CERES_EBAF_Ed4.2 Data Quality Summary

Version 2
Released 1/2/2024

Investigation: **CERES**
Data Product: **EBAF**

Data Set: **Terra (Instruments: CERES-FM1 or CERES-FM2)**
Aqua (Instruments: CERES-FM3 or CERES-FM4)
NOAA-20 (Instrument: CERES-FM6)

Data Set Version: **Edition4.2** **Release Date: January 2, 2024**

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

This document provides a high-level quality assessment of the CERES Energy Balanced and Filled (EBAF) data product. As such, it represents the minimum information needed by scientists for appropriate and successful use of the data product. For a more thorough description of the methodology used to produce EBAF, please see Loeb et al. (2018) and Kato et al. (2018). It is strongly suggested that authors, researchers, and reviewers of research papers re-check this document for the latest status before publication of any scientific papers using this data product.

Notes to Users:

- To ensure you are using the latest version of EBAF, please check the version and release date in the netCDF file you have against the version and release date in this Data Quality Summary.

Important Update as of January 2, 2024:

An older version of the code that processes EBAF was used for Edition 4.2 released in February 2023. Surface fluxes and TOA total area clear-sky fluxes were inadvertently affected. Edition 4.2 released in December 2023 corrects this issue. Please see Section 7.0 for more details.

Please download the dataset again if:

- You ordered from the CERES Visualization, Ordering and Subsetting Tool before January 2, 2024.
- Your file has an end date of June 2023 or before, i.e., CERES_EBAF_Edition4.2_200003-**202306**.nc.

1.0 Introduction

This document simply outlines the differences between EBAF Edition4.2 and Edition4.1. Please see the EBAF Edition4.1 data quality summary for more information.

2.0 Motivation for transitioning to a NOAA20-only EBAF record and introducing EBAF Ed4.2

The EBAF Ed4.2 product combines the a) Terra only record from March 2000 to June 2002, b) the Terra & Aqua record July 2022 to March 2022, and c) the NOAA20-only record from April 2022 onward (see presentation here). The transition from the Terra and Aqua record to a NOAA20-only record was prompted by the Terra and Aqua orbits drifting outside of their maintained 15-minute local equator crossing time. The Terra and Aqua spacecraft have begun orbital maneuvers in 2021 to exit their respective orbits and are slowly drifting towards terminator orbits reaching 9AM and 3PM local equator crossing times in 2026. An Aqua spacecraft anomaly in early April 2022, which caused MODIS WV channel anomalies, accelerated the transition to a NOAA20 record. The corrected WV calibration coefficients will be available in MODIS Collection 7.

The SSF1deg product monthly regional fluxes will be impacted by the changing Terra and Aqua orbital drifts. The SSF1deg product accounts for the diurnal variation by assuming constant meteorology to compute the 24-hour average fluxes. Many regions have systematic diurnal cycles, where the clouds decrease during the day (maritime stratus regions) or where the clouds increase during the afternoon (land afternoon convective regions). For these regions, changing the local crossing time would impact the monthly mean fluxes as the Terra and Aqua orbits start to drift and would therefore impact the long-term regional flux trends. Even a 15-minute drift can result in a SW monthly regional flux changes of 2 Wm^{-2} based on 15-minute Geostationary Earth Radiation Budget (GERB) studies (see presentation here). Since the EBAF product relies on the long-term flux regional flux stability of the SSF1deg product, the decision was made to transition to a NOAA20-only EBAF record beginning in April 2022.

Beginning in April 2022, the Edition4A SYN1deg product will transition from a Terra, Aqua and hourly geostationary (GEO) dataset to a Terra, NOAA20 and hourly GEO dataset. The SYN1deg dataset provides the diurnal asymmetry factors (DAR) needed to apply the diurnal SW models to the CERES SSF1deg SW all-sky observations. The SYN1deg all-sky LW fluxes are the basis for EBAF LW all-sky fluxes. The resulting SYN1deg product LW fluxes should not be impacted by the Terra drifting orbits, since the daily averaged fluxes are mostly based on the hourly GEO fluxes, which are carefully normalized regionally with the CERES fluxes. Once the Terra satellite is decommissioned, the SYN1deg product will transition to a NOAA20 and hourly GEO dataset.

3.0 Using regional climatology adjustments to transition between satellite records

The Terra&Aqua period is considered the most diurnally accurate part of the EBAF record, since the Terra (10:30 MLT) and Aqua (1:30 MLT) observations provide most of the regional diurnal information supplemented by a small geostationary-derived flux contribution (Loeb et al 2018 and Loeb and Doelling 2020). The Terra-only and NOAA20 (1:30MLT) records rely more on the geostationary-derived fluxes to estimate the daily flux means. To mitigate the flux discontinuity between Terra-only and Terra&Aqua records, the CERES EBAF Ed4.2 product applies regional climatology adjustments to the Terra-only record (March 2000 to June 2002) based on 5-years of overlap (July 2002 to June 2007). Calendar month dependent monthly mean flux climatology is computed over the overlap period. The adjustment applied to a calendar month for the Terra-only record is the mean difference of corresponding calendar months over the overlap period. The Terra-only EBAF dataset is processed during the overlap period to compute the regional climatology adjustment,

$$\hat{F} = F(Terra) + [\bar{F}(Terra\&Aqua) - \bar{F}(Terra)] \qquad (1)$$

where $\hat{F}$ is the flux with the climatological adjustment, F(Terra) and F(Terra&Aqua) are fluxes for, respectively, the Terra-only and Terra&Aqua periods, and the overbar indicates the climatological monthly mean fluxes computed for the 5-year overlap period. The bracketed term on the right side of Eq. (1) is the climatological adjustment. The regional climatology adjustment is used for both TOA and surface fluxes and is explained here. Similarly, for the NOAA20-only record (beginning in April 2022) the climatology is based on the May 2018 to March 2022 overlap period. SW and LW flux regional climatology adjustments were computed for both all-sky and clear-sky conditions. For TOA fluxes, the regional flux climatology adjustments were not applied if the year-to-year monthly Terra&Aqua minus Terra-only flux standard deviation or dispersion was greater than 20%. The regional clear-sky flux climatology adjustments were only utilized if all years during the overlap period had valid clear-sky fluxes (from either observed CERES footprints or MODIS narrowband to broadband fluxes) before spatial filling. The SW climatology adjustment was not applied if the resulting SW flux was less than 0.0 Wm^{-2}. To ensure that the climatology adjustments did not impact the regional and global trends, the trend of the climatologically adjusted NOAA20-only minus the Terra&Aqua fluxes during the overlap period was found to be much smaller than the overall Terra&Aqua trend (here). Similarly, the climatologically adjusted NOAA20-only minus the Terra&Aqua fluxes during the overlap period monthly regional or global anomalies were also found to be smaller than the overall Terra&Aqua anomalies. This validates that the flux regional climatology adjustments are not introducing any artificial trends or anomalies in the EBAF Ed4.2 record; the analysis can be found here. The EBAF Ed4.1 dataset did incorporate clear-sky flux climatology adjustments during the Terra-only record but did not incorporate all-sky flux or cloud climatology adjustments. Table 3-1 describes the climatology adjustment strategy as a function of satellite record.

The cloud properties were also climatologically adjusted. The cloud properties were cloud-fraction weighted to obtain the cloud climatology adjustments. No regional cloud property climatology adjustments were made over regions that did not have valid cloud property observations for each year during the overlap period. The cloud climatology adjustments were not applied if the resulting cloud fraction, cloud effective temperature, cloud effective pressure, and cloud optical depth was less than 0%, 200K, 200hPa, 0.05 or greater than 100%, 310K, 980hPa, 40, respectively.

Table 3-1. Satellite data record range and associated climatology adjustment strategy.

Data Range	Clear-sky fluxes	All-sky fluxes	Cloud properties
03/2000 – 06/2002	Terra[a]	Terra[c]	Terra[c]
07/2002 – 03/2022	Aqua	Terra+Aqua	Terra+Aqua
04/2022 – onwards	NOAA20[b]	NOAA20[d]	NOAA20[d]

[a] *Adjusted so that 07/2002-06/2007 climatology matches Aqua's*
[b] *Adjusted so that 05/2018-03/2022 climatology matches Aqua's*
[c] *Adjusted so that 07/2002-06/2007 climatology matches Terra+Aqua's*
[d] *Adjusted so that 05/2018-03/2022 climatology matches Terra+Aqua's*

4.0 The total solar irradiance dataset for the EBAF Ed4.2 product

The EBAF Edition 4.1 total solar irradiance (TSI) reference was based on Solar Radiation and Climate Experiment (SORCE) version 15, which was used between 25Feb2003 to 30Jun2013. The WRC composite (Mar2000 to 24Feb2003), RMIB composite (01Jul2013 to 31Oct2014), SORCE/TSIS-1 composite (01Jan2018 to 25Feb2020) and TSIS-1/TIM V3 beginning in 25Feb 2020 TSI datasets were radiometrically scaled to the SORCE V15 calibration. More information regarding the EBAF Ed4.1 TSI is found here. The solar community has a new TSI composite that combines TSI sensor records and is known as the community consensus TSI dataset; it was created by G. Kopp using the methodology of Dudok de Wit et al. (2017). The daily community consensus TSI composite can be accessed here. Since the community consensus TSI dataset has a longer lag time than the near-real time EBAF product, the TSIS-1/TIM V3 is appended to the community consensus TSI data beginning with May 7, 2022. The TSIS-1/TIM V3 is first radiometrically scaled to the community consensus record, utilizing the previous 100 days of overlap to determine the scaling factor. The EBAF Ed4.2 global TSI record mean is ~0.16 Wm^{-2} greater than the corresponding Ed4.1 value (see Figure 4-1). The EBAF product was energy balanced using the same Ed4.1 ocean heat storage value and based on the same 10-year period between July 2005 and June 2015, avoiding the single satellite periods. The resulting EBAF Ed4.2 minus Ed4.1 global net flux record mean difference (March 2000 to March 2022) is less than 0.02 Wm^{-2}.

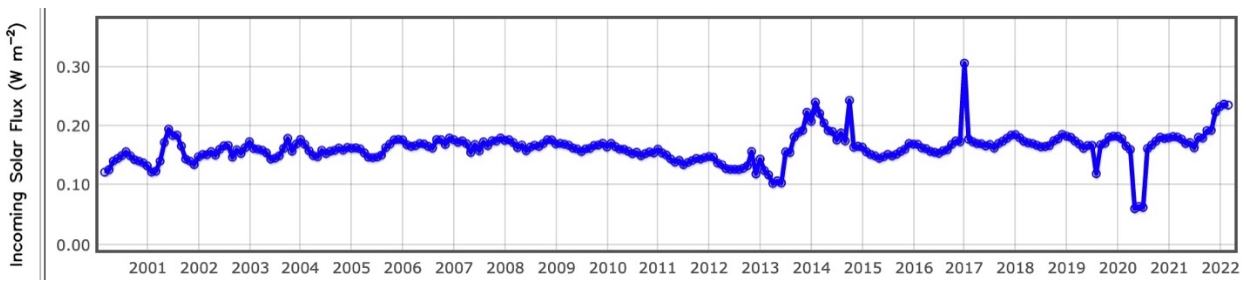


Figure 4-1. The EBAF Ed4.2 minus Ed4.1 total solar incoming difference.

5.0 EBAF Ed4.2 major algorithm improvements

- Fixed the diurnal asymmetry ratio (DAR) coding bug. DAR is computed by taking the morning minus afternoon SW flux ratio from the SYN1deg product. DAR should be computed in local time but was mistakenly computed in GMT, which resulted in pairing the afternoon flux and the morning flux of the following local day. This caused large spurious values of DAR near the dateline (Loeb and Doelling 2020 and here). DAR is used to compute the SW diurnal corrections applied to the SSF1deg product to compute the EBAF SW monthly mean regional fluxes.
- The EBAF product estimates clear-sky SW and LW fluxes in mostly overcast regions, which contain no clear-sky CERES observed footprints, by applying narrowband to broadband coefficients to the MODIS channel radiances within the clear portion of CERES partly cloudy footprints (Loeb et al. 2018). The MODIS narrowband to broadband coefficients are based on regressions of matched clear-sky footprint MODIS channel and CERES radiances. The MODIS-derived broadband radiances are then converted to fluxes using the CERES angular directional models (ADMs) and corrected to match the observed footprint clear-sky fluxes. The EBAF Ed4.1 narrowband to broadband coefficients were based on MODIS collection 5 across the entire record regardless of the MODIS collection used. For EBAF Ed4.2, the MODIS or VIIRS narrowband to broadband coefficients are based on the collection (C) number that is consistent with imager version used in the CERES record. MODIS C5 coefficients were applied between 2000 and February 2016, MODIS C6.1 coefficients were applied between March 2016 and March 2022, and NOAA20 VIIRS C2.1 coefficients are applied beginning in April 2022. See Table 5-1 to note the MODIS and VIIRS collection timelines used in the CERES record.

Table 5-1. The imager and collection used to compute the imager-derived clear-sky fluxes.

Data range	03/2000- 06/2000	07/2002-02/2016	03/2016-03/2022	04/2022-onwards
Imager & collection	Terra-MODIS C5	Aqua-MODIS C5	Aqua-MODIS C6.1	NOAA20-VIIRS C2.1

6.0 EBAF Ed4.2 minor changes

- For October 2004, the EBAF Ed4.2 monthly mean fluxes are based on October 13 to 31 observations, whereas the EBAF Ed4.1 incorrectly based the monthly mean fluxes on all days in October. The Aqua-CERES instrument radiance observations saturated over bright Earth targets resulting in spurious fluxes over the first 12 days of the month. The instrument issue was resolved on October 13, 2004.
- From August 16 to September 3, 2020, the Aqua spacecraft experienced an anomaly. For EBAF Ed4.1, NOAA20 observations were simply substituted for the missing days during the anomaly. For EBAF Ed4.2, the August 2020 monthly mean fluxes and clouds are based entirely on the NOAA-20-only climatology adjusted fluxes and clouds (like the NOAA20-only record beginning in April 2022).
- The EBAF Ed4.1 product did not properly apply the SW flux twilight correction (Kato and Loeb 2003) to all December months. This correction accounts for the refracted SW flux over regions with solar zenith angles greater than 90°. EBAF Ed4.2 applied the SW flux twilight correction for all months.
- The EBAF Ed4.1 product incorporated spurious MODIS granules during August 18, 2000 (Terra-MODIS) and August 6, 2002 (Aqua-MODIS), resulting in noisy cloud property retrievals that impacted the ADM scene selection used to convert the CERES radiance to fluxes. EBAF Ed4.2 product did not utilize those days in its processing.
- During the early Terra-CERES record, data gaps greater than one week occurred during August 6-18, 2000, June 15-July 2, 2001, and March 20-28, 2002. The EBAF Ed4.2 utilized the SW and LW fluxes from the SYN1deg product for the days with no CERES observations over non-polar regions. The SYN1deg GEO-derived fluxes were carefully normalized with CERES observations that were available during other days of the month. Over polar regions (>60° in latitude), the monthly mean fluxes are based on days with data only. This enables a more accurate observed monthly mean flux to facilitate comparisons with climate models.
- The EBAF Ed4.1 product utilized MODIS C5 until March 2018 and transitioned to MODIS C6.1 beginning in April 2018 when MODIS C6.1 became available. MODIS C6.1 mainly addressed spurious WV channel issues that occurred after the Terra spacecraft anomaly (February 18-29, 2016) (Wilson et al. 2017). The entire MODIS C6.1 L1B record was reprocessed; however, the CERES project only reprocessed the SSF1deg and SYN1deg records using MODIS C6.1 between February 2016 and March 2018). EBAF Ed4.2 incorporated the updated February 2016 and March 2018 SSF1deg and SYN1deg records.
- A SYN1deg SW temporal interpolation error was fixed in EBAF Ed4.2 when GEO regions experience glint conditions that occur over tropical oceans. During glint conditions, no GEO SW fluxes are derived but are temporally interpolated between neighboring non-glint hourly GEO fluxes. A more accurate DAR is obtained by this proper SW interpolation.
- Both Edition 4.1 and Edition 4.2 surface fluxes are based on the SYN1deg-Month product, which contains hourly surface fluxes. In the Editon 4.1 product, all MODIS-, VIIRS-, and geostationary satellite-derived cloud properties are used for surface flux computations. Geostationary satellites provide hourly cloud properties outside the MODIS and VIIRS overpass times. In Editon 4.2, only MODIS- and VIIRS-derived cloud properties are used; no geostationary satellite-derived cloud properties are used. Cloud properties derived from

MODIS and VIIRS are temporally interpolated in computing hourly fluxes. For the interpolation, clouds are separated into four types depending on cloud top pressure (Kato et al. 2018). Cloud properties that are interpolated include fraction, cloud top and base pressures, optical depth, particle (ice and liquid) size, and water phase (1 for liquid and 2 for ice).

- In the Edition 4.1 product, GEOS-5.4.1 provides temperatue and humidity profiles for the surface flux computations. In Edition 4.2, MERRA-2 temperature and humidity profiles are used for surface flux computations.

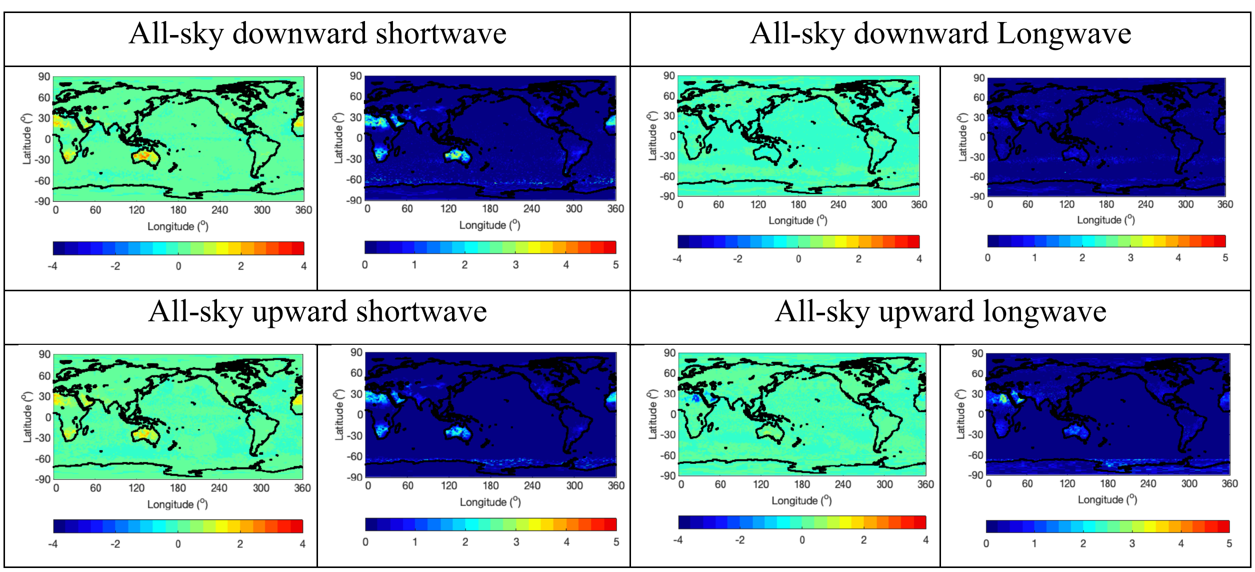
Cautions and Helpful Hints

- Because the GEOS-5.4.1 skin temperatures was inadvertently used in Edition 4.2 instead of the MERRA-2 skin temperatures, when the regional trend of surface net longwave flux is computed over the Amazon, the magnitude of the trend is unphysically large.

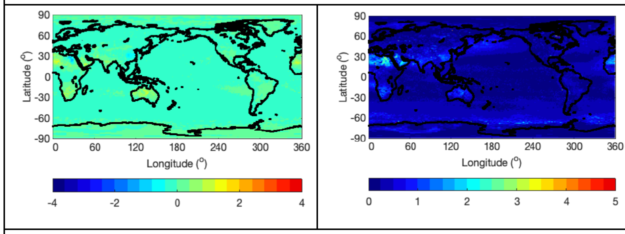
7.0 Revision of surface fluxes and TOA total area clear-sky fluxes

An older version of the code that computes surface fluxes and the clear-sky flux correction for total area clear-sky was used inadvertently when producing Edition 4.2 fluxes from March 2000 through June 2023. Several IF statements in the older version of the code trigger an error flag even when the computations or inputs are valid. For example, when the difference between clear-sky (only uses CERES observations) and all-sky (comes from GEO) observed TOA fluxes is large when cloud fraction is small (e.g. less than 0.05), the old code would not compute any fluxes, flagging them as missing. When this occurs, the code then temporally interpolates surface fluxes. Even when the condition of the scene is clear, a larger difference between observed TOA clear-sky and all-sky fluxes happens because Edition 4.2 EBAF uses interploated MODIS- or VIIRS-derived cloud properties, ignoring GEO-derived cloud properties. If the interpolated cloud fraction is less than 0.05, but GEO detects more clouds, the condition is satisfied and the older code skips the radiative transfer computations.

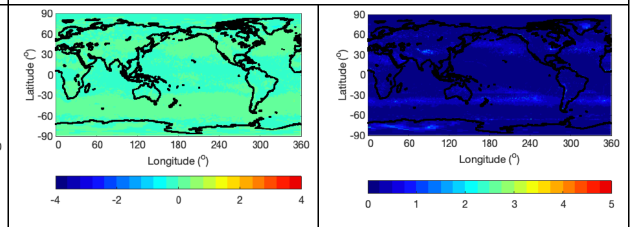
We compared interpolated surface fluxes and properly computed surface fluxes. Regional differences are shown in Figure 7-1. Larger errors occur in December 2000 and December 2001 but the diffferences shown in Figure 7-1 are typical for other months. The effect on global mean fluxes is negligible. Fluxes affected by this issue are TOA clear-sky fluxes for total region, all-sky surface fluxes, surface clear-sky fluxes for total and cloud free regions, and TOA and surface cloud radiative effect. The revised version computes surface fluxes properly to avoid interpolating them.



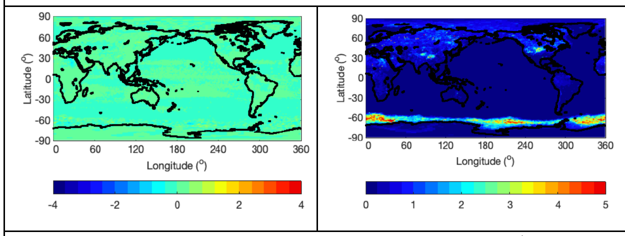
Total area clear-sky downard shortwave



Total area clear-sky downward longwave



Total area clear-sky upward shortwave



Total area clear-sky upward longwave

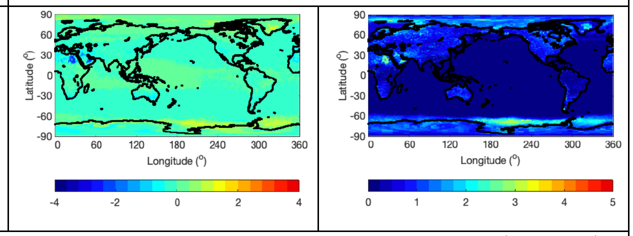


Figure 7-1. Mean difference (1st and 3rd columns) and root-mean square difference (2nd and 4th columns) of reprocessed edition 4.2 and earlier edition 4.2 surface fluxes in Wm^{-2}. The mean difference is the reprocessed version minus the earlier version. March 2000 through June 2023 are used for the plots.

8.0 Version History

December 2022: Released Edition 4.2 EBAF TOA fluxes.

February 2023: Released Edition4.2 EBAF Surface fluxes.

January 2024: Revised surface fluxes and TOA total area clear-sky fluxes from March 2000 through June 2023.

9.0 References

Dudok de Wit, T. G. Kopp, C. Fröhlich, and M. Schöll (2017), Methodology to create a new total solar irradiance record: Making a composite out of multiple data records, *Geophys. Res. Lett.*, **44**, 1196-1203, doi:10.1002/2016GL071866.

Kato, S., and N. G. Loeb, 2003: Twilight irradiance reflected by the earth estimated from Clouds and the Earth's Radiant Energy System (CERES) measurements. *J. Climate*, **16**, 2646–2650.

Kato, S., F. G. Rose, D. A. Rutan, T. E. Thorsen, N. G. Loeb, D. R. Doelling, X. Huang, W. L. Smith, W. Su, and S.-H. Ham, 2018: Surface irradiances of Edition 4.0 Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) data product, *J. Climate*, **31**, 4501-4527, doi:10.1175/JCLI-D-17-0523.1.

Loeb, N. G., D. R. Doelling, H. Wang, W. Su, C. Nguyen, J. G. Corbett, L. Liang, C. Mitrescu, F. G. Rose, and S. Kato, 2018: Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 data product. *J. Climate*, **31**, 895-918, doi: 10.1175/JCLI-D-17-0208.1.

Loeb, N. G. and Doelling, D. R., 2020: CERES Energy Balanced and Filled (EBAF) from Afternoon-Only Satellite Orbits. *Remote Sens.* , **12**, 1280. https://doi.org/10.3390/rs12081280.

Wilson, T.; Wu, A.; Shrestha, A.; Geng, X.; Wang, Z.; Moeller, C.; Frey, R.; Xiong, X., 2017: Development and Implementation of an Electronic Crosstalk Correction for Bands 27–30 in Terra MODIS Collection 6. *Remote Sens.*, **9**, 569. https://doi.org/10.3390/rs9060569.

10.0 Attribution

When referring to the CERES EBAF product, please include the data product and the data set version as "CERES_EBAF_Ed4.2."

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 papers when you publish scientific results with the CERES EBAF_Ed4.2.

Loeb, N. G., D. R. Doelling, H. Wang, W. Su, C. Nguyen, J. G. Corbett, L. Liang, C. Mitrescu, F. G. Rose, and S. Kato, 2018: Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) Top-of-Atmosphere (TOA) Edition-4.0 Data Product. *J. Climate*, **31**, 895-918, doi: 10.1175/JCLI-D-17-0208.1.
PDF available at https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-D-17-0208.1

Kato, S., F. G. Rose, D. A. Rutan, T. E. Thorsen, N. G. Loeb, D. R. Doelling, X. Huang, W. L. Smith, W. Su, and S.-H. Ham, 2018: Surface irradiances of Edition 4.0 Clouds and the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) data product, *J. Climate*, **31**, 4501-4527, doi:10.1175/JCLI-D-17-0523.1.
PDF available at https://journals.ametsoc.org/doi/pdf/10.1175/JCLI-D-17-0523.1

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/."

11.0 Feedback and Questions

For questions or comments on the CERES Data Quality Summary, contact the User and Data Services staff at the Atmospheric Science Data Center. For questions about the CERES subsetting/visualization/ordering tool at https://ceres.larc.nasa.gov/data/ please email LaRC-CERES-Help@mail.nasa.gov.

12.0 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
V0	12/09/2022	• Original document.	All
V1	01/27/2023	• Added text regarding the new Ed4.2 surface fluxes.	Sec. 3.0 and 6.0
V2	01/02/2024	• Added text about the revised Ed4.2 fluxes.	Sec. 7.0