78). Surface fluxes derived from the CERES instrument using several different techniques (algorithms) are also provided. Sampling of the CERES footprints is performed to reduce processing time and data volume. (See Cautions and Helpful Hints.)

CERES defines SW (shortwave or solar) and LW (longwave or thermal infrared) in terms of physical origin, rather than wavelength. We refer to the solar radiation that enters or exits the Earth-atmosphere system as SW. LW is the thermal radiant energy emitted by the Earth-atmosphere system. Emitted radiation that is subsequently scattered is still regarded as LW. Roughly 1% of the incoming SW is at wavelengths greater than 4 µm. Less than 1 W m^{-2} of the OLR is at wavelengths smaller than 4 µm. The CERES unfiltered window (WN) radiance and flux represent emitted thermal radiation over the 8.1 to 11.8 µm wavelength interval.

The SSF product combines the absolute calibration and stability strengths of the broadband CERES radiation data with the high spectral and spatial resolution MODIS imager-based cloud and aerosol properties. A major advantage of the SSF over the traditional ERBE-like ES-8 TOA flux data product is the new ADMs derived from CERES Rotating Azimuth Plane data that now allow accurate radiative fluxes not only for monthly mean regional ensembles (ERBE-like capability) but also as a function of cloud type. Fluxes in the CERES Edition4A SSF are based on updated ADMs. With these ADMs, accurate fluxes can be obtained for both optically thin clouds as a class, as well as optically thick clouds. This is a result of empirical CERES ADMs that classify clouds by optical depth, cloud fraction, and water/ice classes. ERBE-like TOA fluxes are only corrected for simple clear, partly-cloudy, mostly-cloudy, and overcast classes. In addition, clear-sky identification and clear-sky fluxes are expected to be much improved over the ERBE-like equivalent, because of the use of the imager cloud mask, as well as the new ADMs incorporating ocean wind speed and surface vegetation class.

Finally, early estimates of surface radiative fluxes are given using relatively simple parameterizations applied to the SSF radiation and cloud parameters. These estimates strive for simplicity and as directly as possible use the TOA flux observations. More complex radiative transfer computations of surface and atmosphere fluxes using the SSF data and constrained to the observed SSF TOA fluxes will be provided on the CERES CRS Data Product.

CERES footprints containing one or more MODIS imager pixels are included on the SSF product. Since the MODIS imager can only scan to a maximum viewing zenith angle (VZA) of ~65°, this means that only CERES footprints with VZA < 67° are retained on the SSF when CERES is in the crosstrack scan mode. When CERES is scanning in either the Rotating Azimuth Plane (RAP) or the alongtrack scan mode, CERES footprints with VZA > 67° do appear on this product, provided they lie within the MODIS swath. Sampling of the CERES footprints is performed to reduce processing time and data volume. (See Cautions and Helpful Hints.) The nominal CERES Terra and Aqua operation cycle for each instrument was 3 months in crosstrack scan mode followed by three months in RAP mode. The cycles of the two instruments were offset by three months such that there was always one instrument operating in the crosstrack scan mode and one in the RAP mode. Nominally, every fourteen days, the instrument operating in RAP mode switched to alongtrack scan mode for one day. In February 2002 for Terra, the nominal 3-month switching cycle was halted. At that time, the FM1 instrument was placed into crosstrack scan mode, and the FM2 instrument was placed in RAP mode. In June 2005, another change was made and both the FM1 and FM2 instruments were placed in crosstrack scan mode. FM2 was temporarily placed in the stow mode for July and August 2005, and FM1 was temporarily placed in stow for January and February 2006. In November 2003 for Aqua, the nominal 3-month switching cycle was halted. At that time, the FM4 instrument was placed into crosstrack scan mode, and the FM3 instrument was placed in RAP mode. On April 1, 2005, less than 2 days after the FM4 SW channel stopped functioning, both instruments were placed into crosstrack scan mode. The instrument scan modes may again change. To determine operations on any given day, refer to the CERES Operations in orbit for Terra or Aqua Users interested in spatially contiguous image data should use the CERES crosstrack data products. Users interested in full angular coverage over time (but with spatial gaps) should use the CERES RAP data. Users interested in many different angular views of the satellite ground track should use the CERES Along Track data.

A full list of parameters on the SSF is contained in the SSF section of the CERES Data Products Catalog (PDF) and a definition of each parameter is contained in the SSF 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 that 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 Edition4A SSF", "CERES Terra FM2 Edition4A SSF, CERES Aqua FM3 Edition4A SSF, or CERES Aqua FM4 Edition4A SSF.

2.0 Cautions and Helpful Hints

There are several cautions the CERES Science Team notes regarding the use of CERES Edition4A SSF data:

2.1 General

- 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 to Aqua instruments 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.
- The Aqua-FM4 SW channel failure occurred in hour 18 of March 30, 2005. The first ~40 minutes of hour 18 data still contain valid, non-default SW and LW parameter values. Once the SW channel failure occurs, the following SW and LW parameters can no longer be computed and are, therefore, set to CERES default values:
  - SSF-27, "CERES SW ADM type for inversion process"
  - SSF-28, "CERES LW ADM type for inversion process
  - SSF-32, "CERES SW filtered radiance - upwards
  - SSF-35, "CERES SW radiance - upwards"
  - SSF-36, "CERES LW radiance - upwards"
  - SSF-38, "CERES SW TOA flux - upwards"
  - SSF-39, "CERES LW TOA flux - upwards"
  - SSF-41, "CERES downward SW surface flux - Model A"
  - SSF-42, "CERES downward LW surface flux - Model A"
  - SSF-44, "CERES net SW surface flux - Model A"
  - SSF-45, "CERES net LW surface flux - Model A"
  - SSF-46, "CERES downward SW surface flux - Model B"
  - SSF-48, "CERES net SW surface flux - Model B"

- The SSF data sets contain only every other CERES footprint when the viewing zenith is less than 63 °. All footprints with a viewing zenith greater than or equal to 63° are included in the SSF. When SSF-20, "CERES viewing zenith at surface," is less than 63° and SSF-13, "Packet number," is even, then only footprints with an even value in SSF-12, "Scan sample number," are placed on the SSF. When "CERES viewing zenith at surface" is less than 63° and "Packet number" is odd, then only footprints with an odd value in "Scan sample number" are placed on the SSF. (See SSF Collection Guide). The CERES footprints are sufficiently overlapped in the scanning direction, that this use of every other footprint does not leave gaps in the data spatial coverage, or significantly increase errors in gridded data products or instantaneous comparisons to surface data such as BSRN. All CERES footprints are retained on the ES8 data products.

- Before using SSF parameter values, users should check for CERES default values. CERES default values, or fill values, are very large values which vary by data type. (See SSF Collection Guide.) A CERES default value is used when the parameter value is unavailable or considered suspect. SSF-1 through SSF-24 always contains valid parameter values and, therefore, need not be checked for default values. All other parameter values should be checked.
- This SSF contains only CERES footprints with at least one imager pixel of coverage that could be identified as clear or cloudy. This puts more burden on the users to screen footprints according to their needs. For example, if one wants to relate CERES fluxes with imager-derived cloud properties (e.g. cloud fraction), it is very important to check SSF-54, "Imager percent coverage" (i.e., the percentage of the CERES footprint which could be identified as clear or cloudy). When none of the imager pixels within the footprint could be identified as clear or cloudy, the footprint is not included on the SSF. The SSF also contains a flag that provides information on how much of the footprint contains pixels which could not be identified as clear or cloudy. This flag is referred to as "Unknown cloud-mask" and resides in SSF-64, "Notes on general procedures." Footprints with VZA greater than 80° and less than 100% imager coverage may be partial Earth-view. Consult SSF-34, "Radiance and Mode flags," to determine whether the footprint is full Earth-view or not. When the instrument is in the RAP or alongtrack scan mode, there are more footprints and the SSF files are larger. (See SSF Collection Guide.)
- This SSF contains only CERES footprints with at least one valid CERES radiance. All CERES footprints are retained on the ES8 data products.
- The geographic location of a CERES flux estimate is at the surface geodetic latitude and longitude of the CERES footprint centroid. On ERBE, all fluxes are located at a geocentric latitude and longitude corresponding to the 30-km level.
- Users interested in surface type should always examine both SSF-25, "Surface type index," and SSF-26, "Surface type percent coverage." (See SSF Collection Guide.)
- Users searching for footprints free of snow and ice should always examine SSF-25, "Surface type index,"; SSF-69, "Cloud-mask snow/ice percent coverage "; and SSF-30, "Snow/Ice percent coverage clear-sky overhead-sun vis albedo." (See SSF Collection Guide.)
- A footprint is recorded in the hourly SSF file that contains its observation time. However, SSF footprints within the file are ordered on alongtrack angle, SSF-18, and not on time. The alongtrack angle of the satellite is defined to be 0° at the start of the hour. If the instrument is in the RAP or alongtrack scan mode, then footprints can be prior to this start position and yield a negative alongtrack angle.
- Some applications of the SSF data will need to make the distinction between crosstrack, RAP, and alongtrack scan data. Multiple scan modes can occur in the same hour so that bits 8-9 of SSF-34, "Radiance and Mode flags" (see SSF Collection Guide) should be examined for each footprint to properly identify the scan mode. If actual azimuth angle is required, examine SSF-15, "Clock angle of CERES FOV at satellite wrt inertial velocity."
- Data in an area experiencing a solar eclipse is not processed for the duration of the eclipse. The fraction of SSF data with a solar eclipse is very small: 0.019% in 2000, 0.009% in 2001, 0.047% in 2002, and 0.025% in 2003.
- There is at least one period when the MODIS covers were closed, but CERES continued to process SSF footprints. In cases like this, the SSF parameters which are computed from the imager data are set to default; SSF-53, "Number of imager pixels in CERES FOV " and SSF-54, "Imager percent coverage " are set to 0; and CERES fluxes are computed using

neural network derived ADMs. There are footprints where CERES can determine that the scene is clear based on the WN channel brightness temperature. When this happens, the imager pixels within the footprint are assumed to be clear; SSF-54, " Imager percent coverage " is set to 100; SSF-53, "Number of imager pixels in CERES FOV" is non-zero; some imager-based SSF parameters do not contain default values; and the CERES fluxes are computed using clear-sky ADMs. The only known period between the years 2000 and 2002 for which the Terra MODIS covers are closed but the SSF footprints are processed is from 11:14:29 on April 25, 2000 through 20:45:55 on April 28, 2000. (See MODIS Instrument Operations Team Event History for AM-1 (Terra) or PM-1 (Aqua) to determine specifics of MODIS operations, including when MODIS covers were closed.)

2.2 Cloud

- For Edition4A SSF data sets, there is no algorithm for mean asymmetry factor for cloud layer.. Therefore, SSF-106a, Mean asymmetry factor for cloud layer (see SSF Collection Guide), is set to the CERES default fill value for all footprints.
- There are cases where the cloud properties cannot be determined for an imager pixel that is cloudy at a high confidence level. These pixels are included in the area coverage calculations. The cloud layer areas are proportionately adjusted to reflect the contribution these pixels would have made, but the cloud properties for each layer are not adjusted. The amount of extrapolation can be determined by checking SSF-63, "Cloud property extrapolation over cloud area." (See SSF Collection Guide.)
- Cloud parameters are saved by cloud layer. Up to two cloud layers may be recorded within a CERES footprint. The heights of the layers will vary from one footprint to another. When there is a single layer within the footprint, it is defined as the lower layer, regardless of its height. A second, or upper, layer is defined only when a footprint contains two unique layers. It is possible to have two unique cirrus layers or two unique layers below 4 km. Within an SSF file, the lower layer of one footprint may be much higher than the upper layer of another footprint.
- Night and near-terminator cloud properties - The current method for deriving cloud phase, particle size, and optical depth at night has not been fully tested. It has been implemented primarily to improve the nocturnal determination of cloud effective height for optically thin clouds ($\tau < 5$) and is generally effective at retrieving more accurate cloud heights compared to assuming that all clouds act as blackbody radiators at night. (See Cloud Properties Accuracy and Validation.) Because an accurate optical depth is required to obtain the proper altitude correction, the optical depths for optically thin clouds are considered reasonable.
- The mean cloud top height for cloud layer (SSF94a) may not have been correctly calculated for thick ice clouds. In the Cloud Properties Accuracy and Validation p 10, a correction is provided.
- Near-terminator cloud amounts - The cloud mask relies heavily on the brightness temperature differences between channels 3 and 4 for identifying clouds at night and in the daytime. The signals differ between night and day for low clouds. At high SZAs (> 80°), these signals can cancel each other resulting in low clouds mistaken as clear areas when the cloud temperature is close to or warmer than the clear-sky temperature. Terminator cloud amounts have improved since Edition1A, but can still use further improvement.
- Heavy aerosols - Aerosols with relatively large optical depths (τ >1-2) can sometimes be misidentified as clouds over any surface. Thus, in areas known to experience large dust outbreaks, such as large deserts or adjacent ocean areas, caution should be used when interpreting cloud statistics.

- Optical depths over snow - Cloud optical depth in Edition4A is derived using the SINT when it is known that the underlying surface is either snow or ice-covered. Otherwise, the VISST is used, an approach that often results in an overestimate of the optical depth over snow. In general, the optical depths will be overestimated in snow-covered regions if the underlying surface is not properly classified as being snow-covered.
- Multi-layered/mixed-phase cloud properties - Although an experimental product to detect multi-layered clouds was implemented, its results are retained in separate SSF variables. Thus, all clouds properties in the Cloudy Footprint Area are treated as single phase, single-layer clouds in the retrievals. Mixed phase cloud pixels are interpreted as either entirely liquid or ice clouds depending on the relative amounts of each phase in the top of a particular cloud. Overlapped ice and water cloud pixels will be interpreted in a similar fashion depending on the optical thickness and particle size of the overlying cloud. If it is very thin, the cloud will usually be classified as liquid. Thicker ice clouds over liquid clouds will be classified as ice. The resulting ice particle size for the thicker clouds should be representative of the ice cloud, but will often be too small for the thinner clouds. Mixed phase or overlapped thin-ice-over-thick-water clouds will produce either a liquid water effective radius that is too large for the water droplets in the cloud or too small for the ice crystals in the cloud because the 3.7-µm reflectances for the ice and water particles overlap at the low and high end, respectively. Users will need to use some contextual, temperature, or variability indicators to determine if a particular footprint contains both ice and water clouds if phase index for the footprint is either 1 (water) or 2 (ice). Cloud heights for multi-layered clouds will also be in error if the upper cloud deck is optically thin. The retrieved cloud altitude will be between the height of the lower and the upper clouds.
- A multi-layered/mixed phase cloud properties are contained in the Multilayer Cloud Footprint Area (SSF-114a – SSF-114l). The values presented are in relation to the Cloudy Footprint Area.
- "Mean cloud infrared emissivity for cloud layer," SSF-87, is an effective emissivity. Therefore, values greater than 1.0 may occur as a result of IR scattering within the cloud.
- Polar night cloud amounts - The Edition2 algorithm for detecting clouds over regions poleward of 60° at night is still the most uncertain methodology. Missed clouds in those areas can have a significant impact on the computed downwelling longwave flux.
- This SSF includes footprints over hot land and desert for which IR radiances are saturated or otherwise unavailable. The WN brightness temperature is used to identify these scenes. Footprints containing these hot scenes are referred to as "reclassified clear" and flagged in SSF-65, "Notes on cloud algorithms." For "reclassified clear" footprints, most clear footprint area parameters, such as cloud mask percent coverages, and aerosol A parameters, are set to CERES default.
- When averaging cloud properties using multiple footprints, the cloud property should be weighted by cloud area coverage for each level and the denominator would be a sum of cloud area coverage for all levels used. If a straight average is performed, extreme values are minimized. Differences of 150 hPa in effective pressure have been seen between the two techniques when creating 1 degree angular grids in the tropics.
- The 0.65 um and 3.8 um optical depths have a mismatch due to an error in the model look-up tables.
- There can be minor effects on particle radius and optical depth over ice and snow due to an error in the parameterization of 1.24 and 2.13 um reflectances.
- The CO2 algorithm thin ice cloud height correction may overestimate the effective height.

2.3 Aerosol

- The Terra Edition4A SSF contains footprint aerosol parameters from both the MODIS Atmosphere team (SSF-132 through SSF-167) and the NOAA/NESDIS algorithm (SSF-73 through SSF-78). The NOAA/NESDIS parameters provide continuity between the TRMM, Terra, and Aqua SSF data products (with the caveat that VIRS imager on TRMM has a different spatial resolution than MODIS on Terra and Aqua, and also that this latest SSF uses radiances from MODIS Collection 5). The NOAA/NESDIS aerosol algorithm and the CERES cloud retrieval algorithm both start with the same routine for spatial subsampling of the imager data. The MODIS Atmosphere team aerosols are obtained from the MOD04_L2/MYD04_L2 product, which averages a retrieval using full spatial resolution MODIS data into bundles spaced 10-km apart. For Edition4A, the MOD04_L2/MYD04_L2 input is collection 5.1.
- Two NOAA/NESDIS aerosol optical depth parameters, τ_1 (SSF-73) and τ_2 (SSF-74), have been derived over oceans from MODIS bands centered at λ_1=0.659 µm and a near infrared band λ_2=1.640 µm for Terra and λ_2=2.130 for Aqua an AVHRR/VIRS-like single channel algorithm. The objective is to provide continuity with the NOAA/AVHRR and TRMM/VIRS analyses, and to check the consistency of the simplistic "NOAA" retrievals against more sophisticated MODIS aerosols (SSF-146 through SSF-160). The user not involved in those activities is advised to use the MODIS aerosol product which is expected to be more accurate. Additionally, the NOAA-like parameters have not been validated and thoroughly tested yet. From τ_1 and τ_2, the Angstrom exponent is estimated as $\alpha = -\ln(\tau_1 / \tau_2)/\ln(\lambda_1 / \lambda_2)$. Note that errors in α change in inverse proportion to τ (Ignatov and Stowe 2000, 2002b).
- There are systematic variations in the NOAA/NESDIS aerosol retrieval which use this algorithm and VIRS or AVHRR imager data. These variations exist with different sun-view angles, precipitable water, wind speed, and infrared radiance (Ignatov and Nalli 2002). Some of the variations are deemed to be artifacts of the retrieval algorithm, and yet some may be real. In particular, variations with wind speed may suggest that ocean specular reflection or white caps may be artificially elevating aerosol optical depth values. Variations with cloud cover may result from either weak cloud contamination (possibly from cirrus cloud, as noted above), or from real changes in aerosol properties due to the clouds (indirect effect). At the time of this writing, no MODIS studies have been done. However, since variations in aerosol retrievals were observed for VIRS and AVHRR, they probably also exist for MODIS.
- NOAA/NESDIS aerosol retrievals (SSF-73 and SSF-74) are reported on the SSF when the solar zenith angle, SSF-21, is less than 70°. For TRMM SSF data sets, which use VIRS imager data, pronounced biases in retrievals start developing for solar zenith angles > 60° (Ignatov and Nalli 2002; Ignatov and Stowe 2002a). At the time of this writing, no MODIS studies have been done. However, it is thought that similar biases may also occur when using MODIS data as input. At this time, use of aerosol retrievals when solar zenith angles exceed 60° is not recommended.
- NOAA/NESDIS visible and near-IR aerosol optical depths (SSF-73 and SSF-74) are retrieved only over ocean. For a discussion of which pixels are used, refer to Aerosol Properties Terra Edition2B Accuracy and Validation.

2.4 TOA Flux

- The CERES ADMS (see TOA Fluxes Validation section) allow determination of accurate TOA fluxes for a wide range of cloud and aerosol conditions. These fluxes will be most accurate when a class of cloud or clear-sky is averaged over a wide range of viewing zenith angles. Not all anisotropy has been removed, and for highest accuracy users are advised to avoid restricting viewing zenith angles to a narrow range (just near nadir for example).
- In sunglint, SSF-38, "CERES SW TOA flux - upwards", is based upon the ADM mean flux corresponding to the observed scene type rather than the actual radiance-to-flux conversion. This strategy is used to reduce the large anisotropic variability (noise) in the sunglint region, without biasing the large ensemble average fluxes by scene type. To determine whether or not to perform a radiance-to-flux conversion for clear ocean scenes, the standard deviation (σ_{clr}) of the clear ocean ADM anisotropic factors in the vicinity of the measurement (i.e. surrounding w_s, θ_o, θ, and ϕ bins) must be less than 0.05. When clouds are present, a TOA flux retrieval is performed if $(1\text{-}f_{cld})\sigma_{clr} < 0.05$. Over sea-ice, a flux retrieval is performed if $(1\text{-}f_{ice})(1\text{-}f_{cld})\ \sigma_{clr} < 0.05$. If any of these conditions are not met, the ADM mean flux corresponding to the observed scene type is reported. When CERES is in a crosstrack scan mode, approximately 20-25% of the clear ocean CERES FOVs fail to pass sunglint. The frequency decreases with increasing cloud and sea-ice fraction. Overall 96% of the crosstrack CERES data over ocean passes the sunglint test. For more details, please see p. 69 of TOA Radiative Flux Estimation from CERES/Terra Angular Distribution Models (PDF).
- On Edition 4, TOA fluxes are determined using new ADMs developed from CERES on Terra and Aqua using the latest cloud algorithms. The ADM type for inversion (SSF-27 through SSF-29) classification has changed from earlier Editions. For a detailed description of the ADM types used please consult the Angular Distribution Models page.
- To facilitate analysis of CERES SSF by scene type, a cloud classification parameter (called Cloud Classification SSF-29) has been added to the SSF. Users will find the new cloud classification parameter more convenient than SSF-27 and SSF-28 for classifying CERES footprints by scene type. See the Cloud Classification Parameter page. If this classification is inadequate for a particular application, users are encouraged to develop their own classification using the many available SSF parameters.

3.0 Version History

3.1 Changes between Edition3A and Edition4A

New CERES gains and spectral responses are used that provide a consistent radiometric scale between Terra and Aqua. CERES Single Scanner Footprint (SSF) Edition4A incorporate improved imager cloud property algorithms; new ADMs generated from the updated cloud properties; and updated surface flux models. The same MODIS collection, 005, radiances and 5.1 aerosols and a consistent Global Modeling and Assimilation Office (GMAO) reanalysis product, GEOS 5.4.1, are used throughout processing.

3.1.1 CERES Radiances

The Terra instruments now have correction determine by the on-orbit calibration to adjust for shortwave drift.

In Edition4A, a monthly gain correction is applied without using interpolation between values that had been previously done.

Further refinement in the at-launch Spectral Response Function (SRF) improved scene dispersion. A new spectral degradation model is applied to the Total channel that largest effect is to remove LW daytime trends in Aqua instruments.

A comparison of the resulting changes between matched CERES nadir footprints in unfiltered radiances and representative values from Edition3A are given in Table 3-1. The Edition4A SW radiances are about a tenth of a Wm^{-2} lower than Edition3A. The Edition4 LW daytime radiance has also increase, but the change is not as consistent between instruments and seasons. The Edition4 LW nighttime radiance remains basically unchanged.

A similar comparison of the resulting changes between matched CERES nadir footprints in fluxes and representative values from Edition3A are given in Table 3-2. The Edition4A SW fluxes are between 1 and 2 W lower than Edition3A. The Edition4 LW fluxes differ, but the change is not as consistent between instruments and seasons.

Table 3-1. The mean Edition3A unfiltered nadir radiances with no interpolation and difference between Edition4A and Edition3A (Ed4A – Ed3A) during seasonal months in 2004.

		January		April		July		October	
	Unfiltered Radiance	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**
Terra FM1	Shortwave	74.00	-0.100	68.62	-0.131	64.47	-0.111	70.18	-0.117
	Longwave Day	77.14	-0.109	78.63	-0.233	83.03	-0.084	77.36	-0.031
	Longwave Night	73.09	0.004	72.64	0.009	72.24	-0.002	74.42	0.001
Terra FM2	Shortwave	74.17	-0.035	69.10	-0.051	64.59	-0.051	70.46	-0.101
	Longwave Day	77.23	-0.288	78.60	-0.352	83.10	-0.301	77.48	-0.265
	Longwave Night	72.96	0.000	72.96	0.001	72.56	-0.000	74.85	0.008

		January		April		July		October	
	Unfiltered Radiance	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**
Aqua FM3	Shortwave	74.74	-0145	68.23	-0.116	65.17	-0.126	64.77	-0.152
	Longwave Day	77.74	0.063	78.52	-0.059	83.09	-0.213	77.68	-0.168
	Longwave Night	72.91	-0.010	73.07	-0.009	76.62	-0.042	74.03	-0.031
Aqua FM4	Shortwave	74.74	-0.124	68.22	-0.114	64.92	-0.112	63.31	-0.107
	Longwave Day	77.65	-0.121	78.53	-0.145	83.12	-0.230	77.75	-0.244
	Longwave Night	72.83	0.008	72.32	0.011	71.89	-0.008	73.95	-0.001

Table 3-2. The mean Edition3A nadir fluxes with no interpolation and difference between Edition4A and Edition3A (Ed4A – Ed3A) during seasonal months in 2004.

		January		April		July		October	
	Flux	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**	**Mean**	**Diff**
Terra FM1	Shortwave	265.18	0.927	246.16	0.326	231.03	1.867	251.06	1.110
	Longwave Day	230.34	0.416	234.13	0.073	246.68	0.691	230.54	0.727
	Longwave Night	218.31	-0.090	216.47	0.205	214.87	0.206	221.58	0.230
Terra FM2	Shortwave	266.20	1.001	247.68	0.563	231.49	1.954	252.58	1.088
	Longwave Day	230.60	-0.120	234.05	-0.302	246.88	0.031	230.91	0.033
	Longwave Night	217.95	-0.095	217.41	0.173	215.84	0.200	222.86	0.240
Aqua FM3	Shortwave	265.71	0.836	246.09	0.270	233.21	1.468	240.74	0.073
	Longwave Day	230.81	1.507	232.55	1.057	245.46	0.830	230.43	0.807
	Longwave Night	217.59	-0.017	218.06	-0.251	216.33	-0.362	220.49	0.022
Aqua FM4	Shortwave	265.81	1.078	246.51	0.456	232.82	1.562	237.13	0.193
	Longwave Day	230.54	0.977	232.56	0.813	245.55	0.779	230.63	0.571
	Longwave Night	217.34	0.033	216.03	-0.257	214.40	-0.325	220.30	0.093

3.1.2 Clouds Algorithm

Due to noise on the Aqua MODIS 1.60 μm channel, Edition4 used the 1.24 and 2.13 μm channel for cloud detection and secondary cloud particle size for both satellites. Whereas, 1.60 μm had previously been used when processing Terra MODIS and 2.13 μm during Aqua processing. The MODIS radiances from Terra were adjusted to better follow those from Aqua. Since both platforms now use the same imager channels, the microphysical properties are also more consistent. Cloud optical depth and microphysical properties are obtained at 1.24 and 2.13 μm (SSF-108 through SSF-110c).

Improvements made in the cloud mask algorithms, resulted in a global increase of 0.05 in cloud amounts. There are fewer cases where dust is being misidentified as clouds while thin cirrus is better detected using the 1.38 μm reflectance. The distinct transition in cloud fraction that delineated the polar and non-polar masks has been minimized.

Cloud phase statistics changed significantly with an overall shift from ice to liquid of 0.08 with significantly more liquid clouds occurring over nonpolar land.

The cloud top heights and pressures are more consistent between Terra and Aqua then in Edition2. Cloud top and base temperature (SSF-94a, SSF-102a) and top height (SSF-94b) are now included in the product. A monthly, regional variable apparent lapse rate is now used in the boundary layer instead of the previous constant lapse rate. A CO_2 emission method provides cloud properties (SSF-111a through SSF-112).

The lack of retrieved cloud parameters has decreased. Hexagonal ice columns with roughened surfaces are used in the radiative transfer computations instead of the previous smooth surfaces.

An experimental multilayer cloud algorithm, assuming a thin ice cloud over a water cloud, is combined with the VIST algorithm (SSF-114a through SSF-114l).

3.1.3 TOA Fluxes

To account for the new cloud properties, the empirical ADMs were updated using Edition4A RAPS data. The number of bins was increased for many of the ADMs. New algorithms were introduced for others. The most significant changes are over clear ocean, clear land, and polar regions. The flux changes are less than 0.5 W m^{-2} on a monthly global scale, but can result in monthly mean instantaneous fluxes changes of 5 W m^{-2} on a regional 1^{o} latitude by 1^{o} longitude scale.

A modified Ross-Li 3-parameter fit for Normalized Difference Vegetation Index (NDVI), cosine solar zenith angle and surface roughness is now used in the shortwave clear land ADM. The clear land ADM is now used for clear fresh snow while additional surface brightness and cloud fraction bins were added to the partly cloudy and overcast fresh snow ADM. A special ADM was developed for clear conditions over Antarctica to account for the effect of sastrugi and one ADM is used for clear conditions over Greenland. During overcast conditions for permanent snow, ADM for each cloud phase and four log optical depth bin are used. A sea ice brightness index was created to improve the sea-ice ADM. While aerosol type gained an additional stratification in the clear ocean ADM.

The long wave clear ADMs is calculated with interpolation between bins along with increasing the number on various bins. For long wave cloudy ADMs, the third-order polynomial fits between radiance and pseudoradiance was replaced with mean values at 1 W m^{-2} sr^{-1} intervals in pseudoradiances.

The incoming solar radiation constant of 1365 Wm^{-2} has been replaced with the daily value as provided by the Total Solar Irradiance (TSI) from the SOlar Radiation and Climate Experiment (SORCE) as supplemented by World Radiation Center (WRC), Davos and the Royal Meteorological Institute of Belgium (RMIB) data. The Total Incoming Solar Radiation (SSF-38a) is now included on the SSF.

3.1.4 Surface Models

An additional Longwave Algorithm has been added (SSF-49a through SSF-49c) based on Zhou et al. 2007.

The Langley Parameterized Shortwave Algorithm (LPSA) was improved with the switch to albedo maps derived from CERES Terra and aerosol data from the daily Model of Atmospheric Transport and CHemistry (MATCH) datasets. The Rayleigh molecular scattering formulation was replaced with Bodhaine et al. (1999). Revised empirical coefficient in the cloud transmission formula has improved the SW surface flux in partly cloudy condition.

The Langley Parameterized Longwave Algorithm (LPLA) now constrains the lapse rate and inversion strength. The Langley Parameterized Algorithm now provides shortwave (SSF-46a) and longwave (SSF-47a) clear-sky surface flux.

3.1.5 Imager Radiance

The ability to provide up to an additional 7 imager radiance channel with total and clear sky means have been included (SSF-131a through SSF-131e).

3.2 Changes between Terra Edition2B/F/G or Aqua Edition2B/C/D and Edition3A

The Edition3 CERES calibration improvements can be summarized as following:

1. Start-of-mission Spectral Response Function (SRF) and radiometric gain factors were re-derived from pre-launch ground calibration data
2. Using Flight Model One (FM1) as the standard, correction factors were derived to place all CERES instruments on the same radiometric scale. Data for March 2000 was used for FM1 and FM2. Data for July 2002 was used for FM3 and FM4. An intercomparison of Terra FM1 and Aqua FM4 was performed at orbital nodes during July 2002.
3. Using the Internal Calibration Module, in-flight calibration changes were determined. These changes were incorporated into the radiometric gains.
4. A time-dependent change in the SRF was determined that accounts for on-orbit darkening in the short wavelength region of the sensors. A direct nadir radiance comparison for CERES instruments on the same spacecraft was used to correct for the SW changes in SW spectral response for the instrument in RAP mode. The spectral darkening is most pronounced at wavelengths < 0.5 microns. Corrections for degradation in the TOT channel spectral response function assume no time-dependent drift in the relationship between day-night longwave and day-night window radiance differences.

A comparison of Terra Edition2 and Edition3 all sky global fluxes are given in Table 3-3 respectively using ERBE-like ES-8 product nadir data. The same comparison for Aqua Edition2 and Edition3 are given in Table 3-4. Further details on calibration changes can be found in the CERES Science Team Meeting presentation by Thomas, et al (PDF).

Shortwave radiance contribution to the total channel is now removed for solar zenith angle less than 95 degrees instead of the previous 90 degrees in obtaining longwave unfiltered radiance. This results in a small reduction in longwave flux near the terminator.

The surface flux models A and B were updated for both shortwave and longwave. Changes to the surface flux algorithms are discussed in the Surface Fluxes Accuracy and Validation section.

Table 3-3. Terra all sky global flux results for March 2000 based on the ERBE-like ES-8 product nadir data.

	FM1			FM2		
	Edition3 (Wm-2)	Edition2 (Wm-2)	Ed3-Ed2 (Wm-2)	Edition3 (Wm-2)	Edition2 (Wm-2)	Ed3-Ed2 (Wm-2)
LW Day	230.62	228.72	0.80%	230.44	229.8	0.28%
LW Nite	224.70	223.86	0.38%	224.60	223.52	0.49%
SW	256.36	256.24	0.05%	256.60	256.09	0.20%

Table 3-4. Aqua all sky global flux results for July 2002 based on the ERBE-like ES-8 product nadir data.

	FM3			FM4		
	Edition3 (Wm-2)	Edition2 (Wm-2)	Ed3-Ed2 (Wm-2)	Edition3 (Wm-2)	Edition2 (Wm-2)	Ed3-Ed2 (Wm-2)
LW Day	250.44	248.46	0.79%	250.35	249.19	0.47%
LW Nite	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%

The clouds, aerosol, and imager radiance information on Edition3 is the same as used in Terra Edition2B/F/G or Aqua Edition2B/C/D.

The Terra Edition2F data set is a continuation of the Edition2B data set but uses collection 5 MODIS data as input rather than collection 4. MODIS radiances in collection 5 can slightly differ from those in collection 4. Likewise, the Edition2G data set is a continuation of the Edition2B and Edition2F data set. It continues to use collection 5 MODIS radiance, but uses G-5 CERES data assimilation.

For Aqua the related changes are Edition2C data set is a continuation of the Edition2B data set but uses collection 5 MODIS data as input rather than collection 4. MODIS radiances in collection 5 can slightly differ from those in collection 4. Likewise, the Edition2D data set is a continuation of the Edition2B and Edition2C data set. It continues to use collection 5 MODIS radiance, but uses G-5 CERES data assimilation.

The earlier DQS shows the timeline of CERES radiance input (IES) and clouds, aerosol, and imager data from Edition2 SSF products. From the standpoint of CERES processing directed by the CERES team, there were no algorithm or code changes other than what was required to read the new input data sets.

3.3 Changes between Terra Edition2A or Aqua Edition2A to Edition2B

Satellite specific (Terra or Aqua) CERES ADMs were used to calculate the TOA fluxes from the Edition2A CERES radiances, clouds, aerosol, and imager radiance information. The cloud algorithms used for Terra and Aqua differed in Edition2A since the Terra algorithm had already been frozen for forward processing as Aqua those for Aqua were developed.

3.4 Changes between Terra Edition1A or Aqua Edition1B to Edition2A

The gains and spectral response function were updated using a longer baseline then was possible for Edition1 processing. The clouds algorithms had significant improvements to correct issues identified during earlier processing.

4.0 Accuracy and Validation

Accuracy and validation discussions are organized into sections. Please read those sections which correspond to parameters of interest.

5.0 Expected Reprocessing

There is no scheduled reprocessing at this time. However it is expected that the temporal coverage of the CERES SSF products will continue to increase until within six-months of current and then will be updated in 2-month intervals.

Later algorithm improvements will be guided by results of further validation studies.

6.0 Attribution

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 CERES Terra or Aqua SSF Edition4A products:

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.

The calibration used for the CERES measurements can be reference from

Loeb, N.G.; Manalo-Smith, N.; Su, W.; Shankar, M.; Thomas, S. CERES Top-of-Atmosphere Earth Radiation Budget Climate Data Record: Accounting for in-Orbit Changes in Instrument Calibration. *Remote Sens.* **2016**, *8*, 182, doi:10.3390/rs8030182.

When using the cloud results, please reference the following papers:

Minnis, P., Q. Z. Trepte, S. Sun-Mack, Y. Chen, D. R. Doelling, D. F. Young, D. A. Spangenberg, W. F. Miller, B. A. Wielicki, R. R. Brown, S. C. Gibson, and E. B. Geier, 2008: Cloud detection in non-polar regions for CERES using TRMM VIRS and Terra and Aqua MODIS data. *IEEE Trans. Geosci. Remote Sens.*, **46**, 3857-3884.

Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, Q. Z. Trepte, W. L. Smith, Jr., J. K. Ayers, S. C. Gibson, W. F. Miller, V. Chakrapani, Y. Takano, K.-N. Liou, Y. Xie, and P. Yang, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms. *IEEE Trans. Geosci. Remote Sens.*, **49**, *11*, 4374-4400.

Minnis, P., S. Sun-Mack, Y. Chen, M. M. Khaiyer, Y. Yi, J. K. Ayers, R. R. Brown, X. Dong, S. C. Gibson, P. W. Heck, B. Lin, M. L. Nordeen, L. Nguyen, R. Palikonda, W. L. Smith, Jr., D. A. Spangenberg, Q. Z. Trepte, and B. Xi, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part II: Examples of average results and comparisons with other data. *IEEE Trans. Geosci. Remote Sens.*, **49**, *11*, 4401-4430.

When using the CERES fluxes, please reference this paper:

Wenying Su, Joseph Corbett, Zachary Eitzen, Lusheng Liang, Next-Generation Angular Distribution Models for Top-of-Atmosphere Radiative Flux Calculation from the CERES Instruments: Methodology, Atmos. Meas. Tech. Disscuss., 7, doi:10.5194/amtd-7-8817-2014, 8817-8880, 2014.

When using the surface flux data results, please reference the following paper, which details the validation of these fluxes:

Kratz, D. P., S. K. Gupta, A. C. Wilber, and V. E. Sothcott, 2010: "Validation of the CERES Edition 2B Surface-Only Flux Algorithms", J. Appl. Meteor. Climatol., 49(1), 164-180, doi:10.1175/2009JAMC2246.1.

The CERES data products now have dois. To cite the data in publications use this format:

CERES Science Team, Hampton, VA, USA: NASA Atmospheric Science Data Center (ASDC), Accessed <**author citing data inserts date here**> at doi: (appropriate product)

For Terra FM1: 10.5067/Terra/CERES/SSF-FM1_L2.004A
For Terra FM2: 10.5067/Terra/CERES/SSF-FM2_L2.004A
For Aqua FM3: 10.5067/Aqua/CERES/SSF-FM3_L2.004A
For Aqua FM4: 10.5067/Aqua/CERES/SSF-FM4_L2.004A

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 the NASA Langley Research Center."

The Langley Atmospheric Science Data Center requests two 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 important for optimizing product development. It also helps us to keep our product-related references current.

7.0 Feedback and Questions

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

For questions about the CERES subsetting/visualization/ordering tool at http://ceres.larc.nasa.gov/order_data.php, please click on the feedback link on the left-hand banner.

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