MODIS Collection 6.1 (C61) LSR Product User Guide

The C61 MOD09 product is identical in format to the C6 product. This (C61) reprocessing does not contain any change to the science algorithm used to make this product. Any improvement or change in the C61 product compared to the product from the prior major collection reprocessing (C6) is from changes and enhancements to the calibration approach used in generation of the Terra and Aqua MODIS L1B products and changes to the polarization correction used in this collection reprocessing. For further details on C61 calibration changes and other changes user is encouraged to refer to the Collection 6.1 specific changes that have been summarized here: https://landweb.modaps.eosdis.nasa.gov/QA_WWW/forPage/MODIS_C61_Land_Proposed_Changes.pdf

C61 Revision to MODIS Land Surface Reflectance for Estimation of High Aerosols

A change was made in C61 in the approach to estimation of high aerosols in the MODIS Surface Reflectance (MxD09) products. This was prompted by an overestimation of high-aerosol areas, especially over the brighter surfaces, which is caused by use of an approximation on the path radiance. This approximation caused overestimation of high aerosol, mainly on bright surfaces and at higher view angles. Hence, the Surface Reflectance science team decided to port a more robust scheme for estimating aerosol quantities, which has been used in the processing of Landsat and Sentinel 2, to MODIS products. This change to the L2 science processing code does not change the retrieved reflectance at pixel level but could result in change to the aerosol flag (bits 6-7) values in the state quality data set. To provide additional clarity and help user understand the flag better, the quality flag documented as "aerosol quantity" in C6 and prior collections is rightly renamed as "aerosol quantity: level of uncertainty in aerosol correction" (ref: Bits 6-7 in Table 13, section 3.3 of this Users Guide). Most downstream daily and n-day products like, daily and 8-day reflectance, VI, and BRDF-Albedo use the aerosol quantity flag to screen out high aerosol values. So, any change in this quantification of the aerosol categories will have a definite impact on these downstream products.

MODIS Surface Reflectance User's Guide

Collection 6

MODIS Land Surface Reflectance Science Computing Facility

Principal Investigator: Dr. Eric F. Vermote

Web site: http://modis-sr.ltdri.org

Correspondence e-mail address: mod09@ltdri.org

Prepared by J. C. Roger, J. P. Ray, and E. F. Vermote

Version 1.5

July, 2020

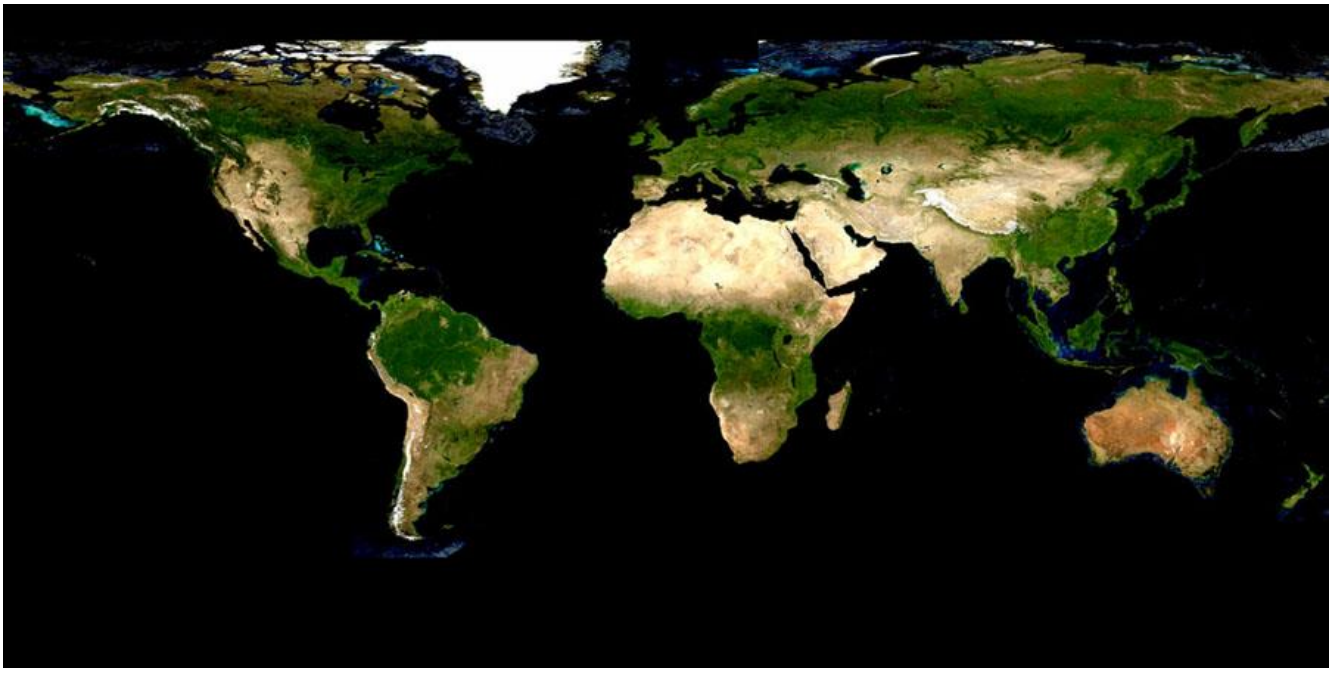

Table of Contents

List of Tables

1. Product description

MOD09 (MODIS Surface Reflectance) is a seven-band product computed from the MODIS Level 1B land bands 1 (620-670 nm), 2 (841-876 nm), 3 (459-479), 4 (545-565 nm), 5 (1230-1250 nm), 6 (1628-1652 nm), and 7 (2105-2155 nm). The product is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level as if there were no atmospheric scattering or absorption. It corrects for the effects of atmospheric gases and aerosols.

2. Overview of MODIS processing

Most satellite data processing systems recognize five distinct levels of processing. Level 0 data is raw satellite feeds: level 1 data has been radiometrically calibrated, but not otherwise altered. Level 2 data is level 1 data that has been atmospherically corrected to yield a surface reflectance product. Level 3 data is level 2 data that has been gridded into a map projection, and usually has also been temporally composited or averaged. Level 4 data are products that have been put through additional processing. All data up to and including level 2 are in an ungridded orbital swath format, with each swath typically cut into small segments, or ***granules***, to facilitate processing. Data at level 3 and up are geolocated into a specific map projection, with the geolocated products typically in a set of non-overlapping ***tiles*** (figure 1).

The advantage of level 3 data over less processed forms of data is that each pixel of L3 data is precisely geolocated; a disadvantage is that the process of compositing or averaging that results in L3 data limits the usefulness of the L3 product. The Level 2G format, consisting of gridded Level 2 data, was developed as a means of separating geolocating from compositing and averaging. The L2G format preserves all the data that maps to a given pixel as observations at that pixel. Programs which produce level 3 data can then have all available data at each pixel to choose from, without having to geolocate everything themselves. An additional step of processing, level 2G-lite, provides a minimal level of compositing of daily level 2G data.

2.1. MODIS surface reflectance data products

MODIS surface reflectance data are found in the MOD09 series of data products, including a level 2 product (MOD09, generated by PGE11's MOD_PR09.exe program), level 2G daily products (MOD09GHK, MOD09GQK, and MOD09GST, generated by PGE12's MOD_PRMGR.exe program), level 2G-Lite daily products (MOD09GA and MOD09GQ, generated by PGE13's MOD_PR09G.exe program), level 3, 8-day composited products (MOD09A1 and MOD09Q1, generated by PGE21's MOD_PR09A.exe program), and daily level 3 CMG (climate modeling grid) products (MOD09CMG and MOD09CMA, generated by PGE75's MOD_PR09C.exe program). See Table 1.

Please note that not all MOD09 products are publically available. This User's Guide is meant to be a guide for the use of publically available MOD09 products, so it is the publically available products that are described here in detail. Other products are described for the sake of completeness (e. g., the MOD09IDN, -IDT and -IDS products).

Table 1: Inputs and outputs of MODIS surface reflectance programs.

	input			output				
program	**file**	**level**	**res.**	**publically available**	**not publically available**	**level**	**res.**	**collection**
MOD_PR09.exe	MOD021KM	1B	1	MOD09		2	1,H,Q	all
	MOD02HKM	1B	H		MOD09IDT	3	5	4 and up
	MOD02QKM	1B	Q		MOD09IDN	3	5	4 and up
	MOD03	1A	1		MOD09IDS	3	5	4 and up
	MOD35_L2	2	1					
MOD_PRMGR.exe	MOD09	2	1,H,Q	MOD09GHK	none	2G	H	all
				MOD09GQK		2G	Q	all
				MOD09GST		2G	1	all
MOD_PR09A.exe	MOD09GHK	2G	H	MOD09A1	none	3	H	up to/and 4
	MOD09GQK	2G	Q	MOD09Q1		3	Q	up to/and 4
	MOD09GST	2G	1					
MOD_PR09G.exe	MOD09GHK	2G	H	MOD09GA	none	2GL	1,H	5 and up
	MOD09GQK	2G	Q	MOD09GQ		2GL	Q	5 and up
	MOD09GST	2G	1					
MOD_PR09A.exe	MOD09GA	2GL	1,H	MOD09A1	none	3	H	5 and up
	MOD09GQ	2GL	Q	MOD09Q1		3	Q	5 and up
MOD_PR09C.exe	MOD09IDT	3	5	MOD09CMG	none	3	5	4 and up
	MOD09IDN	3	5	MOD09CMA				
	MOD09IDS	3	5					

where '2GL' stands for level 2G-lite and resolutions ('res.') are '5', 0.05°, 'Q', 250 m, 'H', 500 m, and '1', 1 km..

Please also note:

1) A ***collection*** is a MODIS data archive that has been reprocessed in order to incorporate better calibration, algorithm refinements, and improved upstream products into all MODIS products. The current collection is 6. Later collections supersede all earlier collections.

2) This table focuses upon MOD09-related products, and for purposes of clarity omits pointer files, coarse-resolution files, browse files, ancillary data files, destriped L1B input files, subsets, et cetera.

3) The "MOD" prefix should be taken as referring to the dataset in general, *not* to Terra-derived data in particular. All programs discussed in this document process either Terra- or Aqua-derived data. All datasets referred to in this document will be referred to as "MOD" data, but meaning either Terra- or Aqua-derived data.

2.2. Products of MOD_PR09.exe -- levels 2 and 3

MOD_PR09.exe is run on whole orbit's worth of level 1B calibrated radiance data at each available resolution (1 km, 500 m and 250 m). Daytime data is corrected for the effects of atmospheric gases and aerosols. Specifically, bands 1 and 2 at 250 m, bands 1 through 7 at 500 m, and bands 1 through 16 at 1 km are corrected, yielding an estimate of the surface spectral reflectance for each band as it would be measured at ground level if there were no atmospheric scattering or absorption. Band quality control information for the correction is also generated (e. g., flags denoting if ancillary data is unavailable, if L1B data is faulty, etc.), for each resolution, and for bands 1 through 7.

The level 2 MOD09 output includes all corrected bands and band quality data, as well as aerosol retrieval data and data for assessing the quality of the aerosol retrieval algorithm (brightness temperature

data from thermal bands 20, 31 and 32, water vapor data, path radiance data, et cetera). Data is written to the output files as Scientific Data Sets (SDSs). One additional data set of importance is the 1 km State QA SDS. While band quality SDSs contain information about the quality of the atmospheric correction of each pixel, the State QA SDS contains information about the pixel's ***state*** -- that is, characteristics of each pixel that are not dependent upon band or resolution. Each State QA pixel contains data such as whether the pixel has been flagged as land, deep ocean, shallow ocean, or as containing cloud, high aerosol, low aerosol, snow, or fire. State QA data reflects the qualities of the pixel itself, not the quality of any of the surface reflectance data.

Other outputs of MOD_PR09.exe are the MOD09 Intermediate Surface Reflectance datasets (MOD09IDN, -IDT and -IDS), in which all surface reflectance data and band quality data for each orbit are geolocated into a linear latitude and longitude projection at 5 km (0.05°) resolution. Data in these files is averaged. These files are intermediate in the sense that they serve as inputs to MOD_PR09C.exe, which composites MOD09IDN, -IDT and -IDS files for each orbit into daily MOD09CMG and MOD09CMA files.

2.3. Products of MOD_PRMGR.exe -- level 2G

MOD_PRMGR.exe is run for each tile in the MODIS sinusoidal grid (figure 1) for each day, and is run on all MOD09 level 2 granules that map to the tile for that day. The number of observations at each pixel is determined not only by the number of orbits at that location (one at the equator and up to 15 at the poles), but also by the spread of observational coverage of off-nadir pixels.

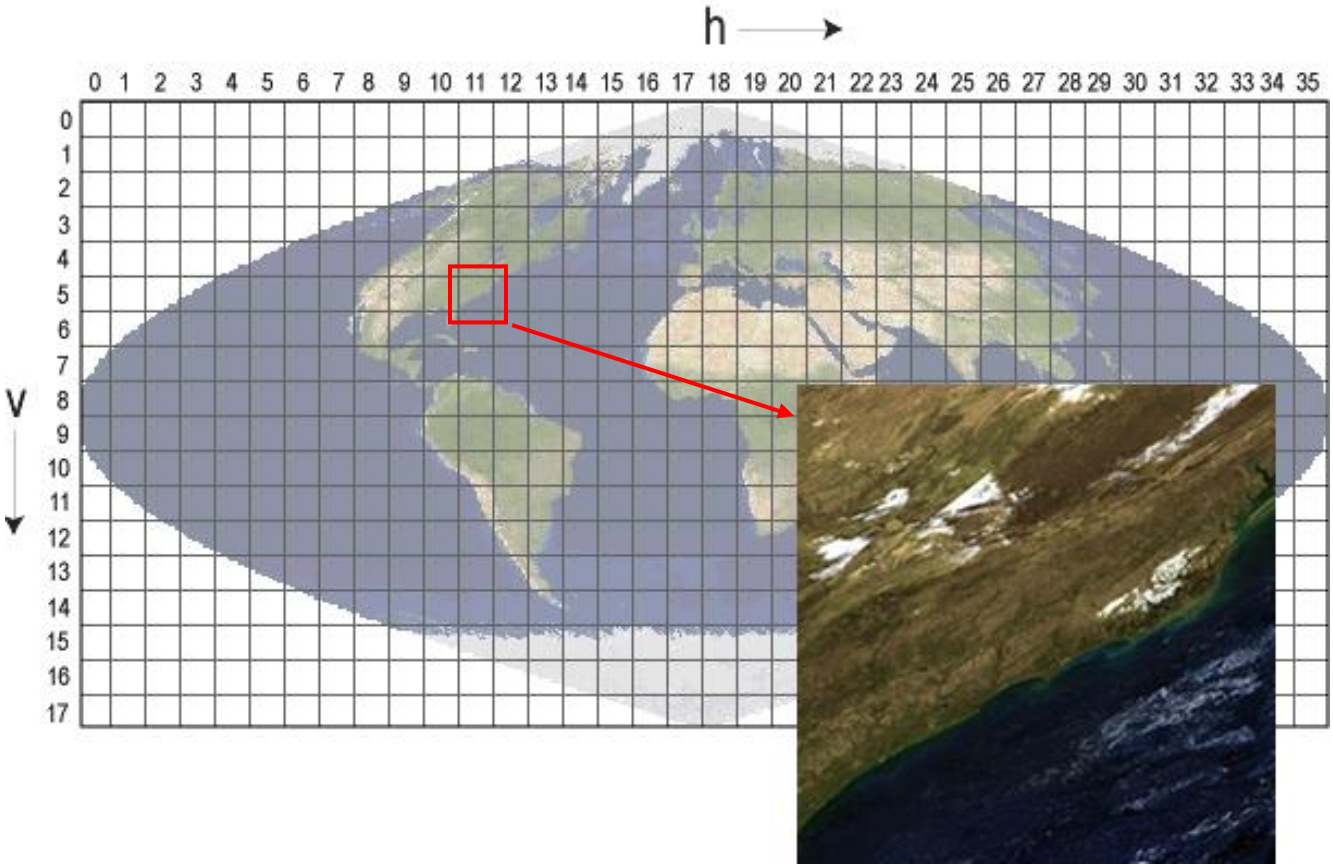

Figure 1. The MODIS sinusoidal grid consists of 460 nonoverlapping tiles which measure approximately 10° x 10°. Data from an example tile (tile h11v05, derived from MOD09A1.A2000337.h11v05.005.2006342055602.hdf) is shown as a RGB-image.

The resulting data can be conceived of as forming a three-dimensional cube, with its depth determined by the number of observations at each pixel. The L2G data is written to output files in two parts: the first part consisting of "first layer" data, data at zero depth in the cube, as a 2-dimensional SDSs; and the second part as either "full format" data (the rest of the observations as 3-dimensional SDSs) or as "compact format" data (the rest of the observations with all fill values removed and written as one-dimensional SDSs). The format operationally generated is the compact format.

The level 2G output includes MOD09GHK (500 m surface reflectance and band quality data), MOD09GQK (250 m surface reflectance and band quality data), and MOD09GST (1 km State QA data). These datasets were archived until collection 5, when they were superseded by level 2G-lite products (see below). Apart from having been geolocated, the 1 km State QA dataset is identical to the State QA in MOD09 files.

2.4. Products of MOD_PR09A.exe -- level 3

MOD_PR09A.exe is run for each tile in the MODIS sinusoidal grid for each 8-day period. Up to and including collection 4, it was run on all MOD09GHK, -GQK and -GST files for that tile and 8-day period. As of collection 5, it is run on all MOD09GA and MOD09GQ files for that tile and 8-day period. All data in input files that map to a given pixel are called observations. The MOD_PR09A compositing process selects the best observation for each pixel. The criteria for selection include observational coverage and view angle, and whether the observation is flagged as cloudy, clear, containing high aerosol or low aerosol, or in cloud shadow.

For each pixel, the compositing steps are

1) Observations from the same orbit are composited by observational coverage. Observations with the highest coverage are saved, and the rest discarded. This yields a list of one observation from each orbit.

2) Each orbit's observation is then assigned a score, based upon whether it is flagged for cloud, cloud shadow, high aerosol or low aerosol, or contains high view angle or low solar zenith angle. The lowest score, 0, is assigned to observations with fill values for data. The remaining scores are

```
 1 BAD          data derived from a faulty or poorly corrected L1B pixel
 2 HIGHVIEW     data with a high view angle (60 degrees or more)
 3 LOWSUN       data with a high solar zenith angle (85 degrees or more)
 4 CLOUDY       data flagged as cloudy or adjacent to cloud
 5 SHADOW       data flagged as containing cloud shadow
 6 UNCORRECTED  data flagged as uncorrected
 7 CLIMAEROSOL  data flagged as containing the default level of aerosols
 8 HIGHAEROSOL  data flagged as containing the highest level of aerosols
 9 SNOW         data flagged as snow
10 GOOD         data which meets none of the above criteria
```

The observation with the highest score and the lowest view angle is selected for the MOD09A1 and MOD09Q1 outputs.

The MOD09A1 outputs also contain a 500 m version of the 1 km State QA composited from all 8-day inputs.

2.5. Products of MOD_PR09G.exe -- level 2G-lite

Each observation in the L2G 'cube' is added not in any meaningful order, but in the order it is read from level 2 files -- so, data in the "first layer" is not inherently more useful than the compact format data. In spite of this, however, in time the "first layer" of the L2G outputs became all that most users paid attention to. In the level 2G-lite format, efforts were made to improve the quality of the "first layer" data by sorting the observations in a manner similar to the selection process of MOD_PR09A.exe (above). The sorting of observations also eliminated the need for several SDSs in the level 2G pointer files, which reduced the overall volume of each day's data.

2.6. Products of MOD_PR09C.exe -- level 3 CMG

The MODIS Surface Reflectance Climate Modeling Grid (CMG) format is level 3 and global; its projection is in linear latitude and longitude (Plate Carre), and its resolution is 0.05° (figure 2). It is derived from MOD09IDN, MOD09IDT and MOD09IDS files for each orbit by compositing the data in these files on the basis of minimum band 3 (459 - 479 nm band) values (after excluding pixels flagged for clouds and high solar zenith angles). The MOD09CMG file contains surface reflectance for bands 1 through 7, band quality data and other important information, but does not contain retrieved aerosol data -- aerosol data is put into a separate file, the MOD09CMA file.

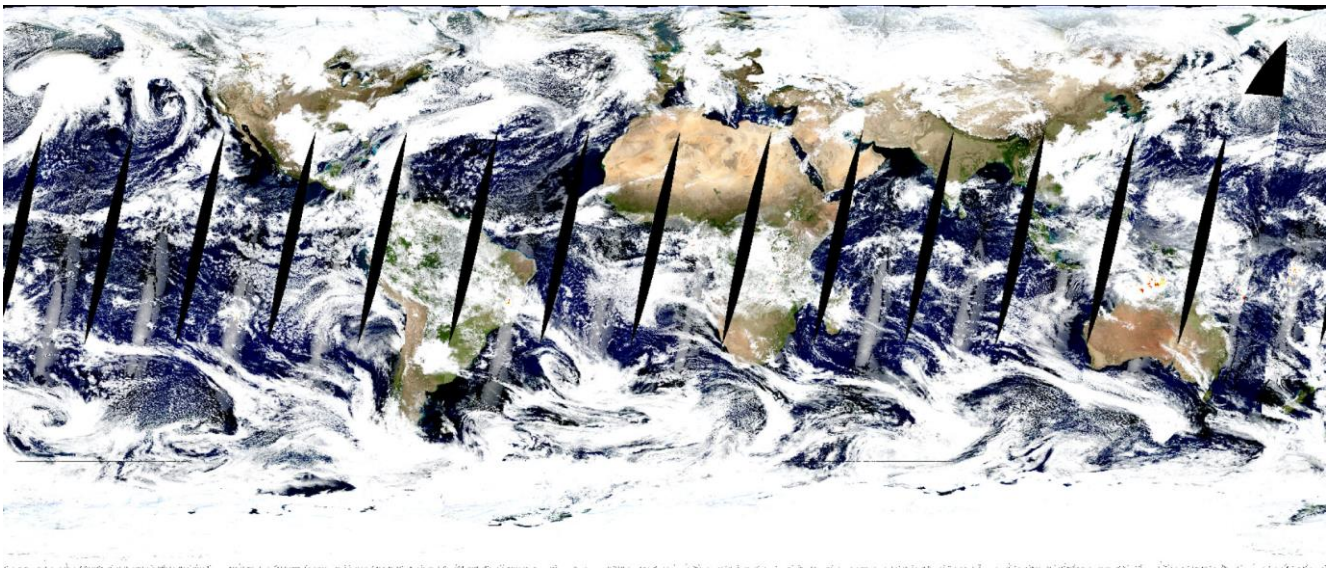

Figure 2. An RGB-image derived from MOD09CMG.A2000338.005.2006332091104.hdf.

3. Detailed product descriptions

3.1. Description and Science Data Sets

3.1.1. MOD09

MODIS Terra/Aqua Surface Reflectance 5-minute L2 Swath

Product description: MOD09 provides MODIS surface reflectance for bands 1 and 2 (at 250m), bands 1 – 7 (at 500 m) and bands 1 – 16 (at 1 km resolution), multiresolution QA, and 1 km observation statistics.

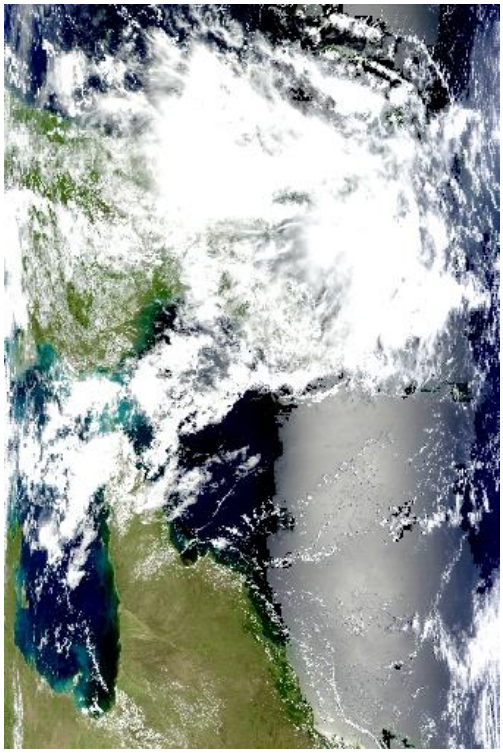

Figure 3. A MOD09 RGB-image composed of surface reflectance measured by MODIS bands 1 (red), 4 (green) and 3 (blue) on January 26, 2011 over northern Australia and Borneo. Product granule ID: MOD09.A2011026.0035.005.2011027195038.hdf

Table 2. Science Data Sets for MOD09.

Data Group	Science Data Sets (HDF Layers (46))	Units	Data Type	Fill Value	Valid Range	Scale Factor
1 km	1km Atmospheric Optical Depth Band 1: (AOT retrieval residual values)	none	16-bit signed integer	60	0 - 5000	0.00001
	1km Atmospheric Optical Depth Band 3	none	16-bit signed integer	60	0 - 5000	0.001
	1km Atmospheric Optical Depth Band 8: (Angstrom exponent values)	none	16-bit signed integer	0	0 - 5000	0.001
	1km Atmospheric Optical Depth Model	none	8-bit unsigned integer	0	1 - 5	1
	1km water_vapor	g/cm^2	16-bit unsigned integer	0	0 - 5000	0.01
	1km Atmospheric Optical Depth Band QA (*see Table 14*)	Bit Field	16-bit unsigned integer	0	0 - 65535	1
	1km Atmospheric Optical Depth Band CM	none	8-bit unsigned integer	0	0 - 19	1
250 m	250m Surface Reflectance Band 1:	Reflectance	16-bit signed	-28672	-100 - 16000	0.0001

	(620-670 nm)		integer			
	250m Surface Reflectance Band 2: (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
500 m	500m Surface Reflectance Band 1: (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 2: (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 3: (459-479 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 4: (545-565 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 5 (1230-1250 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 6: (1628-1652 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	500m Surface Reflectance Band 7: (2105-2155 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
1 km	1km Surface Reflectance Band 1: (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 2: (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 3: (459-479 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 4: (545-565 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 5 (1230-1250 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 6: (1628-1652 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 7: (2105-2155 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 8: (405-420 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 9: (438-448 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 10: (483-493 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 11: (526-536 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 12: (546-556 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 13: (662-672 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001

	1km Surface Reflectance Band 14: (673-683 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 15: (743-753 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	1km Surface Reflectance Band 16: (862-877 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	BAND20: (3.66-3.84 μm)	Degrees K	16-bit un-signed integer	0	0 - 33300	0.01
	1km Surface Reflectance Band 26: (1.36-1.39 μm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	BAND31: (10.78-11.284 μm)	Degrees K	16-bit un-signed integer	0	0 - 3700	0.01
	BAND32: (11.77-12.27 μm)	Degrees K	16-bit un-signed integer	0	0 - 41900	0.01
	BAND20ALBEDO: (3.66-3.84 μm)	Reflectance	16-bit signed integer	-28672	0 - 5000	0.0001
	Latitude	Degrees	32-bit float	0.0	-90.0 – 90.0	1.0
	Longitude	Degrees	32-bit float	0.0	-180 –180	1.0
	250m Reflectance Band Quality (*see Table 8*)	Bit Field	16-bit un-signed integer	-1	0 - 16383	NA
	500m Reflectance Band Quality (*see Table 10*)	Bit Field	32-bit un-signed integer	3	NA	NA
	1km Reflectance Band Quality (*see Table 10*)	Bit Field	32-bit un-signed integer	3	NA	NA
	1km b8-15 Reflectance Band Quality *(see Table 11)*	Bit Field	32-bit un-signed integer	3	NA	NA
	1km b16 Reflectance Band Quality *(see Table 12)*	Bit Field	8-bit un-signed integer	3	0 - 255	NA
	1km Reflectance Data State QA (*see Table 13*)	Bit Field	16-bit un-signed integer	-1	0 - 49151	NA
	1km Band 3 Path Radiance	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001

Note: Tables 2 – 13 list what data fill values should be, but bugs in some programs can result in different fill values for band quality SDSs.

3.1.2. MOD09GQ

MODIS Terra/Aqua Surface Reflectance Daily L2G Global 250 m

Product description: MOD09GQ provides MODIS band 1-2 daily surface reflectance at 250 m resolution. This product is meant to be used in conjunction with the MOD09GA where important quality and viewing geometry information is stored.

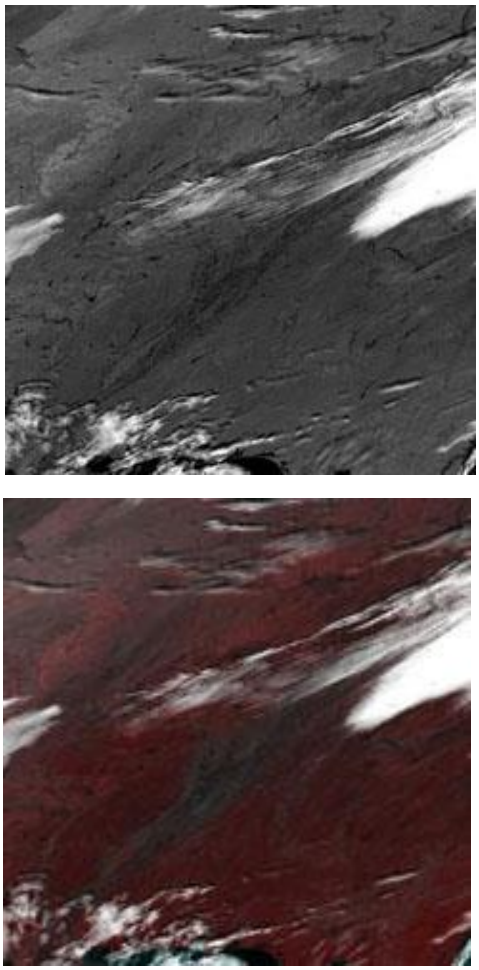

Figure 4. An example of MOD09GQ surface reflectance product. The corresponding MODIS data were collected on December 3, 2000 over Alabama, Mississippi and Florida. Product Granule ID: MOD09GQ.A2000339.h10v05.005.2006339053418.hdf.
Upper image: Band 2 (near-infrared) surface reflectance shown on a gray scale.
Lower image: A false-color RGB combination of bands 2, 1, and 1. Vegetation appears red, water appears black, and clouds appear white.

Table 3. Science Data Sets for MOD09GQ. (Only 2-dimensional SDSs are listed.)

Science Data Sets (HDF Layers) (8)	Units	Data Type	Fill Value	Valid Range	Scale Factor
num_observations: number of observations within a pixel	none	8-bit signed integer	-1	0-127	NA
sur_refl_b01_1: 250m Surface Reflectance Band 1 (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b02_1: 250m Surface Reflectance Band 2 (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
QC_250m_1: 250m Reflectance Band Quality (*see Table 8*)	Bit Field	16-bit unsigned integer	2995	0 - 8000	NA
obscov_1: Observation Coverage (percentage of the grid cell area covered by the observation)	Percent	8-bit signed integer	-1	0 - 100	0.01
iobs_res_1	none	8-bit unsigned integer	255	0 - 254	NA
orbit_pnt_1	none	8-bit signed integer	-1	0 - 15	NA
granule_pnt_1	none	8-bit unsigned integer	255	0 - 254	NA

3.1.3. MOD09GA

MODIS Terra/Aqua Surface Reflectance Daily L2G Global 500 m and 1 km

Product description: MOD09GA provides MODIS band 1-7 daily surface reflectance at 500 m resolution and 1 km observation and geolocation statistics.

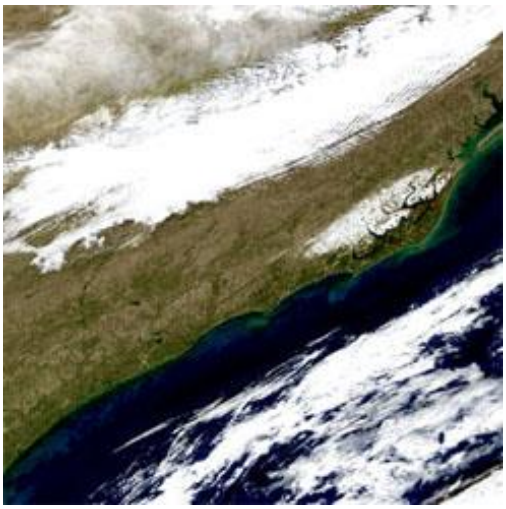

Figure 5. A MOD09GA RGB-image composed of surface reflectance measured by MODIS bands 1 (red), 4 (green) and 3 (blue) on December 6, 2000 over the US East coast. Product granule ID: MOD09GA.A2000340.h11v05.005.2006339102700.hdf

Table 4. Science Data Sets for MOD09GA. (Only 2-dimensional SDSs are listed.)

Data Group	Science Data Sets (HDF Layers (22))	Units	Data Type	Fill Value	Valid Range	Scale Factor
1 km	num_observations_1km: Number of Observations	none	8-bit signed integer	-1	0 - 127	NA
	state_1km_1: Reflectance Data State (*see Table 13*)	Bit Field	16-bit unsigned integer	65535	0 - 57343	NA
	SensorZenith_1	Degree	16-bit signed integer	-32767	0 - 18000	0.01
	SensorAzimuth_1	Degree	16-bit signed integer	-32767	-18000 - 18000	0.01
	Range_1: pixel to sensor	Meter	16-bit unsigned integer		27000 - 65535	0.04
	SolarZenith_1	Degree	16-bit signed integer	-32767	0 - 18000	0.01
	SolarAzimuth_1	Degree	16-bit signed integer	-32767	-18000 - 18000	0.01
	gflags_1: Geolocation flags (*see Table 16*)	Bit Field	8-bit unsigned integer	255	0 - 248	NA
	orbit_pnt_1: Orbit Pointer	none	8-bit signed integer	-1	0 - 15	NA
	granule_pnt_1: Granule Pointer	none	8-bit unsigned integer	255	0-254	NA

500 m	num_observations_500m	none	8-bit signed integer	-1	0 - 127	NA
	sur_refl_b01_1: 500m Surface Reflectance Band 1 (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b02_1: 500m Surface Reflectance Band 2 (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b03_1: 500m Surface Reflectance Band 3 (459-479 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b04_1: 500m Surface Reflectance Band 4 (545-565 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b05_1: 500m Surface Reflectance Band 5 (1230-1250 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b06_1: 500m Surface Reflectance Band 6 (1628-1652 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	sur_refl_b07_1: 500m Surface Reflectance Band 7 (2105-2155 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
	QC_500m_1: 500m Reflectance Band Quality (*see Table 10*)	Bit Field	32-bit unsigned integer	787410671	NA	NA
	obscov_500m_1: Observation coverage	Percent	8-bit signed integer	-1	0 - 100	0.01
	iobs_res_1: Observation number	none	8-bit unsigned integer	255	0 - 254	NA
	q_scan_1: 250m scan value information (*see Table 17*)	none	8-bit unsigned integer	255	0 - 254	NA

3.1.4. MOD09Q1

MODIS Terra/Aqua Surface Reflectance 8-Day L3 Global 250 m

Product description: MOD09Q1 provides MODIS band 1-2 surface reflectance at 250 m resolution. It is a level 3 composite of MOD09GQ. Each MOD09Q1 pixel contains the best possible L2G observation during an 8-day period as selected on the basis of high observation coverage, low view angle, the absence of clouds or cloud shadow, and aerosol loading.

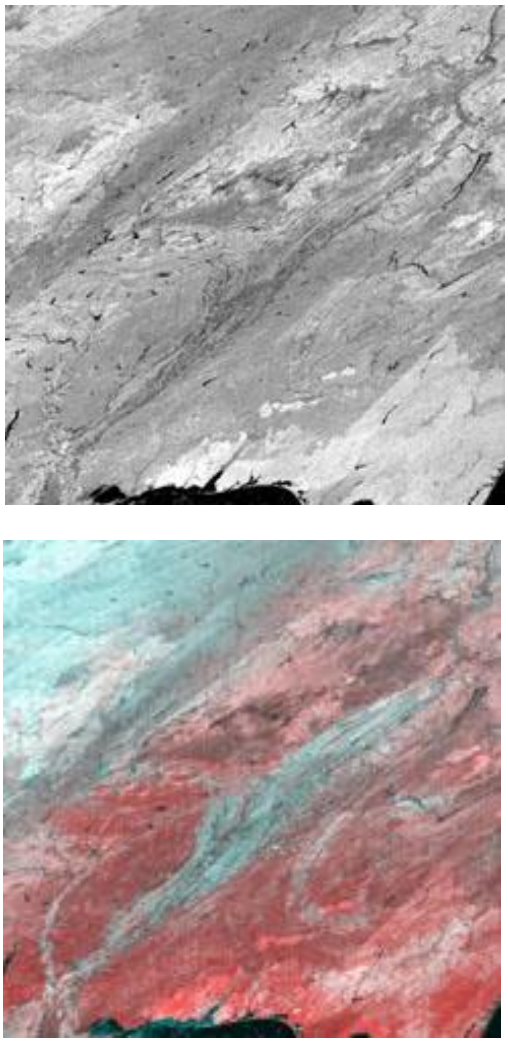

Figure 6. An example of MOD09Q1 surface reflectance product. The corresponding MODIS data were collected in December, 2000 over Alabama, Mississippi and Florida. Product Granule ID: MOD09Q1.A2000337.h10v05.005.2006342044337.hdf.
Upper image: Band 2 (near-infrared) surface reflectance shown on a gray scale.
Lower image: A false-color RGB combination of bands 2, 1, and 1. Vegetation appears red, water appears black, and clouds appear white.

Table 5. Science Data Sets for MOD09Q1

Science Data Sets (HDF Layers (4))	Units	Data Type	Fill Value	Valid Range	Scale Factor
sur_refl_b01:250m Surface Reflectance Band 1 (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b02: 250m Surface Reflectance Band 2 (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_state_250m: 250m Reflectance State QA (*see Table 13*)	Bit Field	16-bit unsigned integer	65535	0 - 57343	NA
sur_refl_qc_250m: 250m Reflectance Band Quality (*see Table 9*)	Bit Field	16-bit unsigned integer	65535	0 - 32767	NA

3.1.5. MOD09A1

MODIS Terra/Aqua Surface Reflectance 8-Day L3 Global 500 m

Product description: MOD09A1 provides MODIS band 1-7 surface reflectance at 500 m resolution. It is a level-3 composite of 500 m resolution MOD09GA. Each product pixel contains the best possible L2G observation during an 8-day period as selected on the basis of high observation coverage, low view angle, absence of clouds or cloud shadow, and aerosol loading.

Figure 7. A MOD09A1 RGB image composed of surface reflectance data measured by bands 1 (red), 4 (green) and 3(blue) in December, 2000 over the US East coast. Granule ID: MOD09A1.A2000337.h11v05.005.2006342055602.hdf

Table 6. Science Data Sets for MOD09A1

Science Data Sets (HDF Layers (13))	Units	Data Type	Fill Value	Valid Range	Scale Factor
sur_refl_b01: 500m Surface Reflectance Band 1 (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b02: 500m Surface Reflectance Band 2 (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b03: 500m Surface Reflectance Band 3 (459-479 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b04: 500m Surface Reflectance Band 4 (545-565 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b05: 500m Surface Reflectance Band 5 (1230-1250 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b06: 500m Surface Reflectance Band 6 (1628-1652 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_b07: 500m Surface Reflectance Band 7 (2105-2155 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
sur_refl_qc_500m: 500m Reflectance Band Quality (*see Table 10*)	Bit Field	32-bit unsigned integer	4294967295	NA	NA
sur_refl_szen: Solar Zenith Angle	Degree	16-bit signed integer	0	0 - 18000	0.01
sur_refl_vzen: View Zenith Angle	Degree	16-bit signed integer	0	0 - 18000	0.01
sur_refl_raz: Relative Azimuth Angle	Degree	16-bit signed integer	0	-18000 - 18000	0.01
sur_refl_state_500m: 500m State Flags (*see Table 13)*	Bit field	16-bit unsigned integer	65535	0 - 57343	NA
sur_refl_day_of_year: Day of Year	Julian day	16-bit unsigned integer	65535	1 - 366	NA

3.1.6. MOD09CMG

MODIS Terra/Aqua Surface Reflectance Daily L3 Global 0.05 Deg CMG

Product description: MOD09CMG provides MODIS band 1-7 surface reflectance at 0.05-degree resolution. This product is based on a Climate Modeling Grid (CMG) for the purpose of being used in climate simulation models.

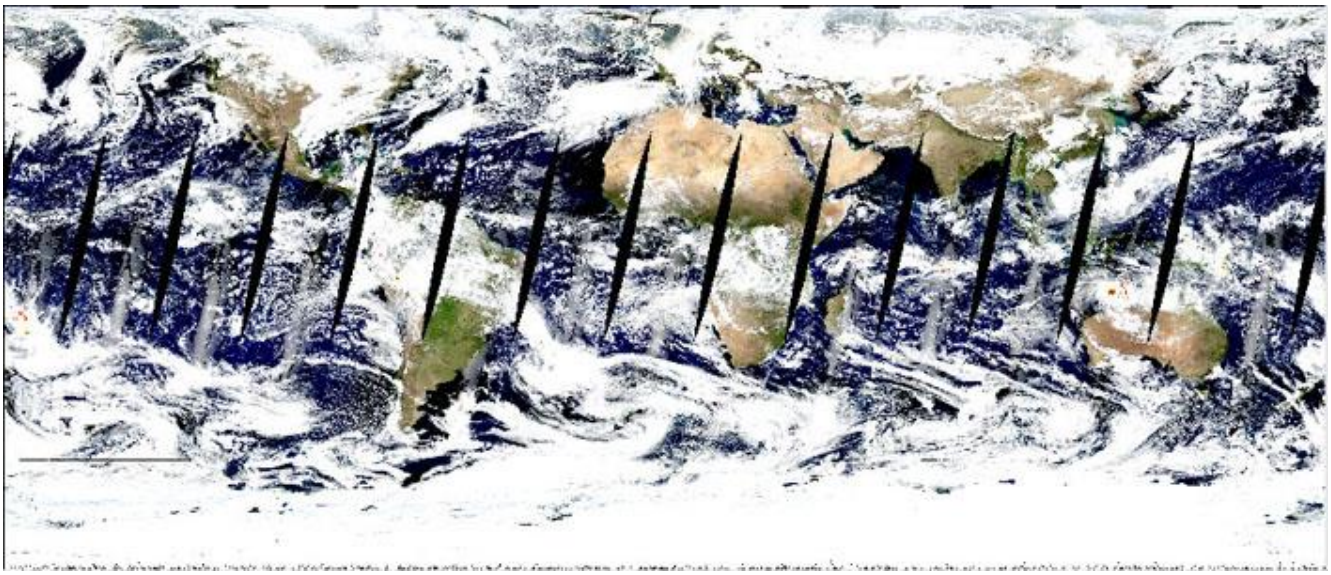

Figure 8. A MOD09CMG RGB-image composed of surface reflectance data measured by bands 1 (red), 4 (green) and 3 (blue) on December 7, 2000. The MODIS product granule ID is MOD09CMG.A2000341.005.2006347161131.hdf.

Table 7. Science Data Sets for MOD09CMG.

Science Data Sets (HDF Layers (25))	Units	Data Type	Fill Value	Valid Range	Scale Factor
Coarse Resolution Surface Reflectance Band 1 (620-670 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 2 (841-876 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 3 (459-479 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 4 (545-565 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 5 (1230-1250 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 6 (1628-1652 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Surface Reflectance Band 7 (2105-2155 nm)	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution Solar Zenith Angle	Degree	16-bit signed integer	-1	0 - 18000	0.01
Coarse Resolution View Zenith Angle	Degree	16-bit signed integer	-1	0 - 18000	0.01
Coarse Resolution Relative Azimuth	Degree	16-bit signed	-1	0 - 18000	0.01

Angle		integer			
Coarse Resolution Ozone	cm atm	8-bit unsigned integer	0	1 -255	0.0025
Coarse Resolution Brightness Temperature Band 20 (3.360-3.840 µm)	degrees K	16-bit unsigned integer	0	1 - 40000	0.01
Coarse Resolution Brightness Temperature Band 21 (3.929-3.989 µm)	degrees K	16-bit unsigned integer	0	1 - 40000	0.01
Coarse Resolution Brightness Temperature Band 31 (10.780-11.280 µm)	degrees K	16-bit unsigned integer	0	1 - 40000	0.01
Coarse Resolution Brightness Temperature Band 32 (11.770-12.270 µm)	degrees K	16-bit unsigned integer	0	1 - 40000	0.01
Coarse Resolution Granule Time	HHMM	16-bit integer	0	1 - 2355	1
Coarse Resolution Band 3 Path Radiance	Reflectance	16-bit signed integer	-28672	-100 - 16000	0.0001
Coarse Resolution QA (*see Table 10*)	Bit Field	32-bit unsigned integer	0	1 -1073741824	NA
Coarse Resolution Internal CM (*see Table 14*)	Bit Field	16-bit unsigned integer	0	1 - 8191	NA
Coarse Resolution State QA (*see Table 13*)	Bit Field	16-bit unsigned integer	0	1 - 65535	NA
Coarse Resolution Number Mapping (*see Table 15*)	Bit Field	32-bit unsigned integer	0	1 - 2097151	NA
number of 500m pixels averaged b3-7	none	16-bit unsigned integer	0	1 - 500	NA
number of 500m rej. detector	none	8-bit unsigned integer	0	1 - 100	NA
number of 250m pixels averaged b1-2	none	16-bit unsigned integer	0	1 - 2000	NA
n pixels averaged	none	8-bit unsigned integer	0	1 - 100	NA

3.2. Data product quality

3.2.1. 250 m resolution QA

Table 8. 250 m Level 2/Level 2G Surface Reflectance Band Quality Description (16-bit). Note that bit 0 is the Least Significant Bit (LSB).

Bit No.	Parameter Name	Bit Comb.	QC_250m
0-1	MODLAND QA bits	00	corrected product produced at ideal quality all bands
		01	corrected product produced at less than ideal quality some or all bands
		10	corrected product not produced due to cloud effects all bands
		11	corrected product not produced due to other reasons some or all bands may be fill value [Note that a value of (11) overrides a value of (01)].
2-3	Spare (unused)	-	---
4-7	band 1 data quality four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds
8-11	band 2 data quality four bit range		SAME AS BAND ABOVE
12	atmospheric correction performed	1	yes
		0	no
13	adjacency correction performed	1	yes
		0	no
14-15	spare (unused)	-	---

Table 9. 250 m Level 3 Surface Reflectance Band Quality Description (16-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	sur_refl_qc_250m
0-1	MODLAND QA bits	00	corrected product produced at ideal quality all bands
		01	corrected product produced at less than ideal quality some or all bands
		10	corrected product not produced due to cloud effects all bands
		11	corrected product not produced due to other reasons some or all bands may be fill value [Note that a value of (11) overrides a value of (01)].
2-3	Spare (unused)	--	--
4-7	band 1 data quality four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds
8-11	band 2 data quality four bit range		SAME AS BAND 1 ABOVE
12	atmospheric correction performed	1	yes
		0	no
13	adjacency correction performed	1	yes
		0	no
14	different orbit from 500 m	1	yes
		0	no
15	spare (unused)	-	---

3.2.2. 500 m, 1km and coarse resolution QA

Table 10. 500 m, 1 km and Coarse Resolution Surface Reflectance Band Quality Description (32-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	QC_500m / Coarse Resolution QA / surf_refl_qc_500m/ 500m Reflectance Band Quality / 1km Reflectance Band Quality
0-1	MODLAND QA bits	00	corrected product produced at ideal quality -- all bands
		01	corrected product produced at less than ideal quality -- some or all bands
		10	corrected product not produced due to cloud effects -- all bands
		11	corrected product not produced for other reasons -- some or all bands, may be fill value (11) [Note that a value of (11) overrides a value of (01)].
2-5	band 1 data quality, four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds
6-9	band 2 data quality four bit range		same as band above
10-13	band 3 data quality four bit range		same as band above
14-17	band 4 data quality four bit range		same as band above
18-21	band 5 data quality four bit range		same as band above
22-25	band 6 data quality four bit range		same as band above
26-29	band 7 data quality four bit range		same as band above
30	atmospheric correction performed	1	yes
		0	no
31	adjacency correction performed	1	yes
		0	no

Table 11. 1 km Surface Reflectance Bands 8-15 Quality Description (32-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	1km Reflectance Band Quality
0-3	band 8 data quality, four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds
4-7	band 9 data quality four bit range		same as band above
8-11	band 10 data quality four bit range		same as band above
12-15	band 11 data quality four bit range		same as band above
16-19	band 12 data quality four bit range		same as band above
20-23	band 13 data quality four bit range		same as band above
24-27	band 14 data quality four bit range		same as band above
28-31	band 15 data quality four bit range		same as band above

Table 12. 1 km Surface Reflectance Band 16 Quality Description (8-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	1km Reflectance Band Quality
0-3	Spare (Unused)		
4-7	band 16 data quality, four bit range	0000	highest quality
		0111	noisy detector
		1000	dead detector, data interpolated in L1B
		1001	solar zenith >= 86 degrees
		1010	solar zenith >= 85 and < 86 degrees
		1011	missing input
		1100	internal constant used in place of climatological data for at least one atmospheric constant
		1101	correction out of bounds, pixel constrained to extreme allowable value
		1110	L1B data faulty
		1111	not processed due to deep ocean or clouds

3.3. Data product state QA flags

Table 13. State QA description (16-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	state_1km / Coarse Resolution State QA / surf_refl_state_500m / 1km Reflectance Data State QA
0-1	cloud state	00	clear
		01	cloudy
		10	mixed
		11	not set, assumed clear
2	cloud shadow	1	yes
		0	no
3-5	land/water flag	000	shallow ocean
		001	land
		010	ocean coastlines and lake shorelines
		011	shallow inland water
		100	ephemeral water
		101	deep inland water
		110	continental/moderate ocean
		111	deep ocean
6-7	aerosol quantity: level of uncertainty in aerosol correction	00	climatology
		01	low
		10	average
		11	high
8-9	cirrus detected	00	none
		01	small
		10	average
		11	high
10	internal cloud algorithm flag	1	cloud
		0	no cloud
11	internal fire algorithm flag	1	fire
		0	no fire
12	MOD35 snow/ice flag	1	yes
		0	no
13	Pixel is adjacent to cloud	1	yes
		0	no
14	Salt pan	1	yes

		0	no
15	internal snow mask	1	snow
		0	no snow

3.4. Internal CM

Table 14. Coarse Resolution Internal CM, 1km Atmospheric Optical Depth Band QA (16-bit). Bit 0 is LSB.

Bit No.	Description	Bit Comb.	state
0	cloudy	1	yes
		0	no
1	clear	1	yes
		0	no
2	high clouds	1	yes
		0	no
3	low clouds	1	yes
		0	no
4	snow	1	yes
		0	no
5	fire	1	yes
		0	no
6	sun glint	1	yes
		0	no
7	dust	1	yes
		0	no
8	cloud shadow	1	yes
		0	no
9	pixel is adjacent to cloud	1	yes
		0	no
10-11	cirrus	00	none
		01	small
		10	average
		11	high
12	pan flag	1	salt pan
		0	no salt pan
13	criteria used for aerosol retrieval	1	criterion 2
		0	criterion 1
14	AOT (aerosol optical thickness) has climatological values	1	yes
		0	no
15	Pixel has interpolated TR, PR or SA data	1	yes
		0	no

3.5. Number Mapping

Table 15. Coarse Resolution Number Mapping (32-bit). Bit 0 is LSB.

Bit No.	Description
0-7	Number of pixel mapping flagged as cloudy
8-15	Number of pixel mapping flagged as cloud shadow
16-23	Number of pixel mapping flagged as adjacent to cloud
24-31	Number of pixel mapping flagged for snow

3.6. Geolocation flags

Table 16. 1 km Geolocation Flags (16-bit). Bit 0 is LSB.

Bit No.	Description	Bit Comb.	state_1km
0-2	Fill	00	Fill
3	Sensor range validity flag	0	Valid
		1	Invalid
4	Digital elevation model quality flag	0	Valid
		1	Missing/inferior
5	Terrain data validity	0	Valid
		1	Invalid
6	Ellipsoid intersection flag	0	Valid intersection
		1	No intersection
7	Input data flag	0	Valid
		1	Invalid

3.7. Scan value information

Table 17. 250 m Scan Value Information Description (8-bit). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	q_scan
0	scan of observation in quadrant 1 [-0.5 row, -0.5 column]	1	yes
		0	no
1	scan of observation in quadrant 2 [-0.5 row, +0.5 column]	1	yes
		0	no
2	scan of observation in quadrant 3 [+0.5 row, -0.5 column]	1	yes
		0	no
3	scan of observation in quadrant 4 [+0.5 row, +0.5 column]	1	yes
		0	no
4	missing observation in quadrant 1 [-0.5 row, -0.5 column]	1	same
		0	different
5	missing observation in quadrant 2 [-0.5 row, +0.5 column]	1	same
		0	different
6	missing observation in quadrant 3 [+0.5 row, -0.5 column]	1	same
		0	different
7	missing observation in quadrant 4 [+0.5 row, +0.5 column]	1	same
		0	different

Note: The 250 m samples are for each of four quadrants within a 500 m cell. The first line/sample is in the upper left (north-west) corner of the image.

- 0 -- first 250m line (row), first 250m sample (column)
- 1 -- first 250m line, second 250m sample
- 2 -- second 250m line, first 250m sample
- 3 -- second 250m line, second 250m sample

3.8. Orbit and coverage

Table 18. Orbit and coverage data set (8-bit) for Collection 4 (the orbit the observation came from and the observation coverage). Bit 0 is LSB.

Bit No.	Parameter Name	Bit Comb.	orb_cov_1
0-3	orbit number	range: from 0 to 13 key: from 0000 (0) to 1011 (13)	
4	scan half flag	0	top half
		1	bottom half
6-7	land/water flag	000	0.0 – 12.5%
		001	12.5 – 25.0%
		010	25.0 – 37.5%
		011	37.5 – 50.0%
		100	50.0 – 62.5%
		101	62.5 – 75.0%
		110	75.0 – 87.5%
		111	87.5 – 100.0%

Note: The orbit number is not the absolute orbit number but a relative orbit number in the file. In addition a flag is stored which distinguishes between observations which are in the top half of the scan (the first 5 1 km scan lines in the along track direction) and the bottom half of the scan (the last 5 1 km scan lines). The observation coverage is the area of intersection of observation footprint and cell divided by the area of the observation.

4. Frequently asked questions.

4.1. How are MODLAND QA bits set, and how should they be used?

The MODLAND QA bits are bits 0 and 1 of the band quality SDS pixel values. They are meant as a brief summary of quality control aspects of each pixel, with ‘00’ meaning the best possible atmospheric correction and any other value indicating errors or problems, and serving as a flag to check other QA data in more detail. Although the MODLAND QA bits are still set in this manner, other band quality bits and other QA products (e. g., the State QA) have superseded the MODLAND QA bits in importance.

a) MOD_PR09.exe processing.

In the MOD_PR09.exe program, the MODLAND QA bits are initialized to '00' and then set in three passes:

Pass #1:

```
The MODLAND QA bits are set to '11' for pixels over oceans, if pixels over
oceans are not being atmospherically corrected.
or else, they are set to '10' for pixels over clouds, if pixels over clouds
are not being atmospherically corrected.
```

However, since at least collection 3 and up to the present, atmospheric correction is being performed over clouds and ocean, so the MODLAND QA bits are not being set in pass #1.

In other words, the description "corrected product not produced due to cloud effects" for bits '10' in the MODLAND QA bits is relevant only for PGEs that process cloudy pixels differently than non-cloudy pixels; but this description is no longer relevant for PGE11, which applies an atmospheric correction algorithm to both cloudy and non-cloudy pixels. PGE11 produces the level 2 MOD09 product from which L2G and L3 MOD09 products are in turn produced. For MOD09 products the MODLAND QA bits are not to be used for determining whether a pixel is cloudy or not. Other QA products (e. g., the state QA) contain cloud information (below).

Pass #2:

```
The MODLAND QA bits are then set to '11' for pixels that have not been at-
mospherically corrected.
```

Pass #3:

Note that passes 1 and 2 are with respect to each pixel, but not with respect to each band. The next pass goes through each band at that pixel and resolution and resets the MODLAND QA bits like this:

```
'11' - for any band
    that is a fill value (after processing), and not because of
           clouds or ocean (band quality value 15).
    that has a solar zenith angle above 86° (band quality value 9)
    that corresponds to missing L1B input (band quality value 11).
    that corresponds to faulty L1B input (band quality value 14).
```

```
or '01' (if it hasn't been set to '11' already), for any band
    that has a solar zenith angle between 85° and 86° (band quality
       value 10)
    in which an internal constant was used in place of climatological
       data for an atmospheric constant (band quality value 12)
     in which the atmospherically-corrected value is out of bounds
       and has been constrained to an extreme allowable value (either
       -100 or 16000) (band quality value 13)
```

In summary: the MODLAND QA bits default to '00' (ideal quality), are set to '01' (less than ideal quality, some or all bands) for data corrected with an internal constant, or data constrained to extreme allowable values, or to data at a high solar zenith angle; and are set to '11' (corrected product not produced for other reasons, some or all bands) for uncorrected data, missing L1B, faulty L1B, or data at solar zenith angles beyond 86°.

b) MOD_PRGR.exe processing.

The MOD_PRGR.exe program grids data from level 2 MOD09 files into MOD09GA and MOD09GQ files. Regions of L2G files that are not populated with MOD09 data (e. g., missing orbits, spaces between orbits) contain fill values for reflectance data and for band quality data. In these places all band quality data bits have a value of 1, and the MODLAND QA bits are '11'. However these regions are clearly flagged for non-use (e. g., containing zeros in the 'num_observations' SDSs).

So from where should cloud information be taken?

All cloud information should be derived from State QA SDSs. Information labeled as cloud information in band quality SDSs is not to be considered as reliable as State QA cloud information. In particular,

1) bits labeled as "cloud state" in MOD09GQ or MOD09GQK files (SDS 'QC_250m') or in MOD09Q1 files (SDS 'sur_refl_qc_250m') are to be ignored: they have not been populated since Collection 3.

2) the MODLAND QA bits are also not to be taken as denoting cloud status. They are meant to denote whether a pixel was not processed because of cloud effects, but PGE11 has been doing atmospheric correction over clouds since at least Collection 3. (See above.)

All cloud information should be derived from State QA SDSs, and in particular, the SDS 'state_1km' in MOD09GA or MOD09GST files, and/or SDS 'sur_refl_state_500m' in MOD09A1 files. In these SDSs, each pixel contains two cloud masks: one that is read from MOD35 (bits 0-1) and one that is generated by PGE11's internal cloud algorithm (bit 10).

4.2. How do you unpack Level 2G or Level 2G-lite's compact data?

Compact data is written to one-dimensional SDSs in observation order; that is, all the additional observations for row 0, column 0 are written, then all additional observations for row 0, column 1, and so on. If a pixel has no additional observations, nothing is written to the compact SDS for that pixel. The number of additional observations written to the compact data at each pixel is stored in the 2-dimensional SDS 'num_observations'.

To expand the compact data to its original three-dimensional form, the compact data and the 'num_observations' SDSs must have memory allocated for them and must be read. Additionally;

1) Determine the number of additional layers in the L2G file.
   This value can be read from the metadatum ADDITIONALLAYERS
   in each L2G file. (In the example below, variable `depth` is set to that value.)

2) For each additional layer, allocate memory for the uncompacted data (variable `uncompact_data[][]` below):
   e. g., for integer data:

```
uncompact_data = (int **)malloc(depth*sizeof(int *));
for(i=0;i<depth;i++) {
    uncompact_data[i] = (int *)malloc(rows*columns*sizeof(int));
      }
```

3) Then, for each column in each row:

```
l=0;
x=0;
for(i=0;i<rows;i++) {
    for(j=0;j<columns;j++) {
        nobs = number_of_observations[l];
        for (k=0;k<nobs-1;k++) uncompact_data[k][l] = compact_data[x++];
       for (   ;k<depth;k++)  uncompact_data[k][l] = fill_value;
        l++;
        }
   }
```

4.3. Of what does the atmospheric correction algorithm consist?

Calibrated radiance data is scaled and divided by the cosine of the solar zenith angle, yielding a top-of-atmosphere value. Parameters related to atmospheric scattering and absorption (atmospheric intrinsic reflectance, gaseous transmission, atmospheric transmission, and spherical albedo) are computed by interpolation from precomputed look-up tables, and applied to the top-of-atmosphere data.

Ancillary data is either read from coarse resolution meterological data and interpolated spatially and temporally (surface pressure, ozone), or is calculated within MOD_PR09.exe (water vapor, aerosol optical thickness). Aerosol optical thickness (AOT) is estimated by comparing actual corrected top-of-atmosphere values to modeled top-of-atmosphere values with known amounts of AOT added. The derived AOT is then used in a second pass of atmospheric correction.

[see also
Vermote E.F. and Saleous, N., 2006, Operational Atmospheric Correction of MODIS Visible to Middle Infrared Land Surface Data in the Case of an Infinite Lambertian Target, chapter 8 in "Earth Science Satellite Remote Sensing, Vol. 1: Science and Instruments" John J. Qu et al., Springer Berlin Heidelberg.
Vermote E.F., El Saleous N., Justice C., 2002, Atmospheric correction of the MODIS data in the visible to middle infrared: First results, Remote Sensing Of Environment, 83, 1-2, 97-111.
Petitcollin F. and Vermote E. F., 2002, Land Surface Reflectance, Emissivity and Temperature from MODIS Middle and Thermal Infrared data, Remote Sensing Of Environment, 83, 1-2,112-134.]

4.4. What is surface reflectance? What are its units?

Surface reflectance is the amount of light reflected by the surface of the earth; it is a ratio of surface radiance to surface irradiance, and as such is unitless, and typically has values between 0.0 and 1.0. MOD09's surface reflectance values are scaled by 10000 and then cast to 16-bit integers, so surface reflectance values in MOD09 files are typically between 0 and 10000. The atmospheric correction algorithm that is used results in values normally between -100 and 16000. Any values outside of this range are either uncorrected L1B data (e. g., data at high solar zenith angles) or fill values (e. g., data between orbits in L2G or L2G-lite files).

4.5. All I've seen in this document is "MOD", meaning Terra -- what about Aqua ("MYD")?

The "MOD" prefix should be taken as referring to the datasets in general, *not* to Terra-derived data in particular. All programs discussed in this document process either Terra- or Aqua-derived data. All datasets referred to in this document will be referred to as "MOD" data, but meaning either Terra- or Aqua-derived data.

No combined Terra+Aqua MOD09 products are available or planned for.

5. Caveats and Known Problems

The performance of the atmospheric correction algorithm degrades as the view and solar zenith angles get larger and as aerosol optical thickness gets larger; the algorithm is also less accurate for bands at shorter wavelengths. The level of accuracy of the atmospheric correction is typically

$$\pm(0.005 + 0.05*\text{reflectance})$$

under favorable conditions (not high aerosol). The look-up tables used in the atmospheric correction algorithm also assume upper limits of 5.0 for aerosol optical thickness and 75° for solar zenith angles.

6. Data ordering (& browsing)

6.1. Where to get data from

All of the file types listed as 'publically available' in Table 1 can be obtained from one or more of the following websites:

a) EOS (Earth Observing System) Data Gateway

The main source of data, a "place an order" database, a quick-start tutorial.

Link: http://eospso.gsfc.nasa.gov/

b) LP DAAC (Land Processes Distributed Active Archive Center)

Useful information and links, ftp-access to a subset of MODIS land products.

Link: https://lpdaac.usgs.gov/

c) US Geological Survey (USGS) Global Visualization (GloVIS)

Access to selected MODIS land products with browse capability.

Link: http://glovis.usgs.gov/

d) MODIS Land Global Browse Images

5-km versions of selected product to enable synoptic quality assessment.

Link: http://landweb.nascom.nasa.gov/cgi-bin/browse/browse.cgi

e) Earth Science Data Interface (ESDI) at the Global Land Cover Facility

32-day composites, images in GeoTiff format, limited products.

Link: http://landcover.org/index.shtml

6.2. Data product granule ID

All archived data is accessed by its LOCALGRANULEID. For data in the sinusoidal grid, the LOCALGRANULEID is constructed like this:

Example 1: MOD09GHK.A2006351.h18v06.004.2006353163945.hdf

MOD09GHK: product name (MODIS Terra Surface Reflectance Daily L2G Global 500 m)

A2000351: Acquisition year (2006) and Julian day (351)

h18v06: tile ID (see figure 1)

004: Collection 4

2006353163945: Production year (2006), Julian day (353), and time (16:39:45)

For Climate Modeling Grid data (CMGs), the LOCALGRANULEID is constructed like this:

Example 2: MOD09CMG.A2000338.005.2006332091104.hdf

MOD09CMG: product name (MODIS Terra Surface Reflectance Daily L3 Global 0.05Deg. CMG)

A2000338: Acquisition year (2000) and Julian day (338)

005: Collection 5

2006332091104: Production year (2006), Julian day (332), and time (09:11:04)

6.3. Data viewing tools

a) Imager (platform: Linux)

A software tool specifically designed by the MODIS LSR SCF for viewing surface reflectance suites. *Link:* http://modis-sr.ltdri.org/pages/software.html

b) HDFLook (platforms: SUN, AIX, SGI, Linux, MacOSX, Cygwin)

A multifunctional data processing and visualization tool for land, ocean and atmosphere MODIS data. *Link:* http://www-loa.univ-lille1.fr/Hdflook/hdflook_gb.html

c) ENVI (platforms: Windows & Linux)

A software for the visualization, analysis, and presentation of all types of digital imagery.

Link: http://www.ittvis.com/envi/

d) HDF Explorer (platform: Windows)

A software environment where data are first viewed in a tree-like interface, and then optionally loaded and visualized in a variety of ways. *Link:* http://www.space-research.org/

7. Useful links

a) Detailed description of changes in the MOD09 algorithm and other MODIS land science algorithms at the MODIS Land Quality Assessment website:

Link: http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi

b) The MODIS Land Surface Reflectance Science Computing Facility's website:

Link: http://modis-sr.ltdri.org.
E-mail: mod09@ltdri.org