Clouds and the Earth's Radiant Energy System (CERES)

Algorithm Theoretical Basis Document

Grid Single Satellite Fluxes and Clouds and Compute Spatial Averages

(Subsystem 6.0)

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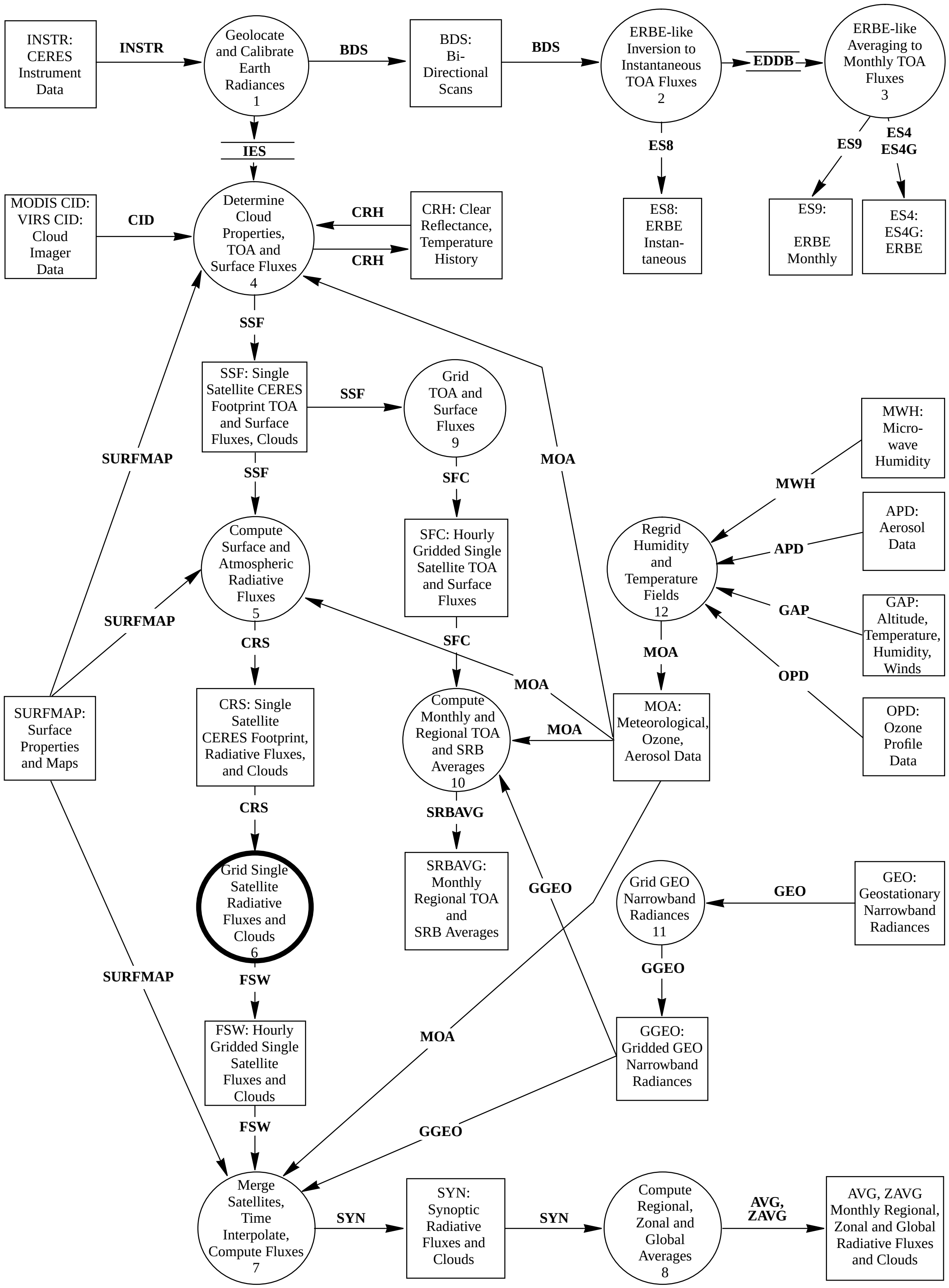
CERES Top Level Data Flow Diagram



Abstract

This subsystem, Grid Single Satellite Fluxes and Clouds and Compute Spatial Averages, provides the transformation from instrument-referenced data to Earth-referenced data. In this subsystem, a CERES footprint is assigned to the appropriate region of a 1° equal-angle grid. Fluxes and cloud properties are spatially averaged over each region on an hourly basis. After passing through this subsystem, the CERES data lose their traceability to specific CERES measurements.

Subsystem 6.0 uses the CRS archival product for input (see Appendix A). The subsystem outputs the FSW archival data product, which includes radiative fluxes at TOA, surface and atmospheric levels for clear sky and total sky conditions, cloud overlap conditions, cloud category properties, column-averaged cloud properties, angular model scene classes, surface-only data, and adjustment parameters (see Appendix B).

The gridding and spatial averaging subsystem performs two major functions. The first is to assign CERES footprints to the proper gridded regions. This assignment is based on the colatitude and longitude of the CERES footprint field of view at the top of the atmosphere. The second major process is to perform spatial averaging of the various radiative fluxes and cloud properties over each region for the time of observation.

6.0. Grid Single Satellite Fluxes and Clouds and Compute Spatial Averages

6.1. Introduction

In order to make the CERES data more useful to researchers, the measured fields are presented in an Earth-based coordinate system. A equal angle grid is defined consisting of regions that are 1° in latitude and 1° in longitude. Average values of the different parameters are computed over each region at the time of observation. Only CERES data obtained when the instrument is operating in the cross-track scan mode will be used in computing regional averages.

Means of basic physical quantities in a region are computed as arithmetic averages of the quantities in those CERES footprints whose centers are within the region. It is also necessary to compute regional values for other quantities which have been computed for individual CERES footprints, such as variances and probability distributions.

The CERES footprints are 25-km in diameter near nadir, so that there are more footprints on the boundary of a region than inside the region. Moreover, as CERES scans away from nadir, the footprints grow such that they are not small compared to the size of the region, and the distance between footprints in the scan direction increases. If the footprints are large compared to the region, as illustrated in figure 1, overlap of the footprints with each other and with the boundaries of the region complicates the problem of computing regional averages. The selection of particular footprints to use at the boundaries of the region and the correlation of values of overlapping footprints needs to be considered. Because of these problems, improved techniques for computing regional averages have been developed (Hazra et al., 1992, 1993). At present, error studies are underway to define the degree of improvement which these methods provide.

6.2. Algorithm Description

Two basic functions are performed in the 6.0 and 9.0 subsystems. The first is the gridding function, in which individual CERES footprints are assigned to the appropriate region or grid box. The second is the averaging function, in which spatial averages of time and geometry data, radiative flux data, cloud overlap conditions, cloud category properties, column-averaged cloud properties, and angular model scene classes are computed. The data flow diagram (see figure 2 in CERES Overview) illustrates these functions. The algorithms used to perform these functions are described below.

6.2.1. Gridding Algorithm

The grid system is an equal area grid of 1° quasi-squares in latitudinal rings or zones. Each 1° square is known as a region. There are 180 zones, which are numbered consecutively starting with 1 at the north pole. The regions in each zone are numbered consecutively starting at the 180° longitude, and progressing eastward. The number of the first region of the Mth latitude zone will be NZONE(M). The Mth zone will contain NZONE(M + 1) − NZONE(M) regions. The regions in zone M will be DLONG(M) degrees wide. DLONG and NZONE arrays will define the grid system. The width of each region in a zone is

$$\mathrm{DLONG}(M) = 360/(\mathrm{NZONE}(M+1) - \mathrm{NZONE}(M)) \tag{6-1}$$

The position COLAT and ALONG for each CERES footprint is computed by Subsystem 1 based on the optical axis position displaced by an angle due to the time response of the detector and electronic filter. The region number is then computed by making distinctions between the colatitude and longitude. First we count the number of zones from the south pole to the point, so that the zone number M is determined by:

$$M = 180 - INT(180 - \mathrm{COLAT}) \tag{1-2}$$

Next we count the number of regions from the 180° longitude to the point and add the number of the first region of the zone. The region number NREGION for a CERES footprint is computed as:

$$\mathrm{NREGION} = \mathrm{NZONE}(M) + \mathrm{INT}(\mathrm{ALONG}/\mathrm{DLONG}(M)) \tag{1-3}$$

6.2.2. Spatial Averaging Algorithms

6.2.2.1. Time and geometry data

Instead of spatially averaging time and location data over a region, time and location data are determined using the concept of a “key” footprint. The time of interest is the “over-flight” time, which is taken as the time corresponding to the “key” footprint assigned to a region. The determination of the key footprint depends upon the scan mode in operation when the CERES data were obtained. During cross-track operation, the region is scanned in an orderly manner. The set of all footprints in region NREGION is denoted as S(NREGION). The KEY footprint is that footprint whose axis is closest to the centroid of the region. The centroid of the region is calculated using an isosceles trapezoid approximation. Given the centroid of the region, the KEY footprint is determined by finding the footprint in S(NREGION) for which

$$(\mathrm{ALAT} - \mathrm{ALATCNR})^{**}2 + ((\mathrm{ALONG} - \mathrm{ALONGCT})^{*}\sin(\mathrm{COLAT}))^{**}2 \tag{1-4}$$

is a minimum, where ALAT and ALONG are the colatitude and longitude of a footprint, ALATCNR and ALONGCT are the latitude and longitude of the centroid of the region, and COLAT is the colatitude of the footprint.

The KEY footprints are used to identify the Julian date and time, Sun longitude and colatitude, solar zenith angle, spacecraft viewing zenith angle, spacecraft viewing azimuth angle, spacecraft relative azimuth viewing angle, and insolation for each region.

6.2.2.2. Spatial averaging algorithm

6.2.2.2.1 Means. The regional average of a quantity x is computed from its measurements x_i as

$$x_{\text{mean}} = \left(\sum_{i \in S} x_i\right) / N_S$$

where N_S is the number of footprints included in the set S for which the average is being computed. This technique was used for ERBE and for many other satellite processing systems. Given one or more observations in a region, one can compute a regional average with no difficulty. Without such measurements, one does not wish to attempt the computation. This algorithm will be applied to fluxes at the top of the atmosphere, surface and at intermediate layers in the atmosphere.

For averaging microphysical properties of clouds, it is necessary to account for the amount of clouds for which a number applies, e.g. in computing the average optical depth for clouds over a region, the average applies only to that part of the region which has clouds. A region may contain no clouds, one cloud or many clouds. It follows that for regional averages of cloud microphysical properties, a weighting by the fraction f_i of cloud in the footprint is included:

$$\tilde{x} = \frac{\sum_i f_i x}{\sum_i f_i}$$

The direct/diffuse ratio r is computed for each CERES footprint for the downward shortwave flux at the surface. The regional average direct/diffuse ratio is computed on a flux-weighted basis, so that the regional average ratio applies to the regional average values of direct, diffuse and total downward shortwave flux. The equation for the regional average direct/diffuse ratio (see Appendix C.1) is:

$$\tilde{r} = \left(\sum_i \frac{r_i F_i}{(1 + r_i)}\right) / \left(\sum_i \frac{F_i}{(1 + r_i)}\right)$$

6.2.2.2.2 Variances. There are two cases of computing variances. For the first case, there will be one measurement of a quantity for each CERES footprint. The variance of this quantity over the region will be given by

$$s^2 = (N - 1)^{-1} \left[\sum_{i=1}^{N} x_i^2 - N x_{\text{mean}}{}^2\right]$$

For the second case, variances will be computed in Subsystem 4 for cloud microphysical properties from MODIS pixels over each CERES footprint weighted by the CERES point spread function as

$$s^2 = \frac{\sum_i w_i (x_i - \hat{x})^2}{\sum_i w_i}$$

It can be shown (see Appendix C.2) that s^2 is related to the variance of the quantity σ^2 by

$$E[s^2] = \sigma^2 F(\alpha)$$

The parenthetical expression of the right-hand side will be a function of the view zenith angle α, which will vary slowly over a given region. Also, the number of MODIS pixels within a CERES footprint will be nearly the same for all footprints within a region. Thus, we can simply average the footprint variances to produce a regional average variance. Because the statistic thus computed is a function of view zenith angle α, its values should not be compared across a satellite measurement swath except as a measure of the variation of the bracket term.

6.2.2.2.3 Optical Depth and Infrared Emissivity Histograms. For each CERES footprint, Subsystem 4 will form a histogram of visible optical depths during the day and infrared emissivities during the night. For compactness, these histograms will be defined in terms of arrays of optical depths and emissivities corresponding to percentiles. In the present subsystem it is necessary to reconstruct the histograms from the percentiles, and from them form regional mean histograms for each cloud height class.

A set of percentile values $\{p_k\}$ is defined for $k \in [1, 13]$. For a given cloud altitude class the set of optical depths $\{x_{ki}\}$ corresponding to these percentiles is computed by Subsystem 4 for each CERES footprint i. In order to spatially average the histograms over a region, we first reconstruct the histogram on a fine optical depth grid consisting of a set of points $\{z_j\}$ for $j \in [1, 50]$. For optical depth computations, these points will not be evenly distributed. The reconstructed histograms $\{p_{ji}\}$ are then averaged over all footprints i within the region, weighted by the fractional cloud area f_i, to produce the regional mean histogram $\{P_j\}$:

$$P_j = P(z_j) = \frac{\sum_i f_i p_i(z_j)}{\sum_i f_i}$$

From these $\{z_j, P_j\}$ pairs, the x_k values corresponding to the selected percentile values of the regional average optical depth can then be computed by interpolation. In producing this regional mean histogram, the optical depth grid $\{z_j\}$ is accepted as sufficient so that there is no loss of accuracy due to interpolation errors. Thus, the grid will be somewhat smaller than the accuracy of the optical depth computation. The infrared emissivity histograms will be computed in the same manner. The interpolation points will differ between optical depth and infrared emissivity because the range of optical depths is [0, 50] and the range of infrared emissivity is [0, 1.].

6.3. Procedural Considerations

6.3.1. Routine Operations Expectations

The gridding and spatial averaging functions are performed on an hourly basis. The input CRS archival data product is an hourly product. The output FSW archival data product is a monthly product. Intermediate FSW-hour data products need to be stored in a data repository until an entire month of data is available to produce an FSW product to be passed on to the next processing subsystem. We expect that the logistics for this will be worked out cooperatively by the CERES Data Management Team, the CERES Science Team, and EOSDIS.

6.3.2. Exception Handling Strategy: Missing Data, Invalid Data

All invalid data are expected to have been eliminated from the input data products by the time FSW processing takes place. Routine limit checks will be made to make sure that data are within reasonable limits. Data that are outside these limits will be excluded from further processing, and a diagnostic report will be issued. These data will also be noted on the quality control (QC) reports generated by the subsystem.

6.3.3. Routine Diagnostics and Quality Control Expectations

Routine diagnostics will include a quality control report for each hourly FSW-hour data product. These reports will include information such as:

- The number of input records processed and the number of output records written
- The number of regions into which data were placed
- The number of CERES footprints of data placed into each region
- Per region, the minimum, maximum, mean, and standard deviation of selected parameters
- Missing data

As the definition of the FSW data product matures, this list will be expanded.

6.3.4. Storage Estimate

We estimate the size of each FSW-hour zonal product to be 69.5MB (see Appendix B). As the definition of the FSW data product matures, this size estimate may change. There will be 24 FSW-hour data products per day, and 744 per month. This latter number is based on an average of 31 days per month. Thus, we anticipate a monthly size of 12.22GB. Since the next step in the CERES data processing system operates on a month of data, FSW will require at least 12.22GB of storage space.

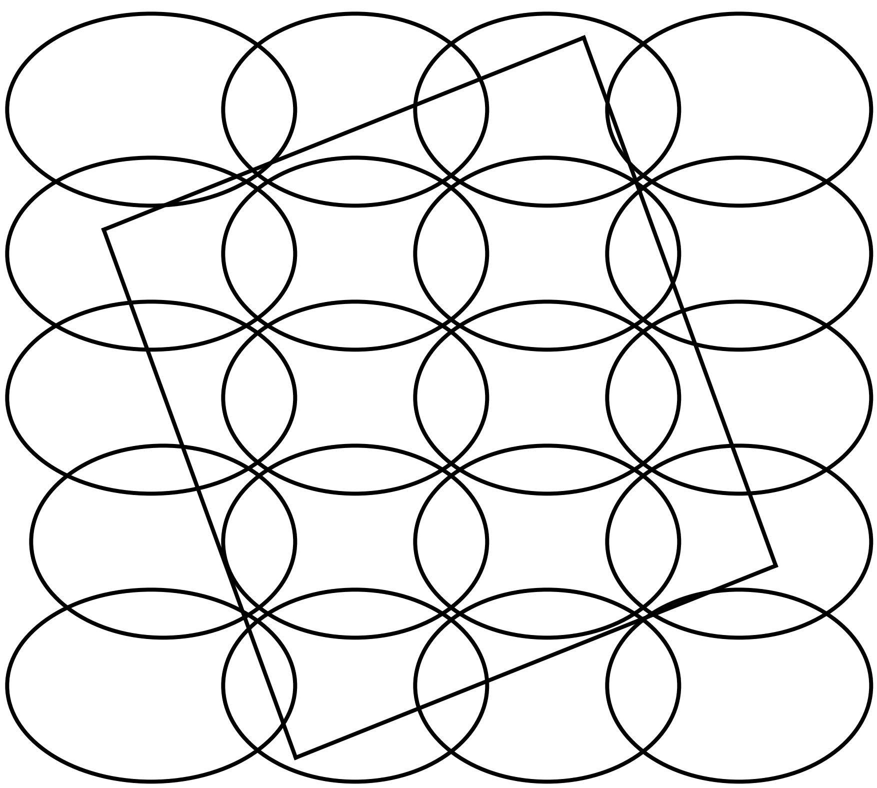


Figure 1. Area coverage by scan modes showing cross-track scan.

Appendix A

Input Data Products

Grid Single Satellite Radiative Fluxes and Clouds (Subsystem 6.0)

This appendix describes the data products which are produced by the algorithms in this subsystem. The table below summarizes these products, listing the CERES and EOSDIS product codes or abbreviations, a short product name, the product type, the production frequency, and volume estimates for each individual product as well as a complete data month of production. The product types are defined as follows:

Archival products:	Assumed to be permanently stored by EOSDIS
Internal products:	Temporary storage by EOSDIS (days to years)

The following pages describe each product. An introductory page provides an overall description of the product and specifies the temporal and spatial coverage. The table which follows the introductory page briefly describes every parameter which is contained in the product. Each product may be thought of as metadata followed by data records. The metadata (or header data) is not well-defined yet and is included mainly as a placeholder. The description of parameters which are present in each data record includes parameter number (a unique number for each distinct parameter), units, dynamic range, the number of elements per record, an estimate of the number of bits required to represent each parameter, and an element number (a unique number for each instance of every parameter). A summary at the bottom of each table shows the current estimated sizes for metadata, each data record, and the total data product. A more detailed description of each data product will be contained in a User's Guide to be published before the first CERES launch.

Table A-1. Input Products Summary

Product Code		Name	Type	Frequency	Size, MB	Monthly Size, MB
CERES	EOSDIS					
CRS	CER04	Clouds and Radiative Swath	Archival	1/Hour	341.32	253944

Clouds and Radiative Swath (CRS)

EOSDIS Product Code: CER04

The CERES archival product Clouds and Radiative Swath (CRS) is produced by the CERES Instantaneous Surface and Atmospheric Radiation Budget (SARB) Subsystem 5. Each CRS file contains longwave and shortwave radiative fluxes for the surface, internal atmosphere and TOA for each CERES field-of-view (FOV). The CRS contains data for an one-hour satellite swath (8-12 percent of the Earth) from one satellite. In addition to being an archival product, the CRS is used by the CERES subsystem Grid Single Satellite Radiative Fluxes and Clouds.

For each CERES FOV, the CRS contains:

- CERES FOV geometry, time, and scene data
- CERES FOV satellite altitude radiance data
- CERES FOV estimated TOA flux data
- CERES FOV surface flux data
- CERES FOV total-sky area data
- CERES FOV clear-sky area data
- Cloud category properties for two of four cloud height categories (low (L), lower middle (LM), upper middle (UM), and high (H)) over the CERES FOV
- Overlap data for four of eleven cloud overlap conditions (clear, L, LM, UM, H, H/UM, H/LM, H/L, UM/LM, UM/L, LM/L) over the CERES FOV
- CERES FOV surface radiative parameters
- Atmospheric flux profiles for both clear-sky and total-sky at the surface, 500hPa, the tropopause, and the TOA over the CERES FOV
- Flux adjustments (tuned-untuned) for clear-sky and total-sky at the surface and TOA over the CERES FOV
- Adjustment parameters for clear-sky (note that these are calculated for both clear-sky and total-sky FOV)
- Adjustment parameters for the two cloud categories over the CERES FOV

Level: 2

Type: Archival

Frequency: 1/ Hour

Portion of Globe Covered

File: Satellite Swath

Record: 1 CERES FOV

Time Interval Covered

File: 1 Hour

Record: Instantaneous

Portion of Atmosphere Covered

File: Surface to TOA

Table A-2. Clouds and Radiative Swath (CRS)

Description	Parameter Number	Units	Range	Elements/ Record	Bits/ Elem	Product Code
CRS Header						
Day and time at hour start		N/A	ASCII string	1	216	A
Character name of satellite		N/A	ASCII string	1	64	A
Character name of CERES instrument		N/A	ASCII string	1	32	A
Character name of high resolution imager instrument		N/A	ASCII string	1	64	A
Number of imager channels used		N/A	1 .. 20	1	16	A
Central wavelengths of imager channels		µm	0.4 .. 15.0	20	32	A
Earth-Sun distance		AU	.98 .. 1.02	1	32	A
Day and time IES processed (SS 1.0)		N/A	ASCII string	1	152	V
Day and time Imager Cloud Properties processed (SS 4.1- 4.3)		N/A	ASCII string	1	152	V
Day and time Convolution of Imager with CERES processed (SS 4.4)		N/A	ASCII string	1	152	V
Day and time TOA and Surface Estimation processed (SS 4.5 - 4.6)		N/A	ASCII string	1	152	A
Number of footprints in CRS product		N/A	0 .. 245275	1	32	A
CERES FOV Geometry, Time, and Scene						
Time of observation	1	day	-0.01 .. 1.01	1	64	A
Radius of satellite from center of Earth at observation	2	km	6000 .. 8000	1	64	A
Colatitude of satellite at observation	3	deg	0 .. 180	1	32	A
Longitude of satellite at observation	4	deg	0 .. 360	1	32	A
Colatitude of Sun at observation	5	deg	0 .. 180	1	32	A
Longitude of Sun at observation	6	deg	0 .. 360	1	32	A
Colatitude of CERES FOV at TOA	7	deg	0 .. 180	1	32	A
Longitude of CERES FOV at TOA	8	deg	0 .. 360	1	32	A
Colatitude of CERES FOV at surface	9	deg	0 .. 180	1	32	A
Longitude of CERES FOV at surface	10	deg	0 .. 360	1	32	A
Scan sample number	11	N/A	1 .. 660	1	16	A
Packet number	12	N/A	0 .. 32767	1	16	A
Cone angle of CERES FOV at satellite	13	deg	0 .. 90	1	32	A
Clock angle of CERES FOV at satellite wrt inertial velocity	14	deg	0 .. 360	1	32	A
Rate of change of cone angle	15	deg sec^{-1}	-100 .. 100	1	32	A
Rate of change of clock angle	16	deg sec^{-1}	-10 .. 10	1	32	A
Along-track angle of CERES FOV at TOA	17	deg	0 .. 360	1	32	A
Cross-track angle of CERES FOV at TOA	18	deg	-90 .. 90	1	32	A
X component of satellite inertial velocity vector	19	km sec^{-1}	-10 .. 10	1	64	A
Y component of satellite inertial velocity vector	20	km sec^{-1}	-10 .. 10	1	64	A
Z component of satellite inertial velocity vector	21	km sec^{-1}	-10 .. 10	1	64	A
CERES viewing zenith angle at TOA	22	deg	0 .. 90	1	32	A
CERES solar zenith angle at TOA	23	deg	0 .. 180	1	32	A
CERES relative azimuth angle at TOA	24	deg	0 .. 360	1	32	A
CERES viewing azimuth angle at TOA wrt North	25	deg	0 .. 360	1	32	V
Surface altitude above sea level	26	m	-1000 .. 10000	1	32	A
Surface type index	27	N/A	1 .. 20	8	16	A
Surface type percent coverage	28	N/A	0 .. 100	8	16	A
CERES SW ADM type for inversion process	29	N/A	0 .. 200	1	16	A
CERES LW ADM type for inversion process	30	N/A	0 .. 600	1	16	A
CERES WN ADM type for inversion process	31	N/A	0 .. 600	1	16	A
CERES FOV Satellite Altitude Radiance Data						
CERES TOT filtered radiance, satellite altitude, upwards	32	W $m^{-2}sr^{-1}$	0 .. 700	1	32	I
CERES SW filtered radiance, satellite altitude, upwards	33	W $m^{-2}sr^{-1}$	-10 .. 510	1	32	I
CERES WN filtered radiance, satellite altitude, upwards	34	W $m^{-2}sr^{-1}$	0 .. 50	1	32	I
IES quality flags	35	N/A	see table TBD	1	32	A
CERES SW unfiltered radiance, satellite altitude, upwards	36	W $m^{-2}sr^{-1}$	-10 .. 510	1	32	A
CERES LW unfiltered radiance, satellite altitude, upwards	37	W $m^{-2}sr^{-1}$	0 .. 200	1	32	A
CERES WN unfiltered radiance, satellite altitude, upwards	38	W $m^{-2}sr^{-1}$	0 .. 50	1	32	A
CERES FOV Estimated TOA Flux Data						
CERES SW flux, TOA, upwards	39	W m^{-2}	0 .. 1400	1	32	A
CERES LW flux, TOA, upwards	40	W m^{-2}	0 .. 500	1	32	A
CERES WN flux, TOA, upwards	41	W m^{-2}	0 .. 1400	1	32	A
CERES FOV Surface Flux Data						
CERES SW flux, surface, downwards, Model A	42	W m^{-2}	0 .. 1400	1	32	A
CERES LW flux, surface, downwards, Model A	43	W m^{-2}	0 .. 700	1	32	A

Table A-2. Clouds and Radiative Swath (CRS) Continued

Description	Parameter Number	Units	Range	Elements/ Record	Bits/ Elem	Product Code
CERES WN flux, surface, downwards, Model A	44	W m^{-2}	0 .. 700	1	32	A
CERES nonWN flux, surface, downwards, Model A	45	W m^{-2}	0 .. 700	1	32	A
CERES SW flux, surface, net, Model A	46	W m^{-2}	0 .. 1400	1	32	A
CERES LW flux, surface, net, Model A	47	W m^{-2}	-250 .. 50	1	32	A
CERES SW flux, surface, downwards, Model B (TBD)	48	W m^{-2}	0 .. 1400	1	32	A
CERES LW flux, surface, downwards, Model B	49	W m^{-2}	0 .. 700	1	32	A
CERES SW flux, surface, net, Model B (TBD)	50	W m^{-2}	0 .. 1400	1	32	A
CERES LW flux, surface, net, Model B	51	W m^{-2}	-250 .. 50	1	32	A
CERES spectral reflectivity	52	N/A	0 .. 1	6	32	I
CERES broadband surface albedo	53	N/A	0 .. 1	1	32	I
CERES LW surface emissivity	54	N/A	0 .. 1	1	32	I
CERES WN surface emissivity	55	N/A	0 .. 1	1	32	I
Imager-based surface skin temperature	56	K	175 .. 375	1	32	I
CERES FOV Total-Sky Area Data						
Number of imager pixels in CERES FOV	57	N/A	0 .. 9000	1	16	A
Imager percent coverage	58	N/A	0 .. 100	1	16	A
Precipitable water	59	cm	0.001 .. 10.000	1	32	A
Shadowed pixels percent coverage (TBD)	60	N/A	0 .. 100	1	16	A
Notes on general procedures	61	N/A	TBD	1	16	A
Notes on cloud algorithms	62	N/A	TBD	1	16	A
Imager viewing zenith angle over CERES FOV, mean	63	deg	0 .. 90	1	32	A
Imager relative azimuth angle over CERES FOV, mean	64	deg	0 .. 360	1	32	A
Imager channel identifier, 5 channels	65	N/A	1 .. 20	5	16	A
Imager radiance over CERES FOV, 5th percentile	66	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	5	32	V
Imager radiance over CERES FOV, mean	67	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	5	32	A
Imager radiance over CERES FOV, 95th percentile	68	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	5	32	V
Sunglint percent coverage	69	N/A	0 .. 100	1	16	A
CERES FOV Clear-Sky Area Data						
Snow/Ice percent coverage	70	N/A	0 .. 100	1	16	A
Smoke percent coverage	71	N/A	0 .. 100	1	16	A
Fire percent coverage	72	N/A	0 .. 100	1	16	A
Imager radiance, clear-sky area, mean	73	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	5	32	A
Imager radiance, clear-sky area, std	74	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	5	32	I
Total aerosol visible optical depth, clear-sky area	75	N/A	0 .. 2	1	32	A
Total aerosol effective radius, clear-sky area	76	μm	0 .. 20	1	32	A
Cloud Properties for Two of Four Cloud Layers						
Area percent coverage	77	N/A	0 .. 100	2	16	A
Overcast percent coverage	78	N/A	0 .. 100	2	16	A
Broken percent coverage	79	N/A	0 .. 100	2	16	A
Imager radiance, mean	80	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	10	32	A
Imager radiance, std	81	W $m^{-2}sr^{-1}\mu m^{-1}$	TBD	10	32	I
Cloud visible optical depth, linear, mean	82	N/A	0 .. 400	2	32	A
Cloud visible optical depth, linear, std	83	N/A	TBD	2	32	A
Cloud visible optical depth, logarithmic, mean	84	N/A	0 .. 6	2	32	A
Cloud visible optical depth, logarithmic, std	85	N/A	TBD	2	32	A
Cloud infrared emissivity, mean	86	N/A	0 .. 1	2	32	A
Cloud infrared emissivity, std	87	N/A	TBD	2	32	A
Liquid water path, mean	88	g m^{-2}	TBD	2	32	A
Liquid water path, std	89	g m^{-2}	TBD	2	32	V
Ice water path, mean	90	g m^{-2}	TBD	2	32	A
Ice water path, std	91	g m^{-2}	TBD	2	32	V
Cloud top pressure, mean	92	hPa	0 .. 1100	2	32	A
Cloud top pressure, std	93	hPa	TBD	2	32	V
Cloud effective pressure, mean	94	hPa	0 .. 1100	2	32	A
Cloud effective pressure, std	95	hPa	TBD	2	32	A
Cloud effective temperature, mean	96	K	100 .. 350	2	32	A
Cloud effective temperature, std	97	K	TBD	2	32	A
Cloud effective height, mean	98	km	0 .. 20	2	32	A
Cloud effective height, std	99	km	TBD	2	32	V
Cloud bottom pressure, mean	100	hPa	0 .. 1100	2	32	A
Cloud bottom pressure, std	101	hPa	TBD	2	32	V
Water particle radius, mean	102	μm	TBD	2	32	A
Water particle radius, std	103	μm	TBD	2	32	A
Ice particle effective diameter, mean	104	μm	TBD	2	32	A

Table A-2. Clouds and Radiative Swath (CRS) Concluded

Description	Parameter Number	Units	Range	Elements/ Record	Bits/ Elem	Product Code
Ice particle effective diameter, std	105	µm	TBD	2	32	A
Cloud particle phase, mean	106	N/A	0 .. 1	2	32	A
Cloud particle phase, std	107	N/A	0 .. 1	2	32	V
Vertical aspect ratio, mean (TBD)	108	N/A	0 .. 1	2	32	A
Vertical aspect ratio, std (TBD)	109	N/A	TBD	2	32	V
Visible optical depth, 13 percentiles	110	N/A	TBD	26	32	I
IR emissivity, 13 percentiles	111	N/A	TBD	26	32	I
CERES FOV Overlap Data for 4 Cloud Overlap Conditions						
Number imager pixels for overlap condition	112	N/A	0 .. 9000	4	16	A
Overlap condition weighted area percentage	113	N/A	0 .. 100	4	16	A
Surface Radiative Parameters						
Photosynthetically active radiation, surface (TBD)	114	W m^{-2}	0 .. 780	1	32	A
Direct/diffuse ratio, surface (TBD)	115	N/A	0 .. 30	1	32	A
Atmospheric Flux Profile for Clear-sky and Total-sky						
Number atmospheric levels	116	N/A	0 .. 4	1	16	A
Level pressures	117	hPa	0 .. 1100	4	32	A
SW flux, atmospheric level, upwards, tuned	118	W m^{-2}	0 .. 1400	8	32	A
SW flux, atmospheric level, downwards, tuned	119	W m^{-2}	0 .. 1400	8	32	A
LW flux, atmospheric level, upwards, tuned	120	W m^{-2}	0 .. 500	8	32	A
LW flux, atmospheric level, downwards, tuned	121	W m^{-2}	0 .. 500	8	32	A
Flux Adjustments (Tuned - Untuned) for Clear-sky and Total-sky						
Number tuning iterations	122	N/A	0 .. 3	1	16	A
SW flux, surface, downwards, delta	123	W m^{-2}	0 .. 1400	2	32	A
SW flux, surface, upwards, delta	124	W m^{-2}	0 .. 1400	2	32	A
SW flux, TOA, upwards, delta	125	W m^{-2}	0 .. 1400	2	32	A
LW flux, surface, downwards, delta	126	W m^{-2}	0 .. 500	2	32	A
LW flux, surface, upwards, delta	127	W m^{-2}	0 .. 500	2	32	A
LW flux, TOA, upwards, delta	128	W m^{-2}	0 .. 500	2	32	A
Adjustment Parameters for Clear Skies						
Adjusted precipitable water, delta	129	cm	0.001 .. 10.000	1	32	A
Adjusted surface albedo, delta	130	N/A	0 .. 1	1	32	A
Adjusted aerosol optical depth, delta	131	N/A	0 .. 2	1	32	A
Adjusted skin temperature, delta	132	K	TBD	1	32	A
Adjustment Parameters for Two Cloud Layers						
Adjusted mean visible optical depth, delta	133	N/A	0 .. 400	2	32	A
Adjusted std visible optical depth, delta	134	N/A	TBD	2	32	A
Adjusted mean cloud fractional area, delta	135	N/A	0 .. 1	2	32	A
Adjusted std cloud fractional area, delta	136	N/A	TBD	2	32	A
Adjusted mean infrared emissivity, delta	137	N/A	0 .. 1	2	32	A
Adjusted std mean infrared emissivity, delta	138	N/A	TBD	2	32	A
Adjusted mean cloud effective temperature, delta	139	K	0 .. 250	2	32	A
Adjusted std cloud effective temperature, delta	140	K	TBD	2	32	A
Adjusted visible optical depth, 13 percentiles, delta	141	N/A	TBD	26	32	A
Adjusted IR emissivity, 13 percentiles, delta	142	N/A	TBD	26	32	A

Total Meta Bits/File:	1672
Total Data Bits/Record:	11664
Total Records/File:	245475
Total Data Bits/File:	2863220400
Total Bits/FIle:	2863222072

Appendix B

Output Data Products

Grid Single Satellite Radiative Fluxes and Clouds (Subsystem 6.0)

This appendix describes the data products which are used by the algorithms in this subsystem. The table below summarizes these products, listing the CERES and EOSDIS product codes or abbreviations, a short product name, the product type, the production frequency, and volume estimates for each individual product as well as a complete data month of production. The product types are defined as follows:

Archival products:	Assumed to be permanently stored by EOSDIS
Internal products:	Temporary storage by EOSDIS (days to years)

The following pages describe each product. An introductory page provides an overall description of the product and specifies the temporal and spatial coverage. The table which follows the introductory page briefly describes every parameter which is contained in the product. Each product may be thought of as metadata followed by data records. The metadata (or header data) is not well-defined yet and is included mainly as a placeholder. The description of parameters which are present in each data record includes parameter number (a unique number for each distinct parameter), units, dynamic range, the number of elements per record, an estimate of the number of bits required to represent each parameter, and an element number (a unique number for each instance of every parameter). A summary at the bottom of each table shows the current estimated sizes of metadata, each data record, and the total data product. A more detailed description of each data product will be contained in a User's Guide to be published before the first CERES launch.

Table B-1. Output Product Summary

Product Code		Name	Type	Frequency	Size, MB	Monthly Size, MB
CERES	EOSDIS					
FSW	CER05	Gridded Single Satellite Fluxes and Clouds	Archival	1/Month	69.5	12511.8

Monthly Gridded Single Satellite Fluxes and Clouds (FSW)

EOSDIS Product Code: CER05

The Monthly Gridded Single Satellite Fluxes and Clouds (FSW) archival data product contains hourly single satellite flux and cloud parameters averaged over 1.0 degree regions. Input to the FSW Subsystem is the Single Satellite CERES Footprint, Radiative Fluxes and Clouds (CRS) archival data product. Each FSW covers a single month swath from a single CERES instrument mounted on one satellite. The product has a product header and multiple records; each record contains spatially averaged data for an individual region.

The major categories of data output on the FSW are as follows:

- Region data
- Total-sky radiative fluxes at TOA, surface, and atmospheric levels
- Clear-sky radiative fluxes at TOA, surface, and atmospheric levels
- Cloud overlap conditions
- Cloud category properties
- Column-averaged cloud properties
- Angular model scene classes
- Surface-only data
- Adjustment parameters

FSW is an archival product generated on an monthly basis. Initially, at the launch of the TRMM spacecraft, this product will be produced in validation mode once every 3 months, or for 4 data months a year. During the first 18 months after the launch of TRMM, the CERES Science Team will derive a production quality set of ADMs, which are needed to produce the SW and LW instantaneous fluxes. Eighteen months after the launch of TRMM, this product will be archived and will contain SW and LW fluxes at the tropopause and at the 500 hPa pressure level, in addition to fluxes at TOA and at the surface. Thirty-six months after the launch of TRMM, this archived product will contain SW and LW fluxes at 26 standard pressure levels. A complete listing of parameters for this data product can be found in Table .

Level: 3
Type: Archival
Frequency: 1/Month

Portion of Globe Covered
File: Gridded satellite swath
Record: 1.0-degree equal-angle regions

Time Interval Covered
File: Month
Record: Hour

Portion of Atmosphere Covered
File: TOA, surface, and atmospheric pressure levels

Table B-2. Monthly Gridded Single Satellite Fluxes and Clouds (FSW)

Description	Parameter Num	Unit	Range	Elements/ Record	Bits/ Elem
FSW Header					
CERES Data Product Code		N/A	N/A	1	32
CERES Spacecraft Identification Code		N/A	N/A	1	32
CERES Instrument Identification code		N/A	N/A	1	32
Zone Number		N/A	1 .. 180	1	32
Data Year		N/A	1996 .. 2099	1	32
Data Month		N/A	1 .. 12	1	32
Number of hours per region		N/A	0 .. 744	360	32
Data Date Processed		N/A	N/A	1	136

FSW Record

Description	Parameter Num	Unit	Range	Elements/ Record	Bits/ Elem
Spatially Averaged Region Parameters					
Time and Position Data					
Key Footprint Parameters					
Julian Time	1	Day	0.0 .. 1.0	1	321
Sun colatitude	2	Degrees	0.0 .. 180.0	1	322
Sun longitude	3	Degrees	0.0 .. 360.0	1	323
Relative azimuth angle at TOA	4	Degrees	0.0 .. 360.0	1	324
Cosine of solar zenith angle at TOA	5	N/A	0.0 .. 1.0	1	325
Spacecraft zenith angle	6	Degrees	0.0 .. 90.0	1	326
Region ID					
Region number	7	Dimensionless	1 .. 64800	1	327
Hour box number	8	Dimensionless	1 .. 744	1	328
Number of Footprints in region	9	N/A	1 .. 40	1	329
Number of imager pixels in CERES fov in the region	10	N/A	1 .. 360000	1	3210
Other Regional Parameters					
Altitude of surface above sea level	11	m	-1000 .. 10000	1	3211
Surface type percentage: mean	12	Percent	0.0 .. 100.0	20	3212
Sunglint percent coverage	13	Percent	0.0 .. 100.0	1	3232
Snow/Ice percent coverage	14	Percent	0.0 .. 100.0	1	3233
Smoke percent coverage	15	Percent	0.0 .. 100.0	1	3234
Fire percent coverage	16	Percent	0.0 .. 100.0	1	3235
Imager radiance, clear-sky area	17	$W\ m^{-2} sr^{-1} um^{-1}$	TBD	5	3236
Total aerosol visible optical depth, clear-sky area	18	N/A	0.0 .. 2.0	1	3241
Total aerosol effective radius, clear-sky area	19	um	0.0 .. 20.0	1	3242
Imager percent coverage	20	Percent	0.0 .. 100.0	1	3243
Precipitable Water	21	cm	0.0001 .. 10.0	1	3244
Shadowed pixels percent coverage (TBD)	22	Percent	0.0 .. 100.0	1	3245
Imager viewing zenith angle over CERES FOV	23	Degrees	0.0 .. 90.0	1	3246
Imager relative azimuth angle over CERES FOV	24	Degrees	0.0 .. 360.0	1	3247
Imager channel identifier	25	N/A	1 .. 20	5	3248
Imager radiance over CERES FOV, 5th percentile	26	$W\ m^{-2} sr^{-1} um^{-1}$	TBD	5	3253
Imager radiance over CERES FOV	27	$W\ m^{-2} sr^{-1} um^{-1}$	TBD	5	3258
Imager radiance over CERES FOV, 95th percentile	28	$W\ m^{-2} sr^{-1} um^{-1}$	TBD	5	3263
Spatially Averaged Radiative Flux Parameters					
TOA Clear-Sky Fluxes is Array[3] of:					
Upward SW flux at TOA: mean, std, num obs	29	$W\ m^{-2}$	0.0 .. 1400.0	3	3268
Upward LW flux at TOA: mean, std, num obs	30	$W\ m^{-2}$	100.0 .. 500.0	3	3271
Upward LW window flux at TOA: mean, std, num obs	31	$W\ m^{-2}$	0.0 .. 800.0	3	3274
Albedo: mean, std, num obs	32	Dimensionless	0.0 .. 1.0	3	3277
TOA Total-Sky Fluxes is Array[3] of:					
Upward SW flux at TOA: mean, std, num obs	33	$W\ m^{-2}$	0.0 .. 1400.0	3	3280
Upward LW flux at TOA: mean, std, num obs	34	$W\ m^{-2}$	100.0 .. 500.0	3	3283
Upward LW window flux at TOA: mean, std, num obs	35	$W\ m^{-2}$	0.0 .. 800.0	3	3286
Albedo: mean, std, num obs	36	Dimensionless	0.0 .. 1.0	3	3289
Atmospheric Clear-Sky Flux Profiles for 4 Layers					
(Layers: sfc, 500hPa, tropopause, and TOA AVG) is Array[3] of:					
Downward SW flux, Model A: mean, std, num obs	37	$W\ m^{-2}$	0.0 .. 1400.0	12	3292
Upward SW flux: mean, std, num obs	38	$W\ m^{-2}$	0.0 .. 1400.0	12	32104
Downward LW flux, Model A: mean, std, num obs	39	$W\ m^{-2}$	0.0 .. 500.0	12	32116
Upward LW flux: mean, std, num obs	40	$W\ m^{-2}$	0.0 .. 500.0	12	32128

Table B-2. Monthly Gridded Single Satellite Fluxes and Clouds (FSW) Continued

Description	Parameter Num	Unit	Range	Elements/ Record	Bits/ Elem
Atmospheric Total-Sky Flux Profiles for 4 Layers					
(Layers: sfc, 500hPa, tropopause, and TOA AVG) is Array[3] of:					
Downward SW flux, Model A: mean, std, num obs	41	W m^{-2}	0.0 .. 1400.0	12	32140
Upward SW flux: mean, std, num obs	42	W m^{-2}	0.0 .. 1400.0	12	32152
Downward LW flux, Model A: mean, std, num obs	43	W m^{-2}	0.0 .. 500.0	12	32164
Upward LW flux: mean, std, num obs	44	W m^{-2}	0.0 .. 500.0	12	32176
Clear-Sky Flux_Adjustments (Tuned-Untuned) is Array[3] of:					
Surface Layer:					
Downward SW flux: mean, std, num obs	45	W m^{-2}	0.0 .. 1400.0	3	32188
Upward SW flux: mean, std, num obs	46	W m^{-2}	0.0 .. 1400.0	3	32191
Downward LW flux: mean, std, num obs	47	W m^{-2}	0.0 .. 500.0	3	32194
Upward LW flux: mean, std, num obs	48	W m^{-2}	0.0 .. 500.0	3	32197
TOA Layer:					
Upward Sw flux: mean, std, num obs	49	W m^{-2}	0.0 .. 1400.0	3	32200
Downward LW flux: mean, std, num obs	50	W m^{-2}	0.0 .. 500.0	3	32203
Upward LW flux: mean, std, num obs	51	W m^{-2}	0.0 .. 500.0	3	32206
Total-Sky Flux_Adjustments (Tuned-Untuned) is Array[3] of:					
Surface Layer:					
Downward SW flux: mean, std, num obs	52	W m^{-2}	0.0 .. 1400.0	3	32209
Upward SW flux: mean, std, num obs	53	W m^{-2}	0.0 .. 1400.0	3	32212
Downward LW flux: mean, std, num obs	54	W m^{-2}	0.0 .. 500.0	3	32215
Upward LW flux: mean, std, num obs	55	W m^{-2}	0.0 .. 500.0	3	32218
TOA Layer:					
Upward Sw flux: mean, std, num obs	56	W m^{-2}	0.0 .. 1400.0	3	32221
Downward LW flux: mean, std, num obs	57	W m^{-2}	0.0 .. 500.0	3	32224
Upward LW flux: mean, std, num obs	58	W m^{-2}	0.0 .. 500.0	3	32227
Emissivity					
LW surface emissivity	59	N/A	0 .. 1	1	32230
WN surface emissivity	60	N/A	0 .. 1	1	32231
Surface Only Data					
Photosynthetically active radiation	61	W m^{-2}	0.0 .. 780.0	1	32232
Direct/Diffuse	62	N/A	0.0 .. 30.0	1	32233
Spatially Averaged Cloud Parameters					
Spatially Averaged Cloud Overlap Conditions					
Overlap condition weighted area percentage	63	Percent	0.0 .. 100.0	11	32234
Spatially Averaged Cloud Category Data for 4 Layers					
(High, Upper Middle, Lower Middle, and Low)					
Spatially Averaged Cloud Area Fractions					
Overcast percent coverage	64	Percent	0.0 .. 100.0	4	32245
Total percent coverage	65	Percent	0.0 .. 100.0	4	32249
Spatially Averaged Cloud Properties is Array[3] of:					
Cloud effective pressure: mean, std, num obs	66	hPa	0.0 .. 1100.0	12	32253
Cloud effective temperature: mean, std, num obs	67	K	100.0 .. 350.0	12	32265
Cloud effective altitude: mean, std, num obs	68	km	0.0 .. 20.0	12	32277
Cloud top pressure: mean, std, num obs	69	hPa	0.0 .. 1100.0	12	32289
Cloud bottom pressure: mean, std, num obs	70	hPa	0.0 .. 1100.0	12	32301
Cloud particle phase: mean, std, num obs	71	Fraction	0.0 .. 1.0	12	32313
Liquid water path: mean, std, num obs	72	kg m^{-2}	0.01 .. 1000.0	12	32325
Ice water path: mean, std, num obs	73	kg m^{-2}	0.01 .. 1000.0	12	32337
Liquid particle radius: mean, std, num obs	74	micron	0.0 .. 1000.0	12	32349
Ice particle effective diameter: mean, std, num obs	75	micron	0.0 .. 100.0	12	32361
Visible optical depth (linear): mean, std, num obs	76	Dimensionless	0.0 .. 50.0	12	32373
Visible optical depth (logarithmic): mean, std, num obs	77	Dimensionless	0.0 .. 50.0	12	32385
Infrared emissivity: mean, std, num obs	78	Dimensionless	0.0 .. 2.0	12	32397
Cloud vertical aspect ratio: mean, std, num obs	79	Dimensionless	TBD	12	32409
Spatially Averaged Adjustment Parameters					
Adjusted visible optical depth: mean, std	80	Dimensionless	0.0 .. 400.0	8	32421
Adjusted cloud fractional area: mean, std	81	Dimensionless	0.0 .. 100.0	8	32429
Adjusted infrared emissivity: mean, std	82	Dimensionless	0.0 .. 1.0	8	32437
Adjusted cloud effective temperature: mean, std	83	K	0.0 .. 250.0	8	32445
Spatially Averaged Weighted Column					
Averaged Cloud Properties for 5 Weightings					
(Five Weightings: SW, LW TOA, SFC LW, LWP, IWP)					
Spatially Averaged Cloud Area Fractions					
Overcast percent coverage	84	Percent	0.0 .. 100.0	5	32453
Total percent coverage	85	Percent	0.0 .. 100.0	5	32458

Table B-2. Monthly Gridded Single Satellite Fluxes and Clouds (FSW) Concluded

Description	Parameter Num	Unit	Range	Elements/ Record	Bits/ Elem
Spatially Averaged Cloud Properties is Array[3] of:					
Cloud effective pressure: mean, std, num obs	86	hPa	0.0 .. 1100.0	15	32463
Cloud effective temperature: mean, std, num obs	87	K	100.0 .. 350.0	15	32478
Cloud effective altitude: mean, std, num obs	88	km	0.0 .. 20.0	15	32493
Cloud top pressure: mean, std, num obs	89	hPa	0.0 .. 1100.0	15	32508
Cloud bottom pressure: mean, std, num obs	90	hPa	0.0 .. 1100.0	15	32523
Cloud particle phase: mean, std, num obs	91	Fraction	0.0 .. 1.0	15	32538
Liquid water path: mean, std, num obs	92	kg m^{-2}	0.01 .. 1000.0	15	32553
Ice water path: mean, std, num obs	93	kg m^{-2}	0.01 .. 1000.0	15	32568
Liquid particle radius: mean, std, num obs	94	micron	0.0 .. 1000.0	15	32583
Ice particle effective diameter: mean, std, num obs	95	micron	0.0 .. 100.0	15	32598
Visible optical depth (linear): mean, std, num obs	96	Dimensionless	0.0 .. 50.0	15	32613
Visible optical depth (logarithmic): mean, std, num obs	97	Dimensionless	0.0 .. 50.0	15	32628
Infrared emissivity: mean, std, num obs	98	Dimensionless	0.0 .. 2.0	15	32643
Cloud vertical aspect ratio: mean, std, num obs	99	Dimensionless	TBD	15	32658
Spatially Averaged Angular Model Scene Type Parameters					
Angular Model Scene Type Parameters for 12 Scene Types					
Fractional area coverage	100	Percent	0.0 .. 100.0	12	32673
Angular Model Scene Type Statistical Data is Array[2] of:					
Incident Solar Flux: mean, std	101	Dimensionless	0.0 .. 1400.0	24	32685
Albedo: mean, std	102	Dimensionless	0.0 .. 1.0	24	32709
LW flux: mean, std	103	W m^{-2}	0.0 .. 400.0	24	32733
Spatially Averaged Clear Sky Adjustment Parameters					
Adjusted precipitable water: mean, std	104	cm	0.001 .. 8.0	2	32757
Adjusted surface albedo: mean, std	105	Dimensionless	0.0 .. 1.0	2	32759
Adjusted aerosol optical depth: mean, std	106	Dimensionless	0.0 .. 2.0	2	32761
Adjusted skin temperature: mean, std	107	K	TBD	2	32763
Spatially Average Surface Data					
Spectral Reflectivity: mean, std, num obs	108	Dimensionless	0.0 .. 1.0	3	32765
Broadband Surface Albedo: mean, std, num obs	109	Dimensionless	0.0 .. 1.0	3	32768
Surface Skin Temperature: mean, std, num obs	110	K	175.0 .. 375.0	3	32771

Total Meta Bits/File:	11848
Total Data Bits/Record:	24736
Total Records/File:	23572
Total Data Bits/File:	583076992
Total Bits/File:	583088840
Total Files/Product:	180
Total Meta Bits/Product:	2132640
Total Data Bits/Product:	104953858560
Total Bits/Product:	104955991200
Total MegaBytes/File:	69.51
Total GigaBytes/Product:	12.22

Appendix C

Theoretical Notes

This appendix gives the derivation of equation for regional average of direct/diffuse ratio used in this subsystem and a brief discussion of point spread function weighted statistics.

C.1. Direct/Diffuse Averaging

At the surface, we have footprint values of the downward shortwave flux F_i and the direct/diffuse ratio r_i. It is required to form the average direct/diffuse ratio $\tilde{r}$ such that the average direct flux and average diffuse flux can be computed from this average ratio $\tilde{r}$ and the average flux $\tilde{F}$. By definition,

$$\text{Direct flux}\,i/\text{diffuse flux}\,i = r_i$$

We note that

$$\text{Direct flux} + \text{diffuse flux} = \text{Total flux}$$

It follows that for each CERES footprint

$$\text{Diffuse flux } i = F_i/(1 + r_i)$$

$$\text{Diffuse flux } i = r_i F_i/(1 + r_i)$$

The average direct flux is $\sum_i \frac{r_i F_i}{(1 + r_i)}$ and the average diffuse flux is $\sum_i \frac{F_i}{(1 + r_i)}$. The regional average direct/diffuse ratio is thus computed

$$\tilde{r} = \left(\sum_i \frac{r_i F_i}{(1 + r_i)}\right)\left(\sum_i \frac{F_i}{(1 + r_i)}\right)$$

The regional mean direct and diffuse components of downward shortwave radiation are given in terms of this mean ratio and the regional mean downward shortwave flux $\tilde{F}$ as

$$\text{Regional mean direct flux} = \tilde{r}\tilde{F} / (1 + \tilde{r})$$

$$\text{Regional mean diffuse flux} = \tilde{F} / (1 + \tilde{r})$$

C.2. Notes on Point Spread Function Weighted Statistics

The statistics

$$\hat{x} = \frac{\sum_i w_i x_i}{\sum_i w_i}$$

and

$$s^2 = \frac{\sum_i w_i (x_i - \hat{x})^2}{\sum_i w_i}$$

are to be computed for each CERES footprint, in which the x_i are computed from MODIS measurements and the w_i are the point spread function values at the MODIS measurement point (see section 4.4).

These statistics have the following properties:

I. $\hat{x}$ is an unbiased estimator of the mean of the x_i values.

II. The variance of $\hat{x}$ about the population mean is

$$\left(\sum_i w_i\right)^{-2}\sigma^2\sum_i\sum_j w_i w_j \rho_{ij}$$

If the x_i are uncorrelated and the weights are 1, the sample mean variance reduces to $\frac{\sigma^2}{n}$.

III. The expected value of the s^2 statistic is $E[s^2] = \sigma^2\left[1 - \left(\sum_i w_i\right)^{-2}\sigma^2\sum_i\sum_j w_i w_j \rho_{ij}\right]$. If the x_i are uncorrelated and the weights are 1, this expression reduces to the familiar expression for the sample variance: $E[s^2] = \sigma^2\left[\frac{n-1}{n}\right]$

We need to consider how we want to average the $\hat{x}$ and s over a region. If the correlations are included, the summations will be functions of the crosstrack scan angle α and may be computed once as a table look-up *if we assume we know the spatial correlation* $\rho_{ij.}$ Thus, we tabulate

$$F(\alpha) = \left[1 - \left(\left(\sum_i w_i\right)^{-2}\sigma^2\sum_i\sum_j w_i w_j \rho_{ij}\right)\right]$$

whence we compute the unbiased estimate of the sample variance $\hat{\sigma}^2 = s^2 F^{-1}(\alpha)$. This quantity can then be spatially averaged. The problem is in the assumption of the correlation structure. When we examine the effects of this approximation, we have to ask, “What is the use of the variance once we have it?” Without an understanding of this, we have no way to assess this approximation or an alternative. If *F*(α) varies slowly with nadir angle, we then can average the CERES footprint s^2 values over a region to obtain an average s^2 value. However, it would be a gross approximation to compare the s^2 values for a region near nadir with those near the limb

Appendix D

Nomenclature

Acronyms

ADEOS	Advanced Earth Observing System
ADM	Angular Distribution Model
AIRS	Atmospheric Infrared Sounder (EOS-AM)
AMSU	Advanced Microwave Sounding Unit (EOS-PM)
APD	Aerosol Profile Data
APID	Application Identifier
ARESE	ARM Enhanced Shortwave Experiment
ARM	Atmospheric Radiation Measurement
ASOS	Automated Surface Observing Sites
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ASTEX	Atlantic Stratocumulus Transition Experiment
ASTR	Atmospheric Structures
ATBD	Algorithm Theoretical Basis Document
AVG	Monthly Regional, Average Radiative Fluxes and Clouds (CERES Archival Data Product)
AVHRR	Advanced Very High Resolution Radiometer
BDS	Bidirectional Scan (CERES Archival Data Product)
BRIE	Best Regional Integral Estimate
BSRN	Baseline Surface Radiation Network
BTD	Brightness Temperature Difference(s)
CCD	Charge Coupled Device
CCSDS	Consultative Committee for Space Data Systems
CEPEX	Central Equatorial Pacific Experiment
CERES	Clouds and the Earth’s Radiant Energy System
CID	Cloud Imager Data
CLAVR	Clouds from AVHRR
CLS	Constrained Least Squares
COPRS	Cloud Optical Property Retrieval System
CPR	Cloud Profiling Radar
CRH	Clear Reflectance, Temperature History (CERES Archival Data Product)
CRS	Single Satellite CERES Footprint, Radiative Fluxes and Clouds (CERES Archival Data Product)
DAAC	Distributed Active Archive Center
DAC	Digital-Analog Converter
DAO	Data Assimilation Office

DB	Database
DFD	Data Flow Diagram
DLF	Downward Longwave Flux
DMSP	Defense Meteorological Satellite Program
EADM	ERBE-Like Albedo Directional Model (CERES Input Data Product)
ECA	Earth Central Angle
ECLIPS	Experimental Cloud Lidar Pilot Study
ECMWF	European Centre for Medium-Range Weather Forecasts
EDDB	ERBE-Like Daily Data Base (CERES Archival Data Product)
EID9	ERBE-Like Internal Data Product 9 (CERES Internal Data Product)
EOS	Earth Observing System
EOSDIS	Earth Observing System Data Information System
EOS-AM	EOS Morning Crossing Mission
EOS-PM	EOS Afternoon Crossing Mission
ENSO	El Niño/Southern Oscillation
ENVISAT	Environmental Satellite
EPHANC	Ephemeris and Ancillary (CERES Input Data Product)
ERB	Earth Radiation Budget
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
ESA	European Space Agency
ES4	ERBE-Like S4 Data Product (CERES Archival Data Product)
ES4G	ERBE-Like S4G Data Product (CERES Archival Data Product)
ES8	ERBE-Like S8 Data Product (CERES Archival Data Product)
ES9	ERBE-Like S9 Data Product (CERES Archival Data Product)
FLOP	Floating Point Operation
FIRE	First ISCCP Regional Experiment
FIRE II IFO	First ISCCP Regional Experiment II Intensive Field Observations
FOV	Field of View
FSW	Hourly Gridded Single Satellite Fluxes and Clouds (CERES Archival Data Product)
FTM	Functional Test Model
GAC	Global Area Coverage (AVHRR data mode)
GAP	Gridded Atmospheric Product (CERES Input Data Product)
GCIP	GEWEX Continental-Phase International Project
GCM	General Circulation Model
GEBA	Global Energy Balance Archive
GEO	ISSCP Radiances (CERES Input Data Product)
GEWEX	Global Energy and Water Cycle Experiment
GLAS	Geoscience Laser Altimetry System

GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
HBTM	Hybrid Bispectral Threshold Method
HIRS	High-Resolution Infrared Radiation Sounder
HIS	High-Resolution Interferometer Sounder
ICM	Internal Calibration Module
ICRCCM	Intercomparison of Radiation Codes in Climate Models
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IES	Instrument Earth Scans (CERES Internal Data Product)
IFO	Intensive Field Observation
INSAT	Indian Satellite
IOP	Intensive Observing Period
IR	Infrared
IRIS	Infrared Interferometer Spectrometer
ISCCP	International Satellite Cloud Climatology Project
ISS	Integrated Sounding System
IWP	Ice Water Path
LAC	Local Area Coverage (AVHRR data mode)
LaRC	Langley Research Center
LBC	Laser Beam Ceilometer
LBTM	Layer Bispectral Threshold Method
Lidar	Light Detection and Ranging
LITE	Lidar In-Space Technology Experiment
Lowtran 7	Low-Resolution Transmittance (Radiative Transfer Code)
LW	Longwave
LWP	Liquid Water Path
MAM	Mirror Attenuator Mosaic
MC	Mostly Cloudy
MCR	Microwave Cloud Radiometer
METEOSAT	Meteorological Operational Satellite (European)
METSAT	Meteorological Satellite
MFLOP	Million FLOP
MIMR	Multifrequency Imaging Microwave Radiometer
MISR	Multiangle Imaging Spectroradiometer
MLE	Maximum Likelihood Estimate
MOA	Meteorology Ozone and Aerosol
MODIS	Moderate-Resolution Imaging Spectroradiometer
MSMR	Multispectral, multiresolution

MTSA	Monthly Time and Space Averaging
MWH	Microwave Humidity
MWP	Microwave Water Path
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NESDIS	National Environmental Satellite, Data, and Information Service
NIR	Near Infrared
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OLR	Outgoing Longwave Radiation
OPD	Ozone Profile Data (CERES Input Data Product)
OV	Overcast
PC	Partly Cloudy
POLDER	Polarization of Directionality of Earth’s Reflectances
PRT	Platinum Resistance Thermometer
PSF	Point Spread Function
PW	Precipitable Water
RAPS	Rotating Azimuth Plane Scan
RPM	Radiance Pairs Method
RTM	Radiometer Test Model
SAB	Sorting by Angular Bins
SAGE	Stratospheric Aerosol and Gas Experiment
SARB	Surface and Atmospheric Radiation Budget Working Group
SDCD	Solar Distance Correction and Declination
SFC	Hourly Gridded Single Satellite TOA and Surface Fluxes (CERES Archival Data Product)
SHEBA	Surface Heat Budget in the Arctic
SPECTRE	Spectral Radiance Experiment
SRB	Surface Radiation Budget
SRBAVG	Surface Radiation Budget Average (CERES Archival Data Product)
SSF	Single Satellite CERES Footprint TOA and Surface Fluxes, Clouds
SSMI	Special Sensor Microwave Imager
SST	Sea Surface Temperature
SURFMAP	Surface Properties and Maps (CERES Input Product)
SW	Shortwave
SWICS	Shortwave Internal Calibration Source
SYN	Synoptic Radiative Fluxes and Clouds (CERES Archival Data Product)

SZA	Solar Zenith Angle
THIR	Temperature/Humidity Infrared Radiometer (Nimbus)
TIROS	Television Infrared Observation Satellite
TISA	Time Interpolation and Spatial Averaging Working Group
TMI	TRMM Microwave Imager
TOA	Top of the Atmosphere
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
TSA	Time-Space Averaging
UAV	Unmanned Aerospace Vehicle
UT	Universal Time
UTC	Universal Time Code
VAS	VISSR Atmospheric Sounder (GOES)
VIRS	Visible Infrared Scanner
VISSR	Visible and Infrared Spin Scan Radiometer
WCRP	World Climate Research Program
WG	Working Group
Win	Window
WN	Window
WMO	World Meteorological Organization
ZAVG	Monthly Zonal and Global Average Radiative Fluxes and Clouds (CERES Archival Data Product)

Symbols

A	atmospheric absorptance
$B_\lambda(T)$	Planck function
C	cloud fractional area coverage
CF_2Cl_2	dichlorofluorocarbon
$CFCl_3$	trichlorofluorocarbon
CH_4	methane
CO_2	carbon dioxide
D	total number of days in the month
D_e	cloud particle equivalent diameter (for ice clouds)
E_o	solar constant or solar irradiance
F	flux
f	fraction
G_a	atmospheric greenhouse effect

g	cloud asymmetry parameter
H_2O	water vapor
I	radiance
i	scene type
m_i	imaginary refractive index
$\hat{N}$	angular momentum vector
N_2O	nitrous oxide
O_3	ozone
P	point spread function
p	pressure
Q_a	absorption efficiency
Q_e	extinction efficiency
Q_s	scattering efficiency
R	anisotropic reflectance factor
r_E	radius of the Earth
r_e	effective cloud droplet radius (for water clouds)
r_h	column-averaged relative humidity
S_o	summed solar incident SW flux
S_o'	integrated solar incident SW flux
T	temperature
T_B	blackbody temperature
t	time or transmittance
W_{liq}	liquid water path
w	precipitable water
$\hat{x}_o$	satellite position at t_o
x, y, z	satellite position vector components
$\dot{x}, \dot{y}, \dot{z}$	satellite velocity vector components
z	altitude
z_{top}	altitude at top of atmosphere
α	albedo or cone angle
β	cross-scan angle
γ	Earth central angle
γ_{at}	along-track angle
γ_{ct}	cross-track angle
δ	along-scan angle
ε	emittance
Θ	colatitude of satellite
θ	viewing zenith angle
θ_o	solar zenith angle

λ	wavelength
μ	viewing zenith angle cosine
μ_o	solar zenith angle cosine
ν	wave number
ρ	bidirectional reflectance
τ	optical depth
$\tau_{aer}(p)$	spectral optical depth profiles of aerosols
$\tau_{H_2O\lambda}(p)$	spectral optical depth profiles of water vapor
$\tau_{O_3}(p)$	spectral optical depth profiles of ozone
Φ	longitude of satellite
ϕ	azimuth angle
$\tilde{\omega}_o$	single-scattering albedo

Subscripts:

c	cloud
cb	cloud base
ce	cloud effective
cld	cloud
cs	clear sky
ct	cloud top
ice	ice water
lc	lower cloud
liq	liquid water
s	surface
uc	upper cloud
λ	spectral wavelength

Units

AU	astronomical unit
cm	centimeter
cm-sec^{-1}	centimeter per second
count	count
day	day, Julian date
deg	degree
deg-sec^{-1}	degree per second
DU	Dobson unit
erg-sec^{-1}	erg per second
fraction	fraction (range of 0–1)
g	gram
g-cm^{-2}	gram per square centimeter

g-g^{-1}	gram per gram
g-m^{-2}	gram per square meter
h	hour
hPa	hectopascal
K	Kelvin
kg	kilogram
kg-m^{-2}	kilogram per square meter
km	kilometer
km-sec^{-1}	kilometer per second
m	meter
mm	millimeter
μm	micrometer, micron
N/A	not applicable, none, unitless, dimensionless
ohm-cm^{-1}	ohm per centimeter
percent	percent (range of 0–100)
rad	radian
rad-sec^{-1}	radian per second
sec	second
sr^{-1}	per steradian
W	watt
W-m^{-2}	watt per square meter
W-m^{-2}sr^{-1}	watt per square meter per steradian
W-m^{-2}sr^{-1}μm^{-1}	watt per square meter per steradian per micrometer