MODIS Land Products Quality Assurance Tutorial: Part-2

How to interpret and use MODIS QA information in the Vegetation Indices product suite

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Introduction

This second part of the MODIS Land Products QA Tutorial provides the knowledge base to interpret and understand the QA information in the MODIS vegetation indices (VI) product (**M*D13**) suite. It contains QA sources specific to the VI 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 quality information** in the MODIS Vegetation Indices product suite.

1. Introduction to the Vegetation Indices product suite

Vegetation Indices (VI) are important ecosystem variables used in a variety of biophysical applications. VIs are optical remote sensing data-derived measures of vegetation greenness (a proxy for vegetation health, vigor and dynamics). Although not a directly measured intrinsic physical quantity (as an LAI, fPAR, etc.), a VI is a ratio derived from the red and near-infrared channels' spectral reflectance, and strongly captures a number of canopy properties and biophysical processes. Terra and Aqua MODIS-produced VIs form an important part of a long continuing record (Huete et al., 2011, Huete et al., 2002) begun with the Advanced Very High Resolution Radiometer, (AVHRR) and expected to continue with the Suomi National Polar-orbiting Partnership's Visible Infrared Imaging Radiometer Suite (VIIRS).

The M*D13 VI suite consists of a dozen data products derived from the Terra and Aqua MODIS sensors and include the following:

Platform	Short Name	Product	Spatial Resolution	Temporal Frequency	Raster Type
Terra	MOD13Q1	Vegetation Indices	250 m	16-days	Tile
Terra	MOD13A1	Vegetation Indices	500 m	16-days	Tile
Terra	MOD13A2	Vegetation Indices	1000 m	16-days	Tile
Terra	MOD13A3	Vegetation Indices	1000 m	Monthly	Tile
Terra	MOD13C1	Vegetation Indices	5600 m	16-days	CMG*
Terra	MOD13C2	Vegetation Indices	5600 m	Monthly	CMG*
Aqua	MYD13Q1	Vegetation Indices	250 m	16-days	Tile
Aqua	MYD13A1	Vegetation Indices	500 m	16-days	Tile
Aqua	MYD13A2	Vegetation Indices	1000 m	16-days	Tile
Aqua	MYD13A3	Vegetation Indices	1000 m	Monthly	Tile
Aqua	MYD13C1	Vegetation Indices	5600 m	16-day	CMG*
Aqua	MYD13C2	Vegetation Indices	5600 m	Monthly	CMG*

*Climate Modeling Grid

2. QA sources within the VI product suite

The Terra and Aqua MODIS VI products contain the following QA Science Dataset (SDS) layers:

Short Name	QA Science Dataset
M*D13Q1	250 m 16 days VI Quality 250 m 16 days Pixel Reliability QA
M*D13A1	500 m 16 days VI Quality 500 m 16 days Pixel Reliability QA
M*D13A2	1 km 16 days VI Quality 1 km 16 days Pixel Reliability QA
M*D13A3	1 km Monthly VI Quality 1 km Monthly Pixel Reliability QA
M*D13C1	CMG 0.05° 16 days VI Quality CMG 0.05° 16 days Pixel Reliability QA
M*D13C2	CMG 0.05° Monthly VI Quality CMG 0.05° Monthly Pixel Reliability QA

An asterisk refers to both Terra [MOD] and Aqua [MYD] versions of the MODIS product

The QA implementation within the VI suite is unique in that besides the **pixel-level QA** information similar to other MODIS land products, it also provides a summary **pixel reliability QA** layer. This 8-bit integer layer provides simple ranks that capture the overall pixel quality. Users may directly interpret and use these ranks unlike the per-pixel quality layer that requires detailed post-processing and interpretation. The pixel reliability ranks

and their descriptions for all M*D13 products include the following (the last rank (4) applies only to the CMG products):

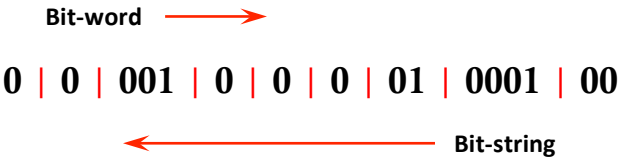
Pixel Reliability Rank	Summary QA	Description
-1	Fill/No data	Not processed
0	Good data	Use with confidence
1	Marginal data	Useful, but look at other QA information
2	Snow/Ice	Target covered with snow/ice
3	Cloudy	Target not visible, covered with cloud
4	Estimated	Based on MODIS historic time-series. All products are gap-filled, and this indicates whether the value was interpolated from long-term averages or not.

3. Interpretation examples from 250 m 16-day VI product

MOD13Q1 16-Day Product: 250 m 16 Days VI Quality interpretation example

Product interpreted: **MOD13Q1** (Terra MODIS Vegetation Indices 16-Day 250 m)
Dataset name: **MOD13Q1.A2006161.h13v09.005.2008234024753.hdf**
Science Data Set Name: 250 m 16 Days VI Quality
Pixel location: Row: 3100 | Column: 3154
Pixel value: **2116**
Pixel Reliability: 0 (Good data/Use with confidence)

Using a scientific calculator or via an online conversion tool, the decimal value of **2116** converts to a 16-bit binary value of **0000100001000100**. Depending on your calculator/convertor, you may need to add one or more zeros to the left to complete the 16-bit string. Based on the QA index specified in the MOD13Q1 product's file specification (see references), the bits in this string will map to a series of quality flags following the table below:



This binary bit-string is parsed from right to left[1], and the individual bits within a bit-field are read from left to right based on the table below:

Bit-No.	Parameter	Bit-Word	Interpretation
0–1	VI Quality (Modland QA)	00 01 10 11	VI produced with good quality VI produced, but check other QA Pixel produced, but most probably cloudy Pixel not produced due to other reasons than clouds
2–5	VI Usefulness	0000 0001 0010 0100 1000 1001 1010 1100 1101 1110 1111	Highest quality Lower quality Decreasing quality Decreasing quality Decreasing quality Decreasing quality Decreasing quality Lowest quality Quality so low that it is not useful L1B data faulty Not useful for any other reason/not processed
6–7	Aerosol quantity	00 01 10 11	Climatology Low Intermediate High
8	Adjacent cloud detected	0 1	No Yes
9	Atmospheric BRDF Correction	0 1	No Yes
10	Mixed clouds	0 1	No Yes
11–13	Land-Water Mask	000 001 010 011 100 101 110 111	Shallow ocean Land (Nothing else but land) Ocean coastlines and lake shorelines Shallow inland water Ephemeral water Ocean coastlines and lake shorelines Moderate or continental ocean Deep ocean
14	Possible snow/ice	0 1	No Yes
15	Possible shadow	0 1	No Yes

[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).

The pixel quality fields are then interpreted as follows:

- VI Quality = 00, meaning pixel produced with good quality and no issues
- VI usefulness = 0001, meaning pixel is of highest quality (this flag is based on a 16-levels rank from 0000 to 1111)
- Aerosol Quantity = 01, meaning the aerosol load was low
- Adjacent Cloud detected = 0, no adjacent clouds detected
- Atmospheric BRDF Correction = 0, no Atmosphere BRDD correction performed (As of collection 5.0 all MODIS land data are not corrected for atmospheric BRDF)
- Mixed Clouds = 0, pixel with no mixed clouds
- Land Water Mask = 001, pixel over land
- Possible Snow/Ice = 0, no snow/ice cover
- Possible Shadow = 0, no cloud shadow

In contrast to the above, another example of a pixel QA deconstruction from the same dataset as the previous example is as follows:

Pixel location: Row: 2609 | Column: 4789
Pixel value: **34897**
Pixel Reliability: 1 (Marginal data/ Useful, but look at other QA information)

1 | 0 | 001 | 0 | 0 | 0 | 01 | 0100 | 01

Following the above table, VI quality is 01, which suggests checking other QA attributes, the usefulness index (0100) indicates decreasing quality, while the last attribute's value (1) suggests the pixel may have been covered with cloud shadow. All these corroborate with the pixel reliability rank of "1" that indicates marginal data.

The same process of converting the pixel-level decimal values to binary before parsing their bit-fields to interpret them applies to the VI Quality SDS layers in the following products, and the previous table is used to interpret them as well:

M*D13A1 (500 m 16-day VI)
M*D13A2 (1000 m 16-day VI)
M*D13A3 (1000 m Monthly VI)

Consult the **MODIS VI User's Guide** (Solano et al., 2010) for additional details regarding specific QA parameters and their relationships as they apply to all products in the VI suite.

4. Interpretation examples from 5600 m 16-day CMG VI product

MOD13C1 CMG Product: CMG 0.05° 16 days VI Quality interpretation example

Product interpreted: **MOD13C1** (Terra MODIS Vegetation Indices 16-Day CMG)
Dataset name: **MOD13C1.A2006193.005.2008139021421.hdf**
Science Data Set Name: CMG 0.05° 16 days VI Quality
Pixel location: Row: 2638 | Column: 6536
Pixel value: **55368**
Pixel Reliability: 0 (Good data/Use with confidence)

Following the decimal to binary conversion, the pixel value breaks down into the following bit-fields:

11 | 011 | 0 | 0 | 0 | 01 | 0010 | 00

The bit-words are interpreted based on the following table. The 0 – 13 detailed QA bits and their descriptions are the same as delineated for MOD13Q1 earlier except for bits 14 – 15:

Bit-No.	Parameter	Bit-Word	Interpretation
0–1	VI Quality (Modland QA)	00 01 10 11	VI produced with good quality VI produced, but check other QA Pixel produced, but most probably cloudy Pixel not produced due to other reasons than clouds
2–5	VI Usefulness	0000 0001 0010 0100 1000 1001 1010 1100 1101 1110 1111	Highest quality Lower quality Decreasing quality Decreasing quality Decreasing quality Decreasing quality Decreasing quality Lowest quality Quality so low that it is not useful L1B data faulty Not useful for any other reason/not processed
6–7	Aerosol quantity	00 01 10	Climatology Low Intermediate

		11	High
8	Adjacent cloud detected	0 1	No Yes
9	Atmospheric BRDF Correction	0 1	No Yes
10	Mixed clouds	0 1	No Yes
11–13	Land-Water Mask	000 001 010 011 100 101 110 111	Shallow ocean Land (Nothing else but land) Ocean coastlines and lake shorelines Shallow inland water Ephemeral water Ocean coastlines and lake shorelines Moderate or continental ocean Deep ocean
14–15	Geospatial quality	00 01 10 11	<= 25% of the finer 1km resolution contributed to this CMG pixel >25% & <= 50% of the finer 1km resolution contributed to this CMG pixel >50% & <= 75% of the finer 1km resolution contributed to this CMG pixel >75% & <=100% of the finer 1km resolution contributed to this CMG pixel

This last bit-field [14-15], Geospatial quality, captures the number of finer 1 km resolution pixels used to compute the corresponding CMG pixel value. At the equator, a maximum of 6 x 6 1 km pixels is used to compute the CMG, however due to the presence of clouds and other data issues, not all finer resolution pixels are retained. Low geospatial quality value may indicate bias in case of heterogeneity (e.g.: In cases where only few pixels were used to construct the CMG pixel value).

The same process applies to the interpretation of the CMG 0.05˚ Monthly VI Quality SDS layer in the monthly VI CMG product.

5. Demonstration examples with LDOPE's unpack_sds_bits utility

The *unpack_sds_bits* provides a useful LDOPE tool for decomposing the pixel-level QA in the VI Quality SDS layers. This tool outputs their values as parsed 16-bit integers, similar to earlier descriptions with the Land Surface Reflectance and BRDF/Albedo products. The syntax to unpack the bits of any MOD13Q1 pixel QA is as follows:

unpack_sds_bits -of = mod13q1_2006153_h13v09_250m-QA.hdf -sds = "250 m 16 days VI Quality" -bit = 0-1, 2-5, 6-7, 8, 9, 10, 11-13, 14, 15
MOD13Q1.A2006161.h13v09.005.2008234024753.hdf

where …

unpack_sds_bits	Executable
-of	Output file flag designation
mod13q1_2006153_h13v09_250m-QA.hdf	User-defined output file name
-sds	Science Dataset flag designation
"250 m 16 days VI Quality"	Specific QA SDS to unpack
-bit	Bit flag designation
0-1, 2-5, 6-7, 8, 9, 10, 11-13, 14, 15	User-defined specific bit-fields to extract
MOD13Q1.A2006161.h13v09.005.2008234024753.hdf	Input HDF file

The above example generates an Hierarchical Data Format (HDF) file that contains the following SDS layers with parsed integer values for each bit-field combination between 0 and 15 for the chosen QA SDS:

250m 16 Days VI Quality_bits_0-1	[VI Quality – MODLAND QA]
250m 16 Days VI Quality_bits_2-5	[VI Usefulness]
250m 16 Days VI Quality_bits_6-7	[Aerosol quantity]
250m 16 Days VI Quality_bits_8	[Adjacent cloud detected]
250m 16 Days VI Quality_bits_9	[Atmospheric BRDF correction]
250m 16 Days VI Quality_bits_10	[Mixed clouds]
250m 16 Days VI Quality_bits_11-13	[Land-Water Mask]
250m 16 Days VI Quality_bits_14	[Possible snow/ice]
250m 16 Days VI Quality_bits_15	[Possible shadow]

Users may open, browse, and query any of these output layers in any of their favorite image processing software tools that can handle HDF files. Further details regarding this bit unpacking tool are available in the LDOPE Tools User Manual cited in the references section.

References

Huete, A., Didan, K., van Leeuwen, W., Miura, T., and Glenn, E. (2011) Moderate Resolution Imaging Spectroradiometer Vegetation Indices. In: Ramachandran, B., Justice, C., and Abrams, M. (Eds.) *Land Remote Sensing and Global Environmental Change, NASA's Earth Observing System and the Science of ASTER and MODIS*. Springer, NY.

Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., and Ferreira, L.G. (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment*, 83, 195–213.

MODIS Land Data Operational Product Evaluation (LDOPE) Tools User Manual (2004) Available from: https://lpdaac.usgs.gov/tools/ldope_tools

MODIS Land Product's File Specifications: http://landweb.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi?fileName=modland_specs (Last accessed: May 31, 2012). *(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., MOD13Q1.fs))*

Solano, R., Didan, K., Jacobson, A., and Huete, A. (2010) MODIS Vegetation Index User's Guide (MOD13 Series), Version 2.00, May 2010 (Collection 5). Available online: http://vip.arizona.edu/MODIS_UsersGuide.php (Last accessed: May 31, 2012).