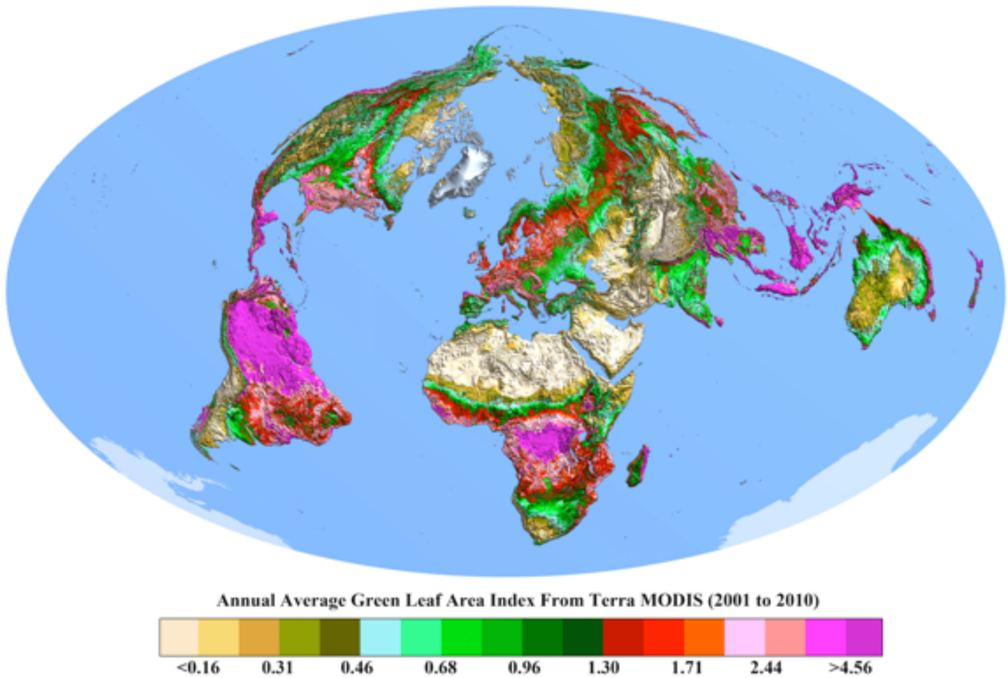
MODIS Collection 6.1 (C6.1) LAI/FPAR Product User's Guide

The C61 MOD/MYD15 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

(Updated: April 21, 2020)


Annual Average Green Leaf Area Index From Terra MODIS (2001 to 2010)
<0.16
0.31
0.46
0.68
0.96
1.30
1.71
2.44
>4.56

Contents

1. Definitions

Leaf area index (LAI; dimensionless) is defined as the one−sided green leaf area per unit ground area in broadleaf canopies and as one−half the total needle surface area per unit ground area in coniferous canopies.

STD LAI is the estimated retrieval uncertainty, i.e., "true LAI" can differ from its retrieval counterpart by ±STD LAI (See Figure 1).

Fraction of Photosynthetically Active Radiation absorbed by vegetation (FPAR; dimensionless) is defined as the fraction of incident photosynthetically active radiation (400−700 nm) absorbed by the green elements of a vegetation canopy.

STD FPAR is the estimated retrieval uncertainty, i.e., "true FPAR" can differ from its retrieval counterpart by ±STD FPAR (See Figure 1).

2. Summary of Changes in C6

- Uses L2G–lite surface reflectance at 500 m resolution as (MOD09GA[1]) input in place of reflectance at 1km resolution (MODAGAGG[2]) in Collection 5. An intermediate daily surface reflectance product (MOD15IP[3]) at 500 m resolution is created from MOD09GA before being used for LAI/FPAR retrieval.
- Products are generated at a spatial resolution of 500m.
- Uses improved multi-year land cover product.

3. Algorithm Description

The MODIS LAI/FPAR algorithm consists of a main Look-up-Table (LUT) based procedure that exploits the spectral information content of the MODIS red (648 nm) and near-infrared (NIR, 858 nm) surface reflectances, and the back-up algorithm that uses empirical relationships between Normalized Difference Vegetation Index (NDVI) and canopy LAI and FPAR. The LUT was generated using 3D radiative transfer equation [Knyazikhin et al., 1998]. Inputs to the algorithm are (*i*) vegetation structural type, (*ii*) sun-sensor geometry, (*iii*) BRFs at red (648 nm) and near-infrared (NIR, 858 nm) spectral bands and (*vi*) their uncertainties (Table 1). Figure 1 illustrates the main algorithm: for

---

[1] *MOD09GA is a MODIS daily surface reflectance product, which provides daily atmospherically corrected surface reflectance at 500 m resolution in seven spectral bands. MOD09GA can be accessed via Reverb tool (Please refer to the Section 5. How to Obtain the Data)*

[2] *MODAGAGG is a MODIS daily aggregated surface reflectance product, which provides daily atmospherically corrected surface reflectance at 1 km resolution in seven spectral bands. MODAGAGG is not an archived product.*

[3] *MOD15IP is the intermediate MODIS daily surface reflectance product at 500 m resolution, which is preprocessed from the daily MOD09GA surface reflectance product, for LAI/FPAR production. This product is an equivalent of MODAGAGG in C5 and not archived.*

each pixel it compares observed and modeled spectral BRFs for a suite of canopy structures and soil patterns that represent an expected range of typical conditions for a given biome type. All canopy/soil patterns and corresponding FPAR values for which modeled and observed BRFs differ within a specified uncertainty level are considered as acceptable solutions. The mean values of LAI, FPAR, their dispersions, STD LAI and STD FPAR, are reported as retrievals and their uncertainties [Knyazikhin et al., 1998]. In the case of dense canopies, the reflectances saturate, and are therefore weakly sensitive to changes in canopy properties. The reliability of parameters retrieved under the condition of saturation is low, that is, the dispersion of the solution distribution is large. Such retrievals are flagged in QA layers (Table 5). When the LUT method fails to localize a solution, the back-up method is utilized. The algorithm path (main or backup) is archived in QA layers (Table 5). Analyses of the algorithm performance indicate that best quality, high precision retrievals are obtained from the main algorithm [Yang et al. 2006b; Yang et al. 2006c]. The algorithm path is therefore a key quality indicator.

The algorithm has interfaces with the MODIS Surface Reflectance Product (MOD09GA) and the MODIS Land Cover Product (MCD12Q1). Technical details of the algorithm can be found in the Algorithm Theoretical Basis Document (ATBD)[4].

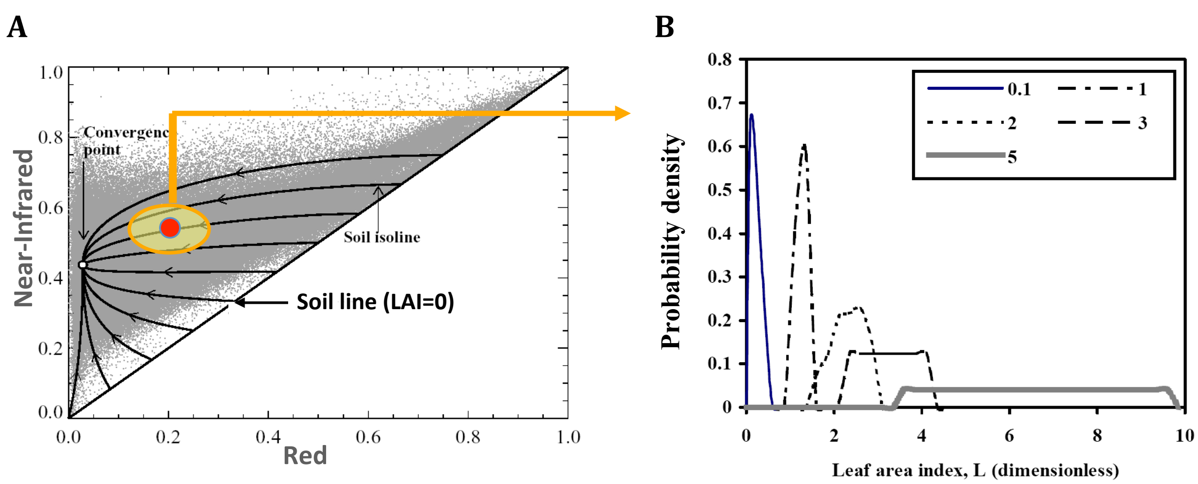


Figure 1. Schematic illustration of the main algorithm. *Panel A*: Distribution of vegetated pixels with respect to their reflectances at red and near-infrared (NIR) spectral bands from Terra MODIS tile h12v04. A point on the red-NIR plane and an area about it (yellow ellipse defined by a χ^2 distribution) are treated as the measured BRF at a given sun-sensor geometry and its uncertainty. Each combination of canopy/soil parameters and corresponding FPAR values for which modeled reflectances belong to the ellipse is an acceptable solution. *Panel B*: Density distribution function of acceptable

[4] *ATBD for MODIS LAI/FPAR product can be directly downloaded from below link: http://modis.gsfc.nasa.gov/data/atbd/atbd_mod15.pdf*

solutions. Shown is solution density distribution function of LAI for five different pixels. The mean LAI and its dispersion (STD LAI) are taken as the LAI retrieval and its uncertainty. This technique is used to estimate mean FPAR and its dispersions (STD FPAR). From [Knyazikhin at al, 1998].

Table 1. Theoretical estimates of uncertainties (%) in the BRFs used in the C6.1 LAI/FPAR algorithm

Biome Type	**Uncertainty**	
	Red (648 nm)	**NIR (858 nm)**
Biome 1 (Grasses/Cereal crops)	20 %	5 %
Biome 2 (Shrubs)	20 %	5 %
Biome 3 (Broadleaf crops)	20 %	5 %
Biome 4 (Savanna)	20 %	5 %
Biome 5 (Evergreen Broadleaf forest)	30 %	15 %
Biome 6 (Deciduous Broadleaf forest)	30 %	15 %
Biome 7 (Evergreen Needleleaf forest)	30 %	15 %
Biome 8 (Deciduous Needleleaf forest)	30 %	15 %

4. Standard MODIS Products

The standard MODIS C6.1 LAI/FPAR products (M*D15A*H) are at 500–meter spatial resolution and include LAI/FPAR retrievals from Terra MODIS, Aqua MODIS and Terra MODIS+Aqua MODIS Combined. The temporal compositing periods are 8 and 4 days (Table 2).

Table 2. Description of the Standard MODIS LAI/FPAR products

Official Name	**Platform**	**Raster Type**	**Spatial Resolution**	**Temporal Granularity**
MOD15A2H	Terra	Tile	500m	8 Day
MYD15A2H	Aqua	Tile	500m	8 Day
MCD15A2H	Terra+Aqua Combined	Tile	500m	8 Day
MCD15A3H	Terra+Aqua Combined	Tile	500m	4 Day

The MODIS LAI/FPAR products use the Sinusoidal grid tilling system (Figure 2). Tiles are 10 degrees by 10 degrees at the equator (Table 3). The tile coordinate system starts at (0, 0) (horizontal tile number, vertical tile number) in the upper left corner and proceeds right (horizontal) and downward (vertical). The tile in the bottom right corner is (35, 17).

Table 3. Data set characteristics of the MODIS LAI/FPAR products

Characteristics	**C6.1 Product**
Temporal Coverage	MOD15: February 18, 2000 – MYD15 & MCD15: July 4, 2002 –
Area	~ 10 x 10 lat/long
File Size	~ 0.8 MB compressed
Projection	Sinusoidal
Data Format	HDF–EOS
Dimensions	2400 x 2400 rows/columns
Resolution	500 meter
Science Data Sets (SDS HDF Layers)	6

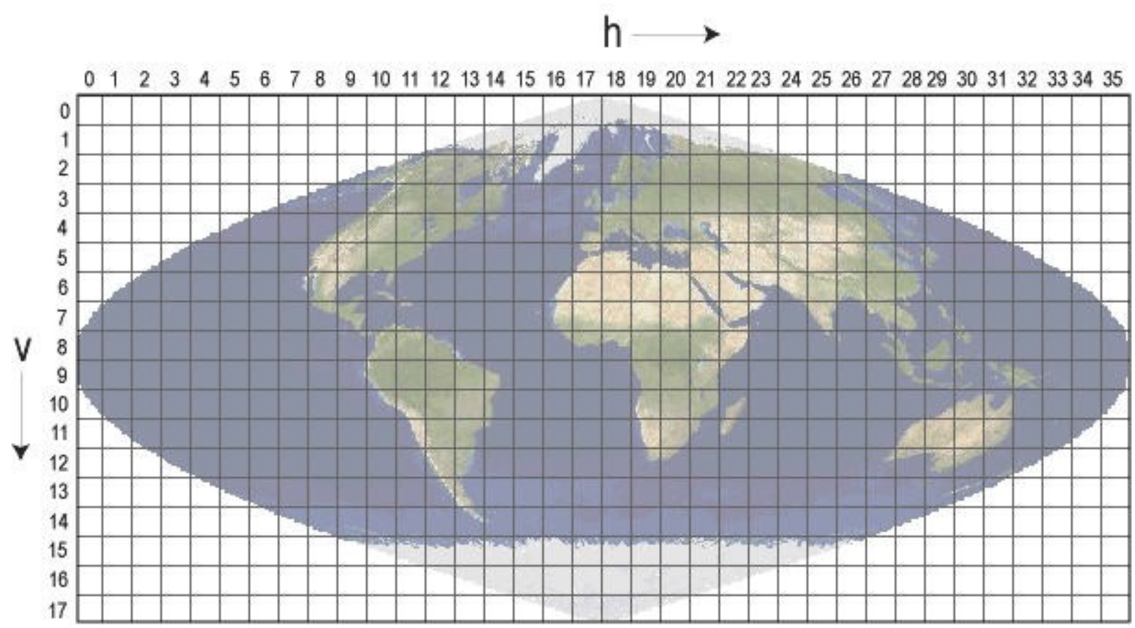


Figure 2. MODIS Sinusoidal Tiling System

MODIS product filenames (i.e., the local granule ID) follow a naming convention that gives useful information regarding the specific product. For example, the filename ***MOD15A2H.A2006001.h08v05.006.2006012234657.hdf*** indicates:

- ✓ ***MOD15A2H*** – Product Short Name

- ✓ ***.A2006001*** **–** Julian Date of Acquisition (A−YYYYDDD)
- ✓ ***.h08v05*** **–** Tile Identifier (horizontal XX, vertical YY)
- ✓ ***.006*** – Collection Version
- ✓ ***.2006012234657*** – Julian Date of Production (YYYYDDDHHMMSS)
- ✓ ***.hdf*** – Data Format (HDF−EOS)

The MODIS LAI/FPAR products have two sources of metadata: the embedded HDF metadata, and the external ECS metadata. The HDF metadata contains valuable information including global attributes and data set−specific attributes pertaining to the granule. The ECS (generated by the EOSDIS Core System) .met file is the external metadata file in XML format, which is delivered to the user along with the MODIS product. It provides a subset of the HDF metadata. Some key features of certain MODIS metadata attributes include the following:

- ✓ The ***Xdim*** and ***Ydim*** represent the rows and columns of the data, respectively.
- ✓ The ***Projection*** and ***ProjParams*** identify the projection and its corresponding projection parameters.
- ✓ The ***Sinusoidal Projection*** is used for most of the gridded MODIS land products, and has a unique sphere measuring 6371007.181 meters.
- ✓ The ***UpperLeftPoinitMtrs*** is in projection coordinates, and identifies the very upper left corner of the upper left pixel of the image data.
- ✓ The ***LowerRightMtrs*** identifies the very lower right corner of the lower right pixel of the image data. These projection coordinates are the only metadata that accurately reflect the extreme corners of the gridded image.
- ✓ There are additional ***BOUNDINGRECTANGLE*** and ***GRINGPOINT*** fields within the metadata, which represent the latitude and longitude coordinates of the geographic tile corresponding to the data.

5. How to Obtain the Data

NASA EARTHDATA (https://earthdata.nasa.gov/): This tool provides access to a complete data record of all MODIS products available from the LP DAAC.

6. Content of the product file

The MODIS LAI/FPAR product is at 500−meter resolution in a Sinusoidal grid. Science Data Sets provided in the product include LAI, FPAR, quality ratings, and standard deviation for each variable, STD LAI and STD FPAR (Table 4).

Table 4. Scientific Data Sets included in the MODIS LAI/FPAR product

Scientific Data Sets (HDF Layers) (6)	Units	Bit Type	Fill Value	Valid Range	Multiply By Scale Factor
Fpar_500m	Dimensionless	8–bit unsigned integer	249–255	0–100	0.01
Lai_500m	Dimensionless	8–bit unsigned integer	249–255	0–100	0.1
FparLai_QC	Class flag	8–bit unsigned integer	255	0–254	N/A
FparExtra_QC	Class flag	8–bit unsigned integer	255	0–254	N/A
FparStdDev_500m[5]	Dimensionless	8–bit unsigned integer	248–255	0–100	0.01
LaiStdDev__500m[5]	Dimensionless	8–bit unsigned integer	248–255	0–100	0.1

6.1. Description of QC SDS

Quality control (QC) measures are produced at both the file (containing one MODIS tile) and at the pixel levels for the M*D15A*H product. At the tile level, these appear as a set of EOSDIS core system (ECS) metadata fields. At the pixel level, quality control information is represented by 2 data layers (FparLai_QC and FparExtra_QC) in the file with M*D15A*H product. Note that the LAI/FPAR algorithm is executed irrespective of input quality. ***Therefore user should consult the QC layers of the LAI/FPAR product to select reliable retrievals.***

[5] *The main algorithm employs a LUT method simulated from a 3-D radiative transfer model. The LUT method essentially searches for LAI/FPARs for a specific set of solar and view zenith angles, observed BRFs at certain spectral bands and biome types. The outputs are the LAI/FPAR mean values (i.e., Lai_500m/Fpar_500m scientific data) averaged over all acceptable solutions, and the standard deviation (i.e., LaiStdDev/FparStdDev scientific data) serving as a measure of the solution accuracy.*

Table 5. Values of FparLAI_QC (8–bit)

Bit No.	Parameter Name	Bit	FparLai_QC
0	MODLAND_QC bits	0	Good quality (main algorithm with or without saturation)
		1	Other quality (back–up algorithm or fill values)
1	Sensor	0	Terra
		1	Aqua
2	DeadDetector	0	Detectors apparently fine for up to 50% of channels 1, 2
		1	Dead detectors caused >50% adjacent detector retrieval
3–4	CloudState (inherited from Aggregate_QC bits {0, 1} cloudstate)	00	0 Significant clouds NOT present (clear)
		01	1 Significant clouds WERE present
		10	2 Mixed cloud present in pixel
		11	3 Cloud state not defined, assumed clear
5–7	SCF_QC (five–level confidence score)	000	0 Main (RT) method used, best result possible (no saturation)
		001	1 Main (RT) method used with saturation. Good, very usable
		010	2 Main (RT) method failed due to bad geometry, empirical algorithm used
		011	3 Main (RT) method failed due to problems other than geometry, empirical algorithm used
		100	4 Pixel not produced at all, value couldn't be retrieved (possible reasons: bad L1B data, unusable MOD09GA data)

Note, in the FparLai_QC, the field MODLAND is the standard one common to the all MODLAND products and specifies the overall quality of the product. Also, several bit fields in the M*D15A*H QA are passed-thru from the corresponding bitfields of the MOD09GA surface reflectances product (CloudState, LandSea, etc.). The key indicator of retrieval quality of the LAI/FPAR product is SCF_QC bitfieldd that represents algorithm path.

M*D15A*H bit patterns are parsed from right to left. Individual bits within a bitword are read from left to right. The following example illustrates the interpretation of FparLai_QC. Let assume a single pixel's value from FparLai_QC layer is 64, thus this decimal value can be converted to a binary value of 1000000 as shown in Figure 3. Interpretation of bit-strings is also shown in Figure 3 based on Table 5.

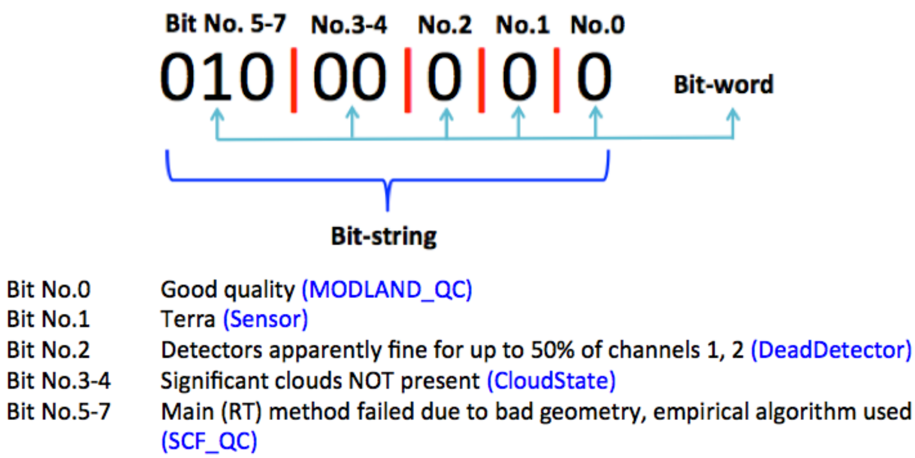


Figure 3. Example of FparLai_QC bit-string and its interpretation

Table 5. Values of FparExtra_QC (8–bit)

Bit No.	Parameter Name	Bit Comb.	FparExtra_QC
0–1	LandSea Pass–Thru	00	0 LAND AggrQC (3,5) values {001}
		01	1 SHORE AggrQC (3,5) values {000, 010, 100}
		10	2 FRESHWATER AggrQC (3,5) values {011, 101}
		11	3 OCEAN AggrQC (3,5) values {110,111}
2	Snow_Ice (from Aggregate_QC bits)	0	No snow/ice detected
		1	Snow/ice detected
3	Aerosol	0	No or low atmospheric aerosol levels detected
		1	Average or high aerosol levels detected
4	Cirrus (from Aggregate_QC bits {8,9})	0	No cirrus detected
		1	Cirrus was detected
5	Internal_CloudMask	0	No clouds
		1	Clouds were detected
6	Cloud_Shadow	0	No cloud shadow detected
		1	Cloud shadow detected
7	SCF_Biome_Mask	0	Biome outside interval <1,4>
		1	Biome in interval <1,4>

Example for interpretation of FparExtra_QC bit-strings is shown in Figure 4.

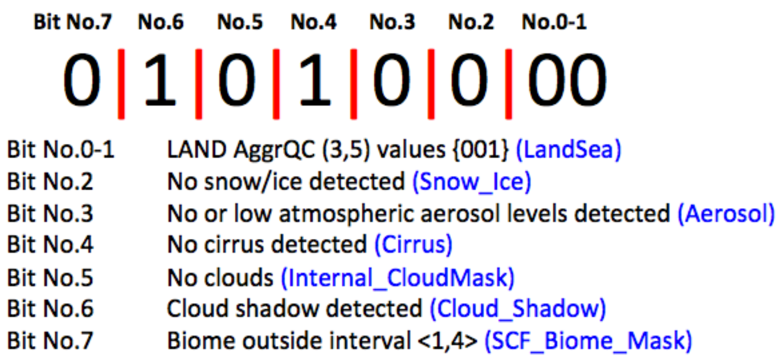


Figure 4. Example of FparExtra_QC bit-string and its interpretation

6.2. Description of Fill value for SDSs

Using the MODIS land cover product (MCD12Q1), each 500m pixel is classified according to its status as a land or non-land pixel. A number of non-terrestrial pixel classes are now carried through in the product data pixels (not QA/QC pixels) when the algorithm could not retrieve a biophysical estimate (Table 6 and 7).

Table 6. LAI and FPAR Fill value Legends

Value	Description
255	Fillvalue, assigned when: the MOD09GA surface reflectance for channel VIS, NIR was assigned its _Fillvalue, or land cover pixel itself was assigned Fillvalue 255 or 254
254	land cover assigned as perennial salt or inland fresh water
253	land cover assigned as barren, sparse vegetation (rock, tundra, desert)
252	land cover assigned as perennial snow, ice
251	land cover assigned as “permanent” wetlands/inundated marshlands
250	land cover assigned as urban/built–up
249	land cover assigned as “unclassified” or not able to determine

Table 7. STD LAI and STD FPAR Fill Value Legends

Value	Description
255	Fillvalue, assigned when: the MOD09GA surface reflectance for channel VIS, NIR was assigned its _Fillvalue, or land cover pixel itself was assigned _Fillvalue 255 or 254
254	land cover assigned as perennial salt or inland fresh water
253	land cover assigned as barren, sparse vegetation (rock, tundra, desert)
252	land cover assigned as perennial snow, ice
251	land cover assigned as “permanent” wetlands/inundated marshlands
250	land cover assigned as urban/built–up
249	land cover assigned as “unclassified” or not able to determine
248	No standard deviation available, pixel produced using backup method

7. Policies

Please find the current MODIS–related Data policies on the MODIS Policies page at https://lpdaac.usgs.gov/lpdaac/products/modis_policies.

For information on how to cite LP DAAC data, please see our Data Citations page at https://lpdaac.usgs.gov/about/citing_lp_daac_and_data.

8. Contact Information

Ranga Myneni
Department of Geography and Environment, Boston University Email:
ranga.myneni@gmail.com
Web: http://cliveg.bu.edu

9. Related Papers

Ahl et al., 2006. Monitoring Spring Canopy Phenology of a Deciduous Broadleaf Forest Using MODIS, Remote Sens. Environ., 104: 88–95.

Baret et al., 2006. Evaluation of the representativeness of networks of sites for the validation and inter–comparison of global land biophysical products. Proposition of the CEOS–BELMANIP. *IEEE Trans. Geosci. Remote Sens*., 44: 1794–1803. DOI: 10.1126/science.1199048, 2011.

Ganguly et al., 2008. Generating vegetation leaf area index earth system data records from multiple sensors. Part 1: Theory. *Remote Sens. Environ*., Vol. 112(2008)4333–4343, doi:10.1016/j.rse.2008.07.014

Ganguly et al., 2008. Generating vegetation leaf area index earth system data records from multiple sensors. Part 2: Implementation, Analysis and Validation. *Remote Sens. Environ*., 112(2008)4318–4332, doi:10.1016/j.rse.2008.07.013

Gao et al., 2008. An Algorithm to Produce Temporally and Spatially Continuous MODIS–LAI Time Series. *Geophys. Res. Lett*., doi: 10.1109/LGRS.2007.907971.

Garrigues et al., 2008. Intercomparison and sensitivity analysis of leaf area index retrievals from LAI–2000, AccuPAR, and digital hemispherical photography over croplands, *Agric. For. Meteorol*., doi:10.1016/j.agrformet.2008.02.014.

Garrigues et al., 2008. Validation and Intercomparison of Global Leaf Area Index Products Derived from Remote Sensing Data, *J. Geophys. Res*., VOL. 113, G02028, doi:10.1029/2007JG000635, 2008.

Hashimoto et al., 2012 Exploring Simple Algorithms for Estimating Gross Primary Production in Forested Areas from Satellite Data, *Remote Sens*., 4, 303–326; doi:10.3390/rs4010303

Huang et al., 2006. The Importance of Measurement Error for Deriving Accurate Reference Leaf Area Index Maps for Validation of the MODIS LAI Product. *IEEE Trans. Geosci. Remote Sens*., 44:1866–1871.

Justice, et al., 1998. The moderate resolution imaging spectroradiometer (MODIS): Land remote sensing for global change research. *IEEE Trans. Geosc. Remote Sens*., 36:1228–1249.

Knyazikhin et al., 1998. Synergistic algorithm for estimating vegetation canopy leaf area index and fraction of absorbed photosynthetically active radiation from MODIS and MISR data. *J. Geophys. Res*., 103:32,257–32,276.

Morisette et al., 2006. Validation of global moderate resolution LAI Products: a framework proposed within the CEOS Land Product Validation subgroup. *IEEE Trans. Geosci. Remote Sens.* 44: 1804–1817.

Myneni et al., 2002. Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. *Remote Sens. Environ*., 83: 214–231.

Myneni et al., 2007. Large seasonal changes in leaf area of amazon rainforests. *Proc. Natl. Acad. Sci.*, 104: 4820–4823, doi:10.1073/pnas.0611338104.

Privette et al., 1998. Global validation of EOS LAI and FPAR products. *Earth Observer*, 10(6):39–42.

Privette et al., 2002. Early spatial and temporal validation of MODIS LAI product in Africa. *Remote Sens. Environ*., 83: 232–243.

Samanta et al., 2011. Comment on "Drought–Induced Reduction in Global Terrestrial Net Primary Production from 2000 Through 2009", *Science*, Vol. 333, p. 1093,

Samanta et al., 2012 Seasonal changes in leaf area of Amazon forests from leaf flushing and abscission, *J. Geophys. Res*. VOL. 117, G01015, doi:10.1029/2011JG001818, 2012

Shabanov et al., 2003. The effect of spatial heterogeneity in validation of the MODIS LAI and FPAR algorithm over broadleaf forests, *Remote Sens. Environ*.,85: 410–423.

Tan et al., 2006. The impact of geolocation offsets on the local spatial properties of MODIS data: Implications for validation, compositing, and band–to–band registration, *Remote Sens. Environ*., 105: 98–114.

Tian et al., 2000. Prototyping of MODIS LAI and FPAR algorithm with LASUR and LANDSAT data. *IEEE Trans. Geosci. Remote Sens*., 38(5): 2387–2401.

Tian et al., 2002a. Multiscale Analysis and Validation of the MODIS LAI Product. I. Uncertainty Assessment. *Remote Sens. Environ*., 83:414–430.

Tian et al., 2002b. Multiscale Analysis and Validation of the MODIS LAI Product. II. Sampling Strategy. *Remote Sens. Environ*., 83:431–441.

Tian et al., 2002c. Radiative transfer based scaling of LAI/FPAR retrievals from reflectance data of different resolutions. *Remote Sens. Environ*., 84:143–159.

Wang et al., 2001. Investigation of product accuracy as a function of input and model uncertainities: Case study with SeaWiFS and MODIS LAI/FPAR Algorithm. *Remote Sens. Environ*., 78:296–311.

Xu et al., 2018. Analysis of global lai/fpar products from viirs and modis sensors for spatio-temporal consistency and uncertainty from 2012–2016. *Forests*, 9(2), p.73.

Xu et al., 2020 Improving leaf area index retrieval over heterogeneous surface mixed with water *Remote Sens. Environ*., 240:111700.

Yan et al., 2016a. Evaluation of MODIS LAI/FPAR product collection 6. Part 1: Consistency and improvements. *Remote Sens.*, 8(5), p.359.

Yan et al., 2016b. Evaluation of MODIS LAI/FPAR product collection 6. Part 2: Validation and intercomparison. *Remote Sens.*, 8(6), p.460.

Yang et al., 2006a. Analysis of Leaf Area Index and Fraction of PAR Absorbed by Vegetation Products from the Terra MODIS Sensor: 2000–2005. *IEEE Trans. Geosci. Remote Sens.,* 44: 1829–1842.

Yang et al., 2006b. Analysis of prototype collection 5 products of leaf area index from Terra and Aqua MODIS sensors, *Remote Sens. Environ*., 104, 297–312.

Yang et al., 2006c. MODIS Leaf Area Index Products: From Validation to Algorithm Improvement. *IEEE Trans. Geosci. Remote Sens*., 44: 1885–1898.