CERES_SYN1deg_Ed4A

Data Quality Summary (4/8/2021)

Investigation: **CERES**
Data Product: **SYN1deg-Month, SYN1deg-Day, SYN1deg-MHour, SYN1deg-3Hour, SYN1deg-1Hour**

Data Sets: **Terra+Aqua+GEO**
Terra+NPP+GEO

Data Set Versions: **Terra-Aqua Edition4A** **Release Date: September 13, 2017**
Terra-NPP Edition1A **Release Date: October 3, 2017**

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

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 (especially Cautions and Helpful Hints) for the latest status before publication of any scientific papers using this data product.

Changes from SYN1deg Ed3A:

- SYN1deg Ed4A uses a consistent source of temperature and humidity throughout for the entire time record.
- SYN1deg Ed4A uses MODIS collection 5 through February 2017. As a consequence, there is no significant discontinuity in the time series of clear-sky downward shortwave flux anomalies over land for the most of the time record.
- Cloud properties from geostationary satellites are derived hourly. Fluxes are also computed hourly. The temporal resolution is improved from 3-hourly used in Ed3A.
- Surface longwave fluxes have improved because of the improvement of nighttime retrieved cloud properties.

Important Update to Note as of April 7, 2021:
Please see the RED bullet in Cautions and Helpful Hints.

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1.0 Nature of the CERES_SYN1deg_Ed4A Products

The CERES SYN1deg-Month,-MHour, -Day, -3Hour and -1Hour (hereinafter SYN1deg) products are Level 3 products containing 1°-regional monthly, monthly hourly, daily, 3-hourly and hourly averaged observed top-of-atmosphere (TOA) fluxes along with computed TOA and surface fluxes and fluxes at four atmospheric pressure levels (70, 200, 500, and 850 hPa). The regional monthly mean parameters are also zonally and globally averaged. SYN1deg products also contain coincident MODIS-derived cloud and aerosol properties and hourly geostationary satellite (GEO) derived cloud properties.

For Ed4A the CERES project has taken advantage of the next generation GEO imager capabilities rather than relying solely on first-generation GEO cloud retrievals. Surface fluxes are computed using 16 GEO and MODIS derived cloud properties. GEO cloud algorithms minimize the difference from the cloud properties derived from MODIS. This is the first attempt for the CERES project to apply a more MODIS-like cloud retrieval algorithm across the GEO satellites; achieving more uniform MODIS and GEO clouds. The new GEO cloud retrievals take advantage of additional channels that were not utilized in the visible and IR-only CERES retrieval code for Ed3A. However, the many GEO imager capability differences, such as number of channels, spectral response, and image quality, make retrieving uniform cloud properties across the GEO constellation more challenging. Improvements in GEO cloud retrieval consistency as well as improved computed surface fluxes are planned for Edition 5.

The SYN1deg Ed4A product is designed to provide the highest temporal resolution TOA and surface flux dataset by incorporating hourly GEO imager data and by taking advantage of the additional GEO imager channels to improve the cloud property retrievals, computed surface fluxes, and GEO-derived TOA fluxes. **The SYN1deg Ed4A should not be used to infer long-term trends of clouds or fluxes and are not of climate quality. Users should be aware that whenever a GEO domain is crossed, whether in time or space, a slight change in mean cloud property values should be expected. Although the GEO derived fluxes have been carefully normalized with CERES fluxes, some residual GEO artifacts will remain.** Users are advised to use the EBAF-TOA and EBAF-Surface products to determine the long-term flux natural variability and temporal trending. The EBAF-TOA Ed4.0 product provides monthly cloud properties suited for EBAF flux analysis by combining Terra and Aqua-MODIS cloud properties. The Terra or Aqua SSF1deg Ed4A MODIS-retrieved cloud properties are of climate quality and can be used to determine long-term regional cloud trends; however, they do not encompass the entire diurnal cycle.

The SYN1deg Ed4A products are also designed to provide diurnally complete surface fluxes, which are computed hourly; these can be compared to ground site fluxes. The SYN1deg Ed4A products are intended for applications that require high (up to 1-hourly) temporal scale TOA fluxes and for regional diurnal process studies. Other possible applications include field campaigns and intensive observation periods (IOPs). For Ed4 CERES has incorporated hourly GEO clouds and fluxes, rather than relying on temporal interpolation between 3-hourly GEO observations, thereby nearly eliminating the extent of temporal interpolation over the GEO domain (±60° in latitude). The EBAF-TOA and EBAF-Surface use the SYN1deg fluxes and clouds as inputs to estimate the regional diurnal flux, but they remove all known GEO artifacts. The CERES LW narrowband to broadband algorithm has replaced the column weighted humidity term based on GEOS with the GEO water vapor channel. This has improved the quality of the SYN1deg Ed4A regional monthly (Terra+Aqua+GEO) LW fluxes that are directly used in the EBAF-TOA product.

TOA fluxes are derived using two different approaches. The first approach uses observed radiances together with angular distribution models (hereinafter called observed TOA fluxes). The second approach uses satellite-derived cloud and aerosol properties together with a radiative transfer model (hereinafter called computed TOA fluxes). The agreement of TOA fluxes produced by these two different approaches is an indicator of the quality of TOA fluxes. Computed surface and in-atmosphere fluxes are only available through the SYN1deg product. For observed fluxes, we combine the Terra and Aqua CERES-observed temporally interpolated TOA radiative fluxes. Broadband fluxes derived from GEOs are normalized with CERES fluxes in order to maintain the consistency with CERES calibration. For computed fluxes, we use the Langley Fu-Liou radiative transfer model and MODIS- and GEO-derived cloud properties.

More details about the algorithms and inputs for the observed TOA fluxes and cloud properties and the computed TOA, surface, and in-atmosphere fluxes are given in the following sections.

We urge users to visit the CERES data subsetting/visualization/ordering tool, which provides an improved user interface and a wider range of data formats (e.g., netCDF, ASCII); the Earthdata Search ordering tool is limited to HDF.

https://ceres.larc.nasa.gov/data/

1.1 Observed TOA Fluxes and Cloud Properties

1.1.1 Algorithm and Inputs

Algorithms that derive the TOA fluxes and cloud properties share common inputs. The NASA-GSFC Global Modeling and Assimilation Office (GMAO) Goddard Earth Observing System (GEOS) version 5.4.1 provides the atmospheric profiles (Rienecker et al. 2008). The snow and ice daily coverage is from the NSIDC (National Snow and Ice Data Center) Near-Real-Time SSM/I-SSMIS EASE-Grid Daily Global Ice Concentration and Snow Extent product. The aerosols are from the NASA-GSFC MODIS MOD04_L2/MYD04_L2 products (Remer et al. 2005) and MATCH Aerosol Transport Model constituents (Collins et al. 2001). The incoming solar daily irradiance is from the SORCE TSI [Solar Radiation and Climate Experiment, Total Solar Irradiance, (Kopp et al. 2005)]. Other inputs to the CERES SYN1deg product include CERES Edition4 instrument gains and time-varying spectral response functions.

The SYN1deg Ed4A product incorporates CERES observed fluxes and MODIS-derived cloud properties as well as GEO image products. The CERES SSF footprint fluxes and MODIS-derived cloud properties are first spatially averaged into 1° gridded regions. The center latitude and longitude of the CERES footprint is used to assign the region. The CERES SSF1deg-Hour product contains these flux and cloud instantaneous spatially gridded means. The MODIS-derived cloud properties are not the official Goddard DAAC MODIS MOD0x or MYD0x cloud retrievals, but are based on the CERES cloud working group Ed4A retrievals (Minnis et al. 2011); these cloud properties are available on the SSF and SSF1deg-Hour/Day/Month Edition 4A products. Similarly, the GEO pixel-level clouds and radiances, which are contained in the CERES individual hourly GEO image products, are instantaneously averaged into 1° gridded regions between ±60° in latitude.

1.1.2 Cloud Retrievals

Figure 1-1 identifies the GEO satellites used in the CERES record. The first-generation GEO cloud properties are retrieved from a two-channel (2-ch) algorithm using only the visible and IR bands (Minnis et al. 1995) similar to the ISCCP-D2 cloud algorithm. GOES second-generation 5-channel imagers include the 0.65µm, 3.9µm, 6.7µm, and 11µm channels. Beginning with GOES-12, the 12µm channel was replaced with the 13.3µm channel. The GOES 8-11 cloud retrievals are based on all 5-channels (5-ch-12) as well as the GOES-12-15 (5-ch-13.3) The Meteosat 8-10 and Himawari-8 are retrieved from multiple channels (M-ch) dependent on the GEO imager channel configuration. The GEO M-ch cloud retrieval is similar to the CERES MODIS cloud retrieval algorithm except that it utilizes fewer channels subject to the number of available GEO imager channels (see Table 1-1). All M/5-ch cloud retrievals are based on the daytime VISST and nighttime SIST algorithms (Minnis et al. 2011a). The GEO1deg-Hour nadir pixel resolution is 8-km, sub-sampled from the nominal 1-km and 4-km visible and IR GEO imager nominal pixel resolution. The instantaneous 1-km (sub-sampled at 2-km) pixel level MODIS cloud properties are averaged within a CERES 20-km footprint and stratified into two possible dynamic cloud layers (Geier et al. 2003 Fig. 4-10). The instantaneous gridded cloud properties from SSF1deg-Hour and GEO1deg-Hour are stratified by four pressure layers (surface-700mb, 700mb-500mb, 500mb-300mb, and 300mb to 50mb).

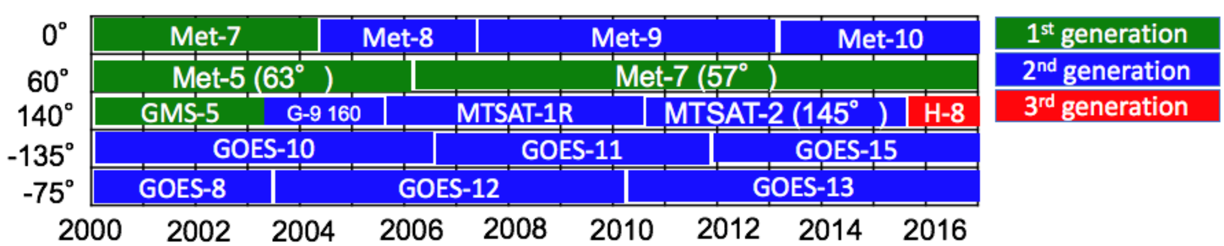

Figure 1-1. The GEO satellites used in the CERES SYN1deg product as a function of longitude position. G-9 and H-8 refer to GOES-9 and Himawari-8, respectively.

Table 1-1. The GEO imager channels used to determine the cloud mask (M) and to retrieve cloud properties (R). The cloud retrieval algorithm is identified along the top row, and the GEO satellites associated with cloud retrieval algorithm are listed in the second row.

channel	**2-ch**	**5-ch-12**	**5-ch-13.3**	**M-ch**	**MODIS**	**VIIRS**
GEOs	GMS-5, Met-5, Met-7	GOES 8-11	GOES 12-15	Met 8-10, Him-8		
0.47 µm					M	M
visible	M,R	M,R	M,R	M,R	M,R	M,R
0.86 µm				M	M	M
1.24 µm					M	M, R
1.38 µm					M, R	M, R
1.6 µm				M,R		M,R
2.1 µm					M	
3.9 µm		M,R	M,R	M,R	M, R	M, R
6.7 µm		M	M	M	M	
8.6 µm				M	M	M
11 µm	M,R	M,R	M,R	M,R	M,R	M,R
12 µm		M,R		M,R	M,R	M,R
13 µm			R	R	R	

The SYN1deg Ed4A cloud parameters are listed in Table 1-2. The MODIS and GEO M/5-ch retrievals provide all the parameters for both daytime and nighttime measurements. The daytime GEO 2-ch assumes static particle radii of 10 µm and 30 µm for liquid and ice clouds, respectively. The daytime GEO 2-ch retrievals use a cloud effective temperature threshold of 253 K to discriminate between liquid and ice phases. The SYN1deg product computes the IWP and LWP from the optical depth and particle size for both GEO and MODIS clouds. The GEO 2-ch cloud retrievals assume an IR emissivity of unity at night; that is, the cloud height is not adjusted upward by optical depth at night. The SYN1deg Ed4A product temporally interpolates cloud properties not retrieved at night from MODIS night and GEO sunset and sunrise retrievals, facilitating hourly surface flux radiative transfer model computations.

Table 1-2. The SYN1deg cloud property parameter availability as a function of MODIS, GEO 5-ch, GEO 2-ch day, and GEO 2-ch night retrievals. For GEO 2-ch day, the cloud particle radii are assumed to be 10 µm and 30 µm for liquid and ice, respectively. +The GEO-2ch LWP and IWP are computed from the assumed particle size and optical depth. *GEO 2-ch cloud top and base retrievals are not available at night since the optical depth is not available.

Cloud property	MODIS Day/Night	GEO (M-ch, 5-ch retrieval)	GEO-day (2-ch retrieval)	GEO-night * (2-ch retrieval)
Cloud Fraction	X	X	X	X
Cloud Effective Pressure	X	X	X	X
Cloud Effective Temperature	X	X	X	X
Cloud Effective Height	X	X	X	X
Cloud Top Pressure	X	X	X	
Cloud Top Temperature	X	X	X	
Cloud Top Height	X	X	X	
Cloud Base Pressure	X	X	X	
Cloud Base Temperature	X	X	X	
Cloud Base Height		X	X	
Cloud Phase	X	X	X	X
Cloud Optical Depth	X	X	X	
Cloud Particle Radius	X	X	10/30 µm	10/30 µm
Liquid/Ice Water Path	X	X	+	+
Cloud IR Emissivity	X	X	X	1.0

Cloud properties are temporally interpolated within each of the four layers across any hourly data gaps. The cloud properties are averaged by layer as follows. The cloud amount is simply averaged. The remaining cloud properties are weighted by their associated cloud amount. The log of the optical depth is used to average optical depths, since the log optical depth is approximately proportional to the visible radiance. The total cloud properties are calculated hourly by averaging the 4-layer cloud properties. The daily mean is computed from hourly cloud properties, and the monthly mean is computed from the daily values.

1.1.3 Observed TOA Fluxes

The CERES SYN1deg products use 1-hourly radiances and cloud property data from geostationary (GEO) imagers to more accurately model variability between CERES observations. To use GEO data to enhance diurnal sampling, several steps are involved. First, GEO radiances are cross-calibrated with the MODIS imager using only data that is coincident in time and ray-matched in angle. Next, the GEO cloud retrievals are inferred from the calibrated GEO radiances. The GEO radiances are converted from narrowband to broadband using empirical regressions and then to broadband GEO TOA fluxes using ADMs and directional models. To ensure the consistency of the GEO and CERES TOA fluxes, a normalization technique is used. Instantaneous matched gridded fluxes from CERES and GEO are regressed against one another over a month from 5°×5° latitude-longitude regions. The regression relation is then applied to all GEO fluxes to remove biases that depend upon cloud amount, solar and view zenith angles, and regional dependencies. The all-sky GEO LW TOA fluxes use the same approach as in Edition2 and employ regional instantaneous normalization.

The regional means are determined for 1° equal-angle grid boxes calculated by first interpolating each parameter between the times of the CERES/GEO observations to produce a complete 1-hourly time series for the month. After interpolation, the time series is used to produce mean parameters. Monthly means are calculated using the combination of observed and interpolated parameters from all days containing at least one CERES observation. Observed TOA fluxes are provided for clear-sky and all-sky conditions for longwave (LW), shortwave (SW), and window (WN) wavelength bands.

1.2 Computed Fluxes

Computed TOA fluxes from SYN1deg do not necessarily agree with the CERES-derived TOA fluxes included in SYN1deg, partly because of the error in inputs used in the computations and, to a smaller extent, due to assumption in the radiative transfer model. Surface fluxes included in the EBAF-Surface product are adjusted within their uncertainty so that the computed TOA fluxes match the observed TOA fluxes. Users who do not need hourly surface fluxes or in-atmosphere fluxes at the 70, 200, 500, and 850 hPa levels are encouraged to use the EBAF-Surface product.

1.2.1 Algorithm and Inputs

The SYN1deg product contains gridded monthly, monthly hourly, daily, 3-hourly and hourly mean computed TOA and surface fluxes along with fluxes at four atmospheric pressure levels (70, 200, 500, and 850 hPa). Surface fluxes in SYN1deg are computed with cloud properties derived from MODIS and geostationary satellites (GEO), where each geostationary satellite instrument is calibrated against MODIS (Doelling et al. 2013). The Ed4 CERES cloud algorithm (Minnis et al. 2016) derives cloud properties (e.g. fraction, optical depth, top height, and particle size) from narrowband radiances measured by MODIS, twice a day from March 2000 through August 2002 (Terra only) and four times a day after September 2002 (Terra plus Aqua). The Edition 4 multi-channel GEO cloud algorithm (Mecikalski et al. 2007; Minnis et al. 2001) provides cloud properties (fraction, top height, optical depth, phase, particle size) every one hour between Terra and Aqua observations. Cloud properties are gridded onto a 1°×1° spatial grid and one-hourly intervals (hour boxes). Although it occurs less frequently than Ed3A, cloud properties are missing in some hour boxes. Missing cloud properties are estimated by interpolating from the nearest hour boxes. Up to four cloud-top heights (cloud types, high, mid-high, mid-low, and low) are retained for each hour box within a 1°×1° grid box. Cloud properties (cloud top height, optical thickness, particle size, phase etc.) are kept separately for four cloud types.

To treat horizontal variability of optical thickness within a cloud type explicitly, both linear and logarithmic means of the cloud optical thicknesses are computed for each cloud type. The distribution of cloud optical thickness expressed as a gamma distribution is estimated from the linear and logarithmic cloud optical thickness means (Barker 1996; Oreopoulos and Barker 1999; Kato et al. 2005). Once the distribution of cloud optical thickness is estimated for each cloud type, a gamma-weighted two-stream radiative transfer model (Kato et al. 2005), when the shape factor is less than 10, otherwise a four-stream model is used to compute the shortwave flux vertical profile for each cloud type. The logarithmic mean optical thickness is used in the longwave flux computation with a modified 2-stream approximation (Toon et al. 1989; Fu et al. 1997). The cloud base pressure, which largely influences the surface downward longwave flux in midlatitude and polar regions, is estimated by an empirical formula described by Minnis et al. (2016).

Temperature and humidity profiles used in the radiative transfer model calculations are from the Goddard Earth Observing System (GEOS-5.4.1) Data Assimilation System reanalysis (Rienecker et al. 2008). Although the GEOS-5.4.1 product has higher temporal and spatial resolutions, six-hourly 1°×1° GEOS-5.4.1 temperature and relative humidity profiles are used for surface computations. Skin temperatures used in the computations are at three-hourly resolution. Column ozone amount is also taken from GEOS-5.4.1. Other inputs used in SYN1deg-Month include ocean spectral surface albedo from Jin et al. (2004). Broadband land surface albedos are inferred from the clear-sky TOA albedo derived from CERES measurements (Rutan et al. 2009). In addition, MODIS spectral radiances over partly cloudy scenes are used to estimate surface albedo over the clear-sky part of partly cloudy scenes. The shape of surface albedo as a function of solar zenith angle depends on IGBP surface type. A solar zenith angle of 55° is used for the cloudy sky surface albedo. The spectral surface albedo over ocean is a function of solar zenith angle, wind speed and cloud and aerosol depth. Broadband ocean surface albedo is not retrieved; it is directly based on look-up tables from Jin et al. (2004). Over land, spectral albedo shapes are taken from the MCD43C1 product. Over snow and ice, the spectral shape is a function of grain size, solar zenith angle and optical depth. For these surface types, a retrieval of broadband surface albedo is based upon the gridded monthly mean of atmospheric corrected CERES and/or MODIS narrowband to broadband instantaneous TOA clear sky albedos. Emissivity is based on Wilber et al. (1999).

Aerosol optical thicknesses are from an aerosol transport model MATCH (Collins et al. 2001) that assimilates and spatially and temporally interpolates MODIS aerosol optical thickness. MATCH also provides aerosol types. We use 7 different aerosol types listed in Table 1-5. To distribute the optical thickness among constituents in the column, we compute the mass of each constituent in a computational layer. We divide the optical thickness by the total mass of aerosols in the column. The optical thickness for a given constituent is computed by multiplying the ratio by the mass of each constituent.

The spectral solar constant used in the shortwave radiative transfer code is Newkur taken from MODTRAN. The solar constant integrated over the entire solar spectral is normalized to match observation provided by the Solar Radiation and Climate Experiment (SORCE) Total Solar Irradiance (TSI) V-15 dataset.

General input sources and references, as well as references for the optical properties of clouds and aerosols are summarized in Table 1-3, Table 1-4, and Table 1-5, respectively.

Table 1-3. Input sources for SYN1deg.

Input variable	**Source**	**References**
Cloud properties	Derived from MODIS and GEOs	Minnis et al. (2017)
Aerosols	MATCH	Collins et al.
Ocean surface albedo	Model	Jin et al. (2004)
Land surface albedo	CERES (broad band) MODIS (spectral shape)	Rutan et al. (2009)
Sea ice snow albedo		
Emissivity		Wilber et al. (1999)
Temperature	GEOS-5.4.1	
Specific humidity	GEOS-5.4.1	
Ozone	GEOS-5.4.1	
Snow and sea ice	NSIDC near-real time snow and ice extent (NISE)	

Table 1-4. Cloud optical property sources for SYN1deg.

Optical property	**Reference/Source**
Warm clouds	
Single scattering albedo	Hu and Stamnes (1993)
Asymmetry parameter	Hu and Stamnes (1993)
Optical thickness	MODIS
Ice clouds	
Single scattering albedo	Fu (2007); Fu (1996)
Asymmetry parameter	Fu (2007); Fu (1996)
Optical thickness	MODIS

Table 1-5. Aerosol optical property sources for SYN1deg.

	Type	**MATCH constituents**	**Reference**
1	Small dust (<0.5 μm)	DSTQ01	Sinyuk et al. (2003)
2	Large dust (>0.5μm)	DSTQ02+DSTQ03+DSTQ04	Sinyuk et al. (2003)
3	Stratospheric	VOLC+stratosphere_SO4	OPAC suso
4	Sea salt	SSLT	D'Almedia maritime
5	Soot	BCPHI+BCPHO	OPAC soot
6	Soluble	OCPHI+tropospheric_SO4	OPAC waso
7	Insoluble	OCPHO	OPAC inso

1.2.2 All-Sky and Clear-Sky Flux Computations

All-sky fluxes are computed hourly for each equal-area grid, defined in Table 1-6. Monthly mean all-sky surface shortwave and longwave fluxes for 1°×1° grids are computed by averaging hourly Ed4 SYN1deg all-sky fluxes. Clear-sky fluxes are also computed hourly for each equal-area grid by removing clouds. Therefore, temperature and humidity profiles used for computations are the same for all-sky and clear-sky fluxes. The sampling of clear-sky fluxes is, therefore, different from observed top-of-atmosphere clear-sky fluxes that are also included in the SYN1deg product. We also provide two more flux types, pristine and cloudy-sky with no aerosols. Pristine fluxes are computed by removing aerosols from clear-sky computations, that is, including only molecular scattering and absorption. Cloudy-sky with no aerosol fluxes are computed by removing aerosols from the all-sky computations.

Table 1-6**.** Equal-area grid.

Latitude range (degree)	Grid size, latitude × longitude (degree)
90-89	1×360
89-90	1×8
90-70	1×4
70-45	1×2
45-0	1×1

2.0 CERES Processing Level and Product Description

This section explains the CERES processing flow from level 0 to level 3 products; the steps are summarized in Table 2-1. This section also briefly describes all of the publicly available CERES products and their processing differences to help the user find the appropriate product for their application.

Table 2-1. CERES processing level descriptions.

Level	Description	Data Product
0	Raw digitized instrument data for all engineering and science data streams in Consultative Committee for Space Data Systems (CCSDS) packet format.	
1B	Instantaneous filtered broadband radiances at the CERES footprint resolution, geolocation and viewing geometry, solar geometry, satellite position and velocity, and all raw engineering and instrument status data.	BiDirectional Scans (BDS)
2	Instantaneous geophysical variables at the CERES footprint resolution. Includes some Level 1B parameters and retrieved or computed geophysical variables. (e.g., filtered and unfiltered radiances, viewing geometry, radiative fluxes, imager cloud and aerosol properties).	SSF
3	Radiative fluxes and cloud properties spatially averaged onto a uniform grid. Includes either instantaneous averages sorted by GMT hour or temporally interpolated averages at 1–hourly, daily, monthly or monthly hourly.	SSF1deg-Hour SSF1deg-Day, -Month SYN1deg-1Hour, -3Hour, -Day,-MHour, -Month
3B	Level 3 data products adjusted within their range of uncertainty to satisfy known constraints (e.g., consistency between average global net TOA flux imbalance and ocean heat storage).	EBAF-TOA EBAF-Surface

CERES instruments fly on the Terra (descending sun-synchronous orbit with an equator crossing time of 10:30 A.M. local time) and Aqua or NPP (ascending sun-synchronous orbit with an equator crossing time of 1:30 P.M. local time) satellites. Each CERES instrument measures filtered radiances in the shortwave (SW; wavelengths between 0.3 and 5 µm), total (TOT; wavelengths between 0.3 and 200 µm), and window (WN; wavelengths between 8 and 12 µm) regions. Unfiltered SW, longwave (LW) and WN radiances are determined following Loeb et al. (2001). CERES instruments provide global coverage daily, and monthly mean regional fluxes are based upon complete daily samples over the entire globe.

Raw digitized instrument data (Level 0) are converted to instantaneous filtered radiances (Level 1) using the latest CERES gains (Thomas et al., 2010). Time-dependent spectral response function values are then used to correct for the imperfect spectral response of the instrument and convert the filtered radiances into unfiltered SW, LW and WN radiances (Loeb et al. 2001; Loeb et al., 2016). Since there is no LW channel on CERES, LW daytime radiances are determined from the difference between the TOT and SW channel radiances. Instantaneous TOA radiative fluxes (Level 2) are estimated from unfiltered radiances using empirical ADMs (Su et al., 2015a) for different scene types identified using cloud property retrievals from MODIS measurements (Minnis et al. 2011). Their accuracy has been evaluated in several articles (Loeb et al. 2005 Loeb et al. 2007; Kato and Loeb 2005; Su et al., 2015b).

Monthly mean fluxes (Level 3) are determined by spatially averaging the instantaneous TOA flux values on a 1°×1° grid, temporally interpolating between observed values at 1-h increments for each hour of every month, and then averaging all hour boxes in a month (Doelling et al. 2013). CERES employs the CERES-only (CO; CERES SSF1deg stream) and the CERES-geostationary (CG; CERES SYN1deg stream) temporal interpolation methods. The CO method assumes that the cloud properties at the time of the CERES observation remain constant and only accounts for changes in albedo with solar zenith angle and diurnal land heating, by assuming a shape for unresolved changes in the diurnal cycle. The CG method enhances the CERES data by explicitly accounting for changes in clouds and radiation between CERES observation times using 1-hourly imager data from five geostationary (GEO) satellites that cover 60°S-60°N at any given time.

The Energy Balanced and Filled (EBAF, Level 3B) leverages off of the CERES Level 1-3 data products to produce a monthly TOA flux dataset that maintains the excellent radiometric stability of the CERES instruments while at the same time incorporating diurnal information from geostationary satellites in such a way as to minimize the impact of any geostationary imager artifacts that can occur over some geostationary domains and time periods. In order to ensure EBAF TOA fluxes satisfy known global mean energy budget constraints (e.g., based upon in-situ data from the Argo network, Roemmich et al. 2009), SW and LW TOA fluxes are adjusted within their range of uncertainty using an objective constrainment method (Loeb et al., 2009). Importantly, this is a one-time adjustment applied to the entire record. Therefore, the time-dependence of EBAF TOA fluxes is tied as closely as possible to the CERES instrument radiometric stability. Unlike other CERES data products, EBAF provides monthly regional clear-sky TOA fluxes that are free of missing regions by making optimal use of coincident CERES and MODIS measurements.

3.0 Cautions and Helpful Hints

The CERES Science Team notes several CAUTIONS and HELPFUL HINTS regarding the use of the CERES SYN1deg Ed4A products:

- The CERES_SYN1deg_1Hour/3Hour/Day/MHour/Month_Ed4A products can be visualized, subsetted, and ordered from: https://ceres.larc.nasa.gov/data/
- A full list of parameters in the CERES_SYN1deg_1Hour/3Hour/Day/MHour/Month_Ed4A products is contained in their respective Data Product Catalogs (PDF):
  SYN1deg-1Hour Data Product Catalog
  SYN1deg-3Hour Data Product Catalog
  SYN1deg-Day Data Product Catalog
  SYN1deg-MHour Data Product Catalog
  SYN1deg-Month Data Product Catalog
- The CERES SYN1deg Terra-NPP Ed1A product is produced with similar codes to the SYN1deg Terra-Aqua product. Most of the discussions within this document can be applied to the SYN1deg Ed1A product.
- Users should be aware that some of the key inputs used to produce the SYN1deg changed at various times during the data record. Such changes, if large enough, may introduce spurious, unphysical jumps in the record. In the past, these changes were reflected in each CERES data product's version through a letter change (e.g., SRBAVG Edition2A, Edition2B, etc.). However, this proved cumbersome and confusing to many users. Therefore, for the SSF1deg product, letter changes will only reflect a reprocessing of the data record (e.g., due to a code bug). Major algorithm improvements will be noted as Editions. Changes to inputs are documented at the following web site: https://ceres.larc.nasa.gov/data/general-product-info/#ceres-input-data-sources. The web site provides a time-line of all input data source changes to date used to produce the SYN1deg Ed4A products. Users are advised to use this table as a reference in their analysis of SYN1deg products.
- The Aqua satellite experienced an anomaly preventing any data transmittal from August 16 to September 3, 2020. CERES processing filled this Aqua gap with the SSF NOAA-20 Ed1B fluxes and clouds from August 16-31. September 1-3 was not filled.
- Only the CERES instrument that is in cross-track mode is used in the SYN1deg Ed4A product, since it provides uniform spatial distribution of footprints. No Rotating Azimuth Plane Scan (RAPS) is used. There are two CERES instruments on the Terra and Aqua satellites. All CERES Terra/Aqua instruments were calibrated to be on the same radiometric scale beginning with CERES Edition 3. For Terra, the FM1 instrument spends the most time in crosstrack mode. For Aqua, FM4 was the prime crosstrack instrument prior to March 2005, when the SW channel failed. After March 2005, Aqua FM3 was permanently placed in crosstrack mode. Only one CERES instrument, FM5, is onboard the NPP satellite, and it operates only in cross-track mode. The CERES input data sources page (https://ceres.larc.nasa.gov/data/general-product-info/#ceres-input-data-sources) shows the Terra and Aqua instrument that is in cross-track mode.
- NPP's imager is VIIRS, which has a set of channels with central wavelengths and bandwidths that differ from MODIS, the imager for Terra and Aqua.

- Processing is performed on a nested grid (Table 3-1). This grid uses 1° equal-angle regions between 45°N and 45°S and maintains area consistency at higher latitudes. The final product contains a complete 360x180 1° grid created by replication.

Table 3-1. CERES nested grid.

Latitude segment	# of zones in segment	Longitude extent (°)	# of regions/zone	# of regions in segment
Equator to 45°	90	1°	360	32400
45° to 70°	50	2°	180	9000
70° to 80°	20	4°	90	1800
80° to 89°	18	8°	45	810
89° to 90°	2	360°	1	2
Total	180	-	-	44012

- Daily means can be computed by averaging the corresponding day of 1-hourly values from the SYN1deg-1Hour product. Similarly, monthly means can be computed from either the daily SYN1deg-Day or hourly SYN1deg-1Hour product. The monthly hourly means can be computed by averaging all of the days of the corresponding hour of the SYN1deg-1Hour product.
- The hour index of the SYN1deg-1Hour Ed4A product is defined in terms of GMT. There are 24 hour indices per day. 0 to 1 GMT is defined as the first hourbox. The corresponding midpoint is 0.5 GMT, except for SW fluxes, where the integrated cosine of the solar zenith angle is considered the midpoint of the hour box in order to facilitate the hour box averaging as described in the previous bullet.
- Zonal and global means are only available for the SYN1deg-Month product.
- Zonal means are the average of all non-default regional values along a latitude band. Caution must be taken when using zonal means where there are many regional default values; examples are clear-sky SW and LW fluxes. No spatial interpolation is performed.
- The global mean is the geodetically area-weighted average of all 180 zonal means. The CERES geodetic weighting factors in look-up table format are located here: https://ceres.larc.nasa.gov/data/general-product-info/#geodetic-zone-weights-information. Where all the regional values are default, zonal means are interpolated between neighboring zones.

Observed Fluxes

- For SYN1deg Ed4A no twilight flux was added to either the daily or monthly product in order to facilitate SW flux hour box averaging between SYN1deg temporal resolutions. In Ed3A, when the solar zenith angle was greater than 90°. twilight flux was added to both the SYN1deg and SSF1deg to account for the atmospheric refraction of light (Kato and Loeb, 2003). In SSF1deg Ed4A, no twilight flux has been added to the daily and monthly SW flux means in order to maintain consistency between the Ed4A SSF1deg and SYN1deg products. For Edition 4, the SW twilight flux is only added in the EBAF product, since the EBAF product is a net flux balanced product. For the EBAF product, the twilight flux component is much smaller than the CERES instrument calibration adjustment.

- For SYN1deg Ed4A the SW flux and albedo are consistent in Ed4A, since the twilight flux is not added to the SW flux. Albedo is defined as a daytime parameter.
- Despite recent improvements in satellite instrument calibration and the algorithms used to determine SW and LW outgoing TOA radiative fluxes, a sizeable imbalance persists in the average global net radiation at the TOA from CERES satellite observations. With the most recent CERES Edition4 instrument calibration improvements, the SYN1deg_Edition4A net imbalance is ~+4.5 W m^{-2}, which is much larger than the expected observed ocean heating rate of ~0.71 W m^{-2} (Johnson et al. 2016). If net balanced fluxes are required for the evaluation of climate models, for example, users are recommended to use the CERES EBAF Ed4A product. The EBAF dataset uses an objective constrainment algorithm to adjust SW and LW TOA fluxes within their ranges of uncertainty to remove the inconsistency between average global net TOA flux and heat storage in the Earth-atmosphere system.
- The CERES Edition 4 solar irradiance is from SORCE that is updated daily (SORCE Level 3 Total Solar Irradiance Version 15 available from: http://lasp.colorado.edu/sorce/data/tsi_data.htm. The SORCE total solar irradiance is ~1361 W m^{-2}. The SORCE observed solar irradiance will vary over the 11-year sunspot cycle with an amplitude of ~0.1%.
- A processing glitch was discovered in the daily TSI file. The TSI daily fluxes during August 2019 and May through November 2020 (shown as the red values in Figure 3-1) were found to be scaled incorrectly resulting in a daily flux that was biased by ~ +0.8 W m^{-2}. The incorrect daily TSI fluxes (based on TSIS-1 TIM Version 3) were correctly scaled to the SORCE Version 15 reference and updated during February 2021. The SYN1deg product was impacted during August 2019 and May 2020 through July 2020. The resultant global averaged daily and monthly fluxes were found to be ~0.2 W m^{-2} too large out of a 20-year mean TSI flux of 339.88 W m^{-2}.

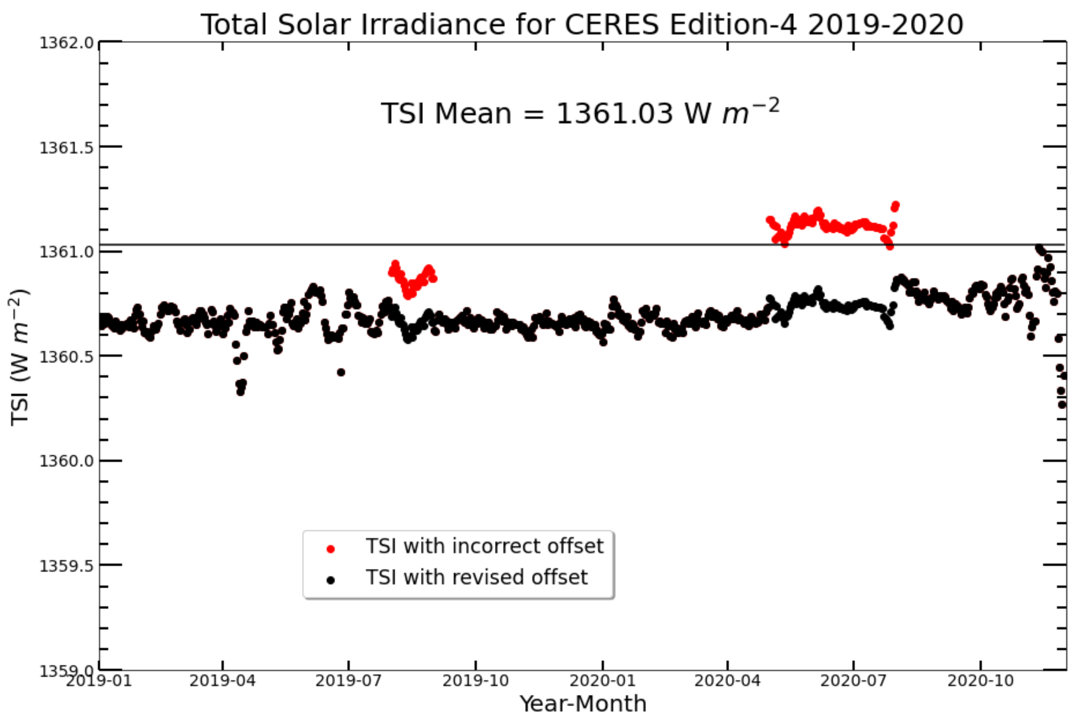

Figure 3-1. TSIS-1 TIM Version 3 at 1 AU incorrect scaling (red daily values) compared to the correct scaling (black daily values).

- Performing monthly deseasonalization or annual anomalies based on the 365-day calendar year (as opposed to 365.256 days for Earth to orbit the sun) may introduce unwanted variability in the CERES fluxes. Care must be taken when interpreting monthly anomalies. Please see the Appendix in section 10 of the SSF1deg Ed4A DQS for more information and examples.
- Geodetic, or oblate spheroid, weighting is used to derive the global flux mean from the zonal values. The geodetic Earth weights the tropics slightly more than the poles; the spherical Earth weights them equally (see Table 3-2). The spherical Earth assumption gives the well-known $S_o/4$ expression for mean solar irradiance, where S_o is the instantaneous solar irradiance at the TOA. When a more careful calculation is made by assuming the Earth is an oblate spheroid instead of a sphere, and the annual cycle in the Earth's declination angle and the Earth-sun distance are taken into account, the division factor becomes 4.0034 instead of 4. The following page provides the zonal geodetic weights used to determine global mean quantities: https://ceres.larc.nasa.gov/data/general-product-info/#geodetic-zone-weights-information.

Table 3-2. The geodetic minus spherical earth annual global flux means.

Flux (W m^{-2})	SW reflected	LW emitted	Net	Solar incoming
All-sky	-0.18	+0.05	-0.16	-0.30
Clear-sky	-0.11	+0.06	+0.07	

- For clear-sky fluxes, if the region does not observe a single clear-sky (cloud fraction <0.1%) footprint for the month, the monthly mean is default. For some months, many regions do not contain clear-sky fluxes. Users wishing to have spatially complete regional clear-sky flux maps should utilize the EBAF product. In EBAF, the problem of gaps in clear-sky TOA flux maps is addressed by inferring clear-sky fluxes from both CERES and Moderate Resolution Imaging Spectrometer (MODIS) measurements to produce a new clear-sky TOA flux climatology that provides TOA fluxes in each 1°x1° region every month.
- The global mean is the geodetic area-weighted average of all 180 zonal means. Where all the regional values are default, zonal means are interpolated between neighboring zones. This interpolation occurs most frequently with SW flux near the polar night terminator. For SW flux the interpolation assumes constant albedo from the last available latitude. SW flux is calculated as the product of this albedo with analytically computed monthly mean solar insolation.
- Zonal and global parameters means are only computed for the SYN1deg-Month Ed4A product. The geographical distribution and number of clear-sky regions are considered insufficient for a representative zonal and global mean for daily, monthly hourly and monthly SYN1deg products. Fluctuations in the daily, monthly hourly, and monthly global mean are more likely to be attributed to spatial sampling and do not reflect the natural variation.
- The Terra and Aqua CERES instruments are placed on a common radiometric scale at the start of mission (March 2000 for Terra; July 2002 for Aqua). For a detailed description of the radiometric scaling, please see the following link (slides 20-70): http://ceres.larc.nasa.gov/documents/STM/2010-04/2_Priestley_0410_STM_Newport News.pdf.
- In the SYN1deg Ed1A Terra-NPP product, the NPP CERES instrument is NOT placed on the same radiometric scale as the Terra CERES instrument.
- The SYN1deg Ed4A clear-sky SW and LW fluxes do not incorporate GEO-derived clear-sky fluxes and rely on CERES-only clear-sky footprint fluxes. The fluxes from the SYN1deg product and the SSF1deg Ed4A combined Terra and Aqua product (internal use only) should be nearly equal. For clear-sky fluxes, if the region did not observe a single CERES Terra or Aqua clear-sky (cloud fraction <0.1%) footprint for the month, the monthly mean is default.
- Terra and Aqua CERES and MODIS measurements were combined beginning with July 2002. Before July 2002, only Terra was used as input.
- Coverage by geostationary satellites is between 60°S and 60°N. GEO calibration coefficients are updated incrementally in 2-month segments.
- The TOA observed fluxes differ between the GEO-enhanced SYN1deg and the SSF1deg Ed4A products over regions with strong diurnal cycles, such as over marine stratus and land convection. The SYN1deg TOA observed fluxes capture the diurnal flux not observed by either the single satellite Terra or Aqua observations (see section 5.1). Monthly mean TOA fluxes can differ by 20 W m^{-2} or more depending on whether or not the diurnal cycle is explicitly taken into account (Doelling et al. 2013; Young et al. 1998). The GEO-derived TOA broadband fluxes are carefully normalized with CERES fluxes in order to maintain the CERES calibration. The many GEO-derived flux improvements from Ed3A to Ed4A that are

described in section 4.1 and validated in section 5.0 may still contain GEO artifacts, but these are much smaller than for Ed3A. The user is advised to use the EBAF product for long-term analysis.

Computed Fluxes

- There are GEO artifacts in the SYN1deg Ed4A surface and in-atmosphere irradiances. We recommend to those who are interested in monthly mean fluxes using EBAF-Surface Ed4A.
- Computed clear-sky surface fluxes are computed by removing clouds. Therefore, the sampling of clear-sky fluxes is the same as the sampling of all-sky fluxes. This is consistent with the method used in climate models, but differs from the sampling of observed top-of-atmosphere clear-sky fluxes.
- Cloud radiative effects may be computed as all-sky flux minus clear-sky flux.
- The net flux is positive when the energy is deposited to the surface, i.e. the net is defined as downward minus upward flux.
- Because of the degradation of Terra water vapor channels that is affecting cloud retrievals starting around 2008, downward longwave flux anomalies over polar regions show a downward trend (see section 5.2).
- Due to bugs in the code, the adjusted fluxes contain errors. Users are advised not to use adjusted shortwave and longwave fluxes. The initial fluxes are affected by artifacts in cloud properties derived from geostationary satellites. Users are advised not to use SYN1deg Ed4A fluxes for trend studies.
- Entropy parameters are computed with adjusted fluxes. A description of entropy-related variables is given in the section 5 of the surface data quality summary.
- Aerosol optical thicknesses used in flux computations are derived from a transport model (MATCH) that assimilates aerosol optical thicknesses derived from Terra and Aqua observations. As a result, clear-sky aerosol optical thicknesses are nearly identical to those derived from Terra and Aqua. Because of an issue in the code, only Aqua aerosol optical thicknesses were used from July 2004 to December 2004. The global mean aerosol optical thickness of this 6-month period is 0.006 to 0.009 smaller than the Terra + Aqua aerosol optical thickness. Smaller aerosol optical thicknesses affect computed fluxes. More details are given in section 6 of the surface data quality summary.
- The time series of surface longwave irradiance anomalies is affected by the use of multiple types of geostationary satellites. Cloud base heights derived from new generation geostationary satellites (e.g. Himawari-8, GOES-16, and GOES17) are higher than those derived from older geostationary satellites. As a consequence, downward longwave irradiance and net surface longwave anomaly time series have a decreasing trend. Details are given in section 7 of the surface data quality summary.

4.0 Version History

- Edition 4.1 was produced with Collection 6.1 MODIS aerosols for the entire period beginning with March 2000. MODIS Collection 5 clouds were used from March 2000 through February 2016, and Collection 6 clouds were used from March 2016 onward.

4.1 Changes between SYN1deg Ed4A and SYN1deg Ed3A

This section discusses the Edition 4A algorithm and input improvements. Some main points to note are:

- Both the MODIS and GEO cloud retrieval algorithms were significantly improved in Edition 4A and are summarized in this section.
- The CERES radiance to flux improvements can be located in the SSF Data Quality Summary.
- SYN1deg Ed4A uses a consistent source of temperature and humidity throughout the record. Using GEOS-5.4.1 for the entire record improves the anomaly time series of surface flux significantly compared to Ed3A.
- In Ed3A, MODIS Collection 4 is switched to Collection 5 at the end of March 2006. The switch caused a shift in the retrieved aerosol optical thickness over land. In Ed4A, Collection 5 is used from March 2000 through February 2017, and Collection 6 is used for March 2017 onward.
- Cloud properties from geostationary satellites are derived hourly. Fluxes are also computed hourly. The temporal resolution is improved from the 3-hourly used in SYN1deg Ed3A.
- The Ed2 GEO cloud algorithm only uses two channels (one visible and one IR). Although geostationary satellites with only two channels are still used in SYN1deg Ed4A, up to 5 channels for other geostationary satellites are used in the Ed4 GEO cloud algorithm. As a consequence, nighttime retrieved cloud properties (e.g. particle size, top pressure, phase) are improved significantly. However, when a geostationary satellite for a given longitude position is upgraded to a newer generation instrument, the discontinuity in fluxes at the temporal boundary is more pronounced in Ed4A than in Ed3A.

4.1.1 GEO Sampling, QC, and Calibration Improvements

The GEO sampling frequency, image QC and GEO imager calibration have all been substantially improved between SYN1deg Ed3A and Ed4 products and are summarized in Table 4-1. Both Editions use visible 1-km and IR 4-km pixel resolution images, which are sub-sampled to 8-km. The Ed3A only ingested the GEO visible and IR window channels, whereas for Ed4A all channels were downloaded (see Table 1-1). For Ed3A 3-hourly GEO full disc (FD) imagery is incorporated, synchronized at 0, 3, 6 UTC, etc., following the ISCCP project GEO sampling. For Ed4A the same 3-hourly FD imagery is incorporated and 1-hourly additional GEO imagery is integrated to provide 1-hourly GEO sampling. The GEO imagery is inserted into the proper hour box defined by 0-1, 1-2, … GMT. Unfortunately, the scan times are not synchronized across GEO domains. Greater GEO scan synchronization is planned for Ed5A. The MTSAT-1R visible optical was slightly blurred causing a non-linear radiance response (Doelling et al. 2015a). The Ed3A cloud retrievals were based on the uncorrected MTSAT-1R visible imagery, whereas the Ed4A applied a pixel-level point spread function (PSF) to correct most of the optical blurring (Khlopenkov et al. 2015). The MTSAT-1R GEO cloud retrievals were improved using the PSF correction in Ed4A.

Table 4-1. Summary of the GEO sampling, QC, and calibration improvements between SYN1deg Ed3A and SYN1deg Ed4A products.

GEO calibration and QC	SYN1deg Ed3A	SYN1deg Ed4A
GEO image sampling	• 3-hourly	• 1-hourly
GEO spurious scan and artifact removal	• Visually inspected visible and IR images • Initiated in January 2012	• Automated bad scan line removal • Visually inspected for artifacts (stray-light) • Applied over the entire record • MTSAT-1R point spread function
GEO calibration reference	• Terra-MODIS Band 1 (0.65µm) Collection 5	• Aqua-MODIS Band 1 (0.65µm) Collection 6
GEO calibration method	• GEO/MODIS all-sky tropical ocean ray-matching	• GEO/MODIS all-sky tropical ocean ray-matching
GEO calibration validation	• Primary: GEO/Terra-MODIS Collection 5 Band 1 (0.65µm) ray-matching	• Primary: GEO/Aqua-MODIS Collection 6 Band 1 (0.65µm) ray-matching • GEO/MODIS deep convective cloud (DCC) ray-matching • Invariant desert and DCC calibration • SCIAMACHY based spectral band adjustment factors (SBAF)

The GEO image quality is compromised by bad scan lines, navigation (image rectification) errors, stray light conditions during equinox conditions (Met-5, Met-7 WV channel), electronic interference patterns (GOES-9 visible channel), and vertical striping swaths (MTSAT-1R all channels). The GEO image quality is dependent on the individual GEO, but in general, is worse at the beginning of the CERES record (2000) and improves over time. The 1st generation GEO images have more image artifacts than the 3rd generation. For Edition 3A, GEO imager artifacts were not removed prior to January 2012; afterwards the 3-hourly GEO imagery was visually examined, and easily identified artifacts were removed. Visual examination is a labor-intensive process and to visually inspect 1-hourly multiple channel imagery is unfeasible. An automated bad scan line detection program was implemented for Ed4A over the whole record (Khlopenkov and Doelling 2016). The automated program identified GEO images with artifacts which were then visually inspected to make sure only the actual bad scan lines are removed, since the automated program tended to have a few false positives in order to ensure that all artifacts were detected. Stray light artifacts tend to occur during equinox at specific GMT times and can only be detected by visual examination and removed during these time intervals. After the GEO image channel radiances and temperatures and their respective cloud properties are gridded into 1° regions and composited into hourly global maps. Hourly "movies" of the regional gridded hourly channel radiances and temperatures are inspected for any 1° regional artificial temporal features that appear for short durations, such as navigation shifts and temperature drifts, and stray light features (slides 17-28 https://ceres.larc.nasa.gov/documents/STM/2015-05/9_CERES_TISA_Doelling_2015_05.pdf).

The GEO imager calibration was improved between Ed3A and E4A. The primary GEO visible imager calibration is based on the GEO and Terra-MODIS Collection 5 (C5) band 1 (0.65µm) ray-matched radiance pairs (Doelling et al. 2013). The Terra-MODIS C5 band 1 was not stable over time. There were two calibration anomalies in late 2003 and early 2009, where the calibration degraded by 1% and 1.5%, respectively (Wu et al. 2013). The Terra-MODIS cloud optical depth retrievals also manifested these anomalies. The Ed4A GEO visible imager calibration uses Aqua-

MODIS C6 band 1 as the calibration reference. The Aqua-MODIS was stable until 2008 and then started to slowly degrade by 1% over the rest of the record (Doelling et al. 2015b). This degradation has a scan angle dependency, where one side of the scan degraded more than the other side (Bhatt et al. 2017). These issues should be resolved in MODIS C6.1.

The Ed3A GEO/MODIS ray-matched radiance 50-km pairs over tropical all-sky ocean was improved by using strict a 5° view and azimuthal angle matching for near clear conditions and relaxing the angles to within 15° for bright cloud conditions (a.k.a. graduated angle matching) for Ed4A (Doelling et al. 2016b). The GEO and MODIS spectral band differences were not accounted for in Ed3A. For Ed4A the spectral band adjustment factors (SBAF) were based on pseudo GEO and MODIS SCIAMACHY hyper-spectral radiances, which were convolved with their respective GEO and MODIS spectral response functions. The SCIAMACHY footprint GEO and MODIS pseudo MODIS radiances were regressed with a second order fit to estimate the SBAF and then applied to the MODIS radiances to make them spectrally equivalent to the GEO radiances.

The primary GEO calibration gains were also compared to the GEO/MODIS ray-matched radiance 30-km pairs obtained over deep convective cloud (DCC) cores. DCC have the smallest Earth viewed SBAF (Doelling et al. 2016b). The primary calibration is also validated using both invariant desert (Bhatt et al. 2014) and DCC targets (Doelling et al. 2011). These invariant targets have been characterized using a reference GEO over each GEO domain, which has been calibrated with the primary method. Generally, all of the validation GEO visible calibration gains were within 1% of the primary gain.

4.1.2 MODIS Cloud Retrieval Improvements

Improvements to the CERES MODIS cloud algorithm in Ed4 compared to Ed3A include using regional mean boundary apparent lapse rates developed using collocated CALIPSO and MODIS data to determine low cloud-top height (Sun-Mack et al. 2014), a CO_2-slicing method to retrieve high cloud over low-lying clouds (Chang et al. 2010), and a rough ice crystal model (Yang et al. 2008) to improve ice cloud retrieval. A detailed description of the Edition 4 cloud algorithm is in preparation. Also the Terra and Aqua MODIS cloud retrievals were made more consistent, especially over polar regions.

The Ed4A MODIS cloud mask substantially improves detection of thin cirrus and low cloud, provides a better discrimination between cloud and dust, and substantially improves cloud detection in polar regions. The cloud mask improvements include the use of additional MODIS channels and threshold tests (MODIS 1.38 µm threshold test, T3.7-T11 and T11-T12 difference tests, 2.1 to 0.6 µm ratio test, 1.24 to 0.65 µm ratio test, and new visible threshold tests) derived with the benefit of years of CALIPSO data for guidance. In contrast, the EBAF Ed2.8 cloud mask was developed prior to CALIPSO. The Ed4.0 cloud mask substantially improves detection of thin cirrus and low cloud, provides a better discrimination between cloud and dust, and substantially improves cloud detection in polar regions.

Because the Aqua MODIS 1.6 µm channel failed shortly after launch, the 1.24 µm channel is used as an alternative in both Aqua and Terra Ed4 daytime cloud optical depth retrievals over snow. However, the 1.24 µm channel is not optimal for cloud optical depth since surface reflectance can affect retrievals more than the 1.6 µm channel. Surface shortwave downward flux validation of radiative transfer results over Dome C using 1.6 µm and 1.24 µm cloud retrievals anecdotally suggest that the 1.24 µm cloud optical depths for thin clouds over snow can be as large as a factor of two. The 1.24 µm and 2.1µm based liquid and ice particle size, and optical depth are not provided in the SYN1deg Ed4A and can only be accessed in the SSF1deg Ed4A product.

The MODIS Collection 5 was used from March 2000 to February 2017 to retrieve the Aqua and MODIS cloud properties available in the SYN1deg Ed4A product. Beginning in March 2017 only Collection 6 (C6) MODIS data will be available and Collection 5 (C5) will no longer be available. In order to minimize any cloud property value differences between the two collections, the MODIS C6 channel radiances will be scaled to C5 to provide MODIS-equivalent C5 radiances from the C6 pixel radiance dataset. This is accomplished by taking identical C5 and C6 MODIS granules and regressing the pixel-level C5 and C6 radiance pairs. The slope through the origin is used to adjust the C6 visible channel calibration. A second-order radiance fit is used to adjust the IR radiance. The second-order fit provides the non-linear adjustment needed for the cold end, especially for band 20 (3.8µm) at night and the water vapor band 27 (6.7µm). The C6 calibration is considered more accurate than C5, since it takes into account the visible channel scan angle dependencies. It must be noted that the CERES cloud working group did adjust the Terra-MODIS band 20 C5 temperature to better match Aqua-MODIS for the cold end (SSF Ed4 DQS). This adjustment was left in place; the C6 to C5 scaling did not remove the original C5 adjustment.

4.1.3 GEO Cloud Retrieval Improvements

Significant improvements were made in the GEO cloud retrieval code between Ed3A and Ed4A and are summarized in Table 4-2. A multiple channel GEO cloud retrieval code that is similar to MODIS, limited by GEO available channels (see Table 1-1), was implemented for Ed4A, for all 2nd and 3rd generation GEO satellites (see Table 1-2). The GEO cloud code was optimized for each set of GEO imager channels. The pixel-level retrieved cloud properties are assigned to the appropriate cloud layer according to their cloud effective pressure and by liquid or ice phase. A pixel is classified as either clear or cloudy (overcast). Optical depth is averaged in log form, which is proportional to radiance.

Table 4-2. Summary of the GEO cloud retrieval improvements between SYN1deg Ed3A and SYN1deg Ed4A products.

GEO cloud retrievals	SYN1deg Ed3A	SYN1deg Ed4A
GEO retrieval resolution	• 1° gridded with 4 PC layers	• pixel level (8km resolution)
GEO retrieval channels	• visible and IR (ISCCP-like)	• multiple channel (MODIS-like)
GEO particle size retrieval	• Assume 10µm and 30µm liquid and ice	• Retrieved based on 3.9µm
GEO night cloud emissivity	• Assume night emissivity = 1	• Emissivity based on IR channels

The 1st generation GEO imagers continued to use the Ed3A visible and IR channel cloud retrieval code (see Table 1-2). For the GEO 2-ch imagers the visible and IR channels were calibrated to have equivalent MODIS radiances in order to facilitate a single GEO cloud algorithm to process all GEO satellites. The GEO 2-ch cloud retrieval code does not output pixel-level clouds, but rather 1° regional cloud layers. To compute the liquid water path (LWP) and IWP, particle sizes of 10 µm and 30 µm in radii are assumed. During the day, the IR emissivity is based on the optical depth. The cloud effective pressure is adjusted upward from black cloud conditions based on the cloud

IR emissivity, cloud effective IR temperature, surface temperature and the GEOS atmospheric profile. At night, the 1st generation GEO cloud properties are based on a single IR channel and assume an IR emissivity of one. At night, clouds are assumed to be black, and the cloud effective pressure is based on the cloud effective temperature and GEOS atmospheric profile.

The SYN1deg Ed4A product is obtained by gridding into the 1° regions the instantaneous pixel level M-ch and MODIS clouds. The MODIS clouds take precedence over the GEO clouds. The hourly clouds are released in the SYN1deg-1Hour product. The total cloud layer is the average of the 4-layer values, again, weighting by cloud fraction and log optical depth. If there are any data gaps in the hourly dataset, the cloud values are linearly interpolated across the data gap for each layer. The SYN1deg-Day and SYN1deg-Month are the averages of all the hour boxes for the day and the month, respectively. The total cloud is computed from the 4-layer daily or monthly means. The SYN1deg-MHour product contains the monthly hourly regional diurnal cloud properties and are the average cloud properties over the days of the month for a given hour box. The SYN1deg-Month product contains zonal and global cloud means. Each layer is averaged (cloud fraction weighted) across all regions over the zone and then averaged across all zones (oblate spheroid weighted; see Table 3-2) to obtain the global mean. The total cloud layer is simply the 4-layer mean for the specific spatial and temporal resolution. The SYN1deg daily and 1-hourly zonal and global means are not computed, since the data is very noisy.

Cloud properties during the MODIS observed hours may differ with the surrounding GEO cloud properties due to their retrieval differences. It is assumed that the MODIS clouds are superior to the GEO clouds, due to the number of imager channels, calibration, and image quality. The SYN1deg Ed4A product provides the number of GEO and MODIS measurements used to compute the monthly mean cloud properties, which can be used as a quality control indicator to detect data gaps and to identify whether MODIS or GEO cloud retrievals were used. If the 3x3 pc-tau rather than the 4-layer format is desired, the user is advised to use the CldTypHist Ed4A product, which uses the same pixel level cloud properties as the SYN1deg Ed4A product, but bins them in the 3x3 pc-tau array. The CldTypHist product does not temporally interpolate in between data gaps and does not provide GEO 2-ch nighttime cloud properties (see CldTypHist DQS).

4.1.4 GEO-derived LW Flux Improvements

There have been a number of algorithm changes in the GEO derived LW fluxes between Ed4A and Ed3A and are listed in Table 4-3. The GEO derived LW flux for Ed3A relied on the IR window (WN) (11µm) radiance and the column weighted relative humidity (colRH) above the cloud top based on the GEOS profile. The WN radiance is converted to nadir conditions using a WN limb darkening function, which is only dependent on VZA and is the same for each GEO. The GEO narrowband flux is converted to broadband flux using a WN flux quadratic relationship along with a colRH term to account for water vapor absorption above the radiating surface. The colRH increases the weight of the upper atmosphere, which is much colder than the lower atmosphere and radiating surface (Thompson and Warren 1982). The coefficients are derived using matched MODIS WN and CERES fluxes based on the CERES SSF footprint product. Since the coefficients were found not to change from month to month, static global ocean and land coefficients were applied over the record. Over the deserts the land LW narrowband to broadband coefficients slightly bias the GEO fluxes over deserts.

Table 4-3. Summary of the GEO derived broadband flux improvements between SYN1deg Ed3A and SYN1deg Ed4A products.

GEO derived broadband fluxes	SYN1deg Ed3A	SYN1deg Ed4A
GEO derived LW flux	• WN (11µm) radiance and Column weighted humidity relative humidity to OLR global parameterization	• WN (11µm) and WV (6.7µm) radiance to OLR LUT based on MODIS and CERES coincident radiance pairs
GEO/CERES LW normalization	• Instantaneous hour box GEO/CERES normalization	• Monthly linear regression of 5° by 5° regional GEO/CERES hour box flux pairs normalization
LW temporal interpolation	• linear interpolation in between 3-hourly measurements	• Hourly SW fluxes, no interpolation unless data gap
GEO derived SW flux	• GEO visible to MODIS 0.65µm radiance conversion (LUT theoretical) • MODIS 0.65µµ to broadband radiance (LUT from SSF MODIS and CERES matches) • Broadband radiance to flux SW TRMM ADM	• Same as Ed3A
GEO/CERES SW normalization	Monthly linear regression of 5° by 5° regional GEO/CERES hour box flux pairs normalization	* Same as Ed3A
SW temporal interpolation	• TRMM SW directional models in between 3-hourly measurements	• SZA<60° Hourly SW fluxes no interpolation unless gap • SZA>60° use TRMM SW directional models
Products	• 3Hour, M3Hour, Daily, Month	• 1Hour, M1hour, Daily, Month

Unlike Ed3A, the GEO derived LW fluxes for Ed4A replaced the colRH with water vapor channel (WV) (6.7µm) radiances. All GEOs have both IR and WV radiances. The linear WN and WV coefficients were derived using coincident and collocated MODIS WN and WV radiances and CERES fluxes from the Aqua-CERES SSF product. The coefficients were binned according to VZA, WN radiance, surface type and day/night. Ed4A has removed the desert OLR bias. These coefficients are derived monthly throughout the record, in order to resolve the natural variability such as El Nino conditions. The Terra-WV channel imager quality and calibration was inadequate to compute the LW narrowband to broadband coefficients. During the Terra record, a climatology of the first three years of Aqua-MODIS-based coefficients are used. Converting directly from narrowband radiance to broadband flux and not using cloud properties to stratify the coefficients was found to be much more accurate. Also, when compared with CERES OLR measurements the Ed4A GEO derived fluxes were more accurate than their Ed3A counterparts.

The SYN1deg Ed3A and Ed4A GEO derived LW fluxes are then normalized to the CERES OLR fluxes in order to preserve the CERES LW calibration. However, the Ed3A and Ed4A normalization methods differ. The observed Ed3A GEO LW fluxes are instantaneously normalized to the CERES fluxes within the same hour box. The normalization scaling factor is linear interpolated between CERES observations. This could lead to large normalization factors when the cloud conditions change in between the GEO and CERES measurements within the hour box. However, this strategy is more accurate to derive a monthly mean flux. The Ed4A GEO LW fluxes are regionally normalized in the same manner as the SW fluxes. All of the instantaneously matched (within 30 minutes) GEO and CERES fluxes for the given 1° region and the 5x5 1° surrounding regions are linearly regressed if the regions have the same surface-type as the given region. This has the advantage of constraining the instantaneous normalization, however, it has a slightly larger monthly regional RMS error.

The normalized GEO fluxes and CERES observed fluxes are assigned to the appropriate hour box. The CERES fluxes take precedence over the GEO fluxes. The Ed3A 3-hourly GEO and CERES fluxes are then linearly interpolated between hour boxes. Over desert regions with large LW diurnal flux cycles, the linear interpolation may not capture the peak of the diurnal cycle. The Ed4A 1-hourly GEO and CERES fluxes are linearly interpolated only when a data gap exists, thus estimating the diurnal cycle more accurately.

The SYN1deg Ed3A and Ed4A clear-sky LW fluxes algorithm has not changed. Only CERES observed clear-sky fluxes are used in the SYN1deg clear-sky product. No GEO clear-sky LW fluxes are sued, due to the inadequate GEO cloud mask. The frequency of CERES clear-sky fluxes was reduced by nearly a half between Ed3A and Ed4A. The Ed4A cloud mask is more conservative, especially over the tropical thin cloud conditions. Also, the Ed4A cloud mask has been greatly improved over polar conditions. Differences between the Ed3A and Ed4A MODIS cloud mask determine most of the clear-sky LW flux differences (See section 4.1.2). Over ocean regions, the clear-sky LW fluxes are linearly interpolated. To estimate the hourly and daily clear-sky land region LW clear-sky flux, daily half-sine fits are used to model the diurnal heating of the region, from which the daily flux is estimated. Over land and desert regions, the monthly hourly clear-sky LW fluxes, which are based on the observed CERES fluxes, are used to compute the half-sine fit to determine the monthly clear-sky LW flux. The daily clear-sky LW fluxes may not be consistent with the monthly flux, especially for sparse clear-sky regions.

For the SYN1deg product the clear-sky LW flux is based on CERES clear-sky footprint fluxes. If there were no clear-sky footprints over the region for the month, then default values are given for the clear-sky flux. If there is only one clear-sky footprint observation, the SYN1deg-Day, -MHour, and -Month products will have the same clear-sky flux value. SYN1deg clear-sky LW fluxes from sparsely sampled regions may not be representative of the true clear-sky fluxes. If monthly clear-sky fluxes are desired, then the user is advised to use the EBAF-TOA product clear-sky fluxes.

4.1.5 GEO-derived SW Flux Improvements

Although the SYN1deg GEO derived SW flux algorithm did not change between Ed3A and Ed4A, the GEO calibration, cloud properties and the GEO temporal resolution changed from 3-hourly to 1-hourly. For both Ed3A and Ed4A, the GEO visible radiance was first converted to an equivalent MODIS band 1 (0.65µm) radiance using theoretical models based on angular geometry and cloud properties. The MODIS band 1 radiances were then converted to broadband flux using empirical models based on the same angular geometry and cloud property as the CERES TRMM SW ADM and were derived from the SSF MODIS and CERES coincident radiances. Cloud properties from the TRMM VIRS imager, which contains the 0.65µm, 1.6µm, 3.8µm, 11µm, and 12µm channels, are very similar to the GEO 5-channel Ed4A retrievals. The CERES TRMM ADM is used to convert the GEO broadband radiances to fluxes. Since the NPP VIIRS cloud properties are more consistent with Ed4A rather than Ed3A GEO cloud properties, they should translate into more accurate GEO-derived SW fluxes.

For Ed4A, hourly GEO SW fluxes are sampled, whereas for Ed3A, 3-hourly observations were sampled. Hourly SW fluxes better replicate the diurnal cycle and improve the GEO and CERES SW normalization, since only the GEO and CERES fluxes that are coincident within a half hour are linearly regressed. For both Ed3A and Ed4A all of the instantaneously matched GEO and CERES fluxes for the given 1° region and the 5x5 1° surrounding regions are linearly regressed, if the regions have the same surface-type as the given region. For Ed3A the GEO and CERES fluxes were matched within 90 minutes, whereas for Ed4A the time difference was reduced to 30 minutes. The 30-minute time difference ensures that the GEO and CERES cloud conditions are more consistent than if 90 minutes were used.

4.2 Difference between SYN1deg Ed4A and SYN1deg Ed3A Surface Fluxes

Differences between the SYN1deg Ed4A and Ed3A surface fluxes are primarily caused by input differences, such as cloud properties, temperature and humidity profiles, surface albedo, and aerosol.

4.2.1 Global Mean Surface Flux Comparisons

Table 4-4 compares the global mean surface fluxes between SYN1deg Ed4A and Ed3A.

Table 4-4. Global mean surface fluxes in W m^{-2} computed from SYN1deg Ed4A and SYN1deg Ed3A for March 2000-February 2016.

All-sky	**Ed4A SYN1deg**	**Ed3A SYN1deg**	**Ed4.0 EBAF-Surface**	**Ed4A – Ed3A**	**Ed4A SYN1deg – Ed4.0 EBAF-Surface**
TOA SW insolation	340.0	339.9	340.0	0.2	0.0
SW down	184.0	187.2	187.0	-3.2	-3.0
SW up	22.5	23.2	23.4	-0.7	-0.9
SW net[1]	161.5	164.0	163.7	-2.5	-2.1
LW down	347.1	342.0	345.0	5.1	2.2
LW up	397.7	397.7	398.3	0.0	-0.6
LW net[1]	-50.6	-55.7	-53.4	5.0	2.8
SW+LW net	110.9	108.3	110.3	2.6	0.6
Clear-sky					
TOA SW insolation	340.0	339.9	340.0	0.2	0.0
SW down	244.8	243.2	243.7	1.6	1.0
SW up	28.5	28.7	29.8	-0.3	-1.4
SW net[1]	216.3	214.4	213.9	2.0	2.4
LW down	314.5	314.1	314.1	0.4	0.4
LW up	396.4	396.6	397.6	-0.2	-1.2
LW net[1]	-82.0	-82.5	-83.5	0.6	1.6
SW+LW net[1]	134.3	131.9	130.4	2.5	3.9

[1] Net is computed by downward – upward.

4.2.2 Regional Mean Surface Flux Comparisons

Figure 4-1, Figure 4-2, and Figure 4-3 show the difference of regional Ed3A and Ed4A computed surface SYN1deg fluxes.

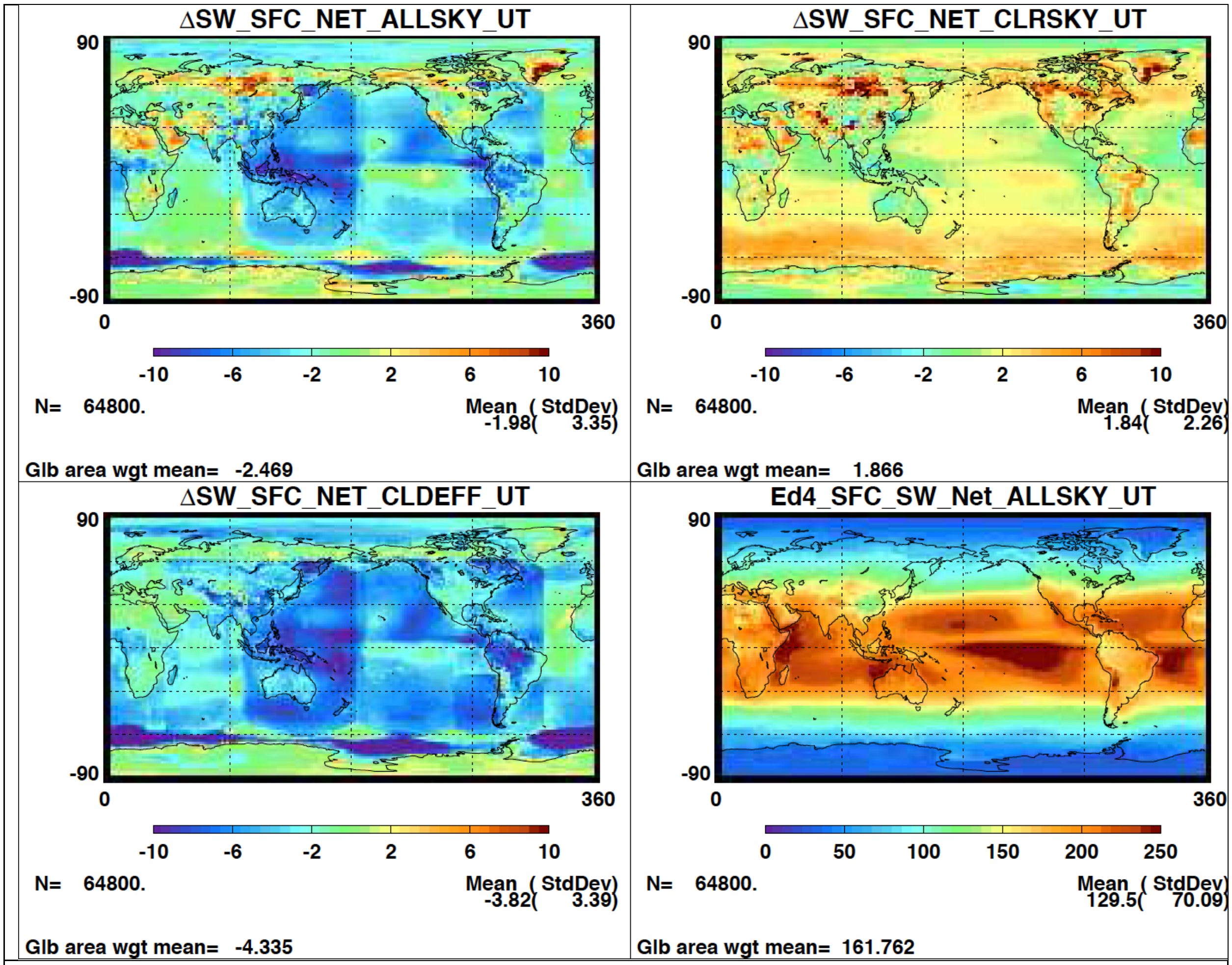

Figure 4-1. SYN1deg Ed4A minus SYN1deg Ed3A surface shortwave (SW) net (downward minus upward) flux for (a) all-sky, (b) clear-sky, (c) cloud radiative effect and (d) SYN1deg Ed4A mean surface net shortwave flux for March 2000 through February 2015.

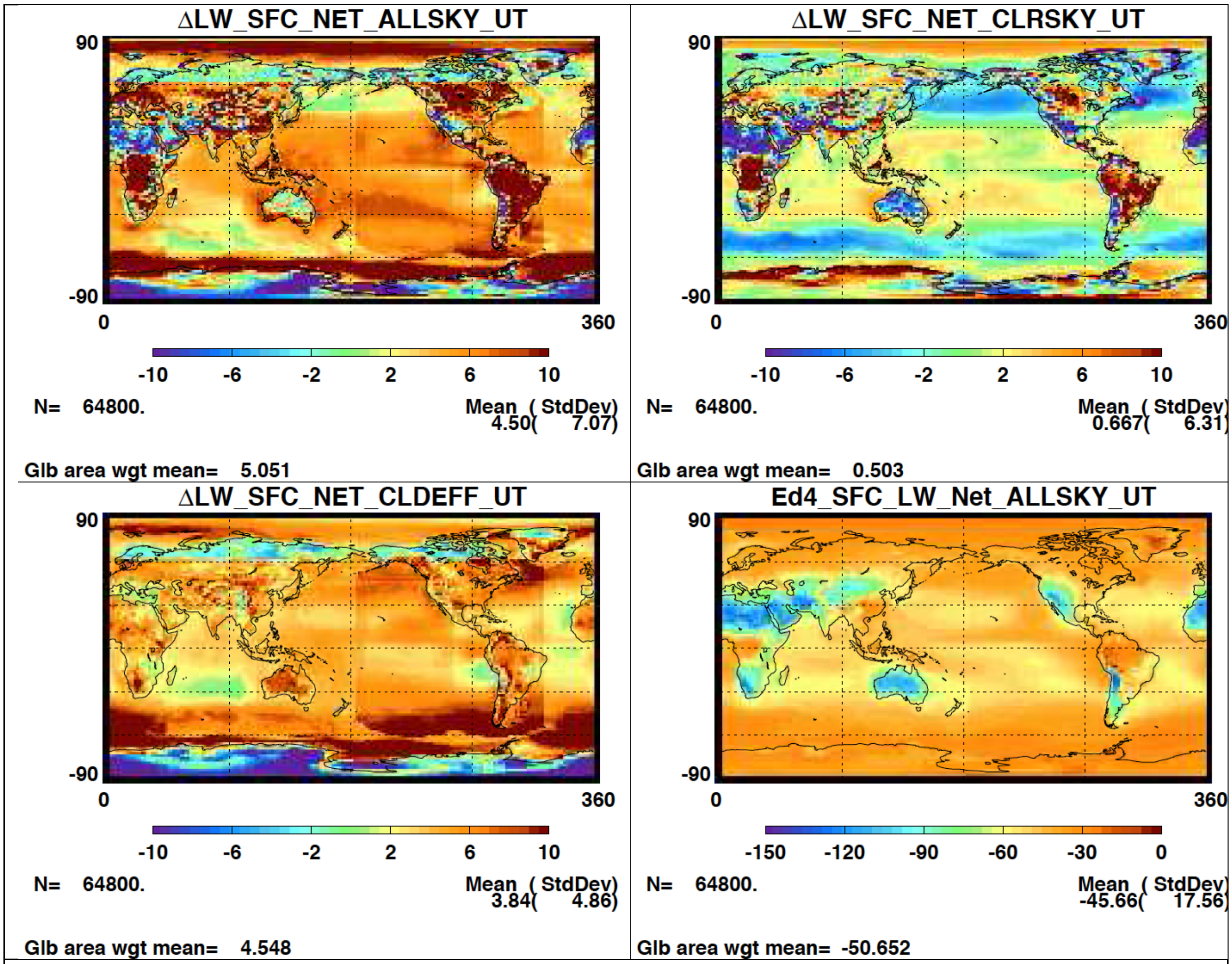

Figure 4-2. SYN1deg Ed4A minus SYN1deg Ed3A surface longwave (LW) net (downward minus upward) flux for (a) all-sky, (b) clear-sky, (c) cloud radiative effect, and (d) SYN1deg Ed4A mean surface net longwave flux for March 2000 through February 2015.

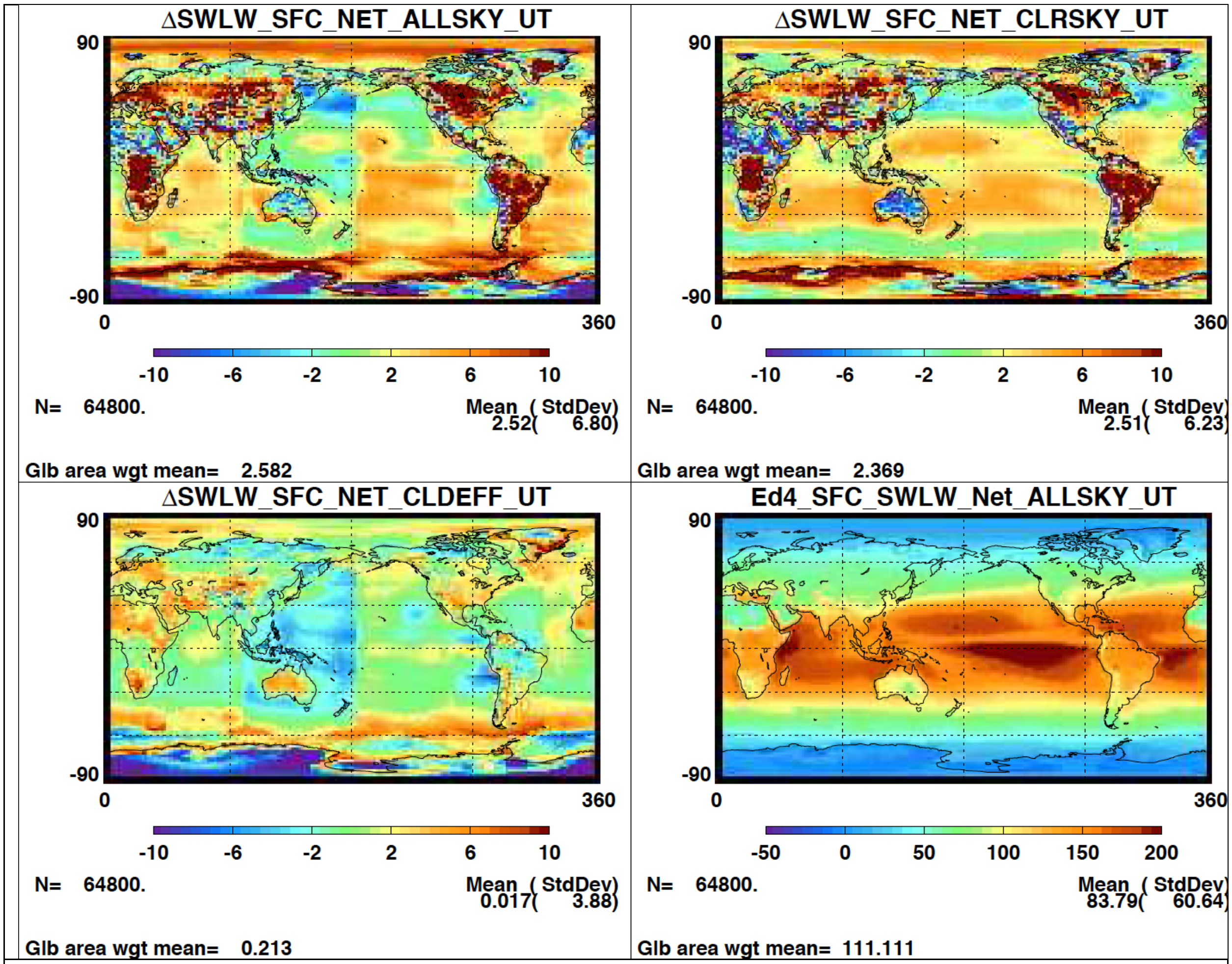

Figure 4-3. SYN1deg Ed4A minus SYN1deg Ed3A surface SW+LW net (downward minus upward) flux for (a) all-sky, (b) clear-sky, (c) cloud radiative effect, and (d) SYN1deg Ed4A mean surface net SW+LW flux for March 2000 through February 2015.

5.0 Accuracy and Validation

Discussions on the accuracy and validation of the SYN1deg product are organized into separate sections. Please read the sections corresponding to parameters of interest.

5.1 Observed TOA Fluxes

5.2 Surface Fluxes

5.3 CERES-only and GEO-only TOA Fluxes

The SYN1deg Ed4A combines the CERES observed and GEO hourly derived fluxes. The accuracy and validation of the CERES-only TOA fluxes is discussed in the SSF1deg Ed4A Data Quality Summary. The GEO flux accuracy and validation is discussed in the CldTypHist Ed4A Data Quality Summary.

5.4 Incoming Solar Radiation

Information about the incoming solar radiation data and associated uncertainties can be found in the EBAF Ed4.0 Data Quality Summary. The incoming solar radiation is the same for both the SSF1deg Ed4A and SYN1deg Ed4A products.

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7.0 Expected Reprocessing

There are no plans to reprocess the SYN1deg Ed4A (Terra+Aqua) record until the CERES Edition 5 suite of data products is available. It is expected that the temporal coverage of the CERES SYN1deg products will be updated in 2-month intervals to remain current. Any updates to the CERES SYN1deg products will be available for subsetting/visualization/ordering at: https://ceres.larc.nasa.gov/data/.

8.0 Attribution

When referring to the CERES SYN1deg product, please include the product and data set version as: “CERES SYN1deg Ed4A”

The CERES Team has put forth considerable effort 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 SYN1deg Ed4A 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 CERES data products now have DOIs. To cite the data in publication 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+Aqua datasets:

SYN1deg-1Hour:	10.5067/Terra+Aqua/CERES/SYN1deg1Hour_L3.004
SYN1deg-3Hour:	10.5067/Terra+Aqua/CERES/SYN1deg3HOUR_L3.004
SYN1deg-Day:	10.5067/Terra+Aqua/CERES/SYN1degDAY_L3.004
SYN1deg-MHour:	10.5067/Terra+Aqua/CERES/SYN1degMHour_L3.004
SYN1deg-Month:	10.5067/Terra+Aqua/CERES/SYN1degMONTH_L3.004

For Terra+NPP datasets:

SYN1deg-1Hour:	10.5067/Terra+NPP/CERES/SYN1deg1Hour_L3.01A
SYN1deg-3Hour:	10.5067/Terra+NPP/CERES/SYN1deg3HOUR_L3.01A
SYN1deg-Day:	10.5067/Terra+NPP/CERES/SYN1degDAY_L3.01A
SYN1deg-MHour:	10.5067/Terra+NPP/CERES/SYN1degMHour_L3.01A
SYN1deg-Month:	10.5067/Terra+NPP/CERES/SYN1degMONTH_L3.01A

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."

The Langley ASDC requests a reprint of any published papers or reports or a brief description of other uses (e.g., posters, oral presentations, etc.) of data that we have distributed. This will help us determine the use of data that we distribute, which is helpful in optimizing product development. It also helps us to keep our product related references current.

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/.”

9.0 Feedback and Questions

For questions or comments on this CERES SYN1deg-1Hour/3Hour/Day/MHour/Month 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 https://ceres.larc.nasa.gov/data/, please email LaRC-CERES-Help@mail.nasa.gov.