CERES Terra Edition1A SSF Data Quality Summary

Investigation:	**CERES**
Data Product:	**Single Scanner Footprint TOA/Surface Fluxes and Clouds (SSF)**
Data Set:	**Terra (Instruments: CERES-FM1 or CERES-FM2, MODIS)**
Data Set Version:	**Edition1A**

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 user applied revisions (e.g. Rev1), 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 also automates registration in order to keep users informed of new validation results, cautions, or improved data sets as they become available.

User applied revisions are a method CERES uses to identify improvements to existing archived data products that are simple for users to implement, and allow correction of data products that would not be possible in the archived versions until the next major reprocessing 1 to 2 years in the future. All revisions applicable to this data set are noted in the section User Applied Revisions to Current Edition.

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.

Table of Contents

Nature of the SSF Product

This document discusses the Single Scanner Footprint (SSF) data set version Edition1A for Terra. Additional information is in the Description/Abstract document. The files in this data product contain one hour of full and partial-Earth view measurements or footprints located in colatitude and longitude at a surface reference level.

The Terra 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) 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 the European Centre for Medium-Range Weather Forecasts (ECMWF). Cloud properties are inferred from the Moderate-Resolution Imaging Spectroradiometer (MODIS) imager, which flies along with CERES on the Terra 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 second 1-km pixel and every second scanline. The Terra SSF retains footprint imager radiance statistics for 5 of the 19 MODIS channels (SSF-115 through SSF-131). The Terra Edition1A SSF contains footprint aerosol parameters from both the 10-km spatial resolution MODIS aerosol product (SSF-132 through SSF-160) 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.

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 angular models derived from TRMM 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 Terra

Edition1A SSF are based on CERES TRMM Edition2B Angular Direction Models (ADMs). A set of ADMS based on 2 years of CERES Terra measurements are under development and will be used to produce the CERES Terra Edition2A SSFs scheduled for release in mid-2003. With the new 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 new empirical CERES TRMM angular models 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 angular models incorporating ocean wind speed and surface vegetation class. Users of this product should take note that since the CERES TRMM Edition2B ADMs were constructed using measurements in the tropics only, fluxes in the middle and upper latitudes will generally have larger uncertainties, particularly over snow and sea ice.

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. Expected delivery of the Terra validated CRS product is Fall 2003. A beta version is expected to be available Fall 2002.

All 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. The nominal CERES Terra operation cycle for each instrument is 3 months in crosstrack scan mode followed by three months in RAP mode. The cycles of the two instruments are offset by three months such that there is 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 switches to alongtrack scan mode for one day. In February 2002, 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. The instrument scan modes may again change. To determine operations on any given day, refer to the CERES Operations in Orbit.

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 Edition1A SSF" or "CERES Terra FM2 Edition1A SSF."

User Applied Revisions for Current Edition

The purpose of User Applied Revisions is to provide the scientific community early access to algorithm improvements which will be included in the future Editions of the CERES data products. The intent is to provide users simple algorithms along with a description of how and why they should be applied in order to capture the most significant improvements prior to their introduction in the production processing environment. ***It is left to the user to apply a revision to data ordered from the Atmospheric Science Data Center.*** Note: Users should never apply more than one revision. Revisions are independent and the latest, most recent revision to a data set includes all of the identified adjustments.

SSF Edition1A-Rev1

The CERES Science Team has approved a table of scaling factors which users should apply to the Edition1A SSF SW parameters.

For the CERES SW TOA upward filtered radiance (SSF-32) and the CERES SW TOA upward unfiltered radiance (SSF-35), users should utilize the following equation:

- $radiance_{rev1} = radiance_{orig}$ * scaling factor

For the CERES SW TOA upward flux (SSF-38), users should utilize the following equation:

- $flux_{rev1} = flux_{orig}$ * scaling factor

For the CERES SW surface net fluxes, Model A (SSF-44) and Model B (SSF-48), users should utilize the following equation:

- $flux_{rev1} = flux_{orig} - (SSF\text{-}38)_{orig}$ * (scaling factor - 1.0)

For the CERES SW surface downward fluxes, Model A (SSF-41) and Model B (SSF-46), no corrections should be applied, and thus:

- $flux_{rev1} = flux_{orig}$

This revision is necessary to account for spectral darkening of the transmissive optics on the CERES SW channels. By June 2005, this darkening has reduced the average global all-sky SW flux measurements by 1.1 and 1.8 percent for Terra FM1 and FM2 data respectively. A complete description of the physics of this darkening appears in the CERES BDS Quality Summaries under the Expected Reprocessing section. After application of this revision to the Edition1A SSF data set, users should refer to the data as Terra Edition1A-Rev1 SSF.

Cautions and Helpful Hints

There are several cautions the CERES Science Team notes regarding the use of CERES Terra Edition1A SSF data:

General

- 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 contain valid parameter values and, therefore, need not be checked for default values. All other parameter values should be checked.

- This SSF contains all CERES footprints with at least one imager pixel of coverage, even if that pixel could not be identified as clear or cloudy. This approach reduces regional biases in fluxes, but it 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 "imager percent coverage" is set to 0 and most imager derived SSF parameters are set to CERES default values. The SSF also contains a new 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.)

- 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 both SSF-25, "Surface type index," and SSF-69, "Cloud-mask snow/ice percent coverage." (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."

Cloud

- For Terra Edition1A SSF, there is no algorithm for mean vertical aspect ratio. Therefore, SSF-111, Mean vertical aspect ratio for cloud layer (see SSF Collection Guide), should have been set to the CERES default fill value for all footprints. However, due to a software error, SSF-111 contains bogus values which should be ignored by all users.

- 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.

- Near-terminator cloud amounts - The cloud mask relies heavily on the brightness temperature differences between channels 3 (3.7 µm) and 4 (10.8 µm) for identifying clouds at night (using 3.7-µm emittance) and in the daytime (using 3.7-µm reflectance). The signals differ between night and day for low clouds. For large solar zenith angles (> 80°), the emittance and reflectance 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.

- Heavy aerosols - Aerosols with relatively large optical depths 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 Edition1A 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 using the Edition1A algorithm if the underlying surface is not properly classified as being snow-covered.

- Phase selection/single-layered clouds - Because of ambiguities in the radiances for broken and optically thin clouds, pixels along the edges of supercooled water clouds will sometimes be classified as ice clouds.

- Multi-layered/mixed-phase cloud properties - Although an experimental product to detect multi-layered clouds was implemented in Edition1A, its results have not been retained in SSF output because it requires additional study. Thus, all clouds 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.

- "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 Edition1A algorithm for detecting clouds over regions poleward of 60° tends to underestimate cloud fraction at night. 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. 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, aerosol A parameters, and imager-based surface skin temperature, are set to CERES default. (See SSF Collection Guide.)

Aerosol

- The Terra Edition1A SSF contains footprint aerosol parameters from both MODIS (SSF-132 through SSF-160) and the NOAA/NESDIS algorithm (SSF-73 through SSF-78). The NOAA/NESDIS parameters provide continuity between the TRMM and Terra SSF data products. The MODIS aerosols are obtained from the MOD04_L2 product, version 3, which has a 10-km spatial resolution.

- 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 λ_2=1.640 µm using a 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 for TERRA 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 trends in the NOAA/NESDIS aerosol retrieval which use this algorithm and VIRS or AVHRR imager data. These trends exist with different sun-view angles, precipitable water, wind speed, and infrared radiance (Ignatov and Nalli 2002). Some of the trends are deemed to be artifacts of the retrieval algorithm, and yet some may be real. In particular, trends with wind speed may suggest that ocean specular reflection or white caps may be artificially elevating aerosol optical depth values. Trends 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 trends 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 - Accuracy and Validation.

TOA Flux

- The CERES TRMM Edition2B angular models (see TOA Fluxes section) are a marked advance over anything previously available, and 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).

- The CERES TRMM Edition2B angular models were constructed using measurements in the tropics only. Therefore, fluxes in the middle and upper latitudes will generally have larger uncertainties, particularly over snow and sea ice.

Surface Flux

- Users are cautioned about a flaw that was discovered in the SW Model B code that produces SW flux parameters SSF-46 and SSF-48. For certain footprints at high latitudes of the northern hemisphere, especially over Siberia during winter and early spring, the value of column ozone exceeded 500 dobson units, the upper limit prescribed in the code. For those footprints, the values of SSF-46 and SSF-48 could not be computed in the code and default values were recorded in their place. The values of SSF-46 and SSF-48 for the affected footprints are, therefore, missing but they are not erroneous.

- CERES downward LW surface flux - Model B (SSF-47) and CERES net LW surface flux - Model B (SSF-49) were found to be incorrectly computed in a small number of cloudy cases. This happens for those footprints where the cloud amounts are retrieved in one or two layers but corresponding cloud-base heights (Mean cloud base pressure for cloud layer; SSF-101) are not retrieved by the processing system. When this occurs, the system assigns a CERES default value to the cloud-base pressures. The LW Model B then specifies a value for the missing cloud-base pressure of 700 hPa in the single layer case, or 800 hPa for the lower layer or 500 hPa for the upper layer in the two layer case. The incorrect computation occurs in regions of high surface altitude (Altitude of surface above sea level; SSF-24) where surface pressure is less than the above specified cloud-base pressures. This was observed to have occurred in a number of cases over Tibetan region. Users are warned to exercise caution when using LW Model B fluxes over high altitude regions.

- Shortwave Model A and Longwave Model A surface fluxes (SSF-41 through SSF-45) are limited to footprints with clear area coverage (SSF-66) of 99.9% or more. Shortwave Model B and Longwave Model B surface fluxes (SSF-46 through SSF-49), however, are available for all-sky.

- The high latitude and polar surface fluxes from Terra Edition1A have not been validated and should be considered "Beta" quality. (See Surface Flux Accuracy and Validation.)

Accuracy and Validation

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

- Cloud properties
- Aerosol properties
- Spatial matching of imager properties and broadband radiation
- TOA fluxes
- Surface fluxes

Expected Reprocessing

Within the next year, the CERES Team expects to twice reprocess the SSF data product for Terra. A Beta data set is expected to be publicly released in Spring 2003. This Beta data set will use an early version of Terra derived ADMs. In Fall 2003, the validated version, Edition2A, is expected to be made publicly available. CERES Terra Edition2A SSF will use the final, validated set of Terra ADMs.

The current "Edition1A" SSF cloud parameters may be reprocessed at some future date after revision of the algorithms to implement a variety of changes. The time frame for executing a later-edition cloud algorithm is currently unknown. Some of the changes that will be included in such an algorithm are noted below:

- Updated clear-sky maps - Results from Edition1A will be used to improve the characterization of the clear-sky emittance, temperature, and reflectance fields to provide an improved cloud mask, especially over bright desert areas and over land and desert at night.

- Multi-layered clouds - A new set of methods for identifying multi-layered clouds will be implemented after thorough testing. This change should improve the screening of such data from statistics that assume a single-phase cloud. With further study, it may be possible to separate the properties of the upper layer from those of the lower layer. Mixed phase clouds will be more difficult to identify and quantify.

- More complete validation statistics - Later algorithm improvements will be guided by results of further validation studies. It is expected that a variety of additional types of comparisons will be conducted including references such as microwave liquid water paths over ocean, radiometer-based optical depths from many surface sites, other ARM sites, and longer time records.
- Improved cloud detection in the polar night - A study is underway to improve the cloud mask for nighttime conditions over the poles.
- The ECMWF analysis varies with time. Therefore, the SSF may be reprocessed with a later DAO fixed 4-dimensional analysis.

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 the NASA Langley Research Center."

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

Feedback and Questions

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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