CERES FLASHFlux Terra/Aqua SSF Version4A Data Quality Summary

Version 1
Updated 9/11/2023

Investigation: **CERES**

Data Product: **FLASHFlux Single Scanner Footprint (SSF) Top of Atmosphere (TOA)/Surface Fluxes and Clouds**

Data Set: **Terra CERES-FM1, MODIS 8/2020-Present; Aqua CERES-FM3, MODIS 8/2020-3/2023**

Data Set Version: **Version4A**

Aqua Data DOI: 10.5067/CERES/FLASH SSF Aqua-FM3-MODIS Version4A
Terra Data DOI: 10.5067/CERES/FLASH SSF Terra-FM1-MODIS Version4A

CERES Visualization, Ordering and Subsetting Tool: https://ceres.larc.nasa.gov/data/

The purpose of this document is to inform users of the attributes of the FLASHFlux Single Scanner Footprint (SSF) Version4A data products and describe differences relative to the previous version as determined by the CERES FLASHFlux Working Group. The document summarizes key validation results, provides cautions where users might easily misinterpret the data, provides links to further information about the data products, 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 (especially Cautions and Helpful Hints) before publication of any scientific papers using this data product.

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1.0 Nature of the CERES FLASHFlux SSF Version4A Product

The Fast Longwave and SHortwave Flux (FLASHFlux, or FF) dataset is a product of the Clouds and the Earth's Radiant Energy Systems (CERES) project designed to process and release top-of-atmosphere (TOA) and surface radiative fluxes within one week of CERES instrument measurement. The CERES project is currently producing world-class climate data products from measurements taken aboard NASA's Terra and Aqua satellites. While of exceptional fidelity, these data products require a considerable amount of processing time to assure quality, verify accuracy, and assess precision. The result is that CERES climate quality data products are typically released several months after acquisition of the initial measurements. For climate studies, such delays are of little consequence especially considering the improved quality of the released data products. There are, however, many actual and potential uses for the CERES-like data products on a close to real-time basis. These include CERES instrument calibration and subsystem quality checks, operational usage by related Earth Science satellites, seasonal predictions, land and ocean assimilations, support of field campaigns, outreach programs such as GLOBE (Global Learning and Observations to Benefit the Environment) and applied science projects for agriculture and energy industries via the POWER (Prediction Of Worldwide Energy Resource) project. Since these applications do not require exacting standards, FLASHFlux products are eminently suitable for all such applications. FLASHFlux data products were envisioned as a resource whereby CERES-like data could be provided to the community within a week of the initial measurements, with some calibration accuracy requirements relaxed to gain speed. Since the FLASHFlux data were created to provide CERES-like TOA and surface radiative flux retrievals for the entire globe within one week of measurement, this document provides general information about the data products, assesses the quality and accuracy of FLASHFlux Version4A, and specifically discusses the algorithm input parameters (SSF-46 through SSF-49, not including SSF-49a, SSF-49b, and SSF-49c). Even though FLASHFlux intends to incorporate the latest input data sets and improvements into algorithms, there are no plans to reprocess the FLASHFlux data products once these modifications are in place. Thus, together with relaxed calibration requirements, the FLASHFlux data products are not of climate quality. *Users seeking multi-year climate quality data sets should instead use the CERES data products.*

Each footprint (nadir resolution 20-km equivalent diameter) on the CERES FLASHFlux SSF includes reflected shortwave (SW) and emitted longwave (LW) radiances and top-of- atmosphere (TOA) fluxes with temporally and spatially coincident imager-based radiances, cloud properties, and meteorological information from a fixed 4-dimensional analysis provided by the Global Modeling and Assimilation Office (GMAO). Each file contains one hour of full and partial-Earth view measurements at the 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 spacecrafts. MODIS is a 36-channel; 1-km, 500-m, and 250-m nadir resolution; narrowband scanner operating in crosstrack mode. To infer cloud properties, FLASHFlux uses the 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 (SSF-115 through SSF-131e, SSF Collection Guide.) for 12 MODIS channels.

Just like CERES, FLASHFlux 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 emitted LW radiation is at wavelengths smaller than 4 μm.

The CERES FLASHFlux SSF product uses the high spectral and spatial resolution MODIS imager-based cloud properties. The CERES FLASHFlux SSF uses the Angular Distribution Models (ADMs) derived from CERES Rotating Azimuth Plane (RAP) data that allow accurate radiative fluxes estimated from CERES radiance observations for each footprint. Fluxes in the CERES FLASHFlux Version4A 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 from empirical CERES ADMs that classify clouds by optical depth, cloud fraction, and water/ice classes.

Finally, early estimates of surface radiative fluxes are given using relatively simple radiation parameterizations applied to the SSF radiation and cloud parameters along with the input meteorology [1][2]. These estimates strive for simplicity and, as directly as possible, use the TOA flux observations.

A full list of parameters on the SSF is contained in the SSF section of the CERES Data Products Catalog, and a definition of each parameter is contained in the SSF Collection Guide.

When referring to a FLASHFlux 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 SSF 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 FLASHFlux Terra FM1 Version4A SSF” or CERES FLASHFlux Aqua FM3 Version4A SSF.

1.1 FLASHFlux Processing Flowchart

Figure 1-1 presents the FLASHFlux data flow diagram through the production of the SSF products. The various subsystems are color coded for identification purposes. The MOA (Meteorology, Ozone and Aerosol) are subsetted and regridded from the NASA Goddard Space Flight Center Global Modeling (GSFC) and Data Assimilation Office (GMAO) operational near-real time data atmospheric reanalysis data products GEOS5124. For Version4A, the Global Earth Observing System (GEOS) 5.12.4 is known as the Forward Processing–Investigation Team (FP-IT), which is available within about 2 days of real-time. **It should be noted that a coding error was discovered in Version3C that did not correctly implement profile ozone from the FP-IT data product; thus, not accounting for ozone absorption.** The correction has been made for Version4A. Currently, FLASHFlux uses an aerosol climatology map derived from MODIS 5 collection. Exploratory work into implementing GMAO aerosol is being conducted.

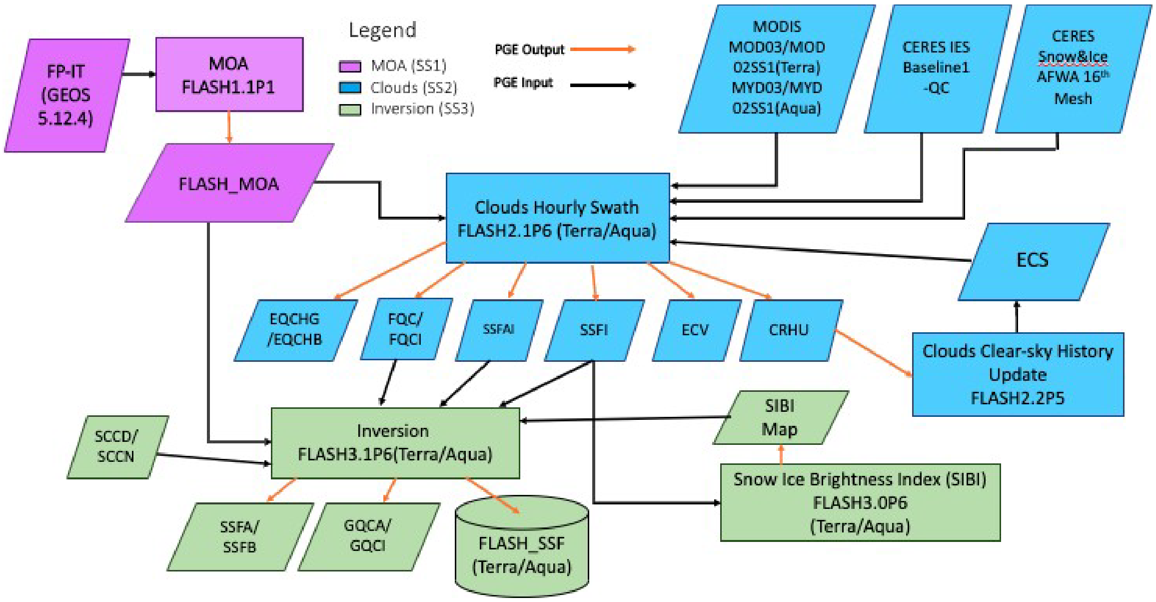


Figure 1-1. FLASHFlux Processing Data Flow Diagram.

The MOA, Clouds, and Inversion production codes are delivered to the FLASHFlux working group by the various CERES working groups responsible for these subsystems. One key input that is different from CERES SSF production is the Baseline1-QC product which only has the nominal calibration coefficients applied. This requires that a special set of combined gain and spectral correction coefficients Day/Night (SCCD/SCCN) be applied in the Inversion subsystem (see Section 1.2). Another key input is the AFWA (Air Force Weather Agency) 16th mesh snow/ice maps, which are available within a day of real-time. All the other CERES and MODIS inputs are similar to those in CERES SSF production. Most of the data production for SSF products follows CERES with a key exception in the Inversion stage. The SIBI (Snow Ice Brightness Index) for snow/ice covered footprints is processed with a rolling 30-day window rather than using the monthly SIBI files produced in standard CERES climatology processing. This difference may lead to angular distribution model (ADM) selection differences in those footprints that may impact the radiative fluxes relative to CERES SSF (see Section 2.1.3).

1.2 FLASHFlux Calibration Coefficients

FLASHFlux uses specially derived gain+spectral coefficients denoted by the SCCD/SCCN box in Figure 1-1. These coefficients are supplied by the CERES instrument team and used to calibrate the radiances moving forward. These correction coefficients contain the latest gain, spectral correction, and Rev1 scaling factor adjustments that are used to process the data. These correction coefficients are updated whenever a new set of adjustments are computed from the CERES Edition data. Table 1-1 provides an example of the nadir ERBE-like TOA flux differences expected due to the calibration coefficients delivered to FLASHFlux for production from the data month June 2019.

Table 1-1. Comparison of ERBE-like nadir TOA radiative fluxes (W m^{-2}) using the FLASHFlux Version4A calibration versus standard CERES calibration.

Satellite	Data Product	SW	LW Day	LW Night
Aqua	FLASHFlux	240.993	248.347	217.197
	CERES Edition4	240.921	248.286	217.186
	Differences	0.03%	0.02%	0.01%
Terra	FLASHFlux	241.27	248.92	218.64
	CERES Edition4	241.24	249.07	218.73
	Differences	0.01%	-0.06%	-0.04%

The FLASHFlux SCCs are determined by calculating the gain ratio of Edition1 vs. Baseline1-QC for each channel. These ratios are then multiplied by the Edition1 spectral response function. While not always possible, the SCC files should be updated on a quarterly basis. Any update to the SCC files will correspond to a change in the six-digit configuration code of the output filename.

2.0 Version History

2.1 Changes Between Version3C and Version4A

New CERES gains and spectral responses 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.

2.1.1 Radiances

The Terra instruments now have correction determined by the on-orbit calibration to adjust for shortwave drift [3]. In Version4A, a monthly gain correction is applied without using interpolation between values that had been previously computed. Further refinement in the at-launch Spectral Response Function (SRF) improved scene dispersion. A new spectral degradation model is applied to the Total channel where the largest effect is to remove LW daytime trends in Aqua instruments.

2.1.2 Cloud Algorithms

Due to noise on the Aqua MODIS 1.60 μm channel, Version4A used the 1.24 and 2.13 μm channels for cloud detection and secondary cloud particle size for both satellites. Previously, the 1.60 μm channel had 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 fraction. 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 in cloud fraction of 0.08 from ice to liquid with significantly more liquid clouds occurring over nonpolar land.

The cloud top heights and pressures are more consistent between Terra and Aqua than in FLASHFlux Version3. 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) [4].

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 VISST (Visible Infrared Solar-infrared Split-Window Technique) algorithm (SSF-114a through SSF-114l).

An experimental Snow Ice Brightness Index (SIBI) map is produced using a 30-day running average.

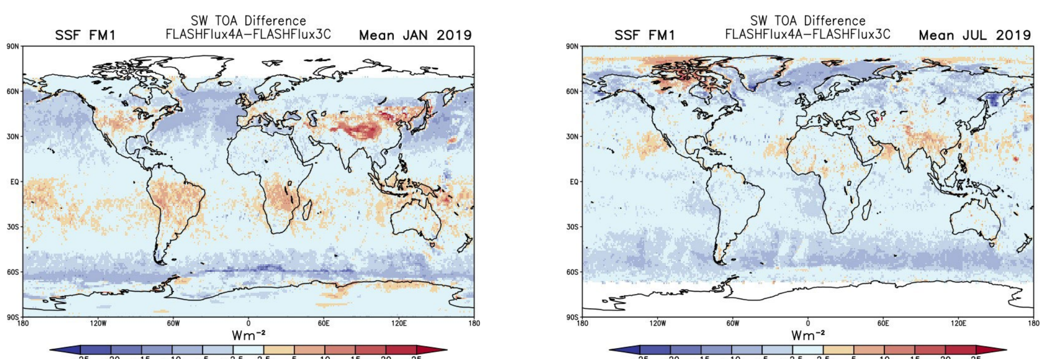
2.1.3 TOA Fluxes

To account for the new cloud properties, the empirical ADMs were updated using CERES 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 between FLASHFlux and CERES are less than 1 W m^{-2} on a monthly global scale from Table 3-1, but can result in monthly mean instantaneous flux changes of 5 W m^{-2} as indicated in Figure 3-1 to Figure 3-3.

A modified Ross-Li 3-parameter fit for Normalized Difference Vegetation Index (NDVI), cosine solar zenith angle, and surface roughness are now used in the shortwave clear land ADMs. The clear land ADMs are now used for clear fresh snow while additional surface brightness and cloud fraction bins were added to the partly cloudy and overcast fresh snow ADMs. 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 [5]. During overcast conditions for permanent snow, the ADMs for each cloud phase and four log optical depth bins are used. A sea ice brightness index was created to improve the sea-ice ADMs. An additional aerosol type stratification was used in the clear ocean ADMs.

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

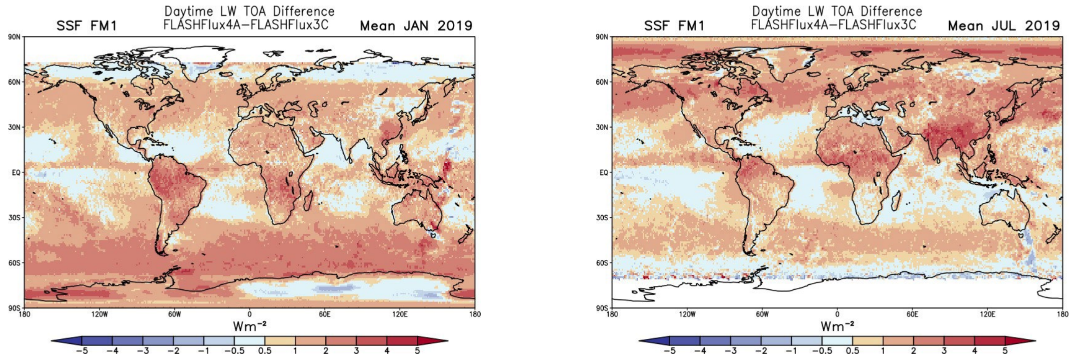
A comparison of the resulting changes between matched FLASHFlux footprints in fluxes between Version3C and Version4A are given in Table 2-1. Figure 2-1 to Figure 2-3 highlight the monthly average differences of the Top of Atmosphere (TOA) fluxes between the two versions for January 2019 and July 2019. These two months are used to highlight seasonal extremes.



(a) Jan. 2019 (b) Jul. 2019

Figure 2-1. Monthly average Shortwave TOA flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.

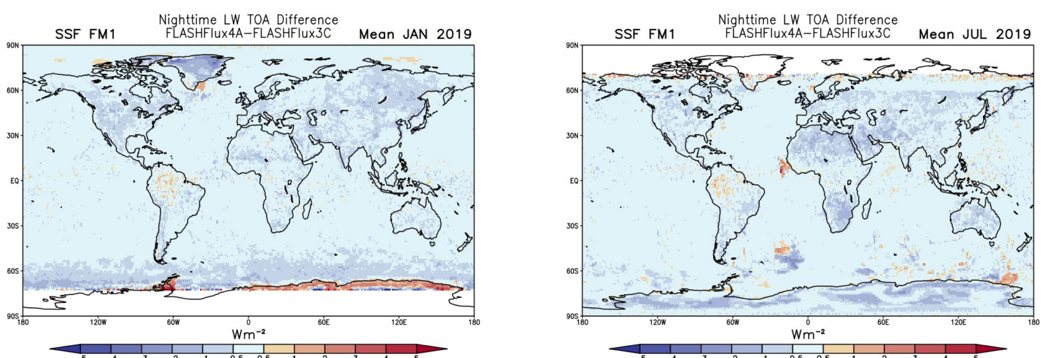
Figure 2-1 shows a large bias over the high latitude oceans that is due to a code error in Version3C that did not include profile ozone, thus resulting in too much reflected TOA SW flux. Version4A corrected this error.



(a) Jan. 2019 (b) Jul. 2019

Figure 2-2. Monthly average daytime Longwave TOA flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.

The daytime Outgoing Longwave Radiation (OLR) in Figure 2-2 shows large differences between Version4A and Version3C with some regions exceeding 5 W m^{-2}. Further investigation reveals that the differences are mainly due to the changes in the Spectral Correction Coefficients (SCCs), which includes the spectral response function and gains. These SCCs appear to impact the daytime OLR the most. The nighttime OLR in Figure 2-3 shows small differences between the two versions. The differences are due to the combination of both SCCs and the addition of profile ozone.



(a) Jan. 2019 (b) Jul. 2019

Figure 2-3. Monthly average nighttime Longwave TOA flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.

This document contains maps of differences from the Terra FM1 instrument only. Comparisons with Aqua FM3 were also done. Table 2-1 shows the differences between Version4A and Version3C for the mid-seasonal months of 2019. The Shortwave TOA flux on board the Aqua platform yields larger differences between the two versions because the updated SCCs for Aqua are radiometrically scaled to Terra for Version4A. The large global monthly mean differences in daytime OLR for both satellites are also due to the SCCs.

Table 2-1. TOA Fluxes comparison of FF Version4A minus FF Version3C for the mean and (standard deviation) in W m^{-2} over all global footprints.

Instruments	Flux	January	April	July	October
Terra-FM1	Shortwave	-0.12 (7.65)	0.65 (7.81)	-0.75 (7.0)	0.04 (6.60)
	Longwave Day	1.56 (1.71)	1.32 (1.84)	1.28 (1.77)	1.38 (1.92)
	Longwave Night	-0.15 (1.02)	-0.23 (1.23)	-0.12 (1.10)	-0.09 (1.08)
Aqua-FM3	Shortwave	-1.22 (6.52)	-1.27 (6.48)	-1.09 (6.40)	-1.30 (6.67)
	Longwave Day	1.42 (2.12)	1.31 (2.62)	0.85 (2.35)	1.18 (2.13)
	Longwave Night	-0.81 (1.08)	-0.82 (1.30)	-0.76 (1.37)	-0.80 (1.15)

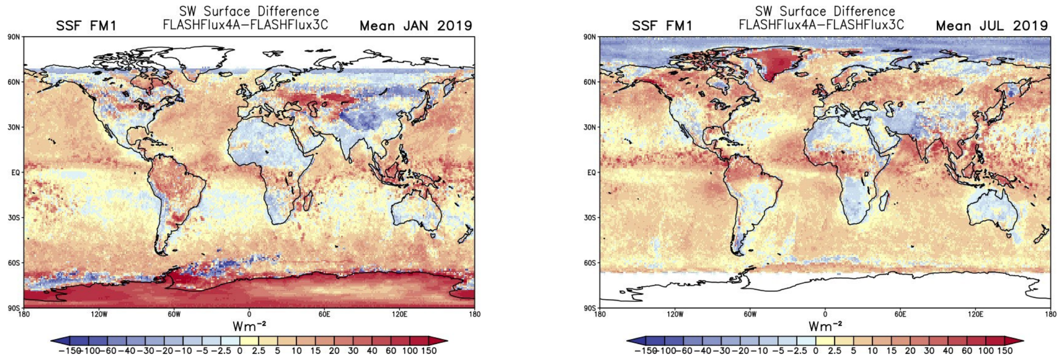
2.1.4 Surface Model

The Langley Parameterized Shortwave Algorithm (LPSA) [6] was improved with the switch to albedo maps that are derived from CERES Terra radiances. Terra daily Model of Atmospheric Transport and Chemistry (MATCH) aerosols are used to create a 10-year aerosol monthly climatology map. The Rayleigh molecular scattering formulation was replaced with Bodhaine et al. (1999) [7]. Revised empirical coefficients in the cloud transmission formula have improved the SW surface flux in partly cloudy conditions. Also, a new parameterization was added to LPSA for conditions when the surface is believed to be snow-and/or ice-covered and the main algorithm fails.

The Langley Parameterized Longwave Algorithm (LPLA) now constrains the lapse rate and inversion strength [8]. The Langley Parameterized Algorithms now provide shortwave (SSF-46a) and longwave (SSF-47a) clear-sky surface flux.

A comparison of the resulting changes between matched FLASHFlux footprints in surface fluxes between Version3C and Version4A are given in Table 2-2. Figure 2-4 to Figure 2-6 highlight the monthly average differences of the Surface Downwelling fluxes between the two versions for January 2019 and July 2019.

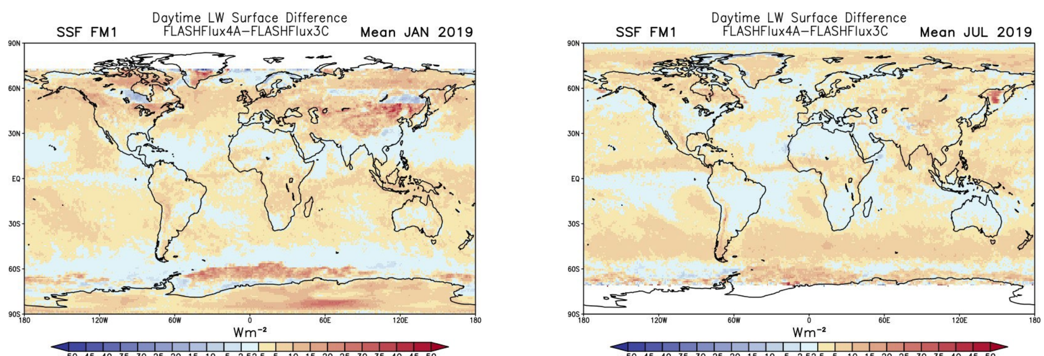
Previous validation results have shown that the LPSA does underestimate the SW surface downwelling fluxes over high latitudes, particularly over snow and ice surfaces. A modification was made in the algorithm to handle the snow and ice surface to increase the amount of SW surface downwelling flux. The deep red color in Figure 2-4 (a) over Antarctica and (b) Greenland is the result of this modification.



(a) Jan. 2019 (b) Jul. 2019

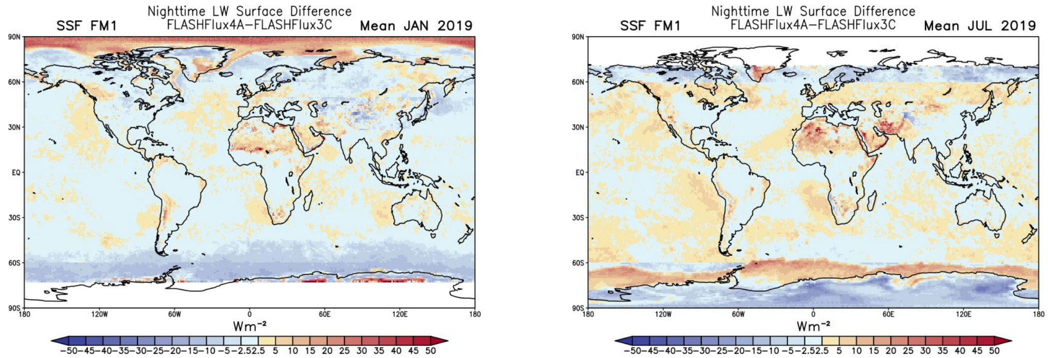
Figure 2-4. Monthly average Shortwave downwelling surface flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.

No modifications were made to the LPLA algorithm. Since Version3C and Version4A employ the same meteorology, the difference seen in Figure 2-5 is likely the result of changes from the SCCs and the addition of profile ozone. Note the uniform bands in the high latitudes for both Figure 2-5 and Figure 2-6. Those bands are the result of adding profile ozone.



(a) Jan. 2019 (b) Jul. 2019

Figure 2-5. Monthly average daytime Longwave downwelling surface flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.



(a) Jan. 2019 (b) Jul. 2019

Figure 2-6. Monthly average nighttime Longwave downwelling surface flux differences of FLASHFlux Version4A compared to Version3C for (a) January 2019 and (b) July 2019.

Table 2-2 shows similar results to Table 2-1, as expected. Shortwave fluxes on the Aqua platform show larger differences because the SW TOA is radiometrically scaled to the Terra platform. Daytime Longwave flux resulted in the largest change due to the new SCCs, and nighttime Longwave shows very little change, similarly to Table 2-1.

Table 2-2. Surface flux comparison of FF Version4A to FF Version3C for the mean and (standard deviation) in W m^{-2} over all global footprints.

Instruments	Flux	January	April	July	October
Terra-FM1	Shortwave	5.53 (32.48)	6.94 (37.86)	6.44 (23.15)	6.02 (39.85)
	Longwave Day	4.67 (8.79)	4.06 (7.28)	3.69 (6.33)	4.00 (10.27)
	Longwave Night	109 (10.73)	2.10 (11.97)	1.77 (14.41)	1.54 (10.27)
Aqua-FM3	Shortwave	6.72 (28.57)	7.18 (33.95)	6.51 (22.00)	2.89 (31.09)
	Longwave Day	4.51 (8.46)	4.51 (7.30)	3.71 (6.02)	4.67 (8.17)
	Longwave Night	2.14 (9.16)	3.02 (8.63)	2.98 (7.47)	2.89 (10.26)

2.1.5 Imager Radiance

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

2.2 Differences Between CERES FLASHFlux SSF Version4A and CERES SSF Edition4A

FLASHFlux and CERES SSF are very similar in many ways; however, there are important differences that users should consider. These are listed below.

1. FLASHFlux will provide high quality data sets to the community within a week of the initial measurements; however, the FLASHFlux data sets will not be reprocessed into consistent time series records, and therefore, they should not be intermixed with the CERES climate quality data sets.

2. FLASHFlux will only be available until CERES climate quality data sets become available. This can take more than three months.

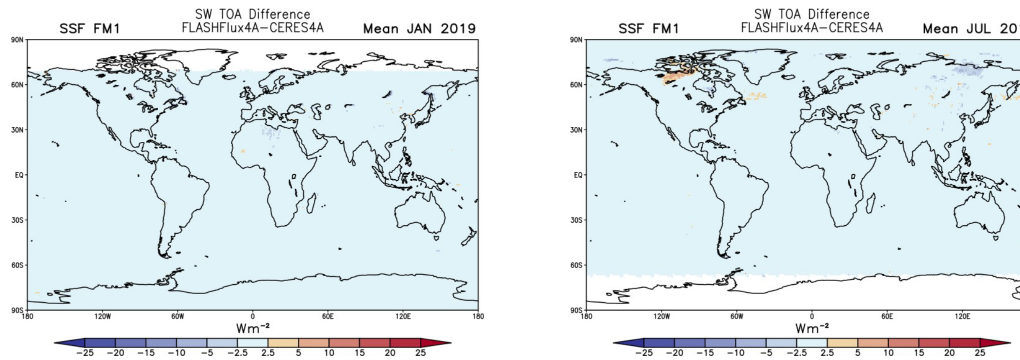
3. FLASHFlux input data sets and algorithms will change as improvements become available; however, no reprocessing is done to make current products backward compatible.

4. FLASHFlux Version4A uses GEOS-5.12.4 FPIT data as meteorology input. In contrast, CERES Ed4A used a frozen version of GEOS-4 (4.0.3) up to 31 December 2007, and a frozen version of CERES G5.4 after that date.

3.0 Accuracy and Validation

3.1 TOA Fluxes Comparison to CERES Edition4A

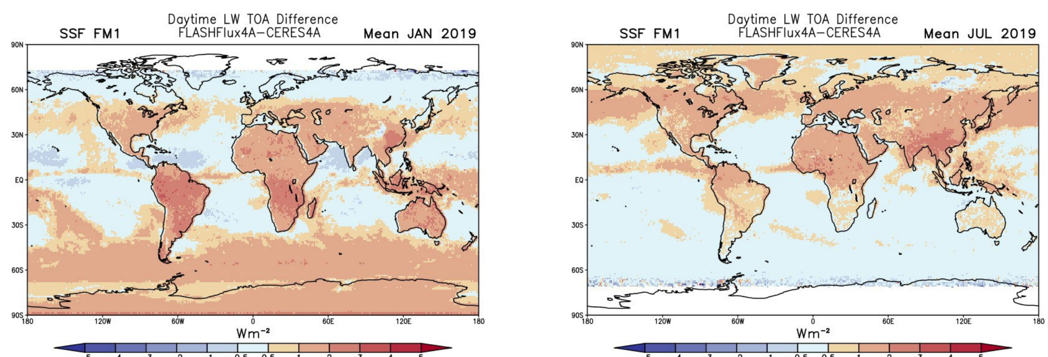
While the FLASHFlux data product is not considered to be “climate” quality, a major motivation for the FLASHFlux Version4A update is to make TOA fluxes as close to the CERES Edition4A fluxes as possible. Figure 3-1 clearly shows that FLASHFlux Version4A and CERES Edition4A are now less than 0.5 W m^{-2} apart for SW TOA.



(a) Jan. 2019 (b) Jul. 2019

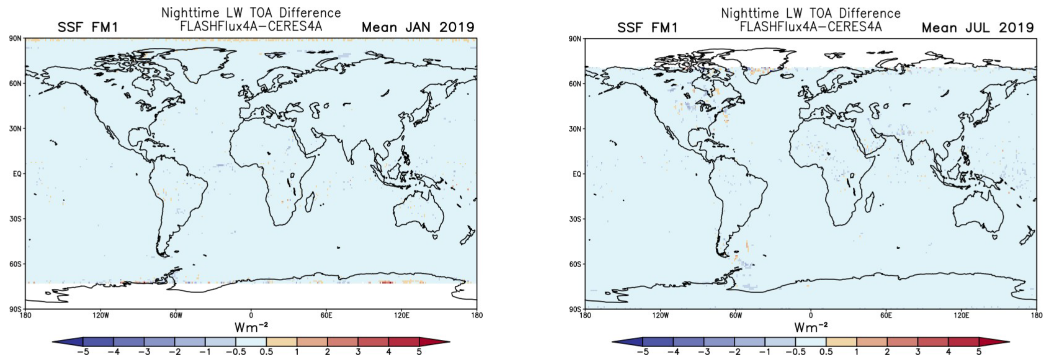
Figure 3-1. Monthly average Shortwave TOA flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.

The FLASHFlux mission is to provide data products within 3 days of observation. To accomplish that, FLASHFlux employs the latest available SCCs. As mentioned in Section 2.1.3, these SCCs can have a large impact on daytime LW TOA. Figure 3-2 shows the difference between FLASHFlux Version4A and CERES Edition4A on LW TOA. The differences can be attributed largely to the previously calibrated SCCs versus Climate quality SCCs. The FLASHFlux working group is currently exploring ways to update these SCCs file more frequently. Figure 3-3 shows the nighttime LW TOA differences, which are minimal, as expected.



(a) Jan. 2019 (b) Jul. 2019

Figure 3-2. Monthly average daytime Longwave TOA flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.



(a) Jan. 2019 (b) Jul. 2019

Figure 3-3. Monthly average nighttime Longwave TOA flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.

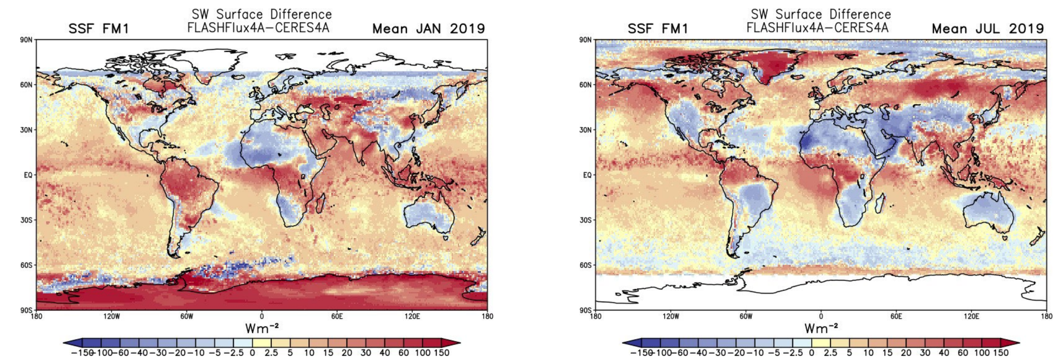
For TOA fluxes, FLASHFlux Version4A compares favorably to CERES Edition4A as shown in Table 3-1. The largest differences are coming from daytime LW TOA flux, which can be attributed to the SCCs files used.

Table 3-1. TOA flux comparison of FF Version4A to CERES Edition4A for the mean and (standard deviation) in W m^{-2} over all global footprints.

Instruments	Flux	January	April	July	October
Terra-FM1	Shortwave	0.04 (1.29)	0.21 (1.30)	0.17 (1.14)	0.12 (1.17)
	Longwave Day	0.77 (1.16)	0.35 (1.17)	0.54 (0.85)	0.47 (1.11)
	Longwave Night	-0.06 (0.46)	-0.07 (0.48)	-0.11 (0.48)	-0.07 (0.46)
Aqua-FM3	Shortwave	-0.04 (1.26)	-0.01 (1.32)	0.07 (1.10)	-0.05 (1.18)
	Longwave Day	-1.04 (0.77)	-0.73 (0.93	-0.29 (0.73)	-1.31 (0.94)
	Longwave Night	-0.53 (0.53)	-0.30 (0.55)	-0.20 (0.55)	-0.42 (0.51)

3.2 Surface Fluxes Comparison to CERES Edition4A

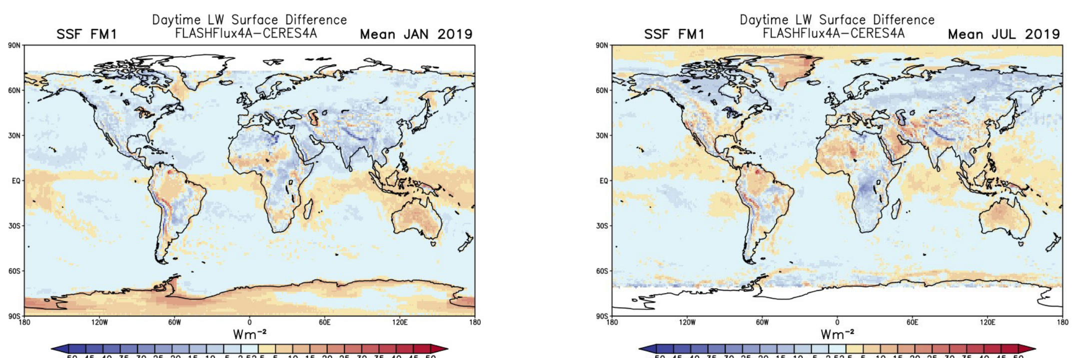
As mentioned in Section 2.1.4, FLASHFlux Version4A modified the LPSA to handle the snow and ice surface. The LPSA used in CERES Edition4A does not contain this modification. In addition, CERES Edition4A uses daily MATCH aerosols where FLASHFlux has adopted a 10-year MATCH climatology map. Hence, this results in the large bias between FLASHFlux and CERES, shown in Figure 3-4.



(a) Jan. 2019 (b) Jul. 2019

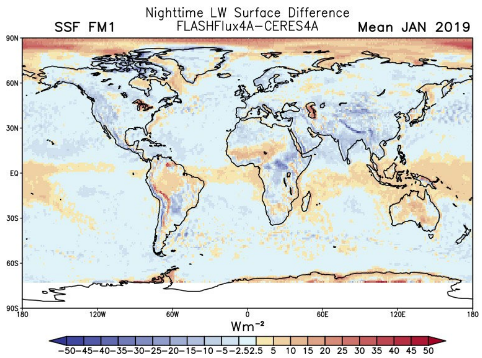
Figure 3-4. Monthly average Shortwave downwelling surface flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.

The LPLA algorithm relies heavily on the Clouds base pressure, Surface Skin Temperature, and water vapor. While both CERES and FLASHFlux use GMAO data products for meteorology, they are data products from two different series. Please refer to Section 1.1 for more information. Figure 3-5 and Figure 3-6 show how these differences can have an impact on the LPLA algorithm.

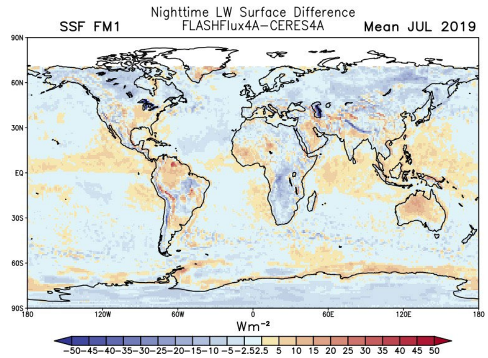


(a) Jan. 2019 (b) Jul. 2019

Figure 3-5. Monthly average daytime Longwave downwelling surface flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.



(a) Jan. 2019



(b) Jul. 2019

Figure 3-6. Monthly average nighttime Longwave downwelling surface flux differences of FLASHFlux Version4A compared to CERES Edition4A for (a) January 2019 and (b) July 2019.

The largest difference between FLASHFlux and CERES surface model B is the modification to the LPSA algorithm to handle the snow and ice surface. Table 3-2 highlights the large differences in the SW surface downwelling over the mid-seasonal months of 2019.

Table 3-2. Surface Fluxes comparison of FF Version4A to CERES Edition4A for the mean and (standard deviation) in W m^{-2} over all global footprints.

Instruments	Flux	January	April	July	October
Terra-FM1	Shortwave	8.36 (40.59)	8.95 (48.86)	8.47 (33.55)	9.2 (51.99
	Longwave Day	0.39 (6.38)	0.19 (6.49)	0.91 (6.16)	0.63 (5.90)
	Longwave Night	0.39 (8.30)	-0.37 (8.56)	0.16 (7.66)	0.44 (8.17)
Aqua-FM3	Shortwave	7.90 (37.82)	8.30 (44.59)	8.67 (33.00)	7.54 (42.52)
	Longwave Day	0.40 (6.18)	0.20 (6.34)	0.89 (6.11)	0.64 (5.82)
	Longwave Night	0.39 (8.25)	-0.13 (7.97)	0.48 (7.60)	0.50 (8.14)

3.3 Surface Sites Validation

CERES FLASHFlux processing makes use of the Model B SSF surface fluxes referred to in the CERES Data Products Catalog. It is formulated to be an all-sky model. This model is highly dependent on the SW radiances. Since FLASHFlux and CERES do not use the same spectral correction coefficients, the differences between the two datasets are highlighted. Additionally, several improvements have been made to the Model B algorithm for FLASHFlux Version4A.

The CERES working group has created a database of reliable ground-based surface flux measurements. The surface sites for this study were selected on the basis of data availability as well as their ability to represent different surface types (e.g., island, coastal, polar, continental, and desert).

Figure 3-7 represents a SW surface downwelling 2D histogram that illustrates the number of coincident flux values within each 20 W m^{-2} square bin from Terra measurements for (a) FF

Version3C, (b) FF Version4A, and (c) CERES Ed4A compared to ground site stations. FF Version4A has an increase of 4.3 W m^{-2} mean bias from the previous FF Version 3C as well as a higher RMS.

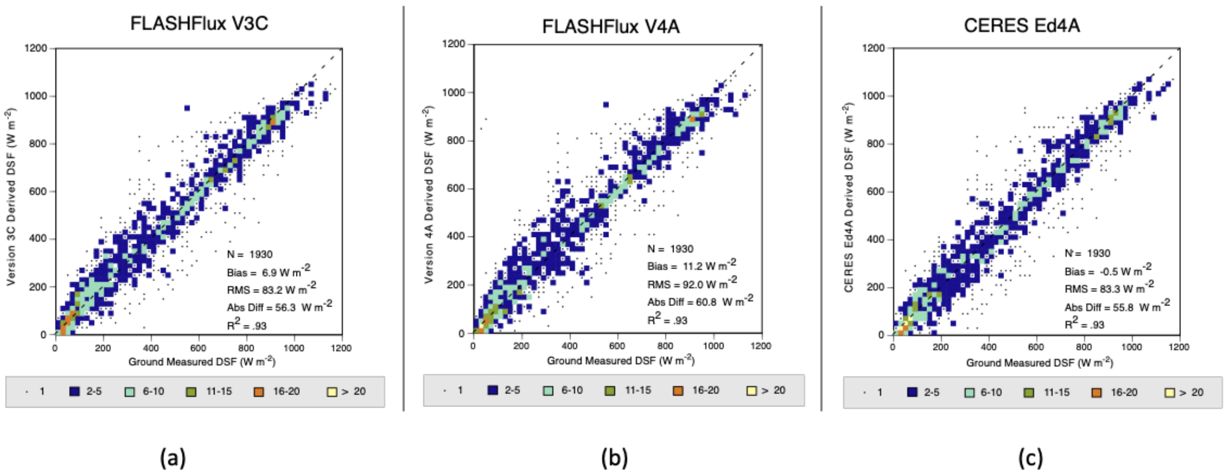


Figure 3-7. SW surface validation to grounds measurements based on Jan., Apr., Jul., Oct. 2019 for a) FLASHFlux Version3C, b) FLASHFlux Version4A, and c) CERES Edition4A.

Due to the underestimation of flux in the High latitude, an improvement in the Model B algorithm was introduced to increase the flux. Table 3-3 shows the High Latitude to have less than 10% bias to the ground sites; however, the RMS is almost 50%. Also note that FF Version4A coincident SW downwelling flux for the month of January and July 2019 compared favorably to CERES Edition4A as indicated in Table 3-4.

Table 3-3. Version4A SW differences to ground observation by surface type in W m^{-2}.

Ensemble Type	N	Mean	Bias	RMS	Absolute Diff.	R^2
All Obs	1930	455.7	11.2 (2.5%)	92.0 (20.2%)	60.8	0.91
Continental	849	512.9	19.1 (3.7%)	94.8 (18.5%)	58.9	0.90
Coastal	418	521.0	-4.7 (-0.9%)	87.7 (16.8%)	60.8	0.89
Desert	97	923.0	-37.5 (-4.1%)	89.0 (9.6%)	68.0	0.73
High Latitude	537	537	17.4 (8.1%)	90.2 (41.7%)	87.9	0.77
Island	29	692.6	55.3 (8.0%)	109.2 (15.8%)	67.5	0.80

Table 3-4. Mean bias (standard deviation) of coincident SW Downwelling Flux differences to ground observations for Jan. & Jul. 2019 in W m^{-2}.

Months	Instruments	FF V3C	FF V4A	CERES Ed4A	# Observations
January, 2019	Terra-FM1 Aqua-FM3	9.2 (77.4) 17.2 (79.9)	4.0 (78.3) 14.9 (80.1)	7.2 (78.6) 17.6 (80.0)	339 316
July, 2019	Terra-FM1 Aqua-FM3	14.2 (75.0) 19.3 (88.4)	5.8 (74.2) 18.5 (99.0)	5.9 (74.3) 16.3 (89.6)	632 673

FF Version4A shows an improvement in the daytime LW downwelling flux when compared to coincident ground measurements. It is now comparable to CERES Edition4A; however, the RMS is still the same as previous FF Version3C as indicated in Figure 3-8. Comparison of coincident daytime LW downwelling fluxes by surface type, in Table 3-5, indicates that mean bias for the different surface types is less than 2%.

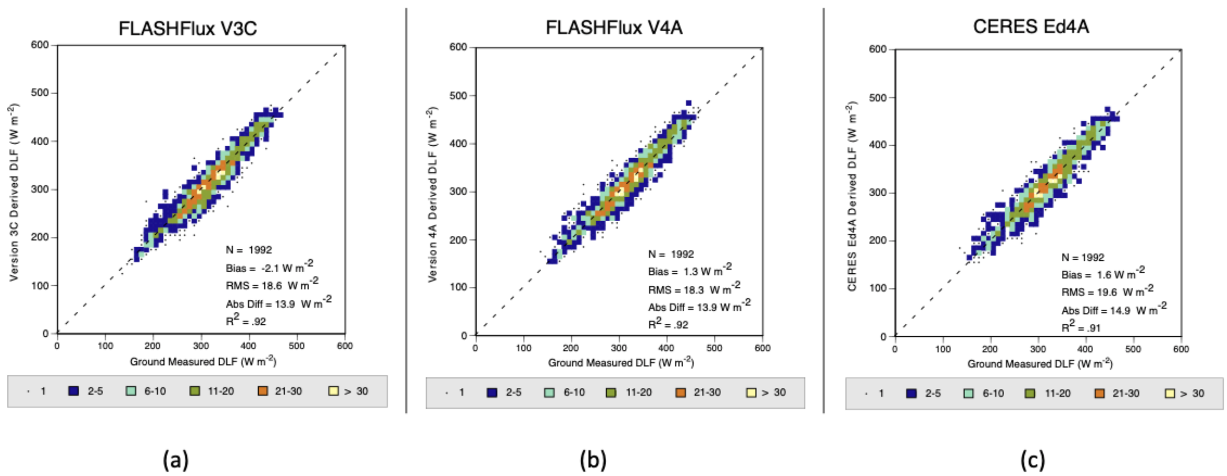


Figure 3-8. Daytime LW surface validation to grounds measurements based on Jan., Apr., Jul., Oct. 2019 for a) FLASHFlux Version3C, b) FLASHFlux Version4A, and c) CERES Edition4A.

Table 3-5. Version4A daytime LW differences to ground observation by surface type in W m^{-2}.

Ensemble Type	N	Mean	Bias	RMS	Absolute Diff.	R^2
All Obs	1992	317.9	1.3 (0.4%)	18.3 (5.8%)	13.9	0.92
Continental	848	317.7	1.6 (0.5%)	18.4 (5.8%)	14.0	0.91
Coastal	418	353.6	5.7 (1.6%)	17.1 (4.8%)	13.2	0.94
Desert	93	337.6	6.1 (1.8%)	18.4 (5.4%)	13.7	0.88
High Latitude	603	286.3	-2.7 (-0.9%)	19.4 (6.8%)	14.3	0.86
Island	30	401.1	-4.4 (-1.1%)	11.6 (2.9%)	10.0	0.94

Nighttime LW downwelling fluxes of FF Version4A indicate an overestimation of derived flux at the lower end of the 2D histogram similar to CERES Edition4A as indicated in Figure 3-9(b) and (c), respectively. Figure 3-9(a) of FF Version3C also shows an overestimation, but not as pronounced. Looking into the distribution by surface types in Table 3-6, it is noteworthy that the High Latitude type has the only positive bias, and thus may be indicative of the overestimation seen in Figure 3-9.

Overall, FF Version4A LW downwelling flux appears to be an improvement over the previous FF Version3C and somewhat better than CERES Edition4A when compared to coincident ground measurements for January and July 2019 seen in Table 3-7.

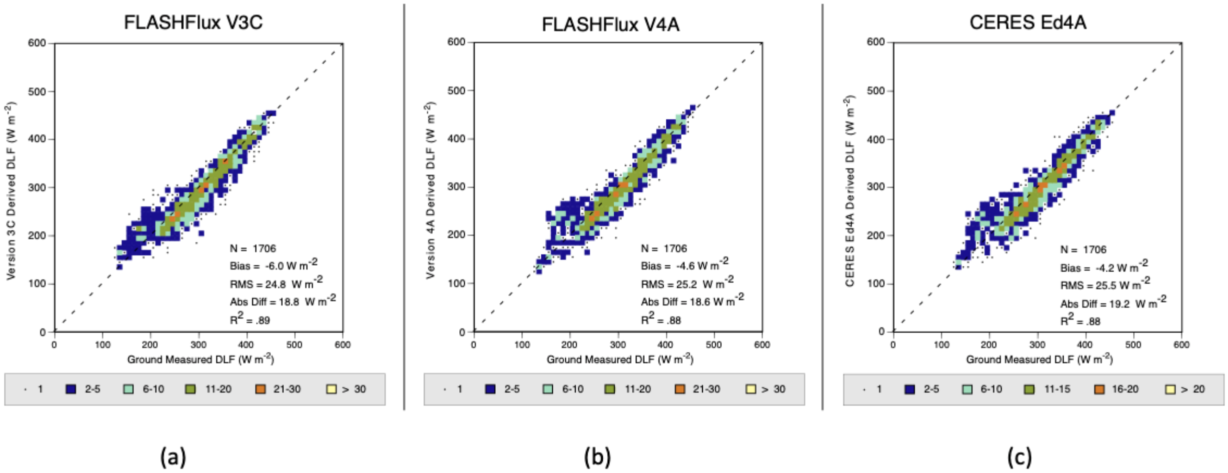


Figure 3-9. Nighttime LW surface validation to grounds measurements Jan., Apr., Jul., Oct. 2019 for a) FLASHFlux Version3C, b) FLASHFlux Version4A, and c) CERES Edition4A.

Table 3-6. Version4A nighttime LW differences to ground observation by surface type in W m^{-2}.

Ensemble Type	N	Mean	Bias	RMS	Absolute Diff.	R^2
All Obs	1706	298.0	-4.6 (-1.5%)	25.2 (8.4%)	18.6	0.88
Continental	803	309.5	-12.6 (-4.1%)	23.3 (7.5%)	17.6	0.89
Coastal	391	344.0	-5.3 (-1.5%)	17.6 (4.8%)	13.7	0.94
Desert	71	324.3	-8.1 (-2.5%)	17.5 (5.4%)	14.1	0.91
High Latitude	414	414	12.1 (5.5%)	34.7 (15.7%)	26.4	0.60
Island	27	398.6	-1.2 (-0.3%)	15.5 (3.9%)	11.3	0.70

Table 3-7. Mean bias (standard deviation) of coincident LW Downwelling Flux differences to ground observations for Jan. & Jul. 2019 in W m^{-2}.

Months	Instruments	FF V3C	FF V4A	CERES Ed4A	# Observations
January 2019 Day	Terra-FM1 Aqua-FM3	-2.5 (19.5) -3.4 (20.2)	1.8 (18.7) -0.02 (17.6)	4.6 (19.7) 2.0 (17.7)	342 321
January 2019 Night	Terra-FM1 Aqua-FM3	-3.6 (28.2) -8.9 (32.8)	-1.3 (33.1) -1.1 (32.1)	-0.8 (30.5) -2.2 (30.7)	595 583
July 2019 Day	Terra-FM1 Aqua-FM3	-7.3 (19.3) -9.6 (21.4)	-5.4 (18.3) -5.9 (19.2)	-4.0 (18.0) -4.2 (19.3)	647 672
July 2019 Night	Terra-FM1 Aqua-FM3	-9.0 (24.2) -10.3 (23.9)	-2.1 (25.2) -6.7 (22.7)	-6.1 (23.0) -6.9 (23.6)	551 573

4.0 Cautions and Helpful Hints

There are several cautions that are noteworthy regarding the use of CERES FLASHFlux Version4A SSF data. These are mostly identical to the CERES Edition4 SSF but are copied here for convenience.

4.1 General

- The SSF data sets contain only every other CERES footprint when the viewing zenith angle is less than 63°. All footprints with a viewing zenith angle 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.
- 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 viewing zenith angles 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.
- This SSF contains only CERES footprints with at least one valid CERES radiance.
- The geographic location of a CERES flux estimate is at the surface geodetic latitude and longitude of the CERES footprint centroid.
- 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.)
- Data in an area experiencing a solar eclipse is not processed for the duration of the eclipse.

4.2 Cloud

- For Version4A 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.

- 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.
- 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 μm and 3.8 μm 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 μm reflectances.
- The CO_2 algorithm thin ice cloud height correction may overestimate the effective height.

5.0 References

[1] David P. Kratz et al. "The Fast Longwave and Shortwave Flux (FLASHFlux) Data Product: Single-Scanner Footprint Fluxes". In: *Journal of Applied Meteorology and Climatology* 53.4 (2014). 00000, pp. 1059–1079. issn: 1558-8424. doi: 10.1175/JAMC-D-13-061.1. url: http://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-13-061.1.

[2] David P. Kratz et al. "Validation of the CERES Edition-4A Surface-Only Flux Algorithms". In: *Journal of Applied Meteorology and Climatology* 59.2 (Jan. 2020), pp. 281– 295. issn: 1558-8424. doi: 10.1175/JAMC-D-19-0068.1. url: https://journals.ametsoc.org/doi/full/10.1175/JAMC-D-19-0068.1.

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[8] Shashi K. Gupta et al. "Improvement of Surface Longwave Flux Algorithms Used in CERES Processing". In: *Journal of Applied Meteorology and Climatology* 49.7 (Mar. 2010). 00013, pp. 1579–1589. issn: 1558-8424. doi: 10.1175/2010JAMC2463.1. url: http://journals.ametsoc.org/doi/abs/10.1175/2010JAMC2463.1.

6.0 Expected Reprocessing

There is no scheduled or planned reprocessing of the FLASHFlux SSF Version4A product.

7.0 Attribution

When referring to the CERES FLASHFlux SSF Version4A product, please include the product and data set version as: “CERES FLASHFlux SSF Version4A.”

The CERES Team has gone to considerable trouble to remove major errors and to verify the quality and accuracy of this data. Please provide a reference to the following paper when you publish scientific results with the CERES FLASHFlux SSF Version4A product:

David P. Kratz et al. “The Fast Longwave and Shortwave Flux (FLASHFlux) Data Product: Single-Scanner Footprint Fluxes”. In: *Journal of Applied Meteorology and Climatology* 53.4 (2014). 00000, pp. 1059–1079. issn: 1558-8424. doi: 10.1175/JAMC-D-13-061.1. url: http://journals.ametsoc.org/doi/abs/10.1175/JAMC-D-13-061.1.

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:
10.5067/CERES/FLASH_SSF_Aqua-FM3-MODIS_Version4A
10.5067/CERES/FLASH_SSF_Terra-FM1-MODIS_Version4A

When CERES data obtained via the CERES web site are used in a publication, we request the following acknowledgment be included: “These data were obtained from the NASA Langley Research Center CERES ordering tool at https://ceres.larc.nasa.gov/data/.”

When Langley ASDC data are used in a publication, we request the following acknowledgment be included: "These data were obtained from the NASA Langley Research Center Atmospheric Science Data Center."

8.0 Feedback and Questions

For questions about or concerning the data and parameters ordered through the CERES subsetting/visualization/ordering tool https://ceres.larc.nasa.gov/data/, please email LaRC-CERES-Help@mail.nasa.gov.

For comments involving the CERES FLASHFlux Version4A Data Quality Summary please email LaRC-CERES-Help@mail.nasa.gov.

For questions concerning data ordered at the Atmospheric Science Data Center (ASDC) https://asdc.larc.nasa.gov/project/CERES contact the User and Data Services staff at the Atmospheric Science Data Center.

9.0 Document Revision Record

The Document Revision Record contains information pertaining to approved document changes. The table lists the Version Number, the date of the last revision, a short description of the revision, and the revised sections.

Document Revision Record

Version Number	Date	Description of Revision	Section(s) Affected
V1	09/06/2023	• Original document.	All