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

# Data Management System

Software Requirements Document

Compute Surface and Atmospheric Radiative Fluxes
(Subsystem 5.0)

Release 1
Version 1

Lisa H. Coleman and Shalini Gupta

Lockheed Engineering & Sciences Company (LESC)
144 Research Drive
Hampton, VA 23666

Atmospheric Sciences Division
NASA Langley Research Center
Hampton, Virginia 23681-0001

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# Preface

The Clouds and the Earth's Radiant Energy System (CERES) Data Management System supports the data processing needs of the CERES Science Team research to increase understanding of the Earth's climate and radiant environment. The CERES Data Management Team works with the CERES Science Team to develop the software necessary to support the science algorithms. This software, being developed to operate at the Langley Distributed Active Archive Center, produces an extensive set of science data products.

The Data Management System consists of 12 subsystems; each subsystem represents a stand-alone executable program. Each subsystem executes when all of its required input data sets are available and produces one or more archival science products.

The documentation for each subsystem describes the software design at various significant milestones and includes items such as Software Requirements Documents, Data Products Catalogs, Software Design Documents, Software Test Plans, and User's Guides.

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## 1.0 Introduction

The Clouds and the Earth's Radiant Energy System (CERES) program is a key component of the Earth Observing System (EOS). The CERES instrument will provide radiometric measurements of the Earth's atmosphere from three broadband channels: a shortwave channel (0.2 - 5.0µm), a total channel (0.2 - 50µm), and an infrared window channel (8-12µm). The CERES instrument is an improved model of the Earth Radiation Budget Experiment (ERBE) scanner, which was first flown aboard the Earth Radiation Budget Satellite (ERBS) from November 1984 until February 1990 in a 57-deg inclination orbit. During much of the same time period, additional ERBE scanner instruments flew on the National Oceanic and Atmospheric Administration (NOAA) Sun-synchronous, polar orbiting satellites NOAA-9 and NOAA-10. To reduce temporal sampling errors, ERBE successfully developed the strategy of flying instruments on Sun-synchronous, polar orbiting satellites with instruments on satellites with lower inclination orbits. Following the same strategy, the first CERES instrument is expected to be launched in 1997 aboard the Tropical Rainfall Measuring Mission (TRMM), a satellite with an orbital inclination of 35 degrees. Additional CERES instruments will be flown aboard the polar orbiting EOS-AM and EOS-PM platforms. The first EOS-AM platform is expected to be launched in 1998, while the first EOS-PM platform is expected to be launched in 2000. As an improvement to the ERBE strategy, CERES will include cloud imager data and other atmospheric parameters in order to increase the certainty of the data and improve the consistency between the cloud parameters and the radiation fields.

While the number of possible measurements per scan line is dependent upon platform, the scan line of a CERES instrument scanner will consist of up to 225 Earth-viewing measurements. The area viewed on the Earth for an individual measurement is referred to as a CERES footprint. The CERES Footprint Surface and Atmospheric Radiation Budget (SARB) Subsystem will consist of software developed to compute the vertical atmospheric profiles of shortwave and longwave radiative fluxes for the Earth-viewing CERES footprints in one hour segments from each satellite. For each footprint, this vertical profile will extend from the Earth's surface to the top-of-the-atmosphere (TOA) and will comprise the surface and atmospheric radiation budget. Given the TOA fluxes as derived by the CERES inversion process and stored on the Single Satellite Fluxes (SSF) product, this Subsystem will implement radiative transfer algorithms to produce an initial, or untuned, set of fluxes. Noting that the radiative transfer algorithms are imperfect, a set of TOA balanced fluxes will be computed by adjusting different input parameters, such as cloud properties and precipitable water. While an exact match is not likely, the initial fluxes will be tuned until the results more closely agree with the CERES TOA. The tuned fluxes, along with the adjustments made to the initial fluxes and various parameters in the tuning process, will be stored on the Cloud Radiative Swath (CRS) file.

Once subsystem processing for the Footprint SARB Subsystem has been initialized, data from the SSF product will be ingested one footprint at a time, and then the vertical profiles will be calculated and written to the CRS file. To calculate this vertical profile, ancillary data from the Meteorological, Ozone, and Aerosol (MOA), the Surface Radiative Properties Climatology (SRC), and the surface map properties (SURFMAP) input files will also be used. The tuning process will require additional input from the empirically precomputed Derivative Tables

(DRIVTAB) product. Once data for all of the SSF footprints have been processed, the Footprint SARB Subsystem will generate the Quality Control Report for Subsystem 5.0 (QC5) and the EOS Data and Information System (EOSDIS) required file of Metadata for Subsystem 5.0 (META5), and perform the necessary finalization procedures. (The Footprint SARB Subsystem is numbered as 5.0 in the CERES subsystem numbering scheme. Process numbers and some file names used by this subsystem will reflect this numbering scheme.) The SSF and other input products required for subsystem processing, along with the output products generated, are discussed in Section 2.0.

The CERES software will be developed in three incremental releases. The first two releases will be completed prior to the launch of the TRMM satellite, while the third release is planned for about 18 months after the TRMM launch. With each release, the associated documentation will be updated. This document is intended to specify the requirements of the Footprint SARB Subsystem software that the CERES Data Management Team (DMT) will be responsible for developing for Release 1. Based on these requirements, both the Release 1 software design and test procedures for this Subsystem will be written.

The software that executes the radiative transfer algorithms and tunes the results is currently being developed and tested by the CERES SARB Working Group. This software may be in more than one package. The requirement for the CERES DMT will be to organize these different packages into one optimized and consistent package. The DMT will also be responsible for developing the portion of software that interfaces with the EOSDIS Toolkit, a library of routines containing commonly used EOS functions. These requirements are discussed in Section 3.0.

A major consideration for the design of this Subsystem is that these algorithms will also be used in the Synoptic SARB portion of the Merge Satellites, Time Interpolate, Compute Fluxes Subsystem. The requirements for the Synoptic SARB software will differ in that the radiative transfer algorithms will be applied on a regional basis instead of the footprint basis required by the Footprint SARB Subsystem.

The overall approach taken to gather the requirements stated in this document include the use of the Algorithm Theoretical Basis Document for this Subsystem (Reference 1), information gleaned from attending meetings of the SARB Working Group, and from collaboration with members of this group and other members of the CERES DMT.

## 2.0 External Interface Requirements

A context diagram indicating the input and output requirements of the Footprint SARB Subsystem is shown in Figure 2-1. Input data required by this Subsystem include the temporally varying SSF, MOA, and SURFMAP products, along with data defined prior to processing, such as the Processing and Control Parameters for Subsystem 5 (PCP5), DRIVTAB, and SRC products. Data from the Clear-sky Reflectance and Temperature History (CRH) product will also be needed, but, since these data are planned to be included on the SSF, a direct link from the Footprint SARB Subsystem to this product will not be necessary. The primary output from this Subsystem is the CRS product. Also required to be output, is the QC5 report that displays run-time statistics and the EOSDIS-required file META5.

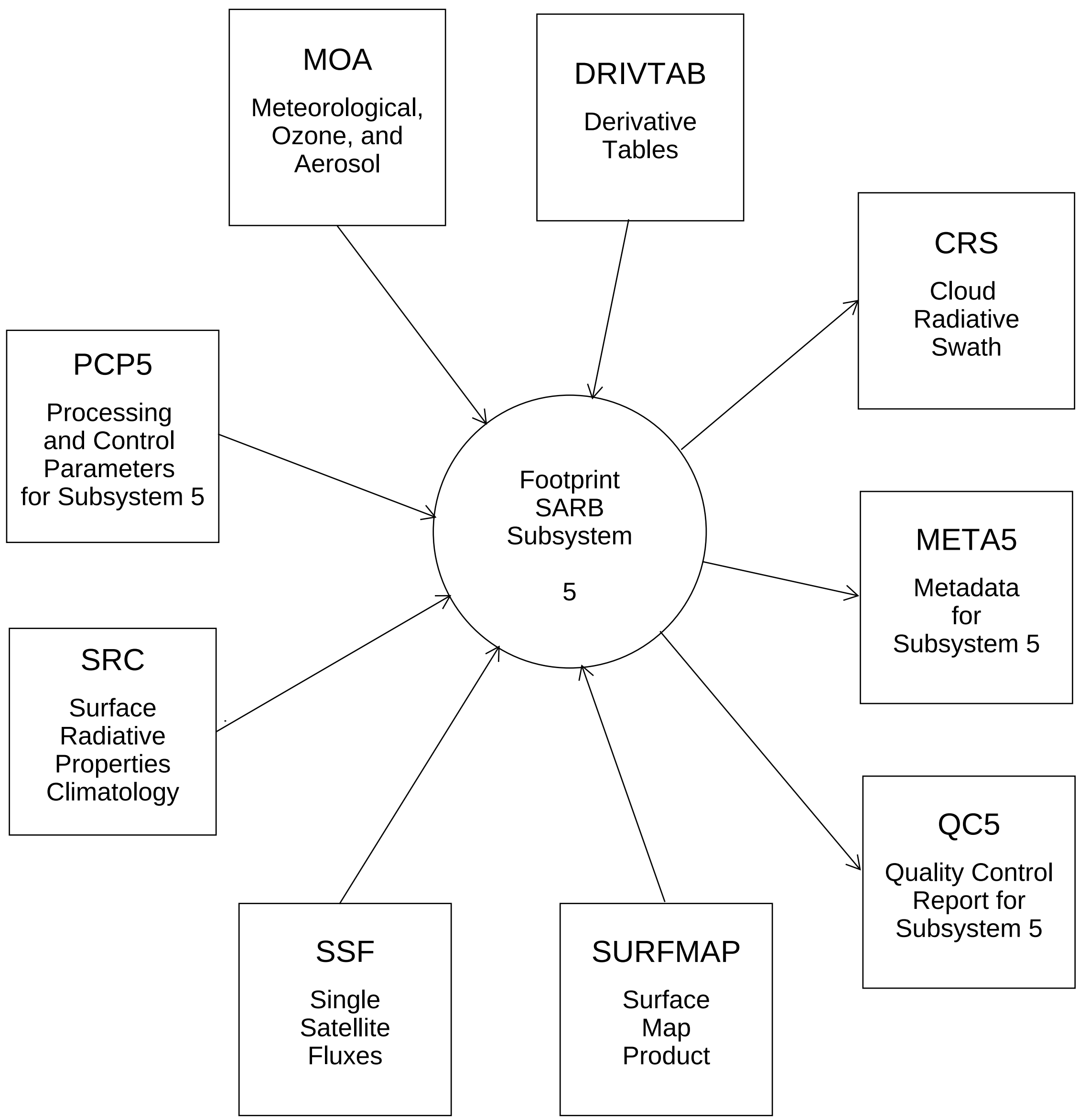


Figure 2-1. Context Diagram

## 2.1 Input Products

### 2.1.1 Derivative Tables (DRIVTAB)

The DRIVTAB product will contain precomputed tables consisting of the finite difference approximations of the derivatives required by the SARB tuning process. The derivatives are the change in TOA fluxes with respect to a small change in a selected tuning parameter, while other input parameters remain fixed. DRIVTAB will contain derivatives of TOA fluxes with respect to several different tuning parameters.

For the shortwave portion of the atmospheric flux profiles, there will be derivatives based on changes to the surface albedo (dTOA/dALB), aerosol optical depth (dTOA/dAER) and cloud optical depth (dTOA/dTAU). These values will be computed and supplied by the SARB Working Group.

Calculations of the shortwave derivatives are based on the following:

dTOA/dALB : 50 precipitable water values, 20 solar zenith angles, and 21 surface albedo values divided into 20 integrals (total of 20,000 derivatives).

dTOA/dAER : 31 precipitable water values, 20 solar zenith angles, 13 surface albedo values, and 15 aerosol optical depth values divided into 14 integrals (total of 112,840 derivatives).

dTOA/dTAU : 14 precipitable water values, 10 solar zenith angles, 10 surface albedo values, 14 cloud heights, and 31 cloud optical depth values divided into 30 integrals (total of 588,000 derivatives).

Definition of the derivatives required for tuning the longwave portion of the atmospheric flux profiles is not yet complete. However, the parameters that will contribute to the longwave derivatives include precipitable water, cloud height, cloud optical depth, and the surface temperature.

### 2.1.2 Meteorological, Ozone, and Aerosol (MOA)

The MOA, a CERES archival product, is produced by the CERES Regrid Humidity and Temperature Subsystem. Each MOA file contains meteorological, ozone, and aerosol data for one hour, and is used by several of the CERES subsystems. Data on the MOA are derived from several data sources external to the CERES system, such as the National Meteorological Center (NMC), the Moderate Resolution Imaging Spectrometer (MODIS), the Stratospheric Aerosols and Gases Experiment (SAGE), and various other sources. These data arrive at intervals ranging from four times daily to once a month, and are horizontally and vertically organized differently from what the CERES system requires. The Regrid Humidity and Temperature Subsystem interpolates these data temporally, horizontally, and vertically to conform with CERES processing requirements. A detailed list of the parameters included on the MOA product is given in Reference 2.

Prior to an EOS-wide review of each project's Algorithm Theoretical Basis Document in May 1994, the MOA was referred to as the Atmospheric Structures (ASTR) file. At the request of the review panel, the name of this file was changed so as to avoid confusion with another EOS project, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

The MOA contains:

- Surface temperature and pressure.
- Vertical profiles of temperature, humidity, and geopotential height as a function of pressure for the internal atmospheric levels requested by the Clouds and SARB Working Groups.
- Column precipitable water.
- Vertical ozone profiles for internal atmospheric levels requested by the SARB Working Group.
- Column ozone.
- Total column aerosol.
- Stratospheric aerosol.

The internal atmospheric levels, in hPa, as requested by the CERES Clouds and SARB Working Groups as of December 1993 are listed in Table 2-1. It should be noted that prior to Release 2, the number of levels most likely will change from 38. Also, the levels themselves may change.

Table 2-1. MOA Internal Atmospheric Levels (in hPa)

| **Floating Levels** | **1000 to 875** | **850 to 725** | **700 to 450** | **400 to 225** | **200 to 70** | **50 to 1** |
|---|---|---|---|---|---|---|
| Surface | 1000 | 850 | 700 | 400 | 200 | 50 |
| Surface - 10 | 975 | 825 | 650 | 350 | 175 | 30 |
| Surface - 20 | 950 | 800 | 600 | 300 | 150 | 10 |
| | 925 | 775 | 550 | 275 | 125 | 5 |
| | 900 | 750 | 500 | 250 | 100 | 1 |
| | 875 | 725 | 450 | 225 | 70 | |

### 2.1.3 Processing and Control Parameters for Subsystem 5 (PCP5)

Processing and Control Parameters used by the Footprint SARB Subsystem, contained in the PCP5 product, are parameters that are defined prior to subsystem processing and ingested by the Subsystem at the time of processing. Potential processing and control parameters known at this time for this Subsystem are listed in Table 2-2. This list will be expanded as more work on the design and actual coding takes place. The SARB Working Group, along with other members of the CERES Science Team, will supply the values of these parameters.

Table 2-2. Known Processing and Control Parameters

| Parameter Description |
|---|
| Maximum number of tuning iterations |
| Maximum longwave flux difference to be considered a match (percentage) |
| Maximum shortwave flux difference to be considered a match (percentage) |
| QC tuning sigmas for adjustment parameters, such as the expected error for input sounding of precipitable water, and the expected error for input sounding of surface skin temperature over sea and land (note that some of these values may be dependent on scene type) |
| Number of archival atmospheric levels |
| Pressure of archival atmospheric levels |
| Maximum difference (in hPa) between a cloud top (or bottom) level and a fixed atmospheric level that warrants the use of the cloud top (or bottom) level in the vertical profile instead of the fixed atmospheric level |

### 2.1.4 Surface Radiative Properties Climatology (SRC)

The definition of the contents of the SRC file, and consequently its structure, is still under development by the SARB Working Group. For the different surface types identified in the SURFMAP data file (see Section 2.1.6), the SRC will contain radiative properties such as albedo, infrared emissivity, and bidirectional reflectance.

### 2.1.5 Single Satellite Flux (SSF)

The SSF, a CERES archival product, is produced from the CERES cloud identification, inversion, and surface flux processes. Each SSF covers a single hour swath from a single CERES instrument mounted on one satellite. The product has a product header and multiple records of approximately 125 parameters, or 315 elements, for each footprint.

The major categories of data output on the SSF are

- CERES footprint geometry and CERES viewing angles.
- CERES footprint radiance and flux (TOA and Surface).
- CERES footprint cloud statistics and imager viewing angles.
- CERES footprint clear area statistics.
- CERES footprint cloudy area statistics for each of four cloud height categories (low, lower middle, upper middle, and high):
  - Visible optical depth (mean and standard deviation).
  - Infrared emissivity (mean and standard deviation).
  - Liquid water path (mean and standard deviation).
  - Ice water path (mean and standard deviation).
  - Cloud top pressure (mean and standard deviation).
  - Cloud effective pressure (mean and standard deviation).
  - Cloud effective temperature (mean and standard deviation).
  - Cloud effective height (mean and standard deviation).
  - Cloud bottom pressure (mean and standard deviation).
  - Water particle radius (mean and standard deviation).
  - Ice particle radius (mean and standard deviation).
  - Particle phase (mean and standard deviation).
  - Vertical aspect ratio (mean and standard deviation).
  - Visible optical depth/IR emissivity (13 percentiles).
- CERES footprint cloud overlap conditions (11 conditions).

The SSF will be run daily in validation mode starting with the TRMM launch until sufficient data have been collected and analyzed to produce a production quality set of CERES Angular Distribution Models (CADM). It is estimated that at TRMM launch plus 18 months, the SSF product will be produced on a routine basis and will be archived within EOSDIS for distribution. The inversion process will be rerun starting with data from the time of the TRMM launch and a new set of SSF products produced, in which case, only the TOA fluxes and surface parameters will be replaced in the inversion rerun process. If the cloud algorithms are rerun, the SSF product itself will be input into the cloud identification process in order to retrieve the CERES radiance and location input data needed. For the latest information on the SSF, see Reference 2.

#### 2.1.6 Surface Map Properties (SURFMAP)

The SURFMAP will consist of multiple files denoting various characteristics of the Earth's surface. These characteristics will be arranged on an equal-area grid of the finest resolution possible. The characteristics to be included on the SURFMAP include:

- Broadband shortwave surface ADM type.
- Digital elevation map.

- Ice map.
- Snow map.
- Spectral emissivity from 3.7µm channel imager data.
- Spectral emissivity from 11.0µm channel imager data.
- Surface type indicator.
- Vegetation map.
- Visible albedo for collimated, overhead Sun illumination.
- Water map.

For more discussion on the SURFMAP, see Reference 2.

## 2.2 Output Products

### 2.2.1 Cloud Radiative Swath (CRS)

The CRS, a CERES archival product, is produced by the Footprint SARB Subsystem. Each CRS record contains data from the SSF, longwave and shortwave radiative fluxes for the surface, internal atmospheric levels and TOA for a CERES footprint. The CRS contains data for a one-hour, single satellite swath (8-12 percent of the Earth). A detailed list of the parameters contained on the CRS is given in Reference 2.

For each CERES footprint, the CRS contains:

- Time and location data.
- TOA fluxes derived by CERES inversion process.
- Cloud identification imager instrument data for the full CERES footprint.
- Full footprint algorithm flags.
- Footprint clear-sky properties.
- Cloud category properties for up to four (low, lower middle, upper middle and high) cloud height categories.
- Overlap data for eleven (clear, low (L), lower middle (LM), upper middle (UM), high (H), H/UM, H/LM, H/L, UM/LM, UM/L, LM/L) cloud overlap conditions.
- Atmospheric flux profiles for both the clear-sky and total-sky conditions at the surface, 500hPa, the tropopause and TOA.
- Flux adjustments (deltas of tuned-untuned) for both the clear-sky and total-sky conditions at the surface and TOA.
- Surface-only data.
- Adjustment parameters for clear-sky (note that these are not only for the footprints flagged as clear-sky, but also for the footprints flagged as total-sky).
- Adjustment parameters for L, LM, UM, and H cloud height categories.

### 2.2.2 Metadata for Subsystem 5 (META5)

The contents of this product, a requirement of EOSDIS, are to be determined (TBD).

### 2.2.3 Quality Control Report for Subsystem 5 (QC5)

The QC5 product will contain statistics accumulated during processing of the Footprint SARB Subsystem. The purpose of this product is to provide both Science Team and DMT members with a diagnostic report from which Subsystem processing results can be reviewed. These reports will be stored electronically and may be reviewed individually or with others as a tool to assist in the study of possible trends. While the exact contents of QC5 are still to be determined (TBD), they may include such things as processing time, the number of footprints processed, the number of occurrences of events such as out-of-range values and unsuccessful tuning attempts, shortwave and longwave flux averages according to colatitudinal bins, and scene-type sampling. As the design and coding take place, the SARB Working Group will indicate what values they would like to see displayed in this report.

## 3.0 Requirements Specification

This section provides the specification of requirements which must be satisfied by the DMT for the Footprint SARB Subsystem. Included are operating modes, functional requirements, design goals and constraints, and resource use.

## 3.1 Operating Modes

The Footprint SARB Subsystem will not operate in a regular production mode until an estimated 18 months after the launch of the first platform carrying a CERES instrument. During this delay period, the Footprint SARB Subsystem will operate in a research mode that will allow for the analysis of the SARB Working Group's algorithms as applied to actual CERES data. Also during this time frame, the CERES Inversion Working Group will be developing the CADM values necessary for calculation of the improved CERES TOA fluxes, which are required as input by the Footprint SARB Subsystem. After this delay period, the Footprint SARB software will produce an archival product containing vertical profiles consisting of upwards and downwards radiative fluxes at the surface, 500hPa, the tropopause, and the TOA.

For approximately another 18 months after the onset of the Footprint SARB's production operating mode, there will simultaneously be a second research operating mode. At the end of this second research period, the Footprint SARB software will produce an archival product containing an expanded vertical profile consisting of radiative fluxes at 18 atmospheric levels. Reference 3 contains a discussion regarding this decision.

## 3.2 Functional Requirements

This section identifies the specific functional requirements of the Footprint SARB Subsystem. These requirements are divided among various processes, the specifications for which are discussed in the sections that follow. A top-level context diagram was previously depicted in Figure 2-1. The first level of decomposition for this Subsystem is depicted in Figure 3-1. The processes depicted in this figure include Process Initialization, Footprint Processing, and Process Finalization. Processes that can be further decomposed into subprocesses, such as Process 5.2, are indicated by the inclusion of an "*" in the diagram beside the process number. If there are no subprocesses, such as for Process 5.1, the diagram will include a "p" beside the process number. These process specifications will be used to define the testing requirements for the system at the time of the preparation of the system test procedures.

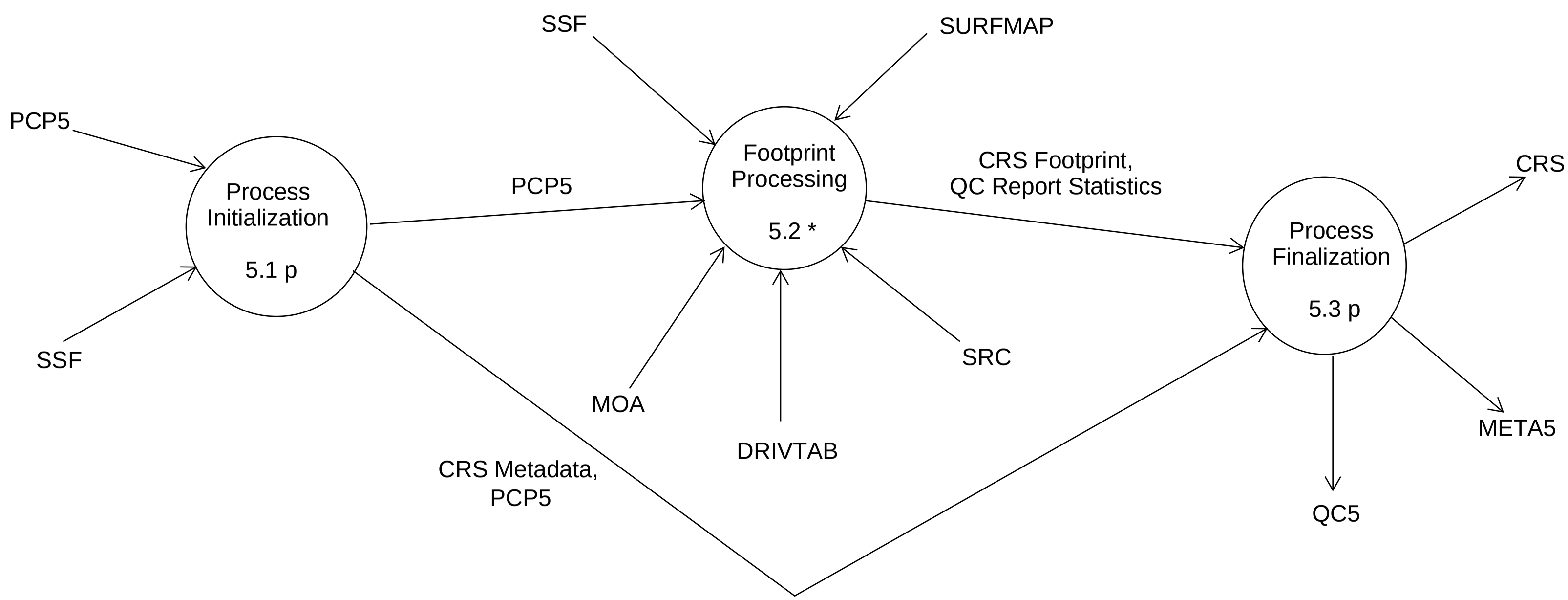


Figure 3-1. Data Flow Diagram for Level 0

### 3.2.1 Process Initialization - Process 5.1

**Input Data Flows**

PCP5
SSF

**Output Data Flows**

PCP5
CRS Metadata

**Process Specification**

Subsystem processing begins by determining for which hour and satellite data is to be processed. The hour and satellite of the data may be available somehow by the EOSDIS Toolkit's scheduling software. Exactly how this data will be available is TBD. Once the hour and satellite have been determined, the input products, SSF and MOA may be opened. Any remaining input data files, such as processing and control parameters, containing data that will be used throughout subsystem processing need to be opened and ingested. Any remaining input files, such as DRIVTAB, SURFMAP, and SRC, also need to be opened. The use of the EOSDIS Toolkit routine to open files is mandatory.

Any parameters that require initialization, such as various counters and cumulative sums, need to be initialized here. Some of these parameters are known now, but most will not be known until more work on the design and actual coding takes place. Parameters known to require initialization at this time are listed in Table 3-1.

Table 3-1. Known Parameters Requiring Initialization

| Parameter | Initial Value |
|---|---|
| Footprint Counter | 0 |
| Bad Footprint Counter | 0 |
| Total-sky Footprint Counter | 0 |
| Clear-sky Footprint Counter | 0 |
| Total-sky No-match Counter | 0 |
| Clear-sky No-match Counter | 0 |
| Tuning Iteration Counter | 0 |
| Adjustment Reject Counter | 0 |

Any metadata required by EOSDIS that can be defined at this point should be defined. It should be noted that what is to be considered metadata is TBD.

To initialize the Footprint SARB Subsystem, the following steps are required:

- Determine hour and satellite of data to be processed.
- Open SSF and MOA products for current hour and satellite using required EOSDIS Toolkit routine.
- Define any CRS metadata that can be defined during the initialization process.
- Open PCP5 using required EOSDIS Toolkit routine.
- Ingest processing and control parameters.
- Open remaining required input files (DRIVTAB and SRC) using required EOSDIS Toolkit routine.
- Initialize required parameters.

### 3.2.2 Footprint Processing - Process 5.2

**Input Data Flows**

DRIVTAB
MOA
PCP5
SRC
SSF
SURFMAP

**Output Data Flows**

CRS Footprint
QC Report Statistics

**Process Specification**

To process data for a footprint, the data must first be read by the subsystem software. Then, the longwave and shortwave atmospheric flux profiles, untuned and tuned, and the associated adjustment parameters are calculated and written to the CRS. Footprint processing is completed when statistics required for the QC5 product are calculated.

The subprocesses that comprise Process 5.2 are depicted in Figure 3-2. These processes will be repeated until all information on the SSF input file has been processed. More detailed discussions regarding the specifications for these subprocesses are given in Sections 3.2.2.1, 3.2.2.2, and 3.2.2.3.

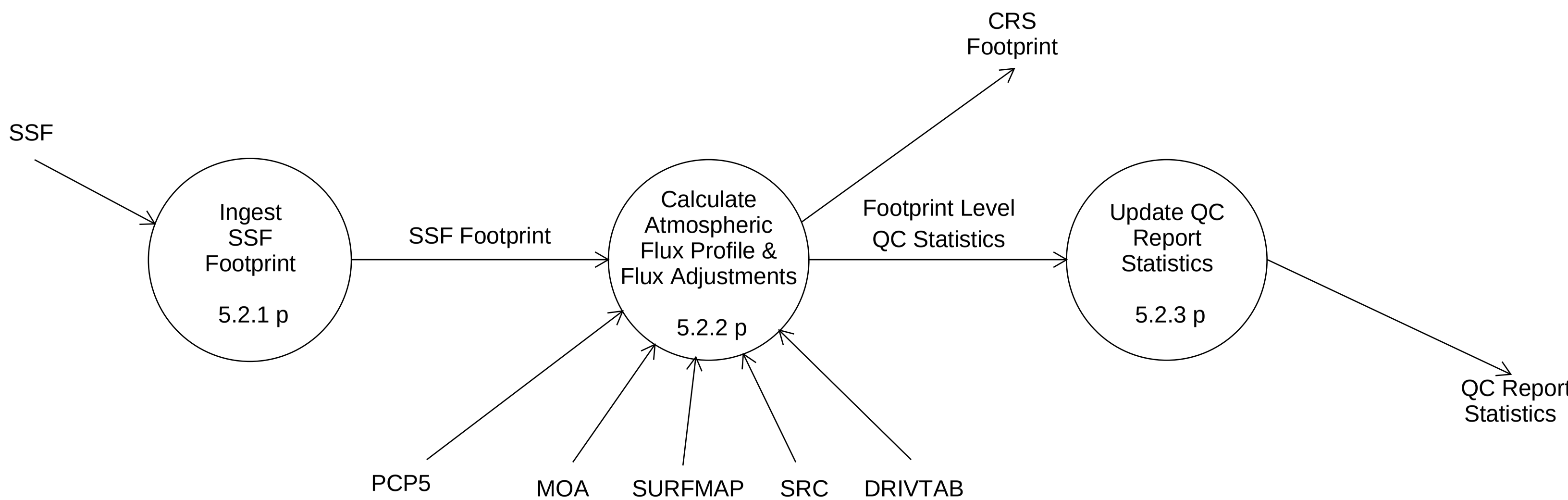


Figure 3-2. Data Flow Diagram for Footprint Processing

#### 3.2.2.1 Ingest SSF Footprint - Process 5.2.1

**Input Data Flows**

SSF

**Output Data Flows**

SSF Footprint

**Process Specification**

Input data for a footprint are stored as one record on the SSF product. The Footprint SARB Subsystem will process each record individually. As the footprint data is ingested, a few QC report statistics, such as footprint counters, can be updated. Also upon ingestion, the SSF footprint data can be loaded into the CRS footprint data.

Ingestion of SSF footprint data requires the following steps. Note that some of these steps, such as reading an input record and invoking a message utility, may be implemented by calling an EOSDIS Toolkit routine or a routine supplied by the CERES DMT (for more information about the EOSDIS Toolkit, see Reference 4).

- Read input record
- If read errors are encountered
  Invoke message utility.
  Terminate subsystem processing.
  End If
- If not at the end of SSF data
  Increment footprint counter (QC report statistic).
  Else
  Initiate Process Finalization.
  End If

  NOTE: In the preceding decision, the "not at the end of SSF data" condition will be encountered most frequently (see Section 3.3.1).
- Store SSF footprint data as CRS footprint data (Time and Location Data, CERES Observed TOA Data, Full Footprint Data, Full Footprint Algorithm Flags, Footprint Clear-sky Properties, Cloud Properties for Four Cloud Layers, Overlap Footprint Data for 11 Cloud Overlap Conditions, and Surface-only Data)
- If the total-sky/clear-sky flag on the SSF indicates that this footprint’s data is total-sky
  Increment total-sky footprint counter (QC report statistic).
  Else
  Increment clear-sky footprint counter (QC report statistic).
  End If

NOTE: In the preceding decision, the total-sky condition is the most frequently encountered condition (see Section 3.3.1).

### 3.2.2.2 Calculate Atmospheric Flux Profile & Flux Adjustments - Process 5.2.2

**Input Data Flows**

- DRIVTAB
- PCP5
- MOA
- SRC
- SSF Footprint
- SURFMAP

**Output Data Flows**

- CRS Footprint
- Footprint Level QC Statistics

**Process Specification**

To calculate the longwave and shortwave atmospheric flux profiles, the TOA fluxes derived by the CERES inversion process, cloud properties for up to four cloud layers, and satellite viewing geometry, all included with the SSF footprint data, are necessary. Also, ancillary meteorological, ozone, and aerosol data from the MOA will be necessary, as will the data contained on the SRC. The derivatives contained in the DRIVTAB product will be necessary for the tuning process. The tuning process will also require quality control parameters included on the PCP5 input file. Additional ancillary input data of interest to the Footprint SARB Subsystem are radiative surface properties, such as surface albedo and 11.0µm emissivity, obtained from SURFMAP.

The SSF will provide information for up to four cloud height categories. These categories are low, lower middle, upper middle, and high. Profile fluxes will be calculated for up to 26 fixed internal atmospheric levels and up to eight variable cloud levels from the surface to the TOA. The eight cloud levels are based on the four cloud height categories provided on the SSF, with top and bottom levels for each of the layers. Should a cloud top or bottom level coincide (within a given TBD limit, included in the PCP5 product) with one of the 26 fixed atmospheric levels, that cloud level will be used instead of the fixed atmospheric level. Otherwise, the cloud level will result in additional fluxes in the atmospheric flux profiles. The ancillary data for the variable cloud levels will be calculated by linearly interpolating the data between the two closest fixed levels. The 26 fixed atmospheric levels, in hPa, are listed in Table 3-2. Note that these levels are a subset of those listed in Table 2-1.

Table 3-2. SARB Fixed Atmospheric Layers (in hPa)

| Floating Levels | 950 to 700 | 650 to 400 | 350 to 100 | 50 to 1 |
|---|---|---|---|---|
| Surface | 950 | 650 | 350 | 50 |
| Surface-10 | 900 | 600 | 300 | 30 |
| Surface-20 | 850 | 550 | 250 | 10 |
| | 800 | 500 | 200 | 5 |
| | 750 | 450 | 150 | 1 |
| | 700 | 400 | 100 | |

As discussed in Section 3.1, at about 18 months after launch the fluxes for four of these levels will be calculated and archived on the CRS. At about 36 months after launch the vertical profile to be archived will be expanded to include 18 of the 26 atmospheric levels. Due to anticipated storage constraints, fluxes for all 26 levels will not be archived. Of the levels comprising the profile, the 18 for which data will be archived is TBD. For each footprint, however, the pressures at the levels for which fluxes are archived will be written to the CRS.

The shortwave and longwave atmospheric flux profiles will be calculated and stored for both total-sky and clear-sky conditions. The calculation of the total-sky profiles considers the clear-sky condition as well as the conditions containing cloud cover. If the SSF flags the footprint as clear-sky, then only the clear-sky profiles will be calculated and an agreed upon fill, or default, value will be written to the CRS for the total-sky profile values. Also, the radiance quality flags for the various CERES channels provided on the SSF are evaluated. If one of these flags indicates bad data, the corresponding values of the atmospheric flux profile are set to a predefined default value.

The atmospheric flux profiles for a footprint will be calculated more than once. After the first calculation, the TOA portion of the newly calculated profile is compared against the TOA flux value derived by the CERES inversion process. If the two are not in agreement (within a given TBD limit, specified in the PCP5 product), the profile is then tuned so that the TOA values will agree. To tune the profile, several parameters can be adjusted (see Reference 1). Should cloud height be one of the adjusted parameters, the cloud levels will be redefined and the ancillary data reinterpolated as necessary.

The SARB Working Group will supply the software to calculate and tune the total-sky and clear-sky atmospheric flux profiles. Currently the plan for Release 1, as discussed in Reference 1, is to use a modified version of software generously provided by Drs. Qiang Fu and Kuo-Nan Liou to calculate the longwave and shortwave atmospheric flux profiles. Since it will not be a requirement of the CERES DMT to develop the software that is to be supplied by the SARB

Working Group, requirements for the Fu-Liou and tuning software will not be addressed in this document. The DMT will, however, be required to develop the portion of the software that integrates the Fu-Liou software with the rest of the code.

The Fu-Liou radiative transfer process is invoked for the clear-sky condition and each existing cloud condition. Then, to tune the profiles, the SARB Working Group plans to adjust various parameters and apply a Lagrangian multiplier technique. Not all parameters will be adjusted every time. Candidate parameters for adjusting are listed in Table 3-3. This list of parameters is most likely incomplete at this time. As more development and testing occurs, additional parameters, such as surface emissivity for clear-sky conditions, may be added to the list.

Table 3-3. Candidate Parameters for Adjustment

| Clear-sky Parameters | Cloudy-sky Parameters |
|---|---|
| Precipitable Water | Cloud Area |
| Surface Skin Temperature | Cloud Visible Optical Depth |
| Surface Albedo | Cloud Infrared Emissivity |
| Aerosol Optical Depth | Cloud Effective Temperature |
| | Cloud Top Height |
| | Cloud Liquid Water Content |

Before a tuning iteration can take place, the magnitude of the adjustment must be evaluated to determine whether or not it is within reason. If the magnitude of the adjustment exceeds a predefined limit, no tuning will take place. These predefined limits are the QC sigmas stored on the PCP5 input file (see Table 2-2). An adjustment may never exceed 3 sigma (nominally). For example, 1 sigma for a temperature parameter may be equal to 5 degrees K; and, therefore, the adjustment may never exceed 15 degrees K. For other parameters, one sigma may be a percentage of the original value.

Once the untuned and tuned profiles have been calculated for the current footprint, these data need to be written to the CRS output file. The value of the tuned fluxes will be stored on the CRS, while it will be the deltas (flux adjustments) between the tuned and untuned fluxes at the surface and TOA that are stored. The deltas between the initial and the adjusted values of the adjustable parameters will also be written to the CRS. Since the CRS is a CERES archival product, it is stored in Hierarchical Data Format (HDF). The EOSDIS Toolkit may provide the routines necessary to do this.

Prior to invoking the Fu-Liou software, the following steps are required:

- Retrieve meteorological, ozone, and aerosol data from the MOA product and surface characteristics from the SURFMAP product according to time, latitude, and longitude. Use EOSDIS Toolkit-provided routine if one is available.

- If the total-sky/clear-sky flag on the SSF indicates that this footprint's data is clear-sky

  Set total-sky flux profile values to a default value.

  End If
- If the radiance quality flags provided with the SSF footprint data indicate that the data is not good for a particular channel

  Increment bad footprint counter for that channel (QC report statistic).

  Set corresponding CRS values to a default value.

  End If

The following steps are required for the clear-sky condition and each existing cloud condition to calculate the longwave and shortwave atmospheric flux profiles and corresponding flux adjustments and adjustment parameters.

- For each condition (clear-sky and each existing cloud condition), define parameters required by Fu-Liou radiative transfer:

  Fixed and variable levels.

  Number of levels (total of fixed and variable for this footprint).

  Temperature, humidity and ozone profiles for fixed and variable vertical levels.

  Those parameters listed as adjustable parameters in Table 3-3.
- Calculate the untuned longwave and shortwave vertical profiles using the Fu-Liou software for radiative transfer.

The following requirements are steps in an iterative process that repeats until either values agree or the maximum number of allowable iterations is met. The technique for selecting which parameter to adjust will be provided by the SARB Working Group.

- If the newly calculated TOA values and the TOA values derived by the CERES inversion process are not in agreement

```
    If maximum number of tuning iterations has not been met
        Increment tuning iteration counter.
        Select and adjust appropriate parameters using Lagrange multiplier adjustments
            adhering to the logic supplied by SARB Working Group.
        If QC tuning sigmas for the adjustment parameters have not been exceeded
            Calculate Flux Adjustment and Adjustment Parameter deltas.
            Reinterpolate temperature, humidity, and ozone profiles for variable vertical
                levels.
            For the clear-sky condition and each existing cloud condition, calculate the
                tuned longwave and shortwave vertical profile using the Fu-Liou
                radiative transfer
        Else
            Set tuned flux profile values to a default value.
            Increment adjustment reject counter.
        End If
    Else
        Increment no-match counter (QC report statistic).
```

End If
End If

NOTE: The IF-THEN-ELSE structure shown in the preceding requirement should be followed for optimal efficiency (see Section 3.3.1).

Once either agreement between the observed TOA fluxes and the newly calculated fluxes has been met or the maximum number of tuning iterations has been met, the following steps are required:

- Store footprint Atmospheric Flux Profile, Flux Adjustments, and Adjustment Parameters for both clear skies and the cloud layers on the CRS product in HDF format.  Use EOSDIS Toolkit routine if one is available.
- Reset tuning iteration counter to zero.

#### 3.2.2.3  Update QC Report Statistics - Process 5.2.3

**Input Data Flows**

Footprint Level QC Statistics

**Output Data Flows**

QC Report Statistics

**Process Specification**

This process will update the QC Report Statistics for all footprints processed by the current run of the Footprint SARB Subsystem with the data acquired while processing the current footprint. However, since the required statistics related to footprint processing are TBD, the necessary requirements to update them are also TBD.

### 3.2.3  Process Finalization - Process 5.3

**Input Data Flows**

CRS Footprint
CRS Metadata
PCP5
QC Report Statistics

**Output Data Flows**

CRS
META5
QC5

**Process Specification**

After all of the scientific algorithms have been implemented for each CERES footprint, the QC report, QC5, listing statistics accumulated during the course of subsystem processing is generated. The contents of QC5 are TBD, and, therefore, the requirements to generate the QC5 report are TBD.

To finalize processing, the following actions are required:

- Finalize CRS metadata.
- Calculate final QC statistics.
- Generate QC5 report.
- Close any files that may still be open.

## 3.3 Design Goals and Constraints

There are two main issues that will require careful consideration in the preparation of the Footprint SARB's software design:

1. Computational intensiveness of the SARB algorithms.

2. Reuse of existing software.

These issues are discussed in Sections 3.3.1 and 3.3.2.

### 3.3.1 Computational Intensiveness of the SARB Algorithms

Current testing of existing SARB software by the working group indicates that the software will be computationally intensive. Since the algorithms require a great deal of iterative processing, care should be taken that every line of code be as optimal as possible. Design and coding practices that may facilitate optimization include at least the following:

1. Decision logic.

   When testing between two or more conditions, the most frequently true condition should be tested first. Doing so minimizes the CPU resources spent testing conditions, especially if the test is repeated thousands of times during the course of subsystem processing. Within this document, whenever such information is known, a note is made in the appropriate process specification included in Section 3.2.

2. Precomputation of coefficients where possible.

   Through testing SARB software that already exists, members of the working group have identified coefficients that use considerable CPU resources to calculate but have little variation in value from run to run. The logic to calculate these values can be removed from the on-line subsystem software and incorporated into off-line programs that will execute on an as-need basis only, saving the results as an input product to the on-line software. An example of this practice is the empirically derived derivative tables contained in the DRIVTAB product described in Section 2.1.1. Exactly which coefficients are candidates for precomputation probably will not be known prior to the design or coding phases and will only be identified after considerable testing. However, it will be useful for the code designer and developer to keep this option in mind.

3. Algorithm breakdown.

   Often the design or coding of an algorithm may break the algorithm down into smaller portions. Reasons for doing so include readability, manageability, or the capturing of intermediate results. While these are all valid reasons, the additional subroutine calls, assignment statements, or the inclusion of additional intermediate parameters can cause an increase in the use of CPU resources. The subsystem designer and developer will need to judiciously decide on a case-by-case basis when to break down an algorithm into smaller portions.

4. Use of integer flags instead of character flags.

   While the use of character flags instead of integer flags within the software may be more readable and require less storage, they require more CPU activity than the use of integer flags.

### 3.3.2 Reuse of Existing Software

In the case of SARB software, the reuse of existing code is a threefold issue. First is the reuse of other software provided by the SARB Working Group. Second is the reuse of Footprint SARB Subsystem software by the Synoptic SARB Subsystem. Third is the reuse of the radiative transfer code supplied by Drs. Fu and Liou, discussed in Section 3.2.2.2.

In addition to evaluating the Fu-Liou software, the SARB Working Group is developing and testing additional software that will be incorporated into the Footprint SARB Subsystem software. The DMT will be responsible for ensuring that this code conforms to CERES software standards and implements the correct calls to the EOSDIS Toolkit.

It is anticipated that the Fu-Liou software will be used both in the Footprint SARB and the Synoptic SARB Subsystems. The primary difference between the two subsystems is the size of the Earth-surface area for which the algorithms are to be applied. While the Footprint SARB Subsystem applies the algorithms to the area within a CERES scanner footprint, the Synoptic SARB Subsystem applies the algorithms to a region sized according to a 1.25-deg equal-area grid.

This difference, however, will have no influence on the algorithms.  Consequently, the Fu-Liou software should be treated as a library of routines accessible from either subsystem.

Based on feedback from the SARB Working Group's testing of this software, Drs. Fu and Liou are planning to modify the software and supply the modified version to the group.  The design of the Footprint SARB's software (and also the Synoptic SARB's software) should allow for easy replacement of the Fu-Liou software whenever it is updated.

## 3.4  Resource Use

For a detailed discussion on the computational burden of the Fu-Liou software, see Reference 1.

While the need for a specific compiler has not been indicated, the software to be supplied by the SARB Working Group and others, such as Drs. Fu and Liou, is being developed in FORTRAN.

## References

1. Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Subsystem 5.0, Charlock, T. P., G. L. Smith, T. D. Bess, D. Rutan, F. Rose, T. Alberta, N. Manalo-Smith, L. Coleman, D. Kratz, K. Bush, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA, April 1994.

2. Clouds and the Earth's Radiant Energy System Data Management System Data Products Catalog, Release 1 Version 1, Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA, August 1994.

3. Clouds and the Earth's Radiant Energy System (CERES), Proceedings of the Eighth CERES Science Team Meeting, Appendix E, held in Williamsburg, VA, June 9-11, 1993.

4. PGS Toolkit Users Guide for the ECS Project (194-809-SD4-001), Version 1 Final, May 1994.

# Abbreviations and Acronyms

| | |
|---|---|
| ADM | Angular Distribution Model |
| ASTR | Atmospheric Structures Product |
| CADM | CERES Angular Distribution Model |
| CERES | Clouds and the Earth’s Radiant Energy System |
| CPU | Central Processing Unit |
| CRH | Clear-sky Reflectance and Temperature History |
| CRS | Cloud Radiative Swath Product |
| DMT | Data Management Team |
| DRIVTAB | Derivative Tables Product |
| dTOA/dAER | Derivative of change in TOA flux with respect to change in aerosol optical depth |
| dTOA/dALB | Derivative of change in TOA flux with respect to change in surface albedo |
| dTOA/dTAU | Derivative of change in TOA flux with respect to change in cloud optical depth |
| EOS | Earth Observing System |
| EOSDIS | EOS Data and Information System |
| ERBE | Earth Radiation Budget Experiment |
| ERBS | Earth Radiation Budget Satellite |
| H | High cloud layer |
| HDF | Hierarchical Data Format |
| hPa | Hectopascal |
| K | Kelvin |
| L | Low cloud layer |
| LM | Lower Middle cloud layer |
| MOA | Meteorological, Ozone, and Aerosol Product |
| MODIS | Moderate Resolution Imaging Spectrometer |
| NMC | National Meteorological Center |
| NOAA | National Oceanic and Atmospheric Administration |
| PCP5 | Processing and Control Parameters for Subsystem 5 |
| PGS | Product Generation System |
| QC | Quality Control |

| | |
|---|---|
| QC5 | Quality Control Report for Subsystem 5 |
| SAGE | Stratospheric Aerosol and Gases Experiment |
| SARB | Surface and Atmospheric Radiation Budget |
| SRC | Surface Radiative Properties Climatology |
| SSF | Single Satellite Fluxes |
| SURFMAP | Surface Map Product |
| TBD | To Be Determined |
| TOA | Top of Atmosphere |
| TRMM | Tropical Rainfall Measuring Mission |
| UM | Upper Middle cloud layer |