

MODIS Level 1B Product User's Guide

For Level 1B Version 7.0.20 (Terra) and Version 7.0.19 (Aqua)



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SECTION 1 INTRODUCTION

Section 1.1 Purpose of the Level 1B Software System and This User's Guide

The purpose of the Level 1B software system, developed by the MODIS Characterization and Support Team (MCST), is to provide calibrated MODIS data to the MODIS Science Team (MST) for many applications in the area of Earth science ([14-16]). One such application is the construction of images from Level 1B output products. Figure 1-1 shows an example of a MODIS image taken from the MODIS Web Image Gallery (<https://modis.gsfc.nasa.gov/gallery/>).



Figure 1-1: Image at 1km Resolution of the Great Lakes Area on March 3, 2000
MODIS bands 1, 4 and 3 were used to construct the image.¹

The Level 1B products do not directly contain images such as the one in Figure 1-1. Rather, they contain the calibrated data used by other software applications to construct the images.

¹ MODIS Web image 1000046, Quick View Image, <https://visibleearth.nasa.gov/>

This document is the MODIS Level 1B Product User's Guide. The contents of the Level 1B products are defined by the Level 1B File Specifications ([8], [9], [10], and [11]). The purpose of this Guide is to provide users with a basic understanding of the architecture of the products – enabling users to interpret and use the products. The Guide assumes that the user has a basic knowledge of the construction and operation of the MODIS instrument, as given in references [1] and [2]. A companion reference document, the Level 1B Products Data Dictionary [5], provides more details of the meaning and origin of individual data items in the Level 1B products.

Section 1.2 Generation of Level 1B Product Files

During the Terra and Aqua missions, the Level 1A, geolocation, and Level 1B software systems generate product files that are archived by the NASA Goddard Space Flight Center (GSFC) MODIS Adaptive Processing System (MODAPS).

The Level 1A code organizes a 2-hour Level 0 dataset into a set of granules, each containing approximately 5 minutes of MODIS data. Since one scan of the MODIS mirror takes 1.4771 seconds, there are typically 203 full scans within a 5-minute Level 1B product file and occasionally 204 full scans. Corrupt data packets can cause erroneous identification of as many as 208 scans. The Level 1A code may create as many as 194 empty scans per granule when the corresponding packets are missing. The geolocation code calculates the coordinates of individual pixels on the ground, as well as information on the positions of the Sun and the MODIS instrument with respect to the ground location. In operations under MODAPS, the Level 1A and geolocation codes execute serially using Product Generation Executive 01 (PGE01). Together, they provide the input MODIS data to the Level 1B software.

The Level 1B software system consists of two serial processes which PGE02 executes in the operations environment. The first process, MOD_PR02 (or MOD_PR02AQUA for Aqua data), is the main calibration processing code within the system. This code performs the following functions:

- Implements calibration algorithms to correct raw, Earth view-sector data for all known instrumental effects and to transform the corrected data into calibrated products. The algorithms were developed by the MODIS Calibration Support Team (MCST) in cooperation with the MODIS Science Team (MST).
- Organizes the calibrated science data into a viewing swath whose structure can be related directly to the geolocation parameters of each pixel (calculated external to Level 1B by the geolocation software system).
- Performs quality assurance tests on the raw and calibrated data.

MOD_PR02 ordinarily inputs three Level 1A files that are consecutive in time, designated as “previous” (or “leading”), “current” (or “middle”), and “subsequent” (or “trailing”). The current granule contains the MODIS data that are calibrated by the execution of the code. The previous and subsequent granules provide the code with abutting MODIS data, for those calibration algorithms that need data that cross the boundaries of the current granule. If the leading or trailing granules are

missing due to data gaps or other reasons, MOD_PR02 will calibrate the data within the current granule without them. MOD_PR02 also inputs the geolocation file corresponding to the current Level 1A granule and the calibration parameters files ("look up tables" or LUTs). MOD_PR02 takes raw signals as input and generates four product files with time boundaries identical to those of the current Level 1A and geolocation granules. Three of the four product files contain calibrated Earth View data organized by the spatial resolution of the data. The fourth contains engineering and calibration data. These four products of MOD_PR02 are the focus of this User's Guide.

Note: within this User's Guide, "Level 1B software" (or "Level 1B") refers to the MOD_PR02 code, described above.

The second process within the Level 1B software system, MOD_PR02QA, copies metadata from an Earth View file created by MOD_PR02 into a small Quality Assurance (QA) file (ASCII format). These QA files support MCST in developing a mature QA algorithm and will not be considered further in this Guide.

The four product files generated by the Level 1B calibration code, MOD_PR02, are summarized in Table 1.2.1.

Table 1.2.1: Summary of Level 1B Products

ECS Short Name		Product Contents
MODIS/Terra	MODIS/Aqua	
MOD02QKM	MYD02QKM	Calibrated Earth View data at 250m resolution
MOD02HKM	MYD02HKM	Calibrated Earth View data at 500m resolution, including the 250m resolution bands aggregated to 500m resolution.
MOD021KM	MYD021KM	Calibrated Earth View data at 1km resolution, including the 250m and 500m resolution bands aggregated to 1km resolution.
MOD02OBC	MYD02OBC	On Board Calibrator (OBC) and Engineering Data

The three Earth View (science) products report calibrated data at the three spatial resolutions of 250m, 500m, and 1km. The On Board Calibrator and Engineering Data file contains on-board measurements in the Space View, Black Body, Spectro-Radiometric Calibration Assembly and Solar Diffuser sectors, and additional engineering data.

The format of these files is the widely used Hierarchical Data Format (HDF) ([3]). The architecture of the files utilizes extensions to HDF made with the *Hierarchical Data Format - Earth Observing System (HDF-EOS)* ([4]). HDF-EOS is designed to support the data archiving and storage needs of the Earth Observing System (EOS). The products are available from the MODIS Adaptive Processing System (MODAPS) through the Level 1 and Atmosphere Archive and Distribution System (LAADS) at <https://ladsweb.modaps.eosdis.nasa.gov/>.

SECTION 2 INTRODUCTION TO THE HDF-EOS DATA FORMAT

The Hierarchical Data Format (HDF) is the standard data storage format selected by the Earth Observing System Data and Information System (EOSDIS) Core System (ECS) ([4]). HDF is developed and maintained by the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (<http://ncsa.uiuc.edu>). EOSDIS has defined an extension called HDF-EOS that establishes standards for storing EOS data and for applying search services to these data ([4]). Those familiar with HDF and HDF-EOS may skip this section.

Broadly speaking, HDF is designed to allow sharing of self-describing files across heterogeneous platforms. "Self-describing" means that a data set, such as a multidimensional array of numbers, can have additional *metadata* logically associated with it that describe things such as the rank of the array, number of elements in each dimension, etc. The ability to access files across heterogeneous platforms is a powerful capability that allows one to read files generated on a machine with a different architecture. For example, a user with a DEC ALPHA machine can read an HDF file generated on a Silicon Graphics machine — where ordinarily the byte ordering of binary files would need to be considered. The HDF library functions take care of such details.

To achieve the above capabilities, HDF borrows from the principles of object-oriented programming. Multidimensional arrays, tables and images can be stored in the same file and viewed as discrete objects, rather than a continuous stream of bits. Knowledge of object-oriented programming and of the physical layout of the files is unnecessary because users interact with these objects only through calls to an HDF library. Rather, the user needs to understand the content of the file being accessed in terms of the various HDF and HDF-EOS data object types. The next section describes these data object types, while Appendix A describes the availability of common libraries and tools used to support read and write access to these objects.

HDF4 and HDF-EOS2 have been used since the beginning of MODIS data production. To make the MODIS data product consistent with the VIIRS data product, NetCDF4/HDF5 (<https://www.unidata.ucar.edu/software/netcdf>) is used in Collection 7 (C7) NASA LAADS DAAC. The NetCDF4/HDF5 API and library are entirely different from the HDF4. The C7 API developed by the Land Data Operational Products Evaluation (LDOPE) is used to facilitate the transition to NetCDF4/HDF5 and HDF-EOS5. As a result of this, minimal or no code change is required for all PGEs. The rest of this document is updated to include the changes to the NetCDF4/HDF5 and HDF-EOS5 data format in the L1B product.

Section 2.1 HDF Data Objects Used in Level 1B Files

Level 1B uses the following data objects supported by HDF to store science and calibration data and associated metadata, which describe the scope and quality of science data:

Section 2.1.1 Scientific Data Sets (SDSs)

SDS is one of the primary HDF4 objects. It is used to refer to the NetCDF4/HDF5 dataset as well in this user guide. These objects contain multidimensional arrays, used to store scientific data. Level 1B employs SDSs to store calibrated science data, their uncertainties, and part of the quality assurance data. The SDSs are made self-describing through a set of attributes — data that may be considered "attached" to the SDS. Figure 2-1 shows a schematic of the components of an SDS.

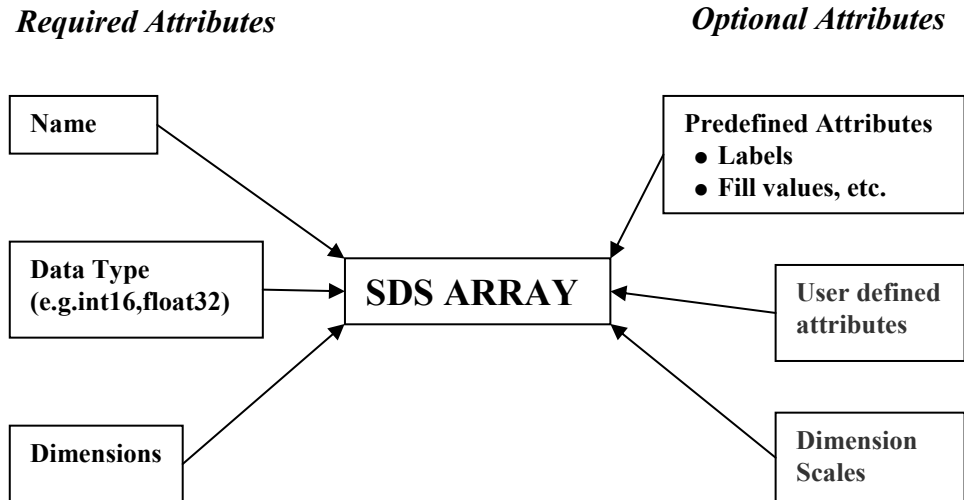


Figure 2-1: Schematic of the Required and Optional Components (Attributes) of an SDS
The required components are shown on the left side of the figure, and the optional components are shown on the right.

The *required attributes* listed below provide the minimum information to allow an HDF library to identify the SDS, and organize the data in it into an array having the correct dimensions and data type:

- **Name:** A string that defines the name of the SDS and uniquely identifies it.
- **Data Type:** Type of data (e.g., float 32) that defines how the data in the array are stored.
- **Dimensions:** The number of dimensions, or rank, of the array.

All other attributes are *optional* attributes, as follows:

- **Predefined attributes**, including but not limited to:
 - **Labels** for all dimensions and for the data
 - **Units** for all dimensions and for the data
 - A **range** specifying maximum and minimum values for the data set.
 - A **fill value** for representing missing data in a data set.
 - A **coordinate system** to use when interpreting or displaying the data

- **User defined attributes:** Level 1B takes advantage of this feature to define dedicated calibration scale and offset parameters for the calibrated products (these differ from similar predefined attributes)

- **Dimension scales:** Scales to be used along the different dimensions when interpreting and displaying the data

Section 2.1.2 Fixed length data (Compound/Vdata)

Compound/Vdata may be thought of as a table that consists of a collection of records whose values are stored in fixed-length fields. All records have the same structure and all values in each field have the same data type, in the same way that a database organizes records. Level 1B uses Compound/Vdata to store metadata collected with each rotation of the scan mirror. Figure 2-2 gives a schematic view of the components of a Compound/Vdata defined by HDF.

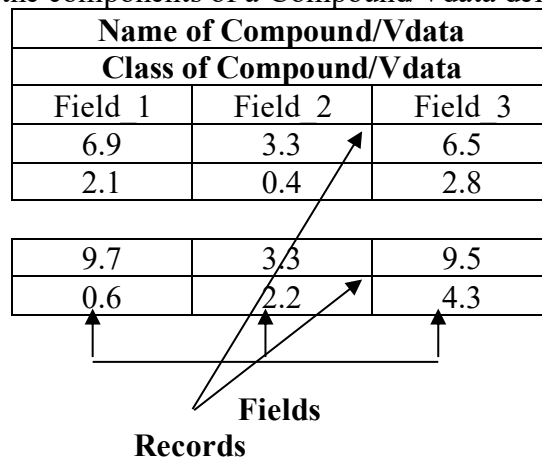


Figure 2-2: Schematic of Compound/Vdata Components Defined by HDF

Compound/Vdata are uniquely identified by a name, a class, and a series of individual field names, as follows:

- **Name:** A label describing the contents of a Compound/Vdata as a whole.
- **Class:** Further distinguishes a particular Compound/Vdata by identifying the purpose or the use of its data.
- **Field names:** Labels assigned to the fields in the vdata.
- **Fields:** Assigned a data type and order when the Compound/Vdata is created. Fields may have any data type. The order identifies the number of individual words of the particular data type which reside in the field.

Section 2.1.3 File (Global) Attributes

In addition to describing features of an SDS, HDF attributes can also describe the contents of a file as a whole. The Level 1B products use such file or *global* attributes to record such information as the number of scans and instrument status. The HDF-EOS extension of HDF makes use of two special types of global attributes to meet the requirements of EOS.

Section 2.2 Extension of HDF to HDF-EOS

The EOS project has two requirements not directly supported by the HDF libraries:

- **EOS needs to provide system-wide search services.** The volume of data generated by EOS platforms is so large that users cannot realistically touch records in many individual files to locate data of interest. EOS therefore requires a means of allowing users to search the contents of files without reading the files themselves.
- **EOS needs to efficiently store geolocated data for remote sensing missions.** Science data may be organized in one of several ways, such as a series of time ordered satellite scans or as a network of ground or sea-going validation stations. HDF data objects do not provide a convenient means of anchoring the science data to specific geographic points on the ground. EOS therefore requires data objects that will tie science data obtained in various modes to geolocation points on the ground.

EOS has satisfied these requirements in the following fashion and implemented them in the HDF-EOS library ([4]):

- **A means of providing system wide search services.** Operations software writes special metadata summarizing temporal and spatial coverage of the data, data quality, and production status into the data products. These metadata are also written to the ECS database, where they can be subject to complex searches through the ECS web based search engine. These metadata are known as *ECS Core Metadata*, and are written according to standards established by ECS for all products archived by EOSDIS. Briefly, the metadata are written in Parameter Value Language, PVL, in which each metadata element has a structure of the form “label = value”. The complete set of metadata is written in the product files in a global attribute as a contiguous block of text. That is, individual fields are not written as individual attributes; rather, the *collection of fields taken together is written as a single attribute*. HDF library calls or any tool that reads global attributes will enable the user to read the whole block, but the user must also supply tools that parse the block to read individual elements. An HDF-EOS file *must* include ECS Core Metadata, and they are written by calls to the Science Data Processing (SDP) Toolkit (see Appendix A.2). The above ECS Core Metadata structure is not used in C7 anymore. Each element in the ECS Core Metadata is now output individually as a global attribute, except the Swath Structure Metadata, which is saved as a dataset in HDFEOS INFORMATION group.
- **A means of storing geolocated data in remote sensing missions.** ECS has defined three new *data types*, composed of standard HDF objects: the **Grid**, **Point**, and **Swath** Data types. The MODIS instrument is equipped with a rotating scan mirror that enables the instrument to collect science data in a series of time-ordered scans, as sketched in Figure 2-3. The Swath data type is designed to store data measured in such a fashion, and Level 1B accordingly uses the Swath data type to record science data.

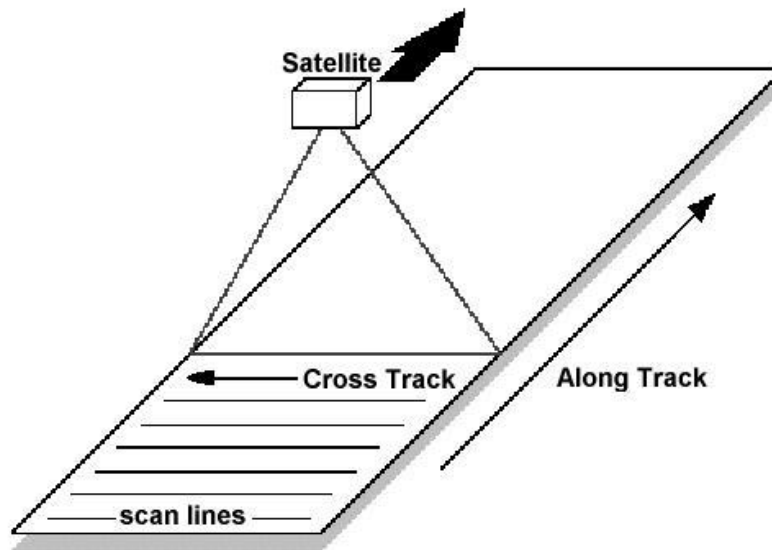


Figure 2-3: Schematic of a MODIS Observation Swath.

This illustrates that scan lines are approximately perpendicular to the direction of motion of the satellite ground track (obtained from [4]).

Section 2.2.1 Overview of the HDF-EOS Swath Structure

The purpose of the swath is simply to map science data to specific points on the Earth's surface. The swath consists of four parts:

- ***data fields***, including science (Earth view) data;
- ***geolocation fields***, which allow the swath to be tied to points on the Earth's surface;
- ***dimensions***, which define the axes of data and geolocation fields, and
- ***dimension maps***, which define the relationship between the data fields and the geolocation fields. When the geolocation dimensions have a different size than the data dimension, an offset and an increment define the relation between them. These maps have been described as "*the glue that holds the swath together.*" Unfortunately, the HDFEOS offsets are required to be integers, and the center of the first 1km geolocation pixel is offset by 1.5 250m pixels in the track direction from center of the first 250m data pixel. Therefore, the MODIS project requires that HDFEOS offsets be supplemented by a separate Fractional Offset file attribute, for each dimension map, that is to be added to the HDFEOS offset to get the true value.

The definitions of the four components of the swath structure are implemented in Level 1B as a global attribute, *i.e.*, a single block of text that contains all the information needed to interpret the geolocated MODIS swath data. This global attribute does, however, have a special hierarchical organization that imitates the organization of a ***Vgroup***, which is simply an association of related HDF data objects. The swath structure global attribute is used by HDF-EOS library functions to

organize calibrated data into the swath structure. *The user should never read this attribute directly. HDF-EOS tools and libraries read the Swath Structure attribute to interpret the relationship between science and geolocation information.* HDF-EOS swath routines are needed only to access data tied to specific regions on the surface of the Earth. Ordinary HDF tools, such as those supplied by NCSA, can read the individual science and geolocation SDSs, but cannot interpret the relationship between them.

The programming model for accessing or creating a swath data set through an HDF-EOS compliant library is as follows:

1. Open the file and initialize the swath interface by obtaining a file id from a file name.
2. Open or create a swath data set by obtaining a swath id from a swath name.
3. Perform desired operations on the data set.
4. Close the swath data set by disposing of the swath id.
5. Terminate swath access to the file by disposing of the file id.

Reference [4] provides programming examples, including the following example of a sequence of calls in the C programming language which gives access to a single swath data set already written in an HDF-EOS file:

```
file_id = SWopen(filename, access_mode);  
sw_id = SWattach(file_id, swath_name);  
<operations on swath data set>  
status = SWdetach(sw_id);  
status = SWclose(file_id);
```

A more advanced description of the swath structure appears in Appendix B. The above HDF-EOS2 API can still be used to process C7 L1B data if the C7 API developed by LDOPE is integrated with user's applications.

SECTION 3 LEVEL 1B EARTH VIEW DATA PRODUCTS

Section 3.1 Architecture Overview

As described in the introduction, one execution of the Level 1B software generates three Earth view (EV) product files and one on-board calibrator (OBC) product file. This section describes the architecture of the EV files, which are:

- **MODIS Level 1B 250M Earth View Data Product** (hereafter, 250m product or file): contains calibrated Earth View observations for MODIS bands 1 and 2, at 250 meter resolution;
- **MODIS Level 1B 500M Earth View Data Product** (hereafter, 500m product or file): contains calibrated Earth View observations from MODIS bands 3 through 7, at 500 meter resolution. In addition, data from MODIS bands 1 and 2 are each aggregated to 500 meter resolution; and
- **MODIS Level 1B 1KM Earth View Data Product** (hereafter, 1km product or file): contains calibrated Earth View observations from MODIS bands 8 through 36, at 1 kilometer resolution in scientific units. It also contains calibrated data from MODIS bands 1 through 7, each aggregated to 1km resolution.

Section 3.1.1 Classes of Data in Earth View Files

Each EV file contains the following classes of data:

- ***Science data on a pixel-by-pixel basis.*** These values (called "scaled integers") may be converted to radiance or reflectance, as appropriate to the band. The methodology to recover radiance and reflectance is described later in Sections Section 5.4 and Section 5.5. These data are stored as HDF SDS objects within the file.
- ***Uncertainty data on a pixel-by-pixel basis.*** These values (called "uncertainty indexes") may be converted to percent uncertainties associated with each value in the corresponding scaled integer SDS, described immediately above. The conversion from uncertainty index to percent uncertainty is described in Section 5.7. These data are stored as HDF SDS objects within the file.
- ***Geolocation data for the pixels.*** These data include latitude and longitude corresponding to a subset of the pixels. Interpolation may be used to recover latitude and longitude of all pixels (HDF-EOS "swath" functions accomplish this in a way transparent to the user). Note that, due to the overlap between consecutive scans, interpolation across scan boundaries such as is

done by these HDF-EOS swath functions, can produce inaccurate results. Near scan boundaries, it is better to extrapolate from within the same scan, than to interpolate with values from the adjacent scan. This is especially true of the 5KM subset stored in the 1km products. These data are stored as HDF SDS objects within the file.

- **Metadata.** These data include a wide variety of ancillary and quality assurance (QA) information for each file. Although these data are not necessary for forming geolocated images, certain of these data are searchable within the ECS system for users attempting to locate data of interest. These data are stored in HDF file attributes, Compound/Vdatas, and SDS objects.

There are also data sets which record, on a pixel-by-pixel basis, the number of samples used in aggregating bands at a higher resolution to appear at a lower resolution (aggregated bands appear in the 500m and 1km EV products).

Figure 3-1 illustrates the approximate volume occupied by the different classes of data described above within a day mode 250m EV file. The differences between day mode and night mode and the impact on product volume are explained in Section 3.4. The general apportionment of volume is roughly similar for the other EV product files in day mode.

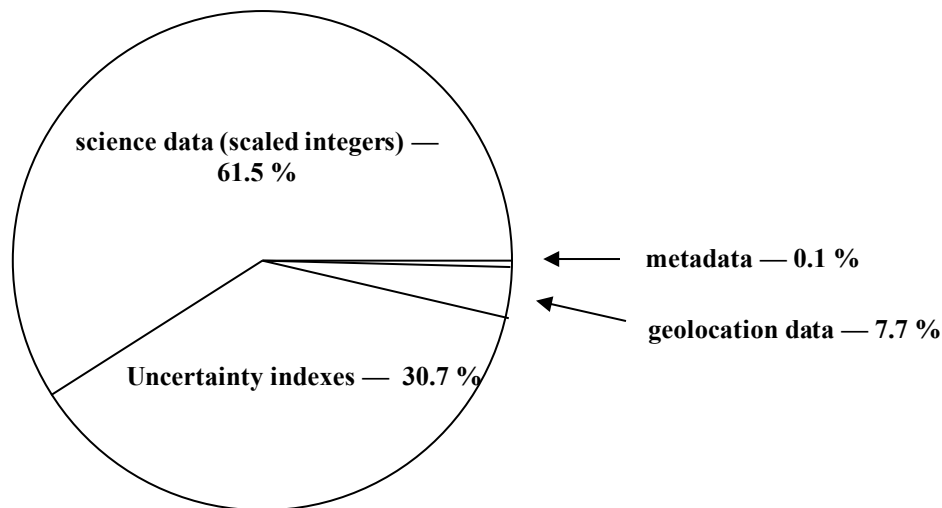


Figure 3-1: Data Volume Occupied by Each Data Class in a 250m Day Mode Product File

Figure 3-2 presents an alternative view of the architecture of a Level 1B EV product file. A block diagram is presented of the 250m product file which shows several different categories of metadata as well as the geolocation and science data sets. This view illustrates that there are several different categories of metadata even though the totality of metadata represents only a tiny fraction of the file volume. Organization of the 500m and 1km EV products is similar.

The following subsections discuss the meanings of the different categories of metadata as well as the science and geolocation data. The descriptions emphasize the architecture and content of individual

HDF objects written in the products rather than the organization of the HDF-EOS swath itself. Users will find this a straightforward way to understand the architecture of the files. The Swath Structure only becomes important when recovering geolocated science data.

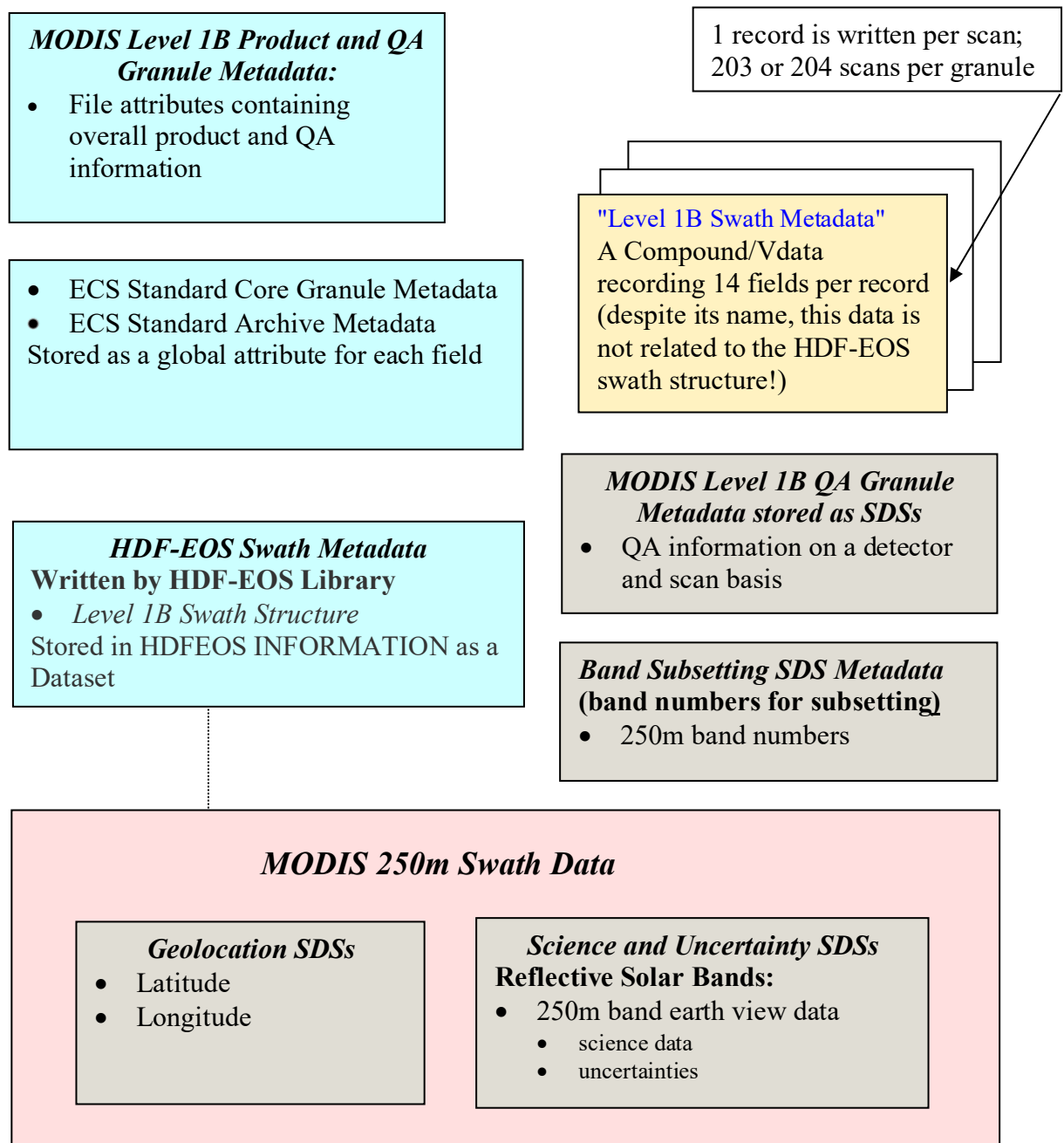


Figure 3-2: Block Diagram of the Architecture of the MODIS Level 1B 250m Products

The HDF EOS Swath Structure attribute is shown in grayed type to indicate that it should not be read directly by the user. It is linked to the science data and geolocation SDSs to indicate that Swath Structure ties the Science data to geolocated points on the ground.

Section 3.2 Metadata in the Level 1B HDF-EOS Earth View Products

Each Level 1B product file contains the mandatory *ECS Core Metadata* defined by ECS to support ECS Search services, as well as *ECS Archive Metadata*, which are similar in architecture to the Core Metadata but not written to the ECS database. Prior to C7 both sets are written as single global attributes, which is to say all the fields in each of these two sets of metadata are written as one block of text. Functions that read HDF file attributes will return the entire block of text, and additional parsing software is required to recover individual fields. The ECS structure is not generated in C7. Each element in the Core Metadata and Archive Metadata is saved individually as a global attribute.

Each Level 1B product also contains file attributes in the categories of Level 1B Product Granule Metadata and QA Granule Metadata. Level 1B Product Granule Metadata contains an accounting of the number of scans within the product in various categories, some overall quality statistics, the state of the electronics, and which Level 1B look up table serial numbers were used. Level 1B QA Granule Metadata contains more detailed quality assurance information.

Metadata that depend on detector and scan are written as six SDSs and are grouped in the file specifications under the heading "*QA granule metadata*". They store information on the behavior of the instrument and detectors within a granule and are used by MCST to assess the quality and fidelity of the calibration data. These six SDSs are:

1. Noise in thermal detectors
2. Change in relative responses of thermal detectors
3. DC Restore Change for Thermal Bands
4. DC Restore Change for Reflective 250m Bands
5. DC Restore Change for Reflective 500m Bands
6. DC Restore Change for Reflective 1km Bands

Additional metadata are contained in the lone Compound/Vdata titled "Level 1B Swath Metadata" and are recorded on a scan-by-scan basis. Despite its name, the Level 1B Swath Metadata Compound/Vdata is not part of the HDF-EOS Swath Structure, but is instead defined by MCST. One Compound/Vdata record is written for each scan line within a granule. Each record reports 14 metadata fields for each scan. The full list of fields is provided and explained in [5], and includes such important information as scan time and mirror side.

The HDF-EOS Swath Metadata attribute defines the organization of the MODIS swath, as per the description in Section 2.2.1. Only HDF-EOS compliant readers should be used to interpret swath data.

The MODIS Level 1B Product Metadata, Level 1B Swath Metadata and QA granule metadata are replicated across all three Earth view product files.

In the three EV files, band-subsetting SDSs are present as an additional metadata type. These data provide numerical equivalent values of each band that may be useful to readers for extracting certain subsets of bands from the science and uncertainty SDSs. The values of these band-subsetting SDSs

are related to the way that band groups are defined in the Level 1B products. The band groups are discussed in Section 3.3.1.

Section 3.3 Science Data in the Level 1B Earth View Products

Section 3.3.1 Organization of Scientific Data Sets

As the Terra or Aqua satellite moves in the along-track direction, the rotation mirror sweeps in the across-track direction. There are typically 203 or 204 consecutive scans of the mirror in each granule. The detectors for a given band are aligned in the along-track direction on four focal plane arrays. A "scan line" in an image represents data for one detector as it is swept across the Earth view sector by the scan mirror. Each 1km band contains 10 detectors, each 500m band contains 20, and each 250m band contains 40. At nadir, the scan lines between detectors appear 1km apart in the along-track direction for the 1km bands, 500m apart for the 500m bands, and 250m apart for the 250m bands. The MODIS instrument collects 3000 frames of data per second. At nadir, under nominal conditions, consecutive frames are collected from ground locations 1km apart in the along-scan direction (roughly perpendicular to the along-track direction). The MODIS instrument records measurements at a rate of one sample per frame for a 1km band, two per frame for a 500m band and four per frame for a 250m band.

The above description of the way that the MODIS instrument records science data suggests that data may be indexed by [band, scan, detector, frame, sample]. However, to represent data in one band as a two-dimensional image, it is more natural to define the data as three-dimensional: [band, along-track, along-scan]. Within this documentation, the "along-track" dimension is a combination of the scan and detector dimensions and the "along-scan" dimension is a combination of the frame and sample dimensions.

Table 3.3.1: Level 1B Product Band Groupings

Cryptic name ¹	Resolution	# bands	Spectral bands
EV 250 RefSB	250 m	2	1, 2
EV 500 RefSB	500 m	5	3,4,5,6,7
EV 1KM RefSB	1 km	15	8-19, 26
EV 1KM Emissive	1 km	16	20-25, 27-36

¹ "RefSB" stands for "Reflective Solar Band" and "Emissive" stands for thermal emissive bands.

Because the different resolutions have different numbers of measurements in the along-track and along-scan dimensions, it would be very inefficient (from a data storage point of view) to have a single SDS contain all data for all bands. Thus, the Level 1B products create *band groupings* based in part on the different spatial resolutions and in part on the spectral nature of the bands. Table 3.3.1 summarizes the band groupings at native resolution in the various Level 1B Earth view product files. Note that the definition of these band groups is different from band groups in the Level 1A output files and different from the Level 1B OBC file (which follows the Level 1A convention). Also, in the set of 1km resolution Reflective Solar Bands, Bands 13 and 14 are split into Bands 13lo, 13hi, 14lo, 14hi (in that order), resulting in 15 bands in the set.

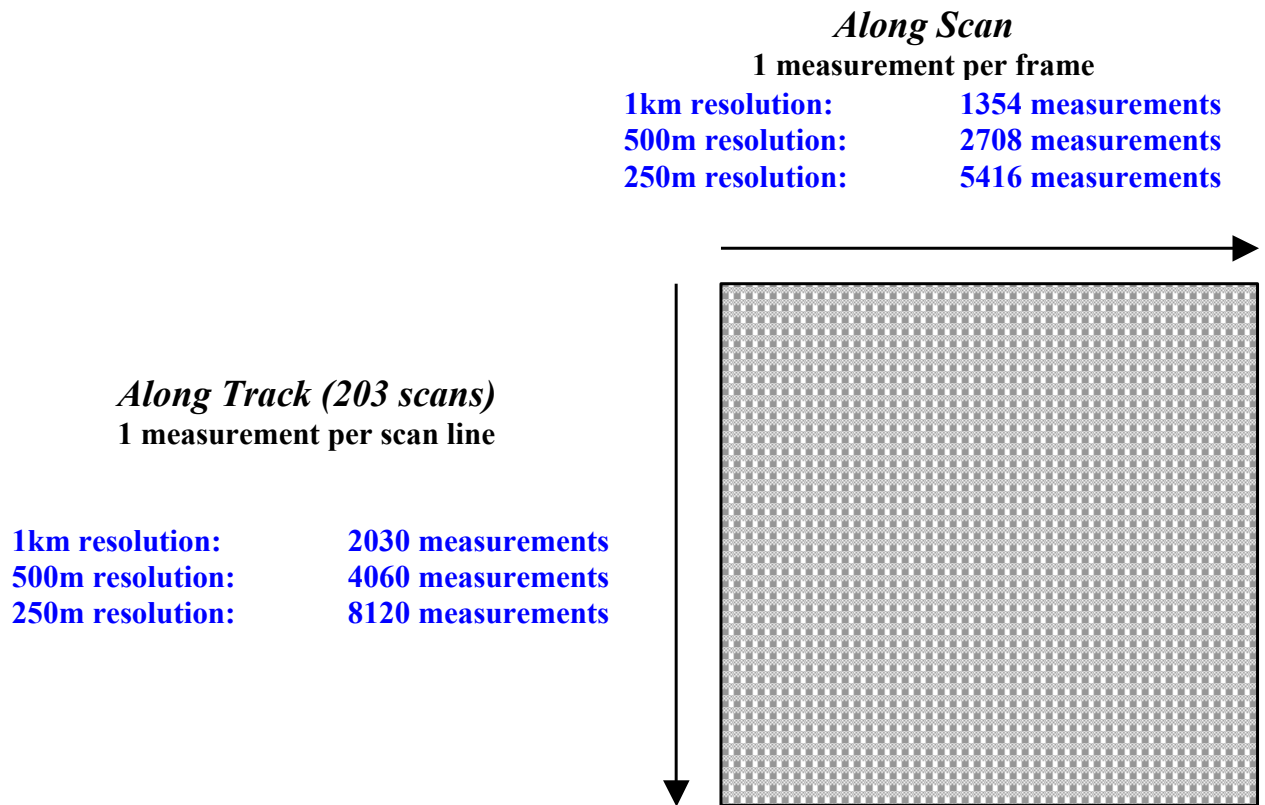


Figure 3-3: Size of 2-Dimensional Images at Different Spatial Resolutions in a 203-Scan Granule

Figure 3-3 illustrates data layout in a two-dimensional image for individual bands at the different resolutions in a 203-scan granule.

Table 3.3.2 summarizes all of the science, uncertainty, and “samples used” SDSs in the three Level 1B EV products.

Table 3.3.2: Summary of Science Data Sets in the MODIS Level 1B Earth View Products

SDS Name and Description	dim. 1 # bands¹	dimension 2 nscans*ndetectors	dimension 3 nframes*nsamples
250m product			
EV_250_RefSB <i>250m Earth View Science data</i>	2	nscans*40	1354*4
EV_250_RefSB_Uncert_Indexes <i>Uncertainty Indices for 250m EV reflectance product</i>	2	nscans*40	1354*4
500m product			
EV_250_Aggr500_RefSB <i>250m Earth View Science data aggregated to 500 m</i>	2	nscans*20	1354*2
EV_250_Aggr500_RefSB_Uncert_Indexes <i>Uncertainty Indices for 250m EV reflectance product aggregated to 500 m</i>	2	nscans*20	1354*2
EV_250_Aggr500_RefSB_Samples_Used <i>Number of samples used to aggregate 250m Science data to 500m resolution</i>	2	nscans*20	1354*2
EV_500_RefSB <i>500m Earth View Science data</i>	5	nscans*20	1354*2
EV_500_RefSB_Uncert_Indexes <i>Uncertainty Indices for 500m EV reflectance product</i>	5	nscans*20	1354*2
1km product			
EV_250_Aggr1km_RefSB <i>250m EV Science data aggregated to 1 km</i>	2	nscans*10	1354*1
EV_250_Aggr1km_RefSB_Uncert_Indexes <i>Uncertainty Indices for 250m EV reflectance product aggregated to 1 km</i>	2	nscans*10	1354*1
EV_250_Aggr1km_RefSB_Samples_Used <i>Number of samples used to aggregate 250m Science data to 1km resolution</i>	2	nscans*10	1354*1
EV_500_Aggr1km_RefSB <i>500m Earth View Science data aggregated to 1 km</i>	5	nscans*10	1354*1
EV_500_Aggr1km_RefSB_Uncert_Indexes <i>Uncertainty Indices for 500m EV reflectance product aggregated to 1 km</i>	5	nscans*10	1354*1
EV_500_Aggr1km_RefSB_Samples_Used <i>Number of samples used to aggregate 500m Science data to 1km resolution</i>	5	nscans*10	1354*1
EV_1KM_RefSB <i>1km EV Science data for Reflective Solar Bands</i>	15	nscans*10	1354*1
EV_1KM_RefSB_Uncert_Indexes <i>Uncertainty Indices for 1km EV reflectance product</i>	15	nscans*10	1354*1
EV_1KM_Emissive <i>1km EV Science data for Thermal Emissive Bands</i>	16	nscans*10	1354*1
EV_1KM_Emissive_Uncert_Indexes <i>Uncertainty Indices for 1km EV thermal emissive radiances</i>	16	nscans*10	1354*1
EV_Band26 <i>1km EV Science data for band 26</i>	1 ²	nscans*10	1354*1
EV_Band26_Uncert_Indexes <i>Uncertainty Indices for Band 26 EV reflectance product</i>	1 ²	nscans*10	1354*1

¹ "dim. 1" is the least rapidly varying in each SDS.

² This is implemented as a 2-dimensional SDS because it reports data for only 1 band.

To aid users in recovering the science data in the "native" dimensions, the following formulae are provided. An "index" in these formulae means a zero-based index (spanning a range of 0 to N-1 rather than 1 to N). A "number" will mean a value in the range of 1 to N. The relation between the along-track index and the detector and scan indices is:

$$\text{along_track_index} = (\text{scan_index} * \text{number_of_detectors_at_resolution}) + \text{detector_index}$$

where *number_of_detectors_at_resolution* = 40 for SDSs in the 250m product, 20 for SDSs in the 500m data product, and 10 for SDSs in the 1km data product. Similarly, the relation between the along-scan index and the frame and sample indices is:

$$\text{along_scan_index} = \text{frame_index} * \text{number_of_samples_at_resolution} + \text{sample_index}$$

where *number_of_samples_at_resolution* = 4 for SDSs in the 250m product, 2 for SDSs in the 500m data product, and 1 for SDSs in the 1km data product.

For example, to access the SDS element in a 250m product corresponding to scan number 19, detector number 6, band number 2, frame number 47, and sample number 3, the SDS array indices are [1, 725, 186], deduced as follows:

$$\begin{aligned} \text{band_index} &= (2 - 1) = 1 \\ \text{along_track_index} &= (18 * 40) + 5 = 725 \\ \text{along_scan_index} &= (46 * 4) + 2 = 186. \end{aligned}$$

The mirror side index corresponding to scan 19 may be read from the "Level 1B Swath Metadata" Vdata.

Section 3.3.2 Geolocation Data

Level 1B copies subsets of the geolocation data from the geolocation file to the Earth View products to support plotting and data visualization. Each product contains subsets of the latitude and longitude data. The 1km file also contains subsets of an additional six geolocation SDSs, including height, range, and the position of the Sun with respect to MODIS. As required by the HDF-EOS swath structure, the mapping between the science data and the corresponding geolocation data is specified in the HDF-EOS swath structure attribute. Software supporting HDF-EOS interprets this mapping to anchor the science data to the correct positions on the Earth. Note that the HDF-EOS dimension map offset is an integer, and therefore requires the addition of the MODIS-specific Fractional Offset file attribute in order to correctly describe the relationship between 250m data and 1km geolocation. Therefore, generic HDF-EOS software that doesn't know about this MODIS addition will display such data incorrectly by ½ pixel in the track direction.

Section 3.4 Day and Night Mode Granules and Their Impact on Products

The MODIS Instrument may be commanded to operate in one of two formatting modes. In "day mode", data from all 36 MODIS bands are transmitted to the ground. In "night mode", only bands 20 through 36 are transmitted. As the names suggest, night mode is generally used during that part of an orbit which corresponds to night at the sub-satellite point and day mode is generally used in that part of the orbit which corresponds to day at that point. During an orbit, the crossover from one mode to the other is commanded to take place at the start of a scan, and so some "mixed" granules will contain both day and night mode scan data. In general, during each orbit, there will be 9 day mode, 9 night mode, and 2 mixed mode granules. Occasionally, the spacecraft is commanded to operate in day mode when it's night at the sub-satellite point, and vice versa, to allow certain validation activities to be carried out.

The existence of the two modes has a substantial impact on product sizes and on the organization of the SDSs. An understanding of this impact requires an understanding of how HDF creates and writes SDSs. When a call to the HDF library is used to create an SDS, the array is considered empty. If this SDS is read before data are written to it, HDF recognizes that the SDS is empty and will return the fill value for every element. Thus, the SDS appears to a user to contain all fill values even though the SDS is physically empty as far as occupying space on a storage device (such as a disk). To save some storage space and eliminate the need to keep track of files containing no useful data, Level 1B allows writing of 250m and 500m data files to be turned off for granules that contain no day mode scans. When data are transmitted in night mode, the Reflective Solar Bands SDSs are empty and appear to contain fill values of 65535 (as specified by the "_FillValue" attribute). This feature of HDF ensures that the "night mode" granules are much smaller than "day mode". Table 3.4.1 shows how dramatic this effect is. While the 1km night mode files are half the size of the day mode files, the 250m and 500m files are 10 times smaller in night mode than day mode. When the instrument operations switch between day mode and night mode within a granule, the file sizes are the same as for day mode because HDF pads the Reflective Solar Band SDSs with fill values at the beginning or end of the granule.

Table 3.4.1: Summary of the MODIS Level 1B Earth View Product Volume

Product Name	Day or mixed mode 203-scan granule size (MB)	Night mode 203-scan granule size (MB)	Approximate Daily Volume (GB)	
			Night mode high resolution data production on	Night mode high resolution data production off
MOD02QKM	286.06	22.19	48.23	45.36
MOD02HKM	275.07	22.19	46.49	43.63
MOD021KM	343.36	142.71	72.06	54.44
Total Daily Earth View Volume			166.8GB	143.4GB

Band 26 is a special case. It is a reflective solar band, but is transmitted along with the thermal band data. Level 1B reorganizes the band ordering of the night mode data so that the Band 26 data are written to the RSB 1km SDSs, and not to the emissive band SDSs (see Table 3.3.2). A consequence of this design is that in night mode, if Band 26 data were to be written to the EV_1KM_RefSB SDS, then the remainder of the SDS would be padded with fill values. To avoid this waste in space, science data for Band 26 are written to a dedicated SDS in both day and night modes (see Table 3.3.2). Band 26 data are not written to the EV_1KM_RefSB SDS in night mode, allowing it to occupy zero disk storage space in night mode. In day mode, the Band 26 data are written to both the EV_1KM_RefSB SDS and the Band 26 SDS.

Section 3.5 Summary of Science Data Volume in Earth View Products

Table 3.5.1 makes clear that the daily Earth View product volume is very large, over 120 GB in normal operations when half the granules are day mode and half are night mode (production of 250m and 500m data sets in night mode is normally turned off). Table 3.5.1, Table 3.5.2, and Table 3.5.3 break down the volume on an SDS basis. The large volume of the SDSs is responsible for almost all the EV product volume, which reflects the construction of the instrument. The 250m band SDS at native resolution, for example, occupies nearly 168 MB. Software developed to read Level 1B data should be designed to read only the desired subset of data, rather than to read the entire data object into memory and then extract the desired subset of data.

Table 3.5.1: Approximate Data Volume in 203-Scan L1B 250m EV Products

SDS Name (or other data description)	Data Type	Dimensions	Day Size (MB) ¹	Night Size (MB) ^{1,2}
EV_250_RefSB	uint16	[2, 8120, 5416]	167.76	0
EV_250_RefSB_Uncert_Indexes	uint8	[2, 8120, 5416]	83.88	0
Latitude	Float32	[2030, 1354]	10.49	10.49
Longitude	Float32	[2030, 1354]	10.49	10.49
all other data (combined)	-	-	0.22	0.22
Total granule size	-	-	272.84	21.20

¹ Granules containing day and night mode are the same size as day mode granules.

² Night mode granules are not produced on a day-to-day basis for 500m data sets.

Table 3.5.2: Approximate Data Volume in 203-Scan L1B 500m EV Products

SDS Name (or other data description)	Data Type	Dimensions	Day Size (MB) ¹	Night Size (MB) ^{1,2}
EV_250_Aggr500_RefSB	uint16	[2, 4060, 2708]	41.94	0
EV_250_Aggr500_RefSB_Uncert_Indexes	uint8	[2, 4060, 2708]	20.97	0
EV_250_Aggr500_RefSB_Samples_Used	int8	[2, 4060, 2708]	20.97	0
EV_500_RefSB	uint16	[5, 4060, 2708]	104.85	0
EV_500_RefSB_Uncert_Indexes	uint8	[5, 4060, 2708]	52.43	0
Latitude	float32	[2030, 1354]	10.49	10.49
Longitude	float32	[2030, 1354]	10.49	10.49
all other data (combined)	-	-	0.22	0.22
Total granule size	-	-	262.36	21.20

¹ Granules containing day and night mode are the same size as day mode granules.

² Night mode granules are not produced on a day-to-day basis for 500m data sets.

Table 3.5.3: Approximate Data Volume in 203-Scan L1B 1km EV Products

SDS Name (or other data description)	Data Type	Dimensions	Day Size (MB) ¹	Night Size (MB) ¹
EV 250 Aggr1km RefSB	uint16	[2, 2030, 1354]	10.49	0
EV 250 Aggr1km RefSB Uncert Indexes	uint8	[2, 2030, 1354]	5.24	0
EV 250 Aggr1km RefSB Samples Used	int8	[2, 2030, 1354]	5.24	0
EV 500 Aggr1km RefSB	uint16	[5, 2030, 1354]	26.21	0
EV 500 Aggr1km RefSB Uncert Indexes	uint8	[5, 2030, 1354]	13.11	0
EV 500 Aggr1km RefSB Samples Used	int8	[5, 2030, 1354]	13.11	0
EV 1KM RefSB	uint16	[15, 2030, 1354]	78.64	0
EV 1KM RefSB Uncert Indexes	uint8	[15, 2030, 1354]	39.32	0
EV 1KM Emissive	uint16	[16, 2030, 1354]	83.88	83.88
EV 1KM Emissive Uncert Indexes	uint8	[16, 2030, 1354]	41.94	41.94
EV Band26	uint16	[2030, 1354]	5.24	5.24
EV Band26 Uncert Indexes	uint8	[2030, 1354]	2.62	2.62
all geolocation SDSs (combined)	-	[406, 271] each	2.20	2.20
all other data (combined)	-	-	0.22	0.22
Total granule size	-	-	327.46	136.10

¹ Granules containing day and night mode are the same size as day mode granules.

SECTION 4 CODE AND LUT VERSION GLOBAL ATTRIBUTES

Two of the most important global attributes are PGEVERSION and ALGORITHMPACKAGEVERSION. These two attributes inform the user of the versions of the code and look-up tables, respectively, used to generate the product files. Frequent updates to the code and tables are made during the Terra and Aqua missions for a number of reasons:

- Calibration algorithms are improved
- Code defects are corrected
- Updates to the look up tables are made to reflect the change with time of the properties of the MODIS instrument and its detectors

Explanations of these changes and their impact on the product are posted on-line during the duration of the mission at the MCST L1B Product Information page (<http://mcst.gsfc.nasa.gov/l1b/product-information>).

Users must be cognizant of the impact of changes in the products caused by changes in the look up tables and in the code, and must be careful to consider the version of the code and the look up tables when comparing measurements of an area made at different times.

Section 4.1 The PGEVERSION Attribute

The global attribute PGEVERSION, a 3-component identifier, "A.B.C", gives the version of the code. The following conditions cause the components denoted by A, B, and C to increment by one from initial values of zero:

- A Changes in the MODIS collection number
- B Major changes to calibration algorithm or code
- C Correction of defects in implementation of algorithms or minor changes to algorithms

Starting with Level 1B code version 3.0.1, code designed for use with MODIS/Terra (PFM) and MODIS/Aqua (FM1) will never have the same PGEVERSION. Users should consult the ALGORITHMPACKAGEVERSION (see Section 4.2 below) to determine the satellite platform for which the code used on the data was intended.

Section 4.2 The ALGORITHMPACKAGEVERSION Attribute

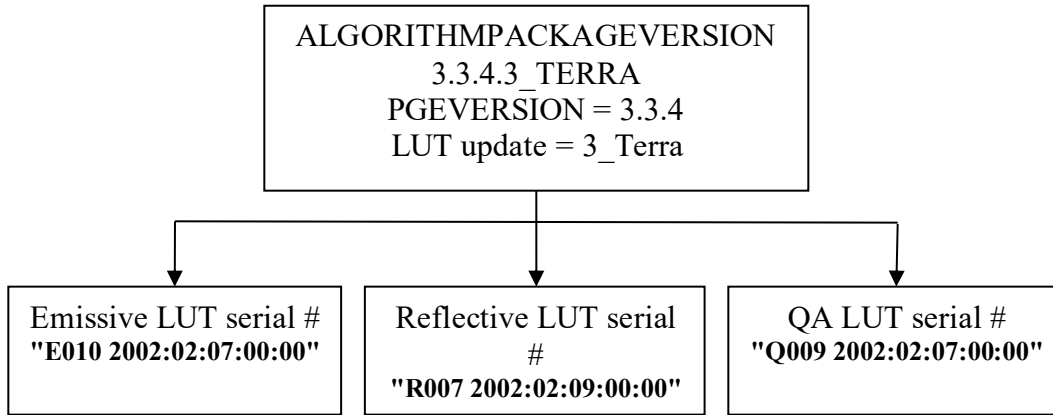
The Look Up Table (LUT) versions are given in the global attribute with the name ALGORITHMPACKAGEVERSION, a four component attribute, A.B.C.D. The first three components are the same as the PGEVERSION, and the fourth component, D, indicates the updated version of the LUTs applicable to the PGEVERSION. D has the format “x_yyyyy” where x is a digit representing the xth up date to the LUTs and “yyyyy” is set to either “Terra” or “Aqua”, representing the satellite platform for which the set of LUTs is to be used. For example, an ALGORITHMPACKAGEVERSION value of “4.0.7.0_Terra” represents the original set of LUTs designed for MODIS/Terra (PFM) for L1B version 4.0.7 whereas “4.1.0.3_Aqua” represents the third LUT update designed for MODIS/Aqua (FM1) and L1B version 4.1.0.

Level 1B inputs three LUT files which contain tables applicable to the reflective solar bands calibration, thermal emissive bands calibration, and quality assurance. The three files should always be thought of as “bound together”. Whenever a field in any one of the three files changes, the numerical portion of the LUT version D for PGEVERSION A.B.C will increment by one. Changes in the individual files are written as global attributes containing serial numbers which specify dates at which the change was made by MCST. Starting in mid-2002, LUT serial numbers are unique to a specific ALGORITHMPACKAGEVERSION. The MCST Level 1B Product Information web page (<http://mcst.gsfc.nasa.gov/11b/product-information>) provides details of what changes are made for each LUT version.

Figure 4-1 illustrates how the version numbers change for a hypothetical update to the emissive LUTs made to PGEVERSION 3.3.4 on 2/14/2002.

Changes in Version Numbers due to an update to the Emissive LUTs on 2/14/2002. (*Version Number changes are in italics*)

Values of Versions of Code and LUTs before update:



**Values of Versions of Code and LUTs after update:
(*Version Number changes are in italics*)**

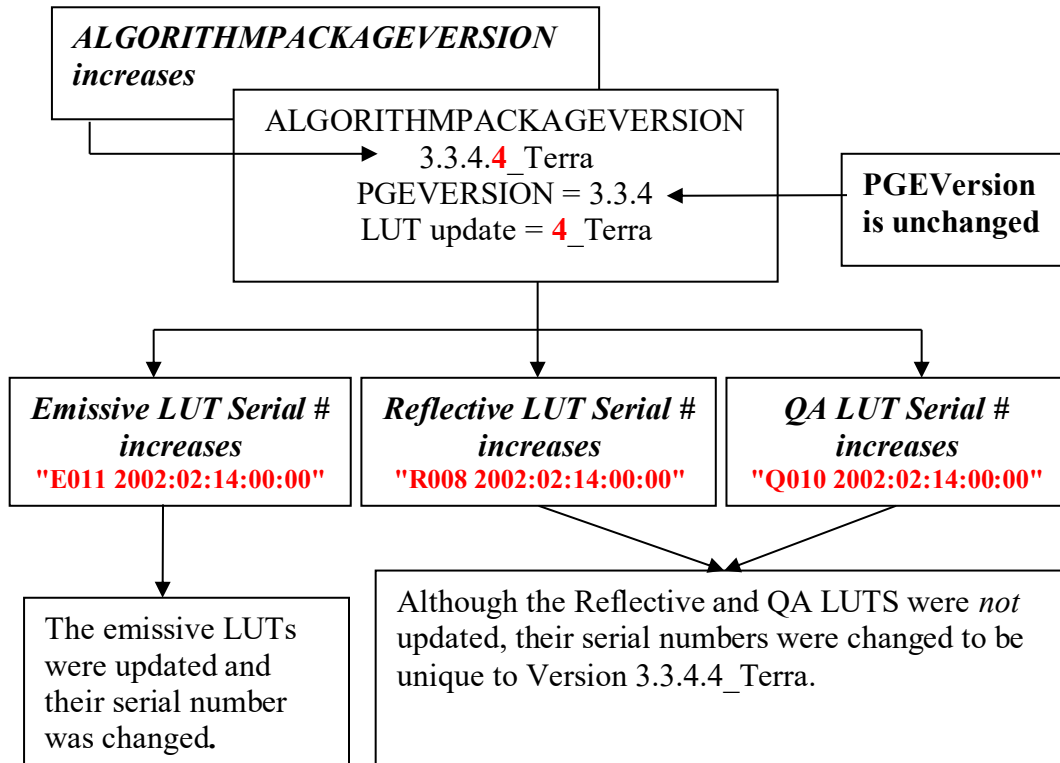


Figure 4-1: Hypothetical Example of the Impact of Look Up Table Changes on Version Numbers

SECTION 5 EARTH VIEW PRODUCT SCIENTIFIC DATA SETS

Section 5.1 Notation

The science data are written in 3-dimensional science data sets (SDSs) indexed by [BAND, TRACK, FRAME_AND_SAMPLE], where BAND is the least rapidly varying index and FRAME_AND_SAMPLE is the most rapidly varying index. In what follows, indices of these dimensions are denoted by upper case subscripts. For example, radiance, L , is denoted as $L_{B,T,FS}$. (These subscripts appear blue on a monitor or in hard-copy color output.)

Section 5.2 Ordering of Bands in the SDSs

The ordering of bands in the SDSs is listed in Table 5.2.1. As described in Section 3.4, Level 1B reorganizes the data sent down in night mode so that Band 26 is reported in the 1km Reflective Solar Bands SDS. For the 1km Emissive bands, Band 27 follows Band 25. For the 1km Reflective Solar bands, Band 26 follows Band 19. The high and low gain signals from the time delay integration (TDI) bands, 13 and 14, are ordered in the same sequence in which they are read from the Level 1A input data. Band 26 data are also placed in a dedicated SDS (see Section 3.4).

Table 5.2.1: Ordering of Bands in Science Data Sets

Spatial Resolution of Band	Band Ordering in Science Data Sets
250m	1,2
500m	3,4,5,6,7
1km Reflective	8,9,10,...,13lo ¹ ,13hi,14lo,14hi,15,...,19,26
1km Emissive	20,21,...,25,27,28,...36
1km Band 26	26

¹ Bands 13 and 14 are Time Delay Integration (TDI) detectors. Data samples are obtained at "lo" and "hi" gains and recorded in successive positions in the SDSs.

Section 5.3 Ordering of Detectors in the Product Files

In the Level 1B products, the lines of data within a swath are stored by increasing detector number (1 to 10, 1 to 20, and 1 to 40 for the 1km, 500m, and 250m bands respectively) in the *increasing-along-track direction* (see Figure 2-3 and Figure 3-3). The data for individual pixels are stored in this way so that consecutive swaths or scans can be "laid down" directly onto a map and have the correct continuity across successive scans. This convention is called "product order". The numbers assigned to the detectors on the instrument by the hardware engineers at Santa Barbara Remote Sensing (SBRS) are the *reverse* of the product order, however, in that the detector numbers increase in the direction *opposite* to the along-track direction. This convention is called "SBRS order". Ordinarily, Level 1B product users do not need to be concerned with the "SBRS order" convention.

If any discussion involves identifying individual detector numbers, however, users should always specify which ordering convention they are using when identifying the detector number.

The two detector numbering schemes described above are compared in Figure 5-1, which shows the relation between track number and both product and detector order for a 1km band. Similar figures would apply to the 500m band and 250m bands, except that they would have 20 and 40 detectors, respectively, instead of 10.

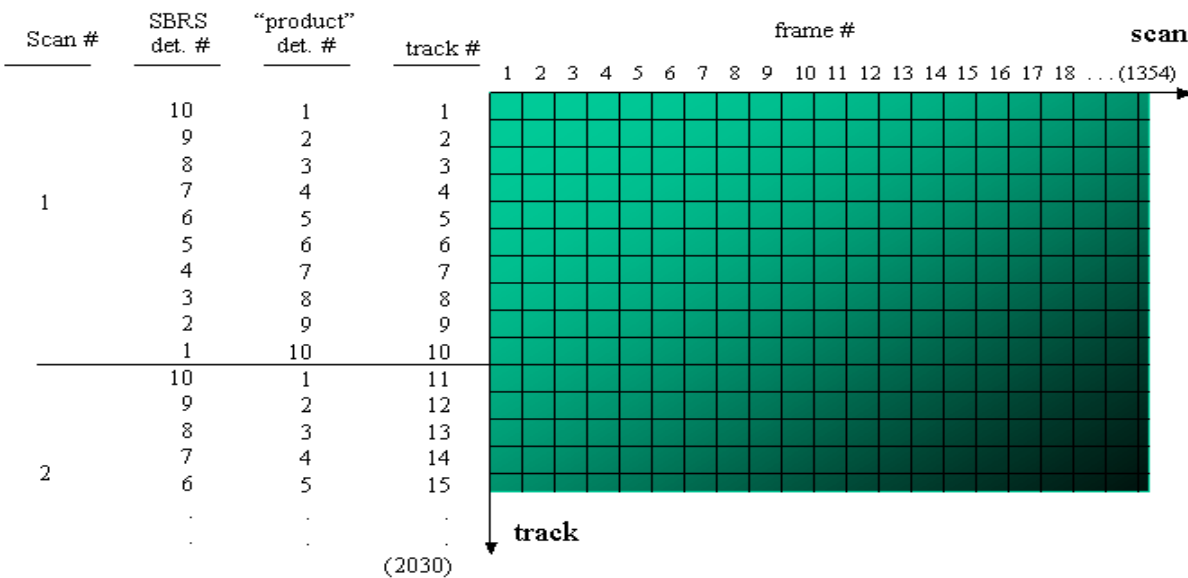


Figure 5-1: Summary of Ordering of Detectors in Level 1B 1km Earth View Science Data Sets

As a matter in interest, all data in the Level 1B Earth View files which are indexed by detector are in product order. However, a few data sets in the Level 1B OBC product utilize the "SBRS order" convention. These are clearly noted at the beginning of the OBC file specification ([11]).

Section 5.4 Technical Content of Reflective Solar Bands SDSs

Level 1B generates two calibrated data products for the Reflective Solar bands (RSBs): the reflectance and the Earth-exiting radiance. Writing these two products in floating-point format to the Level 1B Earth view product files would make the file sizes prohibitively large. Instead, Level 1B writes a 16-bit scaled integer representation of the calibrated digital signals measured by the MODIS, from which the reflectances and radiances can be calculated from two pairs of scale and offset terms written as attributes to the reflective band SDSs. These two pairs are derived from the calibration parameters that are input to Level 1B as look up tables. Reflective Solar Band radiance can also be calculated more precisely using calculated reflectances and appropriate granule metadata; see Section 5.4.3.

Level 1B corrects the *raw digital signals* measured at the Reflective Band detectors, *DN*, for all known instrumental effects, to produce *corrected digital signals*, *dn**. Corrections are applied for the following effects:

- electronic offsets
- nonlinearities in the analog-to-digital converters
- angular variations of the scan mirror reflectance
- variations in gain caused by variations in the instrument and focal plane temperatures
- out-of-band spectral response in the Short Wave Infrared (SWIR) bands 5,6,7 and 26

Level 1B then adjusts the values of *dn** for the effects of variations in calibration parameters from detector to detector within each band so that one pair of calibration terms applies to every detector in each band. The values of *dn** adjusted in this way, called *dn***, are scaled to the 16-bit representation in the RSB SDSs. The science data occupy 15 bits of the 16-bit integer; the most significant bit is set to indicate invalid data.

The conversion of *dn** to *dn*** is transparent to users wishing to simply compute the reflectance and radiance products. For those users wishing to study the digital signals detector-by-detector, Appendix C includes the procedure for the recovery of the corrected digital signals *dn**.

Section 5.4.1 Scaled Integer (SI) Representation of dn^{**}

The values of dn^{**} over the dynamic range of $[D_{min}, D_{max}]$ are scaled to a range of $[0, 32767]$ and placed into an integer variable. The values of D_{max} and D_{min} are input to Level 1B through look up tables, and are indexed by band only. Figure 5-2 shows the relationship between dn^{**} and the scaled integer values, SI .

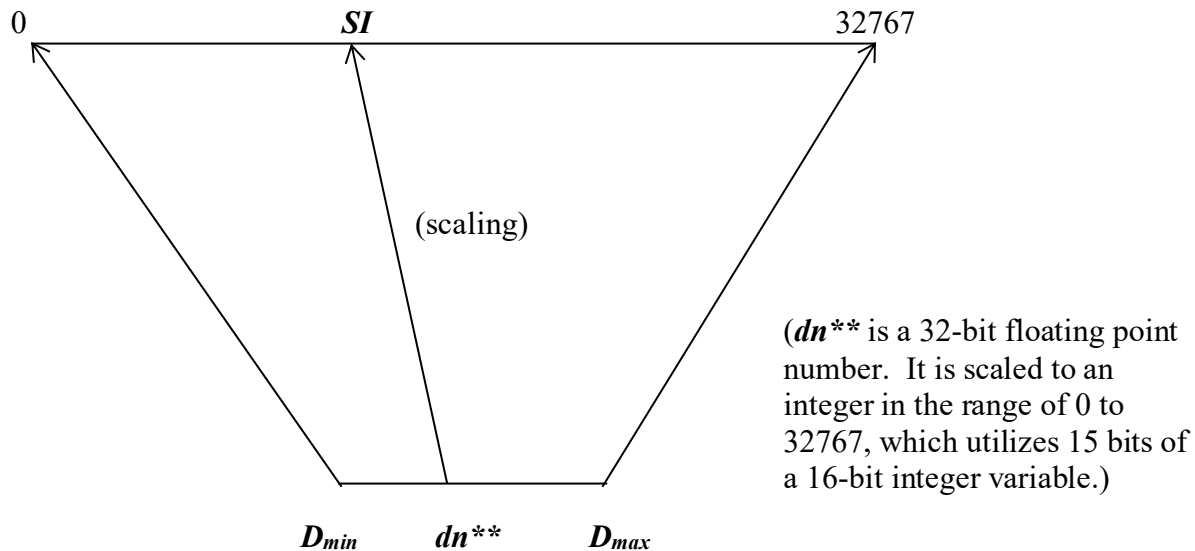


Figure 5-2: Relationship between dn^{**} and its Integer Representation (SI) in the Level 1B Product Files

In the Level 1B product scaled integer SDS (whose data type is 16-bit unsigned integer), the least significant 15 bits are used for the valid range of the scaled value of dn^{**} . The most significant bit of the 16-bit integer is reserved to indicate invalid data. Thus, the dynamic range of valid data in integer representation is $[0, 32767]$ and any value greater than 32767 represents invalid (or unusable) data (see Section 5.6). The relation between dn^{**} and SI is given by the equation

$$dn^{**} B,T,FS = corrected_counts_scaleB (SI_{B,T,FS} - corrected_counts_offsetB) \quad \text{Equation 5.1}$$

where:

$$corrected_counts_scaleB = (D_{max} B - D_{min} B) / 32767 \quad \text{Equation 5.2}$$

$$corrected_counts_offsetB = -(32767 D_{min} B) / (D_{max} B - D_{min} B) \quad \text{Equation 5.3}$$

The values of *corrected_counts_scale* and *corrected_counts_offset* are computed inside Level 1B and are written as attributes to the SDSs. Thus, dn^{**} may be simply recovered from *SI* values by reading these two attributes and applying Equation 5.1.

Values of dn^{**} that lie outside the range $[D_{min}, D_{max}]$ are considered invalid and set to specific values to indicate this condition. Section 5.6 discusses invalid data in detail.

Section 5.4.2 Calculation of Reflectance Products for Reflected Solar Bands

MCST's linear calibration algorithm for the reflectance product, $[\rho \cos(\Theta)]_{EV}$ for any pixel is given by:

$$[\rho \cos(\Theta)]_{EV} = m_0 + m_1 d_{ES}^2 dn^*$$

Equation 5.4

where m_0 and m_1 are calibration parameters refreshed periodically through measurements of the Solar Diffuser illuminated by the Sun and input to Level 1B as look up tables; d_{ES} is the Earth-Sun distance in astronomical units AU at the time of the Earth View measurement (d_{ES} varies sufficiently slowly that the value appropriate to the middle of the granule may be applied throughout each 5-minute granule), and dn^* is the digital signal corrected for instrumental effects.

The parameters m_0 and m_1 are indexed internally in Level 1B by $[BAND, DETECTOR, SAMPLE, MIRROR SIDE]$. This indexing scheme is used by MCST because it captures the quantities affecting the values of the calibration parameters. These calibration parameters are converted by Level 1B to a pair of parameters called *reflectance_scales* and *reflectance_offsets*, which are written as attributes to the reflective band SDSs. The pair of parameters *depends only on band*, such that the reflectance product is given by:

$$\rho \cos(\Theta)_{B,T,FS} = \text{reflectance_scales}_B (SI_{B,T,FS} - \text{reflectance_offsets}_B)$$

Equation 5.5

Appendix C.1 presents the equations that demonstrate how the indexing of m_0 and m_1 and d_{ES} are all absorbed into two parameters that are band dependent only, and Appendix C.2 below describes how the *reflectance_scales* and *reflectance_offsets* attributes are calculated by Level 1B.

Section 5.4.3 Calculation of Radiance Products for Reflected Solar Bands

Radiances are similarly calculable from the equation

$$LB_{B,T,FS} = \text{radiance_scales}_B (SI_{B,T,FS} - \text{radiance_offsets}_B)$$

Equation 5.6

where *radiance_scales* and *radiance_offsets* are deduced from radiometric calibration parameters computed by MCST. Appendix C.3 below describes how Level 1B calculates the *radiance_scales* and *radiance_offsets*.

Note that for reflective Solar bands, more precise radiance values may be computed directly from reflectance by using the global attributes “Earth-Sun Distance” and “Solar Irradiance on RSB Detectors over pi” (see [6]). To do so, compute reflectance using the reflectance scale and offset terms (see Equation 5.5). The derivation of radiance is then

$$radiance = [(E^{sun}_{B,D}/\pi) / dES^2] \cdot reflectance$$

Equation 5.7

where $E^{sun}_{B,D}/\pi$ is the detector-specific weighted Solar irradiance and dES^2 is the square of the Earth-Sun distance.

Section 5.4.4 Science Data Units and Attributes for the Reflective Solar Bands

Table 5.4.1 summarizes the units of the science data and the attributes for the reflective solar bands.

Table 5.4.1: Summary of Units for Reflective Solar Band Calibrated Products

Quantity	Units
Integer Representation of <i>dn**</i>	Dimensionless
Radiance	W/m ² /μm/sr
<i>radiance_scales</i>	W/m ² /μm/sr
<i>radiance_offsets</i>	Dimensionless
Reflectance	Dimensionless
<i>reflectance_scales</i>	Dimensionless
<i>reflectance_offsets</i>	Dimensionless

Section 5.4.5 Aggregation

The 250m and 500m band data are aggregated to lower spatial resolutions with simple weighting functions applied to data at the native resolution: the weighting functions are triangular in the scan direction and rectangular in the track direction. The rationale for these choices is explained in Section 2 of the Geolocation ATBD ([13]).

If data at native resolution cannot be aggregated, then the integer representation of *dn*** is set to a specific bad data value, described in more detail in Section 5.6.

Section 5.5 Technical Content of Thermal Emissive Band SDSs

Level 1B generates the radiances in 32-bit floating-point format for each thermal emissive band measurement. It scales these radiances to an integer representation to the Earth View 1km Emissive SDS.

Level 1B corrects the *raw digital signals* measured at the detector, DN, for the following effects:

- non-linearities in the analog-to-digital converters
- self-emission of the instrument and optics
- optical crosstalk in the long-wave bands.

Calibration parameters are refreshed each scan by measurements of the on-board black body calibrator, and then applied to the signals to produce calibrated radiances.

Section 5.5.1 Scaling of Radiances into 16-bit Integers

The values of radiance, L , over the dynamic range of $[L_{min}, L_{max}]$ are scaled to a range of $[0, 32767]$ and placed into an integer variable. The values of L_{max} and L_{min} are input to Level 1B through look up tables and are indexed by band only. Figure 5-3 shows the relationship between L and the scaled integer values, SI . Values of radiance that lie outside the range of $[L_{min}, L_{max}]$ are set to L_{min} or L_{max} as appropriate.

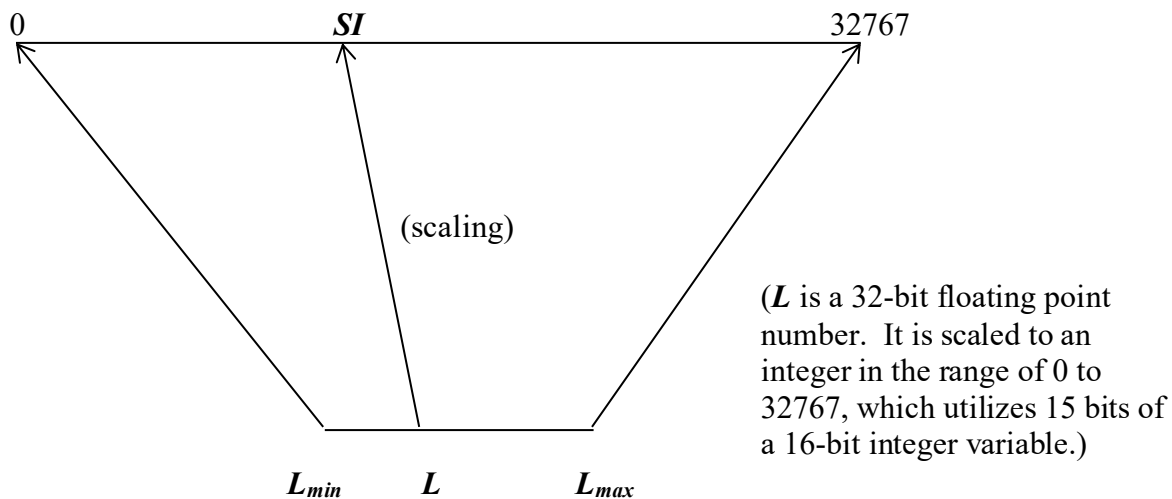


Figure 5-3: Relationship between TEB Radiance (L) and its Integer Representation (SI) in the Level 1B Product Files

In the Level 1B product scaled integer SDS (which is a 16-bit unsigned integer data type), the least significant 15 bits are used for the valid range of the scaled value of L . The most significant bit of the 16-bit integer is reserved to indicate invalid data (see Section 5.6). Thus, the dynamic range of valid data in integer representation is [0, 32767] and any value greater than 32767 represents invalid (or unusable) data. The relation between L and SI is given by an equation of the form:

$$L_{B,T,FS} = \text{radiance_scales}_B (SI_{B,T,FS} - \text{radiance_offsets}_B) \tag{Equation 5.8}$$

where:

$$\text{radiance_scales}_B = (L_{\max B} - L_{\min B}) / 32767 \tag{Equation 5.9}$$

$$\text{radiance_offsets}_B = - (32767 L_{\min B}) / (L_{\max B} - L_{\min B}) \tag{Equation 5.10}$$

The values of *radiance_scales* and *radiance_offsets* are computed inside Level 1B and written as attributes to the Science data sets. Thus, radiance may be simply recovered from SI by reading these two attributes and applying Equation 5.8.

Section 5.5.2 Science Data Units and Attributes for the Thermal Emissive Bands

Table 5.5.1 summarizes the units of the science data and the attributes for the thermal emissive bands.

Table 5.5.1: Summary of Units for Thermal Emissive Band Calibrated Products

Quantity	Units
Integer Representation of radiance	Dimensionless
Radiance	W/m ² /μm/sr
Radiance_scales	W/m ² /μm/sr
Radiance_offsets	Dimensionless

Section 5.6 Quality Assurance: Flagging of Invalid Data Values

The most significant bit of the 16-bit integer representations of dn^{**} and of the radiances indicates data that cannot be calibrated. That is, valid science data lie only in the range [0, 32767]. Specific values greater than 32767 are reserved to indicate why data cannot be calibrated, as listed in Table 5.6.1.

Table 5.6.1: Reserved Data Values Which Signal Why Data Cannot Be Calibrated

Explanation	Data Value
Entire scans of L1A data are missing (same as Fill Value) or RSB Data not transmitted (night mode)	65535
L1A DN is missing within a scan	65534
Detector is saturated	65533
Cannot compute zero point DN	65532
Detector is dead	65531
RSB <i>dn</i> ** below bottom end of range for writing to scaled integer	65530
RSB or TEB <i>dn</i> ** above maximum allowed <i>SI</i> value (32767)	65529
Aggregation algorithm failure	65528
Rotation of Earth view Sector from nominal science collection position	65527
TEB Calibration coefficient b1 could not be computed (previously Moon in SV port for TEB band ¹)	65526
Subframe is dead	65525
Both sides of the PCLW electronics on at the same time (reserved for future use)	65524
	65501 - 65523
NAD closed upper limit	65500

¹In Level 1B Versions 2.4.3 and lower, data value 65526 indicated that a TEB pixel was not calibrated

For data at the native spatial resolution, the following is the order of precedence in which the invalid data values are set:

- Entire scans of L1A data are missing (same as Fill Value).
- Reflective band data not transmitted to the ground (night mode)
- L1A DN is missing within a scan
- Detector is inoperable
- Subframe is inoperable
- Rotation of Earth View Sector from nominal science collection position
- Unable to calibrate due to both sides of PCLW electronics on at the same time
- Detector is saturated
- Cannot compute zero point DN
- TEB calibration coefficient b1 cannot be computed
- RSB *dn*** outside bottom end of dynamic range
- RSB or TEB *dn*** greater than maximum allowed SI value

If the data pass all the tests above but the nadir aperture door (NAD) is closed, the data value will be set in the range 32768 to 65500. The integer values for thermal and reflective bands are calculated normally and then the most significant bit is flipped subject to a ceiling set at 65500.

For the case of aggregation algorithm failure, the value 65528 is set if none of the native resolution pixels which would be used to form an aggregated pixel have a valid value. Users must examine the data at the native resolution to determine why the values are invalid.

Section 5.7 Uncertainty Science Data Sets

The Uncertainty Index SDSs hold 8-bit unsigned integers. The four least significant bits of these integers represent MCST's best estimate of the uncertainty in each measurement of reflectance for the reflective solar bands and radiance for the thermal emissive bands. The uncertainties in the radiance product for the reflective bands are not reported in the Level 1B products. The four most significant bits of the index may eventually record a scene contrast scatter index, but are currently set to zero, except when scans are missing and values are set to a fill value of 255. The indices take on values of 0 through 15, and successive values of the index represent an interval of uncertainty values in which the measured uncertainty lies. The value of 15 is reserved for representing uncertainties of those data that cannot be calibrated, or when the calculated index is higher than 15.

Level 1B computes the Uncertainty Index corresponding to the measured percent uncertainty with the following formula:

$$UI = \textit{scaling_factor } B * \ln (\textit{uncertainty_in_percent } B,T,FS / \textit{specified_uncertainty } B)$$

Equation 5.11

where "ln" is the natural logarithm.

The percent uncertainty can be recovered from the uncertainty index through the formula:

$$\textit{uncertainty_in_percent } B,T,FS = \textit{specified_uncertainty } B * \exp (UI_{B,T,FS} / \textit{scaling_factor } B)$$

Equation 5.12

The *scaling_factor* and *specified_uncertainty* values come from band-dependent look up tables and are attached as attributes to each uncertainty index SDS. The attributes are provided for convenience to those downstream users who convert the uncertainty index to percent uncertainty, given that the values of *scaling_factor* and *specified_uncertainty* are subject to change.

SECTION 6 ON-BOARD CALIBRATION FILE ARCHITECTURE

The principal purpose of the On-Board Calibration (OBC) file is to group the calibration sector, Space View and engineering data in a relatively small file (56 MB) to support MCST's investigations of the behavior of the instrument and of the development of mature calibration algorithms. The file also contains QA information computed inside Level 1B, such as a mask of outlying data in the Space View port, which is required to support MCST's analysis efforts.

The OBC file replicates some information in the 1km Earth View file:

- ECS Core Metadata
- ECS Archive Metadata
- Level 1B Product Granule and QA Metadata implemented as global attributes
- Level 1B QA Metadata implemented as SDSs.
- Some fields of the "Level 1B Swath Metadata" Compound/Vdata are implemented as one-dimensional SDSs in the OBC file

Information in the OBC file that is not contained in the Level 1B EV files includes:

Raw digital numbers for the calibration sectors (Solar Diffuser, Spectro-Radiometric Calibration Assembly, and Black Body) and Space View sector

- All engineering telemetry Compound/Vdatas in the L1A file
- Any miscellaneous SDSs in the L1A file not included in the above categories
- Three SDSs from the geolocation file
- Some processed values computed by Level 1B during calibration (averaged Space View DNs, mask of outlying data rejected, etc.)

Level 1B copies the calibration sector and Space View sector digital number data into the OBC file as 16-bit signed integers. These integers represent the 12-bit integers transmitted from the spacecraft, with fill values implemented in Level 1A to denote missing data. Missing scans have a fill value of -32767 (the HDF default for a 16 bit signed integer) and missing data within a scan have a fill value of -1. These SDSs are very similar to the comparable SDSs in the Level 1A granule:

- The names of these SDSs are identical to those in the Level 1A files;
- The organization of dimensions is the same: [track, band, frame]; and
- The band groups are the same: 250m bands (1 and 2), 500m bands (3 through 7), 1km "day" bands (8 through 19) and 1km "night" bands (20 through 36).

The only differences between these SDSs in the OBC file and their counterparts in the L1A file are the actual sizes of the track and frame dimensions. The SDSs written to the OBC files use the actual number of scans and 1km frames to establish the dimensions of the SDSs. In the L1A file, preset maximums for the number of scans and the number of 1km frames are used. This means that the SDS "size" in the OBC file looks a little smaller than in the L1A file. The technical content is the

same, however, because those array elements in the L1A file that are unused have fill values placed in them.

SECTION 7 ABBREVIATIONS AND ACRONYMS

A&E.....Activation and Evaluation — period following launch (nominally six months) during which MODIS is activated and calibration algorithms are evaluated.

API.....Application Programming Interface. A set of functions designed for use by applications programmers. Often used interchangeably with the term ‘subroutine library’, or ‘toolkit’.

ASCII Text.....Data stored as plain text using the American Standard Code for Information Interchange.

BB.....Black Body

DAACDistributed Data Active Archive Center

DN.....Digital Number, the raw digital signal measured at the detector

dnRaw digital signal, DN corrected for the electronic zero point as derived from Space View average

*dn**For RSBs, the digital signals for each detector corrected for all known instrumental effects

*dn***For RSBs, the corrected digital signals scaled so that a single set of calibration parameters applies for every detector in each band

ECS.....EOSDIS Core System, the core software and hardware system used to support EOSDIS.

EOS.....Earth Observing System.

EOSDISEarth Observing System Data and Information System, the ground based data archive and management system for EOS.

EV.....Earth View

ftp.....file transfer protocol

GSFCGoddard Space Flight Center

HDFHierarchical Data Format, developed and maintained by NCSA at the University of Illinois at Urbana-Champaign

HDF-EOS.....Hierarchical Data Format-Earth Observing System and the software library that implements this extension of HDF

HTML.....HyperText Markup Language

http.....hypertext transport protocol

IDL.....Interactive Data Language, a cross-platform data manipulation and visualization tool developed by Research Systems, Incorporated.

LUT.....Look Up Table

MCST.....MODIS Characterization and Support Team

MODAPS.....MODIS Adaptive Processing System

MODIS.....Moderate Resolution Imaging SpectroRadiometer

MSTMODIS Science Team

NASA.....National Aeronautics and Space Administration

NCSA.....National Center for Supercomputing Applications, creators of HDF, NCSA Image, Datascope, NCSA Telnet, NCSA Mosaic, and Collage.

ODLObject Description Language, developed by the Planetary Data System at the Jet Propulsion Laboratory, it is a text-based language for describing metadata and data dictionaries.

OBCOn Board Calibrator

PVL.....Parameter Value Language, refers to a text-based language developed by CCSDS (Consultative Committee for Space Data Systems) for the storage of metadata and data dictionaries, derived in part from ODL.

QA.....Quality Assurance

RSBReflective Solar Band

SDP.....Science Data Processing, normally applied to the SDP Toolkit, which provides users with an interface between the EOS science data production software and the Science Data Production System

SDS.....Scientific Data Set in HDF4 and Dataset in NetCDF4/HDF5

SI.....Scaled Integer

SRCA.....SpectroRadiometric Calibration Assembly

SVSpace View

TEB.....Thermal Emissive Band

TDI.....Time Delay Integration

SECTION 8 GLOSSARY

- [$\rho\cos(\Theta)$] **EV**.....Symbol for the Earth View reflectance product, relative to the reflectance of a Lambertian reflecting surface, it is the product of ρ , the Bidirectional Reflectance factor of the Earth, and $\cos(\Theta)$, the cosine of the Solar incidence angle on the Earth View scene.
- Attribute.....In HDF, a text or binary data object used to store a single value or a list of values. Attributes can be associated with an SDS or an entire file, and are most often used for storing metadata.
- Computer-Comprehensible....Fields in a data file that a computer program can read and interpret appropriately. An example would be latitude/longitude values, where a program may use these values to display a correctly positioned map grid on an image.
- Data Dictionary.....A record that contains detailed information about keywords, especially keywords used in metadata, or describes the content of fields written to a file. See [6].
- Data Element.....Individual components of *Data Objects* within an HDF file. For example, a Data Object of data type 'scientific dataset' consists of several data elements: one for each of the attributes, another for the array itself, and so on.
- Data ObjectA particular instance of a *Data type*. For example, an HDF file may consist of a series of data objects, each of a different data type (raster, n-dimensional array, and so on).
- Data type.....Classes of data structures such as **Grids**, **Points**, and **Swath** that are supported in HDF-EOS. Often there will be an exact mapping of an HDF-EOS data type to an HDF data object. There are cases where an HDF-EOS data type is made up of several HDF data objects grouped together, however.
- Dimension ScaleA one dimensional SDS with the same name as an SDS dimension, that lists data values which define the meaning of indices on that dimension. In Level 1B products, the only examples are the band-subsetting SDSs.
- Geolocation.....Data locations that are specific to physical locations on the Earth or on another planetary body. Geolocation is usually (but not always) specified in terms of latitude, longitude, and altitude.
- Global Attributes.....Attributes that provide information about an entire file. Also known as file attributes.

- Grid StructureAn HDF-EOS data type designed to support gridded data, where the geolocation for each pixel is defined by a regularly spaced grid in a specified map projection, rather than as a separately stored latitude and longitude for each pixel.
- Local AttributesAttributes that describe the properties of an SDS; also known as Data Set Attributes.
- Metadata.....Data that describes data.
- Multidimensional Array.....A synonym for *N-dimensional Array*.
- N-Dimensional ArrayAn array of any dimension that contains either scalar data values or a record of various data values at every data location in the array.
- Point StructureHDF-EOS data type for storing *Point Data*.
- Record.....In HDF, the repeated sequence of fields in a Compound/Vdata.
- Scientific Data SetIn HDF, a self-describing Multidimensional Array.
- Self-describing.....With a self-describing data file, no outside information is needed to fully comprehend the contained data, other than a subroutine library encapsulating the file format design.
- SwathA data model for the reading and writing of data oriented around satellite orbital track.
- Swath StructureHDF-EOS data type for organizing swath data.
- Track.....In the HDF-EOS Swath Structure, track represents an index through all detectors and scans.
- Compound/Vdata.....Virtual Data, a record-oriented HDF data model and API provided in HDF. A Compound/Vdata corresponds to a data table, where each fixed-length record is made up of a set of individually named and typed fields, which make up the columns of the table. Science Data Tables make extensive use of Compound/Vdata.
- Compound/Vdata Field.....A named and typed set of data values that make up one column in the table-like Comopund/Vdata structure.
- VgroupAn arbitrary grouping mechanism in HDF used to signify associations between otherwise unrelated data objects.

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APPENDIX A AVAILABILITY OF HDF AND HDF TOOLS

Appendix A.1 Availability of HDF

HDF, including HDF4 and HDF5, manuals and software may be obtained via

<https://support.hdfgroup.org>.

NetCDF4 software can be found from <https://www.unidata.ucar.edu/software/netcdf/>

Appendix A.2 SDP Toolkit

The SDP toolkit provides the interface between EOS science data production software and the remainder of the Science Data Production System. It allows portability of science software across approved platforms.

Information on the current release can be found at

<https://wiki.earthdata.nasa.gov/display/DAS/Toolkit+Downloads>

Appendix A.3 HDF-EOS

Data written by an HDF-EOS call can be read by software that reads "vanilla" HDF, but is unlikely to be able to interpret the HDF-EOS geolocation data. The HDF-EOS library should be used to write and access HDF-EOS data. This library consists of standard HDF with ECS conventions for point, grid and swath metadata added; these allow the file contents to be queried by time and geolocation. The library also supports ECS core metadata, used by ECS search services.

The HDF-EOS2/HDF-EOS5 libraries may be downloaded from the HDF-EOS Standards and Tools and Information Center at <http://hdfeos.org/software/>.

Appendix A.4 Tools for Reading, Writing and Displaying HDF-EOS files

Tools for working with MODIS data can be accessed at <http://nsidc.org/data/modis/tools.html>. The following tools are also generally available.

Appendix A.4.1 HDF-EOS Standards and Tools and Information Center

The HDF-EOS Standards and Tools and Information Center has a number of tools available for extracting and displaying ECS metadata. Those tools may be downloaded from <http://hdfeos.org/software/tool.php>

The MODIS -Applications Programmer Interface Version 2.3 Programmer's Reference Guide (SDST-090C) ([12]) describes the HDF-EOS API for the swath structure, and provides many programming examples in FORTRAN and C.

Appendix A.4.2 C7 API

The C7 API is developed by the Land Data Operational Products Evaluation (LDOPE). It includes two packages: api-Trans and SDP-UTILs. The api-Trans is used to translate the HDF4 and HDF-EOS2 calls to the corresponding NetCDF4/HDF5 and HDF-EOS5 functions. The SDP-UTILs is used to handle both HDF4 and NetCDF4/HDF5 metadata, and work with the PCF and MCF files in the new format (key=value). The C7 API can be found via <https://gitlab.modaps.eosdis.nasa.gov>

Appendix A.4.3 Interactive Data Language (IDL)

IDL is a 4th generation language (4GL) offered commercially by Harris Geospatial (<https://13harrisgeospatial.com>). It is a powerful environment for interactive analysis and visualization of data and is widely used by Earth scientists. Releases 5.3 (December 1999) and above provide an API for creating, accessing and manipulating Grid, Swath and Point Structures defined in HDF-EOS.

APPENDIX B SAMPLE OF HDF-EOS SWATH STRUCTURE

Some knowledge of the design philosophy of the MODIS Level 1B Swath Structure may be valuable for users who are expert in HDF who wish a deeper understanding of the subject. The Swath Structure Vgroup is a special example of a Vgroup in that it is implemented as a global attribute. That is, the four components of the swath - definitions of the dimensions, dimension maps, data fields and geolocation fields - are organized in the same way as a Vgroup but implemented as a block of text. ECS was led to this design largely because, at the time HDF-EOS was being designed, HDF did not allow attributes to be defined for Vgroups. The following is an example of the MODIS Level 1B Swath Structure as implemented in the global attribute "StructMetadata.0" in a Level 1B 250m EV file:

```

GROUP = SwathStructure
GROUP = SWATH_1
SwathName = "MODIS_SWATH_Type_L1B"
GROUP = Dimension
OBJECT = Dimension_1
DimensionName = "Band_250M"
Size = 2
END_OBJECT = Dimension_1
OBJECT = Dimension_2
DimensionName = "40*nscans"
Size = 8120
END_OBJECT = Dimension_2
OBJECT = Dimension_3
DimensionName = "4*Max_EV_frames"
Size = 5416
END_OBJECT = Dimension_3
OBJECT = Dimension_4
DimensionName = "10*nscans"
Size = 2030
END_OBJECT = Dimension_4
OBJECT = Dimension_5
DimensionName = "Max_EV_frames"
Size = 1354
END_OBJECT = Dimension_5
END_GROUP = Dimension
GROUP = DimensionMap
OBJECT = DimensionMap_1
GeoDimension = "10*nscans"
DataDimension = "40*nscans"
offset = 0
Increment = 4

```

```
END_OBJECT = DimensionMap_1
OBJECT = DimensionMap_2
GeoDimension = "Max_EV_frames"
DataDimension = "4*Max_EV_frames"
    offset = 0
    Increment = 4
END_OBJECT = DimensionMap_2
END_GROUP = DimensionMap
GROUP = IndexDimensionMap
END_GROUP = IndexDimensionMap
GROUP = GeoField
OBJECT = GeoField_1
    GeoFieldName = "Latitude"
    DataType = DFNT_FLOAT32
DimList = ("10*nscans", "Max_EV_frames")
END_OBJECT = GeoField_1
OBJECT = GeoField_2
    GeoFieldName = "Longitude"
    DataType = DFNT_FLOAT32
DimList = ("10*nscans", "Max_EV_frames")
END_OBJECT = GeoField_2
END_GROUP = GeoField
GROUP = DataField
OBJECT = DataField_1
    DataFieldName = "EV_250_RefSB"
    DataType = DFNT_UINT16
DimList = ("Band_250M", "40*nscans", "4*Max_EV_frames")
END_OBJECT = DataField_1
OBJECT = DataField_2
    DataFieldName = "EV_250_RefSB_Uncert_Indexes"
    DataType = DFNT_UINT8
DimList = ("Band_250M", "40*nscans", "4*Max_EV_frames")
END_OBJECT = DataField_2
OBJECT = DataField_3
    DataFieldName = "Band_250M"
    DataType = DFNT_FLOAT32
    DimList = ("Band_250M")
END_OBJECT = DataField_3
END_GROUP = DataField
GROUP = MergedFields
END_GROUP = MergedFields
END_GROUP = SWATH_1
END_GROUP = SwathStructure
```

The “GROUP = Dimension” table associates names (strings) with actual dimensions present in the “GeoField” and “DataField” SDSs. Any Data or Geolocation SDS defined in the Swath Structure inherits the dimensions already defined in the Dimensions Group. Thus, the axes of the geolocation and science data need be defined only once. The “GROUP = DimensionMap” table associates geolocation dimensions with data dimensions. The offsets and increments allow specific geolocation points to be aligned with the data points (used for visualization and geolocation subsetting). The “GROUP = GeoField” lists the geolocation latitude and longitude SDSs and the “GROUP = DataField” group lists all SDSs. See the file specifications ([8], [9], [10], and [11]) for a full description of the Swath Structure.

The objects in the four components of the swath are implemented in Object Descriptor Language (ODL). This language is superficially similar to PVL in that it defines the structure of an object by statements of the form "label = value".

APPENDIX C RSB EARTH VIEW DATA PRODUCTS

The value of dn^* may be recovered from the integer representation of dn^{**} , SI, by reversing the operation in Level 1B which equalizes the calibration parameters across each band. The detector-to-detector variations in calibration parameters are captured in look up tables input to Level 1B that are not written to the Level 1B products. The indexing scheme applied to the calibration parameters by MCST differs from the indexing scheme used for the RSB SDSs. Knowledge of this indexing scheme and how it used in the equations representing MCST's calibration algorithm is requisite to proper recovery of the dn^* values. This will be described next, followed by the procedure for deriving dn^* .

Appendix C.1 Algorithm for Calculation of dn^{**} inside Level 1B

MCST's linear calibration algorithm for the reflectance product for any pixel is given by:

$$[\rho_{cos(\Theta)}]_{EV} = m_0 + m_1 d_{ES}^2 dn^*$$

Equation C.1

where m_0 and m_1 are *calibration parameters*, refreshed periodically through measurements of the Solar Diffuser and input to Level 1B as look up tables; d_{E-S} is the Earth-Sun distance in AU at the time of the Earth View measurement (d_{E-S} varies sufficiently slowly that the value appropriate to the middle of the granule may be applied throughout each 5-minute granule), and dn^* is the digital signal corrected for instrumental effects.

The parameters m_0 and m_1 are indexed by [\[BAND, DETECTOR, SAMPLES IN A 1km FRAME , MIRROR SIDE\]](#). This indexing scheme has been chosen by MCST because it captures the quantities affecting the values of the calibration parameters. Thus, the indexing in MCST's calibration equation can be expressed by:

$$[\rho_{cos(\Theta)}]_{EV,B,T,FS} = m_{0,B,D,S,M} + m_{1,B,D,S,M} d_{ES}^2 dn^{*,B,T,FS}$$

Equation C.2

where S is the sample index in each 1 km-frame index and may have values of 0 (1km bands), 0–1 (500m bands) or 0–3 (250m bands).

The architecture of the Level 1B products requires that a single calibration be used for each band. This is equivalent to saying that that Equation C.2 must be rewritten in the form:

$$[\rho_{cos(\Theta)}]_{EV,B,T,FS} = (M_{1,B} d_{E-S}^2) dn^{**,B,T,FS}$$

Equation C.3

This is easily achieved by defining quantity dn^{**} for *each measured pixel* as follows:

$$dn^{**} B,T,FS = [m_0 B,D,S,M + m_1 B,D,S,M d_{ES}^2 dn^* B,D,S,M] / [M_1 B d_{ES}^2]$$

Equation C.4

where values indexed by mirror side correspond to the correct track index in the product. Equation C.4 shows that dn^{**} is simply the reflectance product divided by an arbitrary scaling factor that depends on band only. The quantity M_1 has been chosen by MCST as the maximum value of m_1 in each band.

Appendix C.2 Calculation of reflectance scales and offsets in Level 1B

The *reflectance_scales* and *reflectance_offsets* are computed from the calibration parameters in such a fashion that the reflectance product can be found directly from the integer representation of dn^{**} , SI, by an equation of the form:

$$\rho \cos(\Theta) B,T,FS = reflectance_scales B (SI B,T,FS - reflectance_offsets B)$$

Equation C.5

Level 1B finds the maximum value, M_1 of the input calibration parameter, m_1 , for each band, and computes the Earth Sun distance for the granule. The values of $[M_1 B d_{ES}^2]$ are transformed into *reflectance_scales* and *reflectance_offsets* by the following equations:

$$reflectance_scales B = [M_1 B d_{ES}^2] corrected_counts_scales B$$

Equation C.6

$$reflectance_offsets B = corrected_counts_offsets B$$

Equation C.7

Appendix C.3 Calculation of radiance scales and offsets in Level 1B.

Level 1B also computes the values of *radiance_scales* and *radiance_offsets* from the input radiometric gain factors. The radiance, L, is given by:

$$L B,T,FS = [1/R^*]B dn^{**} B,T,FS$$

Equation C.8

where $[1/R^*]B$ is a gain factor that depends on band only. There is no Earth–Sun distance correction factor in the radiance product.

The values of $[1/R^*]_B$ are transformed in Level 1B into *radiance_scales* and *radiance_offsets* terms so that the radiance can be recovered from the products by an equation of the form:

$$L_{B,T,FS} = \text{radiance_scales}_B (SI_{B,T,FS} - \text{radiance_offsets}_B)$$

Equation C.9

The transformations from $[1/R^*]_B$ to *radiance_scales* and *radiance_offsets* are given by:

$$\text{radiance_scales}_B = [1/R^*]_B \text{corrected_counts_scales}_B$$

Equation C.10

$$\text{radiance_offsets}_B = \text{corrected_counts_offsets}_B$$

Equation C.11

As noted in Section 5.4.3, RSB radiance may also be computed directly from reflectance by using the global attributes “Earth-Sun Distance” and “Solar Irradiance on RSB Detectors over pi” (see [6]). To do so, compute reflectance using the reflectance scale and offset terms (see Equation C.5). The derivation of radiance is then

$$\text{radiance} = [(E^{\text{sun}}_{B,D}/\pi) / d_{ES}^2] \cdot \text{reflectance}$$

Equation C.12

where $(E^{\text{sun}}_{B,D}/\pi)$ is the detector-specific weighted Solar irradiance and d_{ES}^2 is the square of the Earth-Sun distance.

Appendix C.4 Calculation of dn^* from dn^{**}

With the above discussion in mind, the procedure for calculating dn^* can be simply described:

1. Contact MCST to obtain the calibration parameter look up tables. Specify the value of ALGORITHMPACKAGEVERSION (found in ECS archive metadata) or the value of "Reflective LUT Serial Number and Date of Last Change" (a product granule metadata attribute). Specifying the ALGORITHMPACKAGEVERSION is the preferred method.
2. Follow the steps below to ensure correct matching of the indexing of the products to the indexing of the calibration coefficients:
 - a. Convert SI to dn^{**} via the relation:

$$dn^{**}_{B,T,FS} = \text{corrected_counts_scales}_B (SI_{B,T,FS} - \text{corrected_counts_offsets}_B)$$

Equation C.13

b. Obtain the mirror side index, M , from the product Vdata "Level 1B Swath Metadata". Each scan has a corresponding mirror side index and thus the first step is to determine the scan index ($scan_index$) corresponding to the track index (T) from

$$scan_index = int [T / N_D(B)]$$

Equation C.14

where $N_D(B)$ = number of detectors in band B . Use the recovered scan index to obtain the corresponding mirror side index.

c. Get the value of Earth-Sun distance, d_{ES} , used during the Level 1B code execution from the product metadata attribute "Earth-Sun Distance". The single value applies to all scans of the granule.

d. Get the values of $[M_{I B} d_{ES}^2]$ from the $reflectance_scales$ attributes to the RSB SDSs from the following relation:

$$(M_{I B} d_{ES}^2) = reflectance_scales B / corrected_counts_scales B$$

Equation C.15

e. Apply the equation below to convert dn^{**} to dn^* :

$$dn^*_{B,T,FS} = [dn^{**}_{B,T,FS} M_{I B} d_{ES}^2 - m_{0 B,D,S,M}] / [m_{I B,D,S,M} d_{ES}^2]$$

Equation C.16

where the detector index (D) corresponding to the track index (T) is given by:

$$D = T - scan_index * N_D(B)$$

Equation C.17

and the sample index (S) is determined from the frame-and-sample index (FS) and the 1km frame index (F) by:

$$S = [FS - F * N_S(B)]$$

Equation C.18

and where $N_S(B)$ = number of samples per 1km frame in band B . F is given by:

$$F = int [FS / N_S(B)]$$

Equation C.19

Table C-1 gives the number of detectors at full resolution and the number of samples for each Reflective Solar Band.

Table C-1: Number of Detectors, Samples and Resolutions for Reflective Solar Bands

Band	Number of detectors	Number of samples/frame	Resolution
1, 2	40	4	250m
3 – 7*	20	2	500m
4 – 12*	10	1	1km
13lo, 13hi	10	1	1km
14lo, 14hi	10	1	1km
15 – 19*	10	1	1km
26	10	1	1km

* inclusive, e.g. “3-7” = 3, 4, 5, 6, 7