MODIS Land Products Quality Assurance Tutorial: Part-4

How to interpret and use MODIS QA information in the BRDF and Albedo product suite

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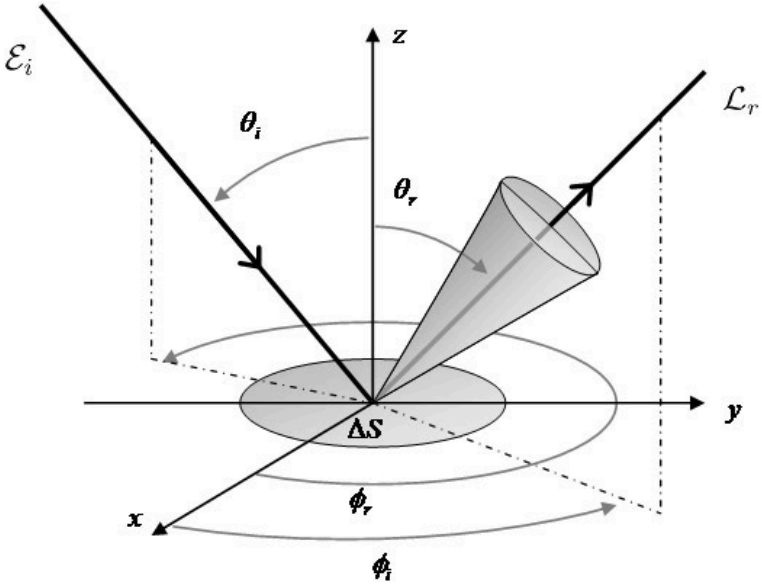
Introduction

This fourth and final part of the MODIS Land Products QA Tutorial provides the knowledge base to interpret and understand the QA information in the MODIS BRDF and Albedo (MCD43) product suite. It contains QA sources specific to the BRDF and Albedo product collection, interpretation examples, and a demonstration of how one of the LDOPE tools helps deconstruct the QA information. As described in **Part-1** of this tutorial, file-level metadata broadly summarizes data quality at the file-level, and is only intended to help in the search and discovery process. Users should not solely depend on file-level metadata as they evaluate data for their application needs but should instead consult the pixel-level information. **The primary focus of this tutorial is pixel-level metadata** in the MODIS BRDF and Albedo product suites.

1. Introduction to the BRDF and Albedo product suite

The MODIS land mission offers a number of Bi-directional Reflectance Distribution Function (BRDF) and Albedo products that are generated using inputs derived from both the Terra and Aqua incarnations of the MODIS instrument (Schaaf et al., 2002).

A surface's BRDF defines how it reflects light from an opaque surface through scattering as a function of the illumination and viewing angle geometries at particular wavelengths. Each of the directions, i.e., incoming radiance (or irradiance) and outgoing radiance (or exitance) is defined by two parameters, the azimuth angle and the zenith angle (Fig. 1).



Ei: Irradiance (light incident on the material)
Lr: Radiance (light reflected by the material)
θi, θr: (Zenith) angles made by the irradiance and radiance with the surface normal (z)
ΔS: Elementary/arbitrary patch of surface
φi, φr: (Azimuth) angles between the orthogonal axis, and irradiance and radiance, respectively

Fig. 1: Defining parameters for BRDF

Albedo is the fraction of solar energy reflected back from Earth into space, and is a measure of Earth surface's reflectivity. The nature of illumination (direct versus diffuse) determines two kinds of albedo: directional-hemispherical and bi-hemispherical.

Directional-hemispherical albedo is the reflectance of a surface under direct illumination (with no diffuse illumination component). Directional-hemispherical reflectance is the integral of the BRDF over all viewing directions, and is also called "black-sky albedo".

Bi-hemispherical reflectance is the reflectance of a surface under diffuse illumination (with no direct illumination component). Bi-hemispherical reflectance is the integral of the BRDF over all viewing and illumination directions of a hemisphere, and is also called "white-sky albedo."

BRDF models play a key role in the inference of land surface parameters (Leaf-Area Index, Fraction of Photosynthetically Active Radiation, etc.) at regional and global scales by helping us better understand the transfer of energy and mass between terrestrial ecosystems and the atmosphere. They help define the lower radiometric boundary condition for any radiative transfer problem in the atmosphere, and are therefore relevant to climate modeling and energy budget investigations. Albedo-informed global surface reflectance is very useful to monitor annual growth cycles of crops and vegetation besides evaluating drought conditions.

The MCD43 BRDF-Albedo suite consists of the following twelve combined Terra and Aqua MODIS products:

Platform	Short Name	Product	Spatial Resolution	Temporal Frequency	Raster Type
Terra+Aqua	MCD43A1	BRDF-Alb. Parameters	500 m	16-day	Tile
Terra+Aqua	MCD43B1	BRDF-Alb. Parameters	1000 m	16-day	Tile
Terra+Aqua	MCD43C1	BRDF-Alb. Parameters	5600 m	16-day	CMG*
Terra+Aqua	MCD43A2	BRDF-Alb. Quality	500 m	16-day	Tile
Terra+Aqua	MCD43B2	BRDF-Alb. Quality	1000 m	16-day	Tile
Terra+Aqua	MCD43C2	BRDF-Alb. Snow-Free Quality	5600 m	16-day	CMG*
Terra+Aqua	MCD43A3	Albedo	500 m	16-day	Tile
Terra+Aqua	MCD43B3	Albedo	1000 m	16-day	Tile
Terra+Aqua	MCD43C3	Albedo	5600 m	16-day	CMG*
Terra+Aqua	MCD43A4	BRDF-Nadir Adj. Reflectance	500 m	16-day	Tile
Terra+Aqua	MCD43B4	BRDF-Nadir Adj. Reflectance	1000 m	16-day	Tile
Terra+Aqua	MCD43C4	BRDF-Nadir Adj. Reflectance	5600 m	16-day	CMG*

*Climate Modeling Grid

2. QA sources within the BRDF and Albedo product suite

The Combined Terra and Aqua MODIS BRDF and Albedo products contain the following QA Science Data Set (SDS) layers:

Short Name	QA Science Datasets
MCD43A2	BRDF Albedo Quality Snow BRDF Albedo BRDF Albedo Ancillary BRDF Albedo Band Quality
MCD43B2	BRDF Albedo Quality Snow BRDF Albedo BRDF Albedo Ancillary BRDF Albedo Band Quality
MCD43C1	BRDF Quality
MCD43C2	BRDF Quality
MCD43C3	BRDF Quality
MCD43C4	BRDF Quality

Important Reminder

How QA information is packaged and made available within the BRDF-Albedo product suite changed following the V4 (or C4) MODIS collection. Starting with the V5 (or C5) collection, there are dedicated QA products that supply information applicable to the other products in this suite. In other words, 500 m and 1000 m BRDF-Albedo Parameters, Albedo, and Nadir BRDF-Adjusted Reflectance products do not carry their own QA layers but are centrally served by separate QA-specific MCD43A2 and MCD43B2 products.

The Climate Modeling Grid products do carry their own dedicated QA information. MCD43C1, MCD43C2, MCD43C3 and MCD43C4 each contain a QA layer called "BRDF_Quality." MCD43C2 (BRDF-Albedo Quality CMG), contrary to its name, is not a universal QA-specific product serving the MCD43C suite. MCD43C2 is an additional BRDF-Albedo parameters product (identical to the MCD43C1 BRDF-Albedo Parameters CMG) that conveys information on snow-free pixels. MCD43C1 retrieves information on snow-covered pixels. The following diagram (Fig. 2) describes the broad arrangement and structure of the MODIS BRDF-Albedo suite vis-à-vis their QA information source.

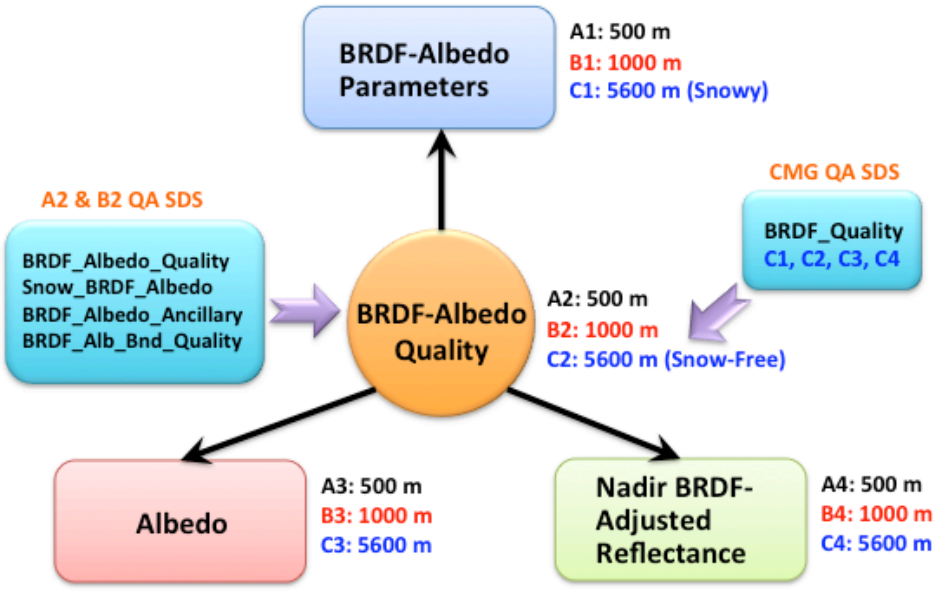


Fig. 2: Terra + Aqua MODIS BRDF-Albedo (MCD43) QA information structure

3. Interpretation examples from 500 m 16-day BRDF-Albedo Parameters, Albedo, and Nadir BRDF-Adjusted Reflectance products

Products interpreted:
MCD43A1 (Terra+Aqua MODIS BRDF-Albedo Model Parameters 16-Day Global 500 m)
MCD43A3 (Terra+Aqua MODIS Albedo 16-Day Global 500 m)
MCD43A4 (Terra+Aqua MODIS Nadir BRDF-Adj. Reflectance 16-Day Global 500 m)

Dataset names:
MCD43A1.A2006153.h13v09.005.2008126030730.hdf (BRDF-Albedo Parameters)
MCD43A3.A2006153.h13v09.005.2008126030730.hdf (Albedo)
MCD43A4.A2006153.h13v09.005.2008126030731.hdf (Nadir BRDF-Adj. Reflectance)

Associated QA dataset name:
MCD43A2.A2006153.h13v09.005.2008126030730.hdf

All three 500 m products (MCD43A1, MCD43A3, and MCD43A4) are mapped to uniform gridded tiles, and their associated QA dataset (MCD43A2) contains four SDS layers: BRDF Albedo Quality, Snow BRDF Quality, BRDF Albedo Ancillary, and BRDF Albedo Band Quality. The following examples illustrate how to interpret QA information from each of these SDS layers.

BRDF Albedo Quality is a mandatory QA layer, which conveys BRDF and Albedo quality information in 8-bit unsigned integers that are not bit-packed, and hence, do not require any decimal-to-binary conversion before they are ready for interpretation. Users may read and interpret directly from existing values. The range of values and their meanings include the following:

Value (BRDF Albedo Quality)	Interpretation
0	Processed, Good quality (Full BRDF inversions)
1	Processed, see other QA (Magnitude BRDF inversions)
255	Fill-value

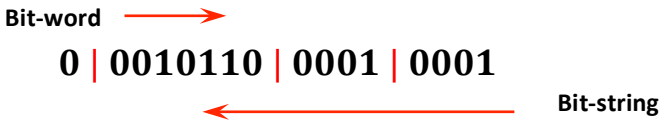
Snow BRDF Quality is also a mandatory QA layer, which conveys (at the pixel-level) if the BRDF-Albedo retrieval is either snow-free or snow-accompanied in 8-bit unsigned integers that are not bit-packed, and ready for direct interpretation. The range of values and their meanings include the following:

Value (Snow BRDF Quality)	Interpretation
0	Snow-free Albedo retrieved
1	Snow Albedo retrieved
255	Fill-value

BRDF Albedo Ancillary provides relevant ancillary information in 16-bit integers (bit-packed) that requires parsing before interpretation. The decimal integers are first converted to binary. A slight departure in the case of the bit-packed BRDF-Albedo QA products is that following the decimal-to-binary conversion, the individual bit-words (in binary) are interpreted through their decimal equivalent. The following examples demonstrate how to deconstruct two pixels from the 500 m QA (MCD43A2) product:

5649 (Row: 98 and Column: 233)
8225 (Row: 2385 and Column: 2018)

The first decimal value of **5649** converts to a 16-bit binary value of **0001011000010001**. This bit-string, as assigned to the individual bit numbers, breaks down thus (based on the QA index specified in the MCD43A2 product's file specifications, whose URL is provided in the references):



This binary bit-string is parsed from right to left[1], and the individual bits within a bit-word are read from left to right as we convert them to ascertain their decimal values as described in the following table:

[1]All HDF-EOS products are written in the big-endian referencing scheme. The bits are always numbered from right (least-significant bit) to left (most-significant bit).

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Platform	0001	1	Terra/Aqua
04–07	Land/Water	0001	1	Land (Nothing else but land)
08–14	Solar Zenith Angle at Local Solar Noon	0010110	22	22°
15	QA-Fill	0	0	Not Fill-value

The second decimal value of **8225** converts to a 16-bit binary value of **0010000000100001**. This bit-string, as assigned to the individual bit numbers, breaks down thus:

0 | 0100000 | 0010 | 0001 … which is interpreted as follows:

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Platform	0001	1	Terra/Aqua
04–07	Land/Water	0010	2	Ocean coastlines & lake shorelines
08–14	Solar Zenith Angle at Local Solar Noon	0100000	32	32°
15	QA-Fill	0	0	Not Fill-value

BRDF Albedo Band Quality is the last SDS in the MCD43A2 product, and is identified as BRDF Albedo Inversion in the File Specifications. It provides the quality of the BRDF inversion for MODIS bands 1 through 7. This information is encoded in a 32-bit binary string that is bit-packed and requires parsing and interpretation similar to the previous SDS. The following examples demonstrate how to deconstruct two pixels from the 500 m QA (MCD43A2) product:

33554432 (Row: 1341 and Column: 1542)
53687091 (Row: 2157 and Column: 2196)

The first decimal value of **33554432** converts to a 32-bit binary value of **0000|00100000000000000000000000000**. Users need to add four zeros on the left to complete the 32-bits. This bit-string, as assigned to the individual bit numbers, breaks down thus:

0 | 000 | 0010 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 … which is interpreted as follows:

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Band-1 Quality	0000	0	Best quality, Full inversion
04–07	Band-2 Quality	0000	0	Best quality, Full inversion
08–11	Band-3 Quality	0000	0	Best quality, Full inversion
12–15	Band-4 Quality	0000	0	Best quality, Full inversion
16–19	Band-5 Quality	0000	0	Best quality, Full inversion
20–23	Band-6 Quality	0000	0	Best quality, Full inversion
24–27	Band-7 Quality	0010	2	Magnitude inversion (numobs >= 7)
28–30	TBD	000		
31	QA-Fill	0	0	Not Fill-value

The second decimal value of **53687091** converts to a 32-bit binary value of **0000|00110011001100110011001100110011**. Users need to add four zeros on the left to complete the 32-bits. This bit-string, as assigned to the individual bit numbers, breaks down thus:

0 | 000 | 0011 | 0011 | 0011 | 0011 | 0011 | 0011 | 0011 … which is interpreted as follows:

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Band-1 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
04–07	Band-2 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
08–11	Band-3 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
12–15	Band-4 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
16–19	Band-5 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
20–23	Band-6 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
24–27	Band-7 Quality	0011	3	Magnitude inversion (numobs >= 3 & < 7)
28–30	TBD	000		
31	QA-Fill	0	0	Not Fill-value

4. Interpretation examples from 1000 m 16-day BRDF-Albedo Parameters, Albedo, and Nadir BRDF-Adjusted Reflectance products

Products interpreted:

MCD43B1 (Terra+Aqua MODIS BRDF-Albedo Model Parameters 16-Day Global 1 km)

MCD43B3 (Terra+Aqua MODIS Albedo 16-Day Global 1 km)

MCD43B4 (Terra+Aqua MODIS Nadir BRDF-Adjusted Reflectance 16-Day Global 1 km)

Dataset names:

MCD43B1.A2006153.h13v09.005.2008126030732.hdf (BRDF-Albedo Parameters)

MCD43B3.A2006153.h13v09.005.2008126030731.hdf (Albedo)

MCD43B4.A2006153.h13v09.005.2008126030731.hdf (Nadir Adj.-BRDF Reflectance)

Associated QA dataset name:

MCD43B2.A2006153.h13v09.005.2008126030732.hdf

All three 1 km products (MCD43B1, MCD43B3, and MCD43B4) are mapped to uniform gridded tiles, and their associated QA dataset (MCD43B2) contains four SDS layers: BRDF Albedo Quality, Snow BRDF Quality, BRDF Albedo Ancillary, and BRDF Albedo Band Quality. The process of interpreting the QA information in the 1000 m products is the same as described in sub-section-9 for 500 m products. The only exception exists with the BRDF Albedo Band Quality SDS layer, which has a slightly different bit-legend, as illustrated in the following examples.

53687091 (Row: 573 and Column: 1194)

8706 (Row: 585 and Column: 1192)

The first decimal value of **53687091** converts to a 32-bit binary value of **0000|00110011001100110011001100110011**. Users need to add four zeros on the left to complete the 32-bits. This bit-string, as assigned to the individual bit numbers, breaks down thus:

0 | 000 | 0011 | 0011 | 0011 | 0011 | 0011 | 0011 | 0011 … which is interpreted as follows:

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Band-1 Quality	0011	3	All magnitude inversions or 50% or less fill-values
04–07	Band-2 Quality	0011	3	All magnitude inversions or 50% or less fill-values
08–11	Band-3 Quality	0011	3	All magnitude inversions or 50% or less fill-values
12–15	Band-4 Quality	0011	3	All magnitude inversions or 50% or less fill-values
16–19	Band-5 Quality	0011	3	All magnitude inversions or 50% or less fill-values
20–23	Band-6 Quality	0011	3	All magnitude inversions or 50% or less fill-values
24–27	Band-7 Quality	0011	3	All magnitude inversions or 50% or less fill-values
28–30	TBD	000		
31	QA-Fill	0	0	Not Fill-value

The second decimal value of **8706** converts to a 32-bit binary value of **0000000000000000|0010001000000010**. Users need to add sixteen zeros on the left to complete the 32-bits. This bit-string, as assigned to the individual bit numbers, breaks down thus:

0 | 000 | 0000 | 0000 | 0000 | 0010 | 0010 | 0000 | 0010 … which is interpreted as follows:

Bit-No.	Parameter	Binary Bit-Word	Decimal Equivalent	Interpretation
00–03	Band-1 Quality	0010	2	Mixed, 50% or less full inversions & 25% or less fill values
04–07	Band-2 Quality	0000	0	Best quality, 75% or more with best full inversions
08–11	Band-3 Quality	0010	2	Mixed, 50% or less full inversions & 25% or less fill values
12–15	Band-4 Quality	0010	2	Mixed, 50% or less full inversions & 25% or less fill values
16–19	Band-5 Quality	0000	0	Best quality, 75% or more with best full inversions
20–23	Band-6 Quality	0000	0	Best quality, 75% or more with best full inversions
24–27	Band-7 Quality	0000	0	Best quality, 75% or more with best full inversions
28–30	TBD	000		
31	QA-Fill	0	0	Not Fill-value

5. Quality Assurance information in the 5600 m 16-day BRDF-Albedo Parameters, BRDF-Albedo Snow-Free Quality, Albedo, and Nadir BRDF-Adjusted Reflectance CMG products

The four Climate Modeling Grid (CMG) products in the BRDF-Albedo suite are structured differently in terms of their QA information as alluded to earlier in sub-section-8. They all carry their own parameter SDS layers besides a dedicated, single 8-bit BRDF_Quality SDS layer that is not bit-packed, and hence, ready for direct interpretation. Users should also note the similarities and the single difference between the BRDF-Albedo Model Parameters CMG (MCD43C1) and BRDF-Albedo Snow-Free Quality CMG (MCD43C2) products that was also pointed out earlier in sub-section-8. The following table provides the BRDF_Quality legend that is common to all four CMG products, which is used to directly interpret the BRDF and albedo quality information.

8-bit integer value	Interpretation
0	Best quality, 75% or more with best full inversions
1	Good quality, 75% or more with full inversions
2	Mixed, 75% or less full inversions and 25% or less fill-values
3	All magnitude inversions or 50% or less fill-values
4	50% or more fill-values
255	Fill-value

6. Demonstration examples with LDOPE's unpack_sds_bits utility

LDOPE's unpack_sds_bits utility, which was demonstrated in the Land Surface Reflectance products suite sub-section earlier, is potentially useful in deconstructing the BRDF Albedo Ancillary and BRDF Albedo Band Quality bit-packed SDS layers in the two BRDF-Albedo quality products (MCD43A2 and MCD43B2). For example, the syntax to unpack the BRDF Albedo Band Quality layer from the 500 m product includes the following:

unpack_sds_bits -of = mcd43a2_2006153_h13v09_500m-QA.hdf -sds = "BRDF Albedo Band Quality" -bit = 0-3, 4-7, 8-11, 12-15, 16-19, 20-23, 24-27, 28-30, 31
MCD43A2.A2006153.h13v09.005.2008126030730.hdf

where …

unpack_sds_bits	Executable
-of	Output file flag designation
mcd43a2_2006153_h13v09_500m-QA.hdf	User-defined output name
-sds	Science Dataset flag designation
"BRDF Albedo Band Quality"	Specific QA SDS to unpack
-bit	Bit flag designation
0-3, 4-7, 8-11, 12-15, 16-19, 20-23, 24-27, 28-30, 31	User-defined specific bits
MCD43A2.A2006153.h13v09.005.2008126030730.hdf	Input HDF file

The above run generates an HDF file that contains the following SDS layers with parsed integer values for each existing bit combination between 0 and 31 for the chosen QA SDS:

BRDF_Albedo_Band_Quality_bits_00-03 [Band-1 Data Quality]
BRDF_Albedo_Band_Quality_bits_04-07 [Band-2 Data Quality]
BRDF_Albedo_Band_Quality_bits_08-11 [Band-3 Data Quality]
BRDF_Albedo_Band_Quality_bits_12-15 [Band-4 Data Quality]
BRDF_Albedo_Band_Quality_bits_16-19 [Band-5 Data Quality]

BRDF_Albedo_Band_Quality_bits_20-23 [Band-6 Data Quality]
BRDF_Albedo_Band_Quality_bits_24-27 [Band-7 Data Quality]
BRDF_Albedo_Band_Quality_bits_28-30 [TBD]
BRDF_Albedo_Band_Quality_bits_31 [QA-Fill]

Users may open, browse, and query any of these output layers in any of the proprietary as well as public domain image processing software tools that handle HDF.

References

MODIS Land Product's File Specifications: http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi?fileName=modland_specs
(The MODIS land product file specifications are grouped by their collection version. Look for your product file specification of interest by its Short Name (e.g., MC43A2.fs))

Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N. C., Zhang, X., Jin, Y., Muller, J.-P., Lewis, P., Barnsley, M., Hobson, P., Disney, M., Roberts, G., Dunderdale, M., Doll, C., d'Entremont, R., Hu, B., Liang, S., and Privette, J. L., 2002. First Operational BRDF, Albedo and Nadir Reflectance Products from MODIS. *Remote Sensing of Environment*, 83, 135–148.